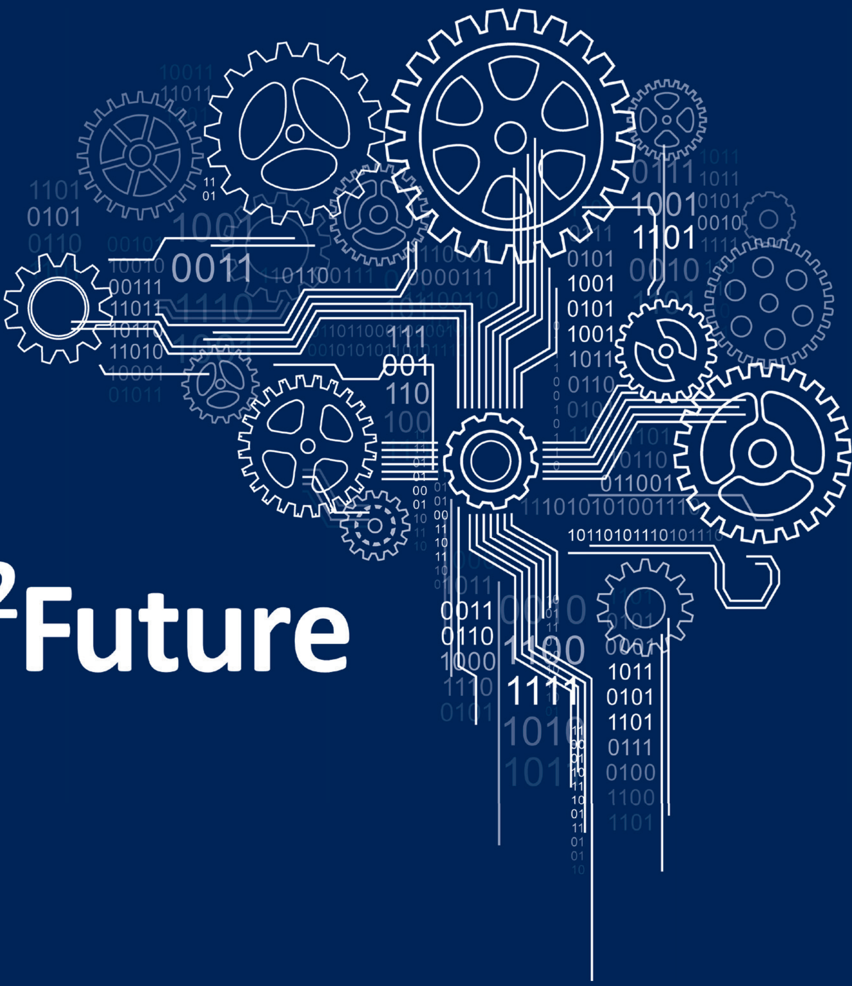
Pro^{2}Future



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Introduction

One of the most profound socio-technical phenomena of the last decade is the increasing blurring of boundaries between the digital and the physical world, dramatically impacting product creation and manufacturing industries. Digitalisation, and consequently virtualisation have opened an unexpectedly wide spectrum for possible future scenarios of how we think about future products (smart/ digital/ online products), and their production processes and systems (smart factories, digital production, online manufacturing) together with new services. **Pro²Future** aims to be the first Centre of Excellence worldwide, addressing this entanglement in research, development, deployment and industrial practice.

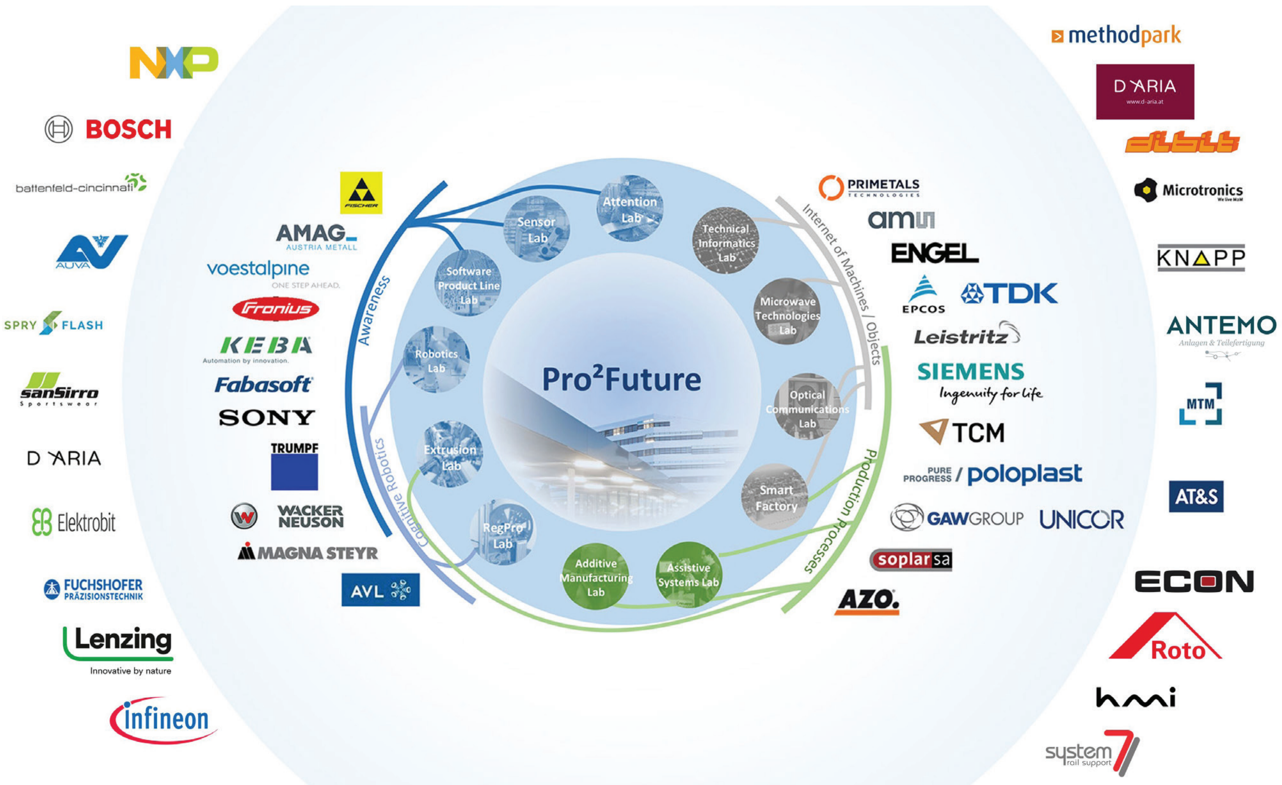
Pro²Future (**Pro**ducts and **Pro**duction Systems of the **Future**) is an Austrian Research and **Competence Centre for Excellent Technologies** funded by the **Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology**, the **Federal Ministry for Digital and Economic Affairs**, and Austria's **strongest provinces** in **industrial leadership**, the **Provinces** of **Upper Austria** and **Styria**, within the **COMET K1 4th Call** funding scheme under **contract FFG** 854184. The legal entity of **Pro²Future** has been founded on March 27, 2017 (Landesgericht Linz FN 469403z, April 20, 2017), and the **corporation Pro2Future GmbH**, owned by Johannes **Kepler University Linz (JKU)** (20%), **Graz University of Technology (TU Graz)** (20%) **FRONIUS International GmbH** (20%), **AVL List GmbH** (20%) and **Upper Austrian Research GmbH** (20%) is in operation since **April 1, 2017**. **Pro²Future** operates a **headquarter** at **JKU** in **Linz**, and **subsidiaries** in **Graz** and **Steyr**.

Pro²Future attempts for next generation products and machines equipped with **cognitive capabilities** as to **perceive**, **understand**, **interpret**, **learn**, **reason** and **deduce**. Cognitive systems exceed established smart or intelligent systems by evolving from (i) **sensing to perceiving** - interpretation of semantic background of gathered sensor data, (ii) **analysing to understanding** - identification of causal connections between semantic data representations to create a fundamental, context-based understanding of input data, (iii) **relating to reasoning** - evaluation of critical aspects for decision making, and (iv) **adapting to learning** - evolution from pre-programmed system behaviour to automatic adaption of behaviour models according to changing environmental contexts. In popular science terms, cognitive products could be referred to as "**products that think**" and "**production systems that think**".

Pro²Future develops **Cognitive Industrial Systems (CIS)** by **embedding cognitive capabilities** into **products** and **manufacturing systems** so as to enable them to **perceive**, **understand**, **comprehend**, **interpret**, **learn**, **reason** and **deduce**, and **act** in an **autonomous**, **self-organized** way - together **with humans**. Pro²Future seeks the consolidation of the Centre's research results in **two core areas**, namely **(i) Cognitive Products (Area 4.1)**, and **(ii) Cognitive Production Systems (Area 4.2)**. In order for this, Pro²Future involves **goal-oriented research** to underpin **product** and **manufacturing innovations** based on **empirically evidenced** applied research results. This is coming from three **underpinning areas**: **(i) Perception and Aware Systems (Area 1)**, **(ii) Cognitive Robotics and Shop Floors (Area 2)**, and **(iii) Cognitive Decision Making (Area 3)**. These five thematic fields are the basis of the **research** and **organisational structure** of **Pro²Future**.

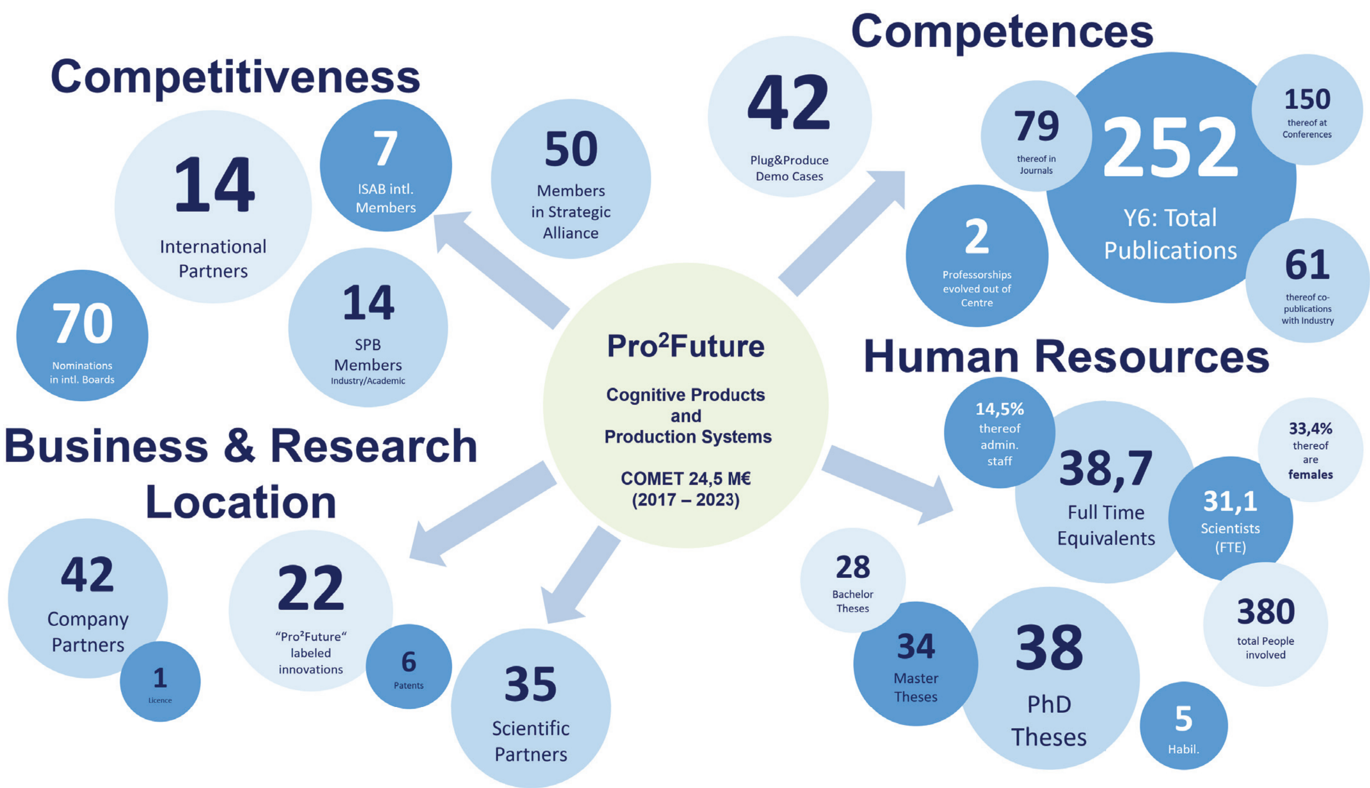
Pro²Future is a joint effort of (i) Austria's **top-level industries**. The consortium of **company partners** in the first funding period (2017-2021) have been **world leading Austrian industrials** in the domain **process industry** (steel: **AMAG**, **Primetals Technologies**, **voestalpine Stahl**, polymers: **Azo**, **GAW Group**, **Leistritz Group**, **Poloplast**, **UNICOR**), software, automation and control (**AVL List**, **Fabasoft**, **KEBA**, **Siemens**, **System7**), equipment and components (**EPCOS**, **Magna**, **SONY Europe**, **Trumpf**, **Wacker Neuson**), and end-products (**Fischer Sports**, **Fronius**) for cooperative research and innovation. For the upcoming funding period (2021 – 2025) consortium of **company partners** has significantly expanded. Among the **new company partners** are **Antemo**, **AT & S**, **AUVA**, **Elektrobit**, **battenfeld-cincinnati**, **D-ARIA**, **D-MTM**, **Fuchshofer**, **sanSirro**, **Spryflash**.

On the **scientific partner** side, Pro²Future is underpinned by the nations **top academic institutions** in **Technology and Engineering** in Upper Austria (**JKU, Johannes Kepler University Linz**, Faculty of Engineering and Natural Sciences) and Styria (TU Graz University of Technology, Faculty of Electrical Engineering and Information Technology, Faculty of Computer Science and Biomedical Engineering, Faculty of Mechanical Engineering and Economic Sciences), and alliance with the **most distinguished European and international universities** in the field of cognitive industrial production systems (ETH Zürich, EPFL Lausanne, TU München, DFKI Kaiserslautern, KIT Karlsruhe, DFKI Saarbrücken, University of Stuttgart, University of Passau, Nanyang Technological University Singapore, Osaka University).



Naturally, the activities of Pro²Future are embedded into the EU Research Agenda, especially the H2020 program in the pillars Excellence in Science (ERC, FET), Industrial Leadership (LEIT) and Societal Challenges regarding energy, transport and materials, and aligned with the upcoming Horizon Europe funding framework.

Pro²Future is endorsed by the Provinces of Upper Austria and Styria, Austria's strongest provinces in industrial leadership, with a R&D quota of 3.19% (Upper Austria, 2019) and 4.91 % (Styria, 2019), compared to the average of 3.2 % of GDP (Austria, 2019). The creation of a COMET K1 Centre along this geographical and industrial axis will enhance and enrich the map of Austrian research institutes in a significant manner, scientifically as well as from a competence viewpoint, and sustainably boost the innovational strength of these industrial regions.
The graphic above shows the industrial partner network since the centre's foundation, the graphic below the outstanding achievements.



2

Pro²Future: A COMET K1 Centre

Since the late 1990's research and innovation support programmes began to go beyond the provision of funding for research and innovation via institutional funding or single, rather narrowly defined research and innovation projects and instead, increasingly more innovation system oriented approaches were deployed. Competence Centres Programmes present such approaches.

By definition, Competence Centres (CCs) are structured, long-term, research and innovation collaborations in strategically important areas between academia and industry/public sector. They focus on strategic research agendas, support strong interaction between science and industry, providing truly collaborative research with a medium to long-term perspective.

Competence Centre Programmes (CCPs) are usually major initiatives within their national innovation systems. Several innovation agencies have launched this type of programme to support CCs with public funding.

Core activities of Competence Centre Programmes at the centre level are the development and operation of research programmes in strategic and multi-firm projects. Competence Centres perform distinguishable activities separate from the operation of the R&D programme and focus on: (i) **Exploitation of research results** by means of IPR and spin-offs, (ii) **Training of PhDs and master students**, (iii) **Dissemination of research results** via publications, conferences etc., (iv) **Stimulation of networking and knowledge transfer**, (v) **Acquisition of third-party funding** (incl. EU sources), (vi) Provision of research infrastructures, and **(vii) Provision of market intelligence**.

In Austria, the "COMET Centre" is one of the lines of the Austrian programme COMET, the "Competence Centres for Excellent Technologies". The programme is a funding scheme of the Austrian Research Promotion Agency FFG, already launched in 2006, to develop new expertise and encourage greater internationalisation as a sign of excellent cooperative research.

The COMET objectives are:

(i) **Developing and focusing competences through long-term research cooperation between science and industry at the highest level** Within the scope of multi-firm projects with strong company partners (Fronius, voestalpine, AVL, KEBA, Wacker Neuson, Trumpf, SONY, System 7), Pro²Future created insights for the industry regarding various techniques in **machine learning** and **artificial intelligence**, showcased novel forms of **embedded cognitive computing** and demonstrated the abilities of **cognitive products** like **workflow** or **worker skill-level recognition**. A road map for **harnessing process information** from the **assembly floor** for the long-term goals of **discovering effective assembly processes**, **optimizing production schedules**, and **reducing** assembly line **re-design.** The ultimate research goal of achieving a **feedback loop over assembly planning** and **execution** has been constituted at the heart of this long-term research cooperation. Significant scientific outcome has been achieved (see Annex 2), and collaborative scientific networking has been established with e.g. TU Munich and DFKI in AI in robotics and manufacturing, or MFP-level e.g. with University of Konstanz (ConMon) and Nanyang Technological University in Singapore (Redusa).

(ii) **Strengthening Austria as a business location** Pro²Future has accelerated technology transfer to industry and helped to create new products, processes and services, porentially able to **open up new markets** and **increase the innovative capacity** of our partners (Fronius, Trumpf, ENGEL, AVL, Fabasoft, Siemens, AMAG, Fischer). Pro²Future has continuously showcased the value of **digitalisation** throughout **production processes**, e.g. for **quality control** or **employee training**, so that company partners have started to create **new digital processes and services** to **target new customers**, to enable an **embedding of Pro²Future technology** into their **products**, but also into their **own IT landscape**. Concepts and tools (e.g., **visual analytics tools**) have been provided that should ensure good quality in manufacturing/production and thus improve the competitiveness of the local companies in international competition. For instance, we have created methods for company partners (voestalpine) to forecast the steel production and international steel markets. In the project **Cognitive Energy Management Systems in Industrial Production**, a strategy for lowering the energy consumption and also reducing the CO2 footprint has been developed. Implementing these results in industrial environments will strengthen Austria as a business location also in the **upcoming green technology markets**.

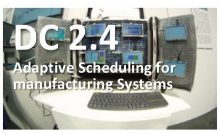
(iii) **Strengthening Austria as a research location** Pro²Future has induced and progressed excellent cooperative research to trigger **new research impulses in industrial innovation** and establish promising/ emerging fields of research. At the core of this strategy has been a focused, strict, deep and technical approach to the (now at the end of FP1 significantly growing) field of **Cognitive Systems** in general, and specifically therein **Cognitive Industrial Systems (CIS)**. Along this strategy, Pro²Future has consistently avoided to follow technology hype cycles in research, or to engage in popular science topics (like "Industry 4.0" or "Internet-of-Things"). With its contribution to "**embedded intelligence**", "**cognitive data analytics**", "**cognitive products and production**", Austria is gaining as a research location in **AI in Manufacturing**, **Robotics** and **AI**, **Human(-worker-)centric AI**, and recently also in **Sustainable Manufacturing** and technology to implement the **"European Green Deal".**

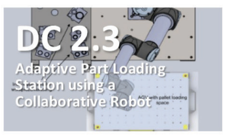
(iv) **Strengthening the competitiveness of science and industry by driving internationalisation as a sign of high-quality cooperative research** Towards this objective, Pro²Future is involving internationally-renowned scientists and organisations. An **International Strategic Alliance** already prepared well in advance to the foundation of Pro²Future, and fostered in **FP1**, has been established, thereby giving the center an invaluable resource for **(i) hiring high-profile researchers** as well as newly graduated tech innovators, **(ii) international scientific cooperation** and **dissemination** of results, **(iii)** support **reciprocal impulses** between regional and international industry. This alliance consists of representatives from the **most distinguished European and international universities** in the field of cognitive industrial production systems (ETH Zürich, EPFL Lausanne, TU München, DFKI Kaiserslautern, KIT Karlsruhe, DFKI Saarbrücken, University of Stuttgart, University of Passau, Nanyang Technological University Singapore Osaka University). A **benchmarking process** at the end of **FP1** is initiated to position Pro²Future in the context of related stakeholders like the Max-Planck Society, the Helmholtz-Gemeinschaft, the Hasso-Plattner Institute, KIT Karlsruhe, DFKI, and Fraunhofer Gesellschaft.

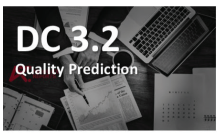
(v) **Establishing and developing human resources** The center is an incentive to **strengthen** and **attract human capital** and **creative innovation potential** in the **federal provinces** of **Upper Austria** and **Styria** - thus to further develop it as a **European innovation leader** and showcase for cognitive production systems. In the 2017 ranking of **276 European Regions** the province of **Styria** (**4.91 % R&D rate,** with 39 % coming from the company sector) has achieved the **top rank**, while the province of Upper Austria (**3.46 % R&D rate**, with 73 % coming from the company sector) is **ranked 13**. The Pro²Future co-located technological universities **JKU** and **TUG** attract high potential, international students, which at the same time represent potential future Pro²Future co-workers or employees. As for example, in the winterterm 2019/2020 **JKU** had **705/226** (bachelor/master) students in **Computer Science**, **296/157** in **Artificial Intelligence** and **597/197** in **Mechatronics**, with Pro²Future **Area Leaders** (JKU Professors Ferscha, Egyed, Fürnkranz, Miethlinger, Hild, Schlacher, Müller) **teaching classes** in these curricula. **TUG ,** at the same time had **995/348** (bachelor/master) students in **Computer Science**, **624/218** in **Information and Communication Engineering, 787/157** in **Software Engineering and Management** and **738/203** in **Electrical Engineering**. This **strong entanglement** between the **academic research** and **education** at the partner **universities**, and the **industrial use inspired research** at the respective Pro²Futurec sites Linz and Graz represents a **perfect setting** for **human resource development,** attracting **internationally renowned scientists**, and creating and offering structured **career models** for **scientists**.

The achievement of the COMET objectives and its impact are assessed by quantitative and qualitative indicators at project and programme level. The indicators and **target values** are directly derived from the programme objectives and include among others (i) the **number of publication**s, IPRs, etc., (ii) the **share of strategic research** in overall research programme, (iii) the number of **international partners**, (iv) the **participation in international R&D projects** (e.g. EU projects), and (v) the acquisition of additional external funds from contracts with companies.

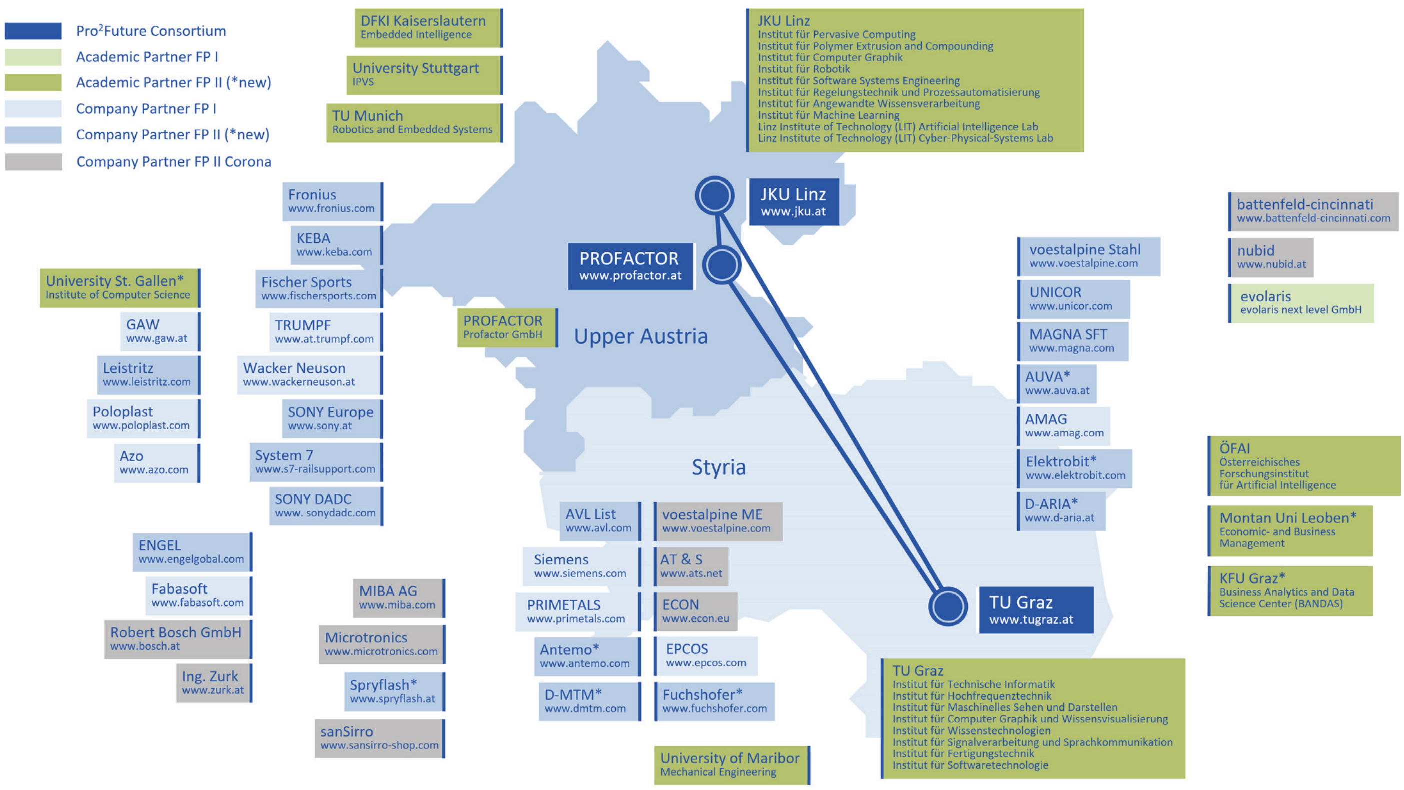
COMET K1 Centres aim to develop and focus competences COMET K1 Centres aim to develop and focus competences through excellent cooperative research with a medium to long-term perspective. They conduct research at top international level and stimulate new research ideas in their fields. They contribute to initiating product, process and service innovations with a view to future relevant markets. K1 Centres define multi-year research programmes aligned to the strategic interests of science and industry. They include at least five company partners and consolidate their competences by establishing relevant human resources being further developed via structured career models. Their general duration is 8 years (stop-or-go evaluation after 4 years), the public funding ranges from 40 to 55 %, and the Federal funding is limited to max. EUR 1.7 million per year.







Pro²Future and a second COMET K1 competence centre, the Centre for Digital Production (**CDP**), jointly developeded a **Common Research Programme (CRP)** -based on the respective complementary competencies- in the form of **demonstrator projects**. **24 (Pro²Future)** and **27 (CDP) researchers** worked on CRP, successfully delivering **proofs of concepts** for **new solutions** to **technologically significant** and **industrially relevant** problems, in **3 demonstrator projects** exhibiting **12 demo cases** in FP1.



Throughout **FP1**, **Pro²Future** has successfully developed **Cognitive Industrial Systems (CIS)** by **embedding cognitive capabilities** into **products** and **manufacturing systems** so as to enable them to **perceive**, **understand**, **comprehend**, **interpret**, **learn**, **reason** and **deduce,** and **act** in an **autonomous, self-organized** way - together **with humans**. Pro²Future is structured so as to consolidate research results into the **two core areas (i) Cognitive Products (Area 4.1)** and (**ii) Cognitive Production Systems (Area 4.2)**. **Area 4.1** and **Area 4.2** thus represent the **very essential Centre goals**. To address these, Pro²Future involves **goal-oriented research** to underpin **product** and **manufacturing innovations** based on **empirically evidenced** applied research results. These are contributed by the three **underpinning areas**: **(i) Perception and Aware Systems (Area 1)**, **(ii) Cognitive Robotics and Shop Floors (Area 2)**, and **(iii) Cognitive Decision Making (Area 3)**.

These five thematic fields are the basis of the research and organizational structure of Pro²Future which have **strengthened** the Centre and have **proven well** in **FP1**.

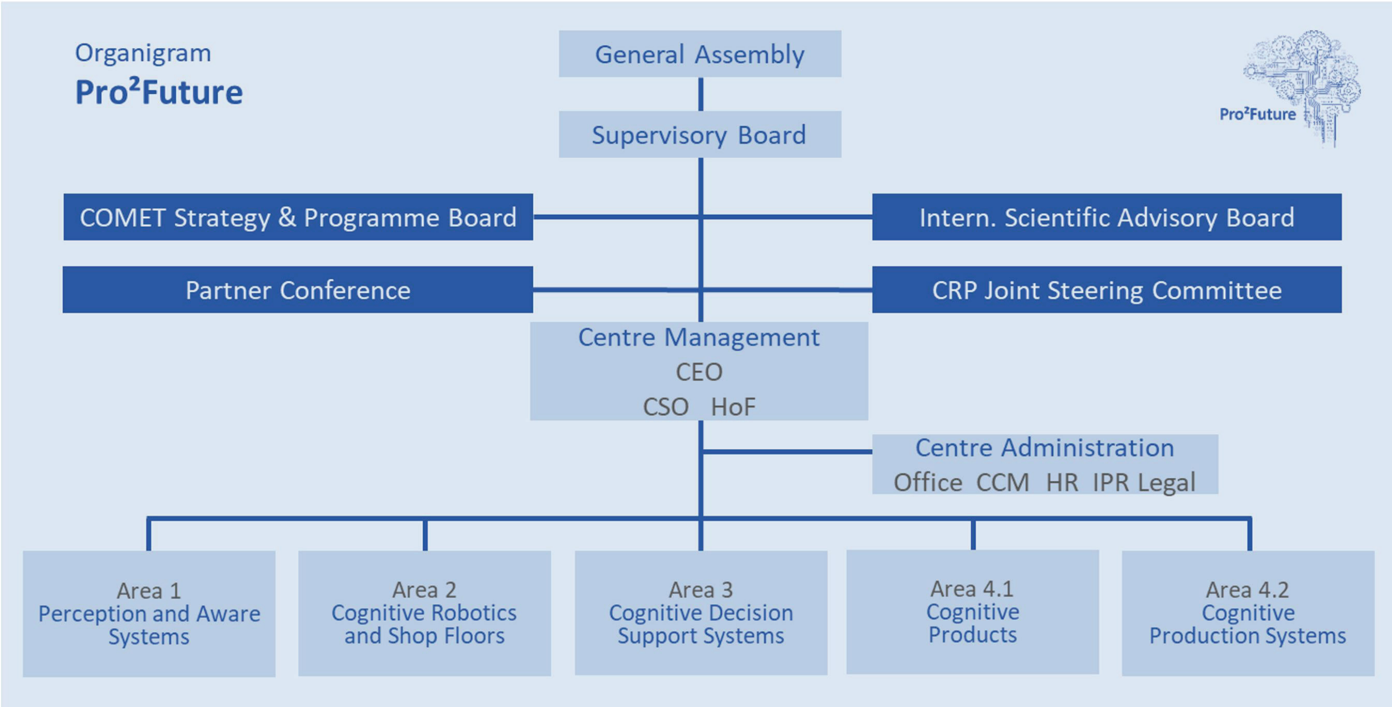
In **FP2**, Pro²Future will **follow** and **deepen** on its **thematic focus** as reflected in its well established and proven **area structure (Areas 1, 2, 3, 4.1, 4.2)**. Considering recent international trends in **industrial research** (**digitalisation** in **manufacturing, AI driven production, AI** based **supply chain management, sustainable production** and the **WHO SDGs**, etc.) but also **recent technological advances** in **ICT**, **Software Systems Engineering**, **Mechanical Engineering**, **Industrial Internet of Things**, etc. a **for-sighted calibration** of the area research agendas appears obvious. In addition, the Pro²Future **International Scientific Advisory Board** (**ISAB**) after its board meeting with Pro²Future on February 28 (and its evaluation report in May 2019) has (aside other matters) recommended to put specific focus on topics like **Artificial Intelligence** as **THE major technological trend** in "**digitalization**".

This recommendation has ultimately led to the integration of **cross-area themes** into the research agenda of Pro²Future. Addressing research topics along **PervasiveAI, Engineering for Distributed AI, ExplainableAI, Analytical User Guidance, Causality, Edge Analytics, Failsafe** and **Robust AI, and AI for Sustainable Production** will fertilize all area research agendas and lead to profound CIS results at the state-of-the-art in AI.

The **cross-area topics** addressed extending the research focus are partially deduced from **partner workshop theme solicitations (Partner Conferences** on 2019-10-22 and 2020-02-06, and **Strategy and Programme Board Meetings** on 2019-11-12 and 2020-03-30), and thus reflect the current concerns and needs of the company partners.

As the COMET Centre Pro²Future is operated by **Pro2Future GmbH**, the core structure represents bodies stated by **Austrian GmbH law (GmbH-Gesetz): General Assembly**, **Supervisory Board** (see board-illustration on the next page) and **Executive Board**. These bodies are accompanied by additional boards and governing platforms supporting the overall development of the Centre (**COMET Strategy & Programme Board, International Scientific Advisory Board, Partner Conference, CRP Joint Steering Committee**). The operational research activities are carried out in the **five Areas**, each forming a **self-contained business unit**, but with strong interlinkages to the other Areas. **Area X**, the cross area for the execution of **CRP**, was implemented as a **virtual area** in FP1.

Though the **continuation** of the **CRP** collaboration with CDP is planned for FP2, this will be arranged directly by the five Areas (as opposed to an extra "virtual Area X" as in FP1). Furthermore, the lean Administrative Units support both the Centre Management and the Areas with their supporting functions like Scientific Assistance, Center Communications, Finance, HR, Legal Affairs, PR etc.



Pro2Future GmbH, the funding recipient and consortium leader of the COMET Centre Pro^{2}Future, was founded as GmbH under Austrian Law right before the start of FP1, on March 27, 2017. The company was taken up to the commercial register by April 20, 2017 (Landesgericht Linz FN 469403 z).

Right from the Centre start in 2017, the **ownership structure** of Pro2Future GmbH clearly reflects the **key players** involved in Pro^{2}Future and is well **balanced** in terms of **academic** and **industry ownership** and in terms of **regional** aspects. While academic interest is reflected in the share ownership by the main proponents JKU Linz and TU Graz, Company Partners' share is equally distributed between FRONIUS International GmbH and AVL List GmbH. Upper Austrian Research GmbH (UAR) as the fifth shareholder completes a regionally well-balanced ownership structure. Moreover, this ownership structure was deliberately chosen so that Pro2Future GmbH can act as an SME in national and international R&D funding programs.

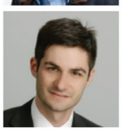
Pro^{2}Future is **located** at three sites **Linz**, **Graz** and **Steyr** in order to be as close as possible to the main Centre partners and to strengthen the industrial axis **Upper Austria**–**Styria**. The **headquarters** as well as the registered business address of Pro2Future GmbH is situated in **Linz** on the **Science Park campus** of **JKU** Linz and connected to the newly founded pilot factory **LIT-Factory**.

Similar to the Linz situation, **Pro^{2}Future Graz** is located on the **campus of Graz University of Technology**. Right from the Centre start in April 2017, Pro^{2}Future Graz could move into a new university building which has been dedicated to production science and to **SmartFactory@TU-Graz**, the pilot factory run by the Institute of Production Engineering. Pro^{2}Future Graz therefore closely shares its premises with the personnel of this institute, and synergies in daily work between the Centre and the pilot factory can be achieved. The third and smallest **site Steyr** is located at PROFACTOR GmbH.

Members of the Pro^{2}Future Supervisory Board

Univ.-Prof. Dr. Horst Bischof
Graz University of Technology
Head of the General Assembly

Mag. Ingrid Rabmer
Upper Austrian Research GmbH
1st Deputy Head of the General Assembly



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Amt der OÖ Landesregierung

Ing. Herbert Ritter, MBA
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Johannes Kepler University Linz
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Mag. Georg Hoffberger
Pro2Future GmbH
Head of Finance

Thomas Martetschläger
Pro2Future GmbH
Protokollführung

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voestalpine Stahl GmbH


Dr. Gerhard Dimmler
ENGEL Austria GmbH


DI Dr. Helmut Ennsbrunner
Fronius International GmbH
Chairman of the SPB


Dr. Petra Krahwinkler
Primetals Technologies Austria


DI Alexander Rinderhofer, MBA
GAW Group


DI Herbert Tanner
Siemens AG Österreich


DI Martin Weinzerl
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Scientific Partner & Academic Members


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Johannes Kepler University Linz


Univ.-Prof. Mag. Dr. Alois Ferscha
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Scientific Director Pro2Future GmbH


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Vice-Chairman of the SPB


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Univ.-Prof. Dr. Gabriele Kotsis
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Univ.-Prof. Dr. Kay Uwe Römer
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Univ.-Prof. Dr. Marc Streit
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DI Klaus Oberreiter, MBA
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Manuela Maier
Steirische Wirtschaftsförderungs-gesellschaft m.b.H. SFG

Though losing in compactness compared to a single-located center, the multi-nodal Centre structure **proved** to **work well during FP1**. **Advantages** are seen a) in the **use of existing research infrastructure** of the key scientific partners to execute the planned research program, b) in the **immediate closeness** to **large-scale industrial installations** available at key company partners for use cases and prototyping, and c) in a close collaboration and sound economic development within each of the three **industrial regions**. The Centre interactions between the research sites therefore facilitate cross-linking of the regions.

COMET Strategy & Programme Board (SPB)

Different from the plan stated in the original K1 application, a strategy board was established separately from and not embedded in the Supervisory Board and combined with the originally planned Programme Committee. The motivation for this was mainly that further Company and Scientific Partners should get involved in strategic issues of Pro²-Future's COMET programme development, in addition to the core partners being represented as shareholders in the Supervisory Board. Hence, the COMET Strategy & Programme Board (SPB) was formed by six delegates each from Company and Scientific Partners, appointed by the General Assembly. A good balance could be achieved in terms of (i) academic and industrial perspectives, (ii) thematic coverage of the five Areas and (iii) regional balance between Upper Austria and Styria. Additionally, the SPB was open for attendance of representatives from the funding agencies. The SPB board member configuration is shown above.

Members of the Pro²Future International Scientific Advisory Board


Prof. Michael Beigl
Pervasive Computing Systems
KIT Karlsruhe Institute of Technology


Prof. Joseph A. Paradiso
MIT Media Lab
Massachusetts Institute of Technology


Prof. Albrecht Schmidt
Human-Centered Ubiquitous Media
LMU Munich


Prof. Wentong Cai
Parallel and Distributed Simulation of Manufacturing Systems
NTU Singapore


Prof. Anind K. Dey
UW iSchool
University of Washington


Prof. Dr. Gerhard Tröster
Information Technology and Electrical Engineering
ETH Zurich


Prof. Antonio Krüger
Innovative Retail Laboratory
DFKI - German Research Center for Artificial Intelligence

International Scientific Advisory Board (ISAB)
With a distinct focus on the scientific orientation, the ISAB supports the SPB, the Supervisory Board and especially the Scientific Director and the Area Leaders. It recommends on scientific matters related to the research program and its strategic development, the long-term impact of the conducted work and the quality and impact of the scientific results with special regard on the Centre's international visibility.
The ISAB is constituted by a maximum of seven members, who are independent and internationally renowned experts in their respective research fields.

The **ISAB has met on February 28, 2019** at Pro²Future Linz. The date was thoroughly selected with the ideas of (i) providing sufficient **research progress** as a basis for discussion and **evaluation**, (ii) **collecting feedback** from the international experts regarding the further scientific orientation, with special focus on the crucial **evaluation milestones** of **2YE** (**CRP**) and **4YE**. In more detail, feedback was asked for the following issues: to assess Pro²Future's **mid-term standing of achievement**, to evaluate if and how **past activities**, **resources** and **plans** comply with the Pro²Future **vision and strategy**, to **assess strengths** and **weaknesses** of Pro²Future as a whole and of its five research areas, to **recommend actions** as to what areas/subprojects should be **focussed** on during the **two remaining years of FP1**, specifically **towards 4YE**, to recommend strategies and actions for the **2YE of** the **CRP** in Sept 2019, and to recommend as to what **areas/subprojects** should be **focussed** on when **attempting** for a **continuation proposal** for **FP2 (2021-2025)**.
The ISAB's manifold and invaluable **feedback** has been thoroughly discussed and implemented (SPB, Supervisory Board, Partner Conference, preparation of 2YE and 4YE evaluation reports, etc.).

Members of the CRP Joint Steering Committee

Pro²Future

Company Partner Members


Dr. Eric Armengaud
AVL List GmbH


DI Dr. Helmut Ennsbrunner
Fronius International GmbH


DI Jürgen Minichmayr
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Ao. Univ.-Prof. Mag. Dr Christian Huemer
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Weitere eingeladene Teilnehmer


Univ.-Prof. Mag. Dr. Alois Ferscha
Pro2Future GmbH
Scientific Director


DI Gerd Hribernig
Pro2Future GmbH
CEO


DI Dr. Christoph Pollak
CDP GmbH, GF


DI Alexander Raschendorfer
CDP GmbH, Area Manager


DI Dr. Markus Jäger, MLBT
Pro2Future GmbH
Assistance Scientific Director


DI Gernot Mauthner
TU Wien

CRP Joint Steering Committee (JSC)
For guiding the execution of the Common Research Programme (CRP), the JSC was implemented. Its specific role is acting as the strategic governance body for the development, execution, and supervision of the CRP. The JSC consists of **12 members**: Each Centre has appointed to the JSC **three Company Partner representatives** and **three Scientific Partner representatives** (two regular members and one substitute each). The CEOs attend the meetings without vote. They can bring the CRP project managers for reporting on project status and outlook.
Following this, the subsequent members were nominated which also included – according to CRP panel requirement – representatives from the strategy boards of both Centres, and additionally from Pro²Future even the chairman of the Supervisory Board.

For the second funding period, there were no requirements to install a similar board, nevertheless, the cooperation between Pro²Future and CDP continued within the CRP II programme (Sustainable Products and Production), thus a **CRP II Programme Board** was installed, which coordinates and manages the progess in the CRP II, by aligning the research and project progress on a regular base.

Members of the CRP II Programme Board

Pro²Future


Univ.-Prof. Mag. Dr. Alois Ferscha
Pro2Future GmbH
Scientific Director


DI Dr. Michael Haslgrübler
Pro2Future GmbH
Area Manager


DI Dr. Michael Krisper
Pro2Future GmbH
Area Manager


DI Dr. Markus Brillinger
Pro2Future GmbH
Area Manager

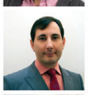

DI Dr. Markus Jäger, MLBT
Pro2Future GmbH
Center Communications Manager

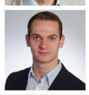

DI Gerd Hribernig
Pro2Future GmbH
CEO

CDP


DI Arnold Braunsteiner
CDP GmbH
CEO


DI Bernhard Oberegger
CDP GmbH
Research Engineer


DI(FH) Dieter Etz, MBA
CDP GmbH
Research Engineer


DI Dr. Thomas Frühwirth
CDP GmbH
Research Engineer

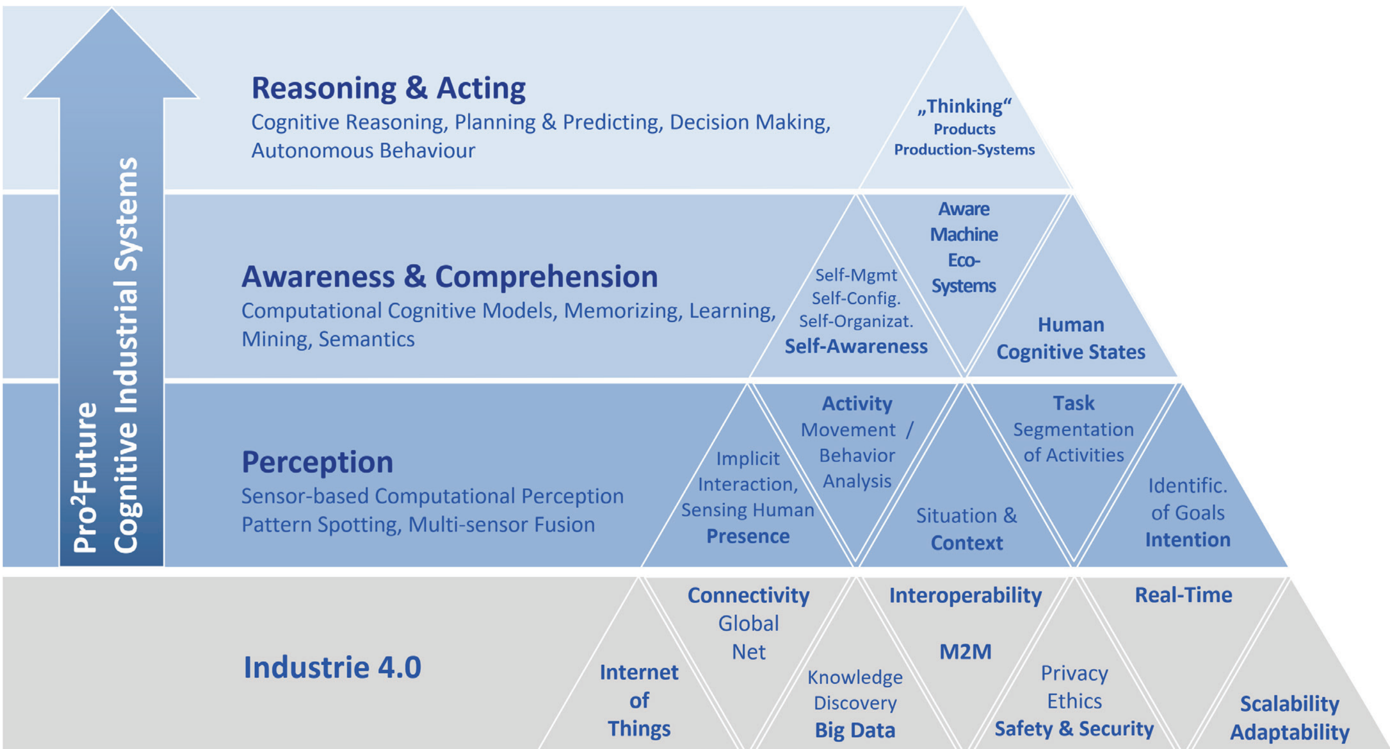

Jan Werner, MSc
CDP GmbH
Research Engineer


Ing. Sascha Gent, MSc
CDP GmbH
Area Manager

3

Vision and Objectives of Pro²Future

Pro²Future has been founded at times (2017) when the blurring of boundaries between the **digital** and the **physical world** started to dramatically impact **product creation** and **manufacturing industries**. At these very first steps towards a radical **"Digitalisation of Industries"** a wide spectrum for possible future scenarios of how we think about **future products** (smart products, digital products, online products), and the processes and **production systems that create them** (smart factories, digital production, online manufacturing) together with new services and business models emerged. Key to our thinking was a **Product-Production Systems Co-Design**, **Co-Creation**, **Co-Operation** and **Co-Existence** of **products** and **production**. The overall vision of **Pro²Future** thus was to attempt to be the first center of excellence worldwide, addressing the **entanglement of products and production systems of the future**, in **research**, **development**, **deployment** and **industrial** best **practice**.



Pro²Future research goals fostering Cognitive Industrial Systems towards next level ICT in industries.

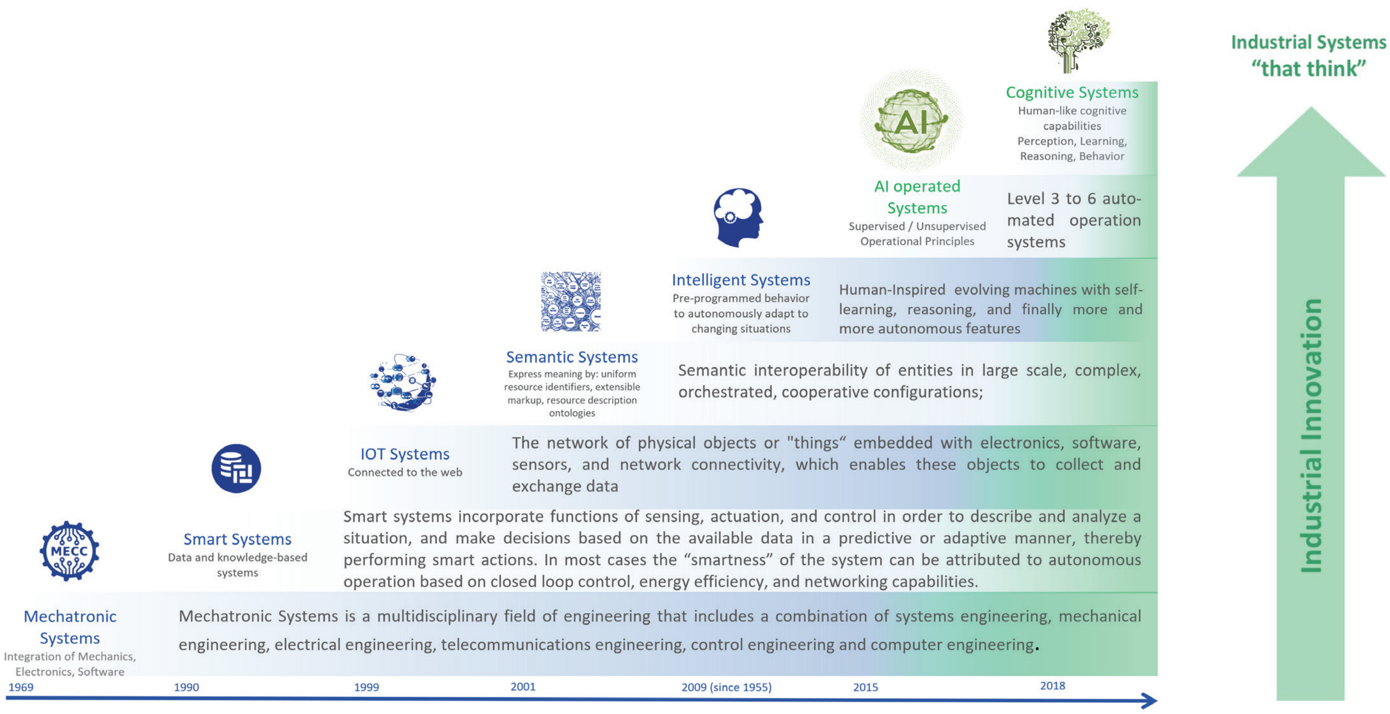
In research, the **Pro²Future** initiative builds on top of the consortiums expertise in mechatronic systems, networked embedded systems, engineering of distributed software, cyber-physical systems, smart/pervasive/ubiquitous systems, systems of systems, big data analytics and data-driven predictive models, semantic and intelligent systems, and the exploration of innovative ICT that intended to go far beyond the then popular science approaches (like Industrie 4.0, Industrial Internet of Things, Web of Services and Physical Internet, etc.), namely to the next level of ICT in industries referred to as **Cognitive Industrial Systems**.

Pro²Future attempts for next generation **products** and **manufacturing machinery** (holistically combining batch and continuous process industries), with **embedded cognitive capabilities** so as to **perceive**, **comprehend/understand**, **interpret**, **learn**, **reason** and **deduce**, and act in an **autonomous**, self-organized way together with humans, i.e., **human consumers** and **human (industrial) workers**. Expressed in popular science terms, the **Pro²Future** research aims for ***"products that think"*** and ***"production systems that think"***. In the upcoming funding period (2021-2025), **Pro²Future** will attempt to rigorously work on the embedding of **AI** (Artificial Intelligence) **technology** into **products** of the future, and the **symbiosis** of **Human Intelligence** and **AI** in **production systems** of the future.

*The **overall goal** of the K1-Center Pro²Future is to carry out **Cognitive Systems Research** and **integrate** the **achievements** into the **Industrial Lifecycle** of **Products** and **Production**. **Building on** and **exploiting existing research** areas and expertise from the last six decades of technological evolution (Figure 1.1 2), the K1-Center has successfully created and will continue to deliver **Cognitive Industrial Systems, as a joint undertaking** between **Austria's top-level industries** (formed around **process industry, software, automation and control, equipment and components**, and **end-products**) together with the nation's **top academic institutions in Technology and Engineering** in Upper Austria (**JKU, Johannes Kepler University Linz**, Faculty of Engineering and Natural Sciences) and Styria (Graz University of Technology, Faculty of Electrical Engineering and Information Technology, Faculty of Computer Science and Biomedical Engineering, Faculty of Mechanical Engineering and Economic Sciences).*

The **long-term vision** of the **Pro²Future initiative** addresses cognitive products and production systems in an overarching and interleaved way.

The **research visions** are structured along the following lines of the evolution of ICT in industrial research and innovation:



- **Mechatronic Systems** – a symbiosis of mechanics, electronics and software, originating at the conjunction of **MECHAnical** and **elecTRONICal** engineering by the Japanese engineer Tetsuro Mori in 1969, that was later extended to computer, telecommunications and systems engineering representing the backbone of ICS, providing shop floors, robotics, tools and machines in an industrial context.

- **Smart Systems** – represent data and knowledge-based technologies. The focus lies on the acquisition, storage and retrieval of knowledge and data. It provides the means to perform decision-making based on facts, trends or historical data. The respective technologies serve as the **perception system** and contribute to the **reasoning system** of an ICS.

- **IoT Systems** – build upon the connectedness of devices to the internet or other devices within a network. This connectedness is exploited as a transportation network to gather information from or send commands to devices. This represents the **nervous system** of an ICS.

- **Semantic Systems** – explore how to express meaning or information in a standardized way which can be used e.g. for machine-to-machine communications. The respective technologies serve as the **"language system"** of an ICS.

- **Intelligent Systems** – investigate how to use pre-programmed human-like behavior to adapt to changing environments (self-organization, adaptation and cooperation of systems). The respective technologies provide the **learning**, **planning** and **reasoning** component of an ICS.

- **AI operated Systems** – very recent (since around 2020) advances of AI based methods for controlling the behavior of systems have impacted the research goals of Pro²Future at its transition into the upcoming funding. ICS are concerned more and more with situations where **human intelligence** comes across **AI controlled/ operated machinery** or **product functionality**. This poses a grand challenge to the future of AI in general and has been adopted as a top priority research agenda for Pro²Future in FP2.

- **Cognitive Systems** – require **innovation breakthroughs** at every layer of information technology, starting with **computing systems design**, **information management**, **programming**, and **machine learning**, and, finally, the **interfaces between machines and humans**. **Cognitive Products and Cognitive Production Systems** will have to adopt human-like capabilities like perception, learning, reasoning, planning and behavioral control, or in short, will have to be able to **"think"**, **understand** contextual information, and to provide a **seamless interfaces** to the user to **adapt**, **act** and **react** in **real-time** to spontaneous **information**, **goals** and **tasks**. They **exceed on AI operated systems** by **evolving** (i) from **sensing to perceiving** – interpretation of semantic background of gathered sensor data, (ii) from **analyzing to understanding** - identification of causal connections between semantic data representations to create a fundamental, context-based understanding of input data, (iii) from **relating to reasoning** - evaluation of critical aspects for decision making, and (iv) from **adapting to learning** - evolution from pre-programmed system behaviour to automatic adaption of behaviour models according to changing environmental contexts.

In order to develop such **Cognitive Industrial Systems (CIS)**, the research program of Pro²Future seeks the consolidation of the Centre's research results in **two core areas**, namely **(i) Cognitive Products** (Area 4.1), and **(ii) Cognitive Production Systems** (Area 4.2). So **Products** and **Production** are the very essential concerns of the centre. In order for this, **Pro²Future** involves **goal-oriented research** to underpin product and production innovations based on empirically evidenced applied research results. Support is thus coming from three **underpinning areas**: **(i) Perception and Aware Systems**, **(ii) Cognitive Robotics and Shop Floors**, and **(iii) Cognitive Decision Making**. These five thematic fields are the basis of the **research** and **organisational structure** of **Pro²Future**.

Pro²Future focuses its research on the topics (i) **system and software architectures** for cognitive industrial systems, (ii) **methods and approaches** for ICT-supported system-/automation-/perception-/ control engineering, (iii) **control of complex material-/production-/ product-/process chains**, (iv) **construction methods** for cognitive industrial systems, (v) **engineering of complex industrial systems**, (vi) **engineering of autonomous industrial systems**, and (vii) **engineering of heterogeneous industrial systems**.

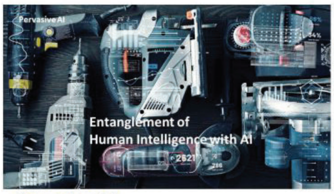
The type and nature of research work in these **five areas** yields \`technology concepts formulated´ (TRL 2), \`experimental proofs of concept´ (TRL 3), and \`technology validated in lab´ (TRL 4), and are conducted in multifirm-projects (**MFPs**) and strategic projects (**SPs**) within the **COMET funding scheme**. Activities aiming at technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies) (TRL 5), technology demonstrated in relevant environment (TRL 6), and system prototype demonstrations in operational environments (TRL 7) are performed in the **non-COMET scheme**. **Basic research** creating the foundational grounds of the goal oriented research in the core areas of Pro²Future is provided by the **academic partners** of Pro²Future in their own domain, and **outside the COMET funding scheme**.

Building upon the research development of FP1 and on the cross-area topics, the main expected results for FP2 research can be summarized as follows:
Cognitive Systems supporting Workers, increasing the Complexity handled: Based on our research on **Pervasive AI** we expect to deliver results in the three pillars of our research work: sensing, reasoning, and actuat-ing. These results will be in the form of prototypes and empirical evidence of improvement areas. We will compare our work with existing solutions, e.g., on the shop floor or on the research field.

In addition, in line with existing work, we will gather also evidence regarding well-being of our prototypes and ensure that potential negative cognitive or physical impairments are investigated early on and addressed in the creation of the prototypes. We foresee that, e.g., on the shop floor **worker-in-the-Loop** AI systems increase efficiency and handle complexity and re-skilling of workers. We also broaden the entan-glement of competencies of Human Intelligence with AI with our solutions, as well as improving fault toler-ance and robustness via distributed pervasive AI across infrastructure and wearable devices and, finally, min-imize the distraction of ICT technology through adaptation of guidance level by shifting cognitive load from machines to machines.

Collaborative Engineering Support System for distributed Cyber Physical Production Systems: We expect the research results with respect to **Engineering for Distributed AI** to have effects at two levels: first, to obtain techniques and prototypes that significantly reduce the effort to design AI-centric actors that can react to their context in near real-time, that are easy to adapt and evolve (thus in general reduce the engineering effort for designing complex and distributed cyber physical production systems), and second to reduce the integration and deployment effort for participants in robust and scalable cyber physical production systems.
The expected results: along the lines of the techniques outlined in the approach section would enable collab-orative engineering and designing of **CPPS** (rapid feedback and change impact assessment across domain boundaries), efficient deployment and management strategies, automated re-configuration of actors and their communication structure, collaborative operators (Operator 4.0), as well as flexible, autonomous robot-ic systems.

Demonstration of **xAI** methods for Production: The expected results in **Explainable AI** of this amendment topic are best-practice guidelines for xAI methods which should be used in industrial applications to make complex AI system understandable. This will be done by selecting and testing a set of xAI methods, algo-rithms and demonstrating their applicability in industrial scenarios where many critical decisions should be made based on the prediction of an AI algorithm. Furthermore, we will analyse which cognitive factors of the employees can influence the acceptance of the explanations that in the end may de-



Pervasive AI

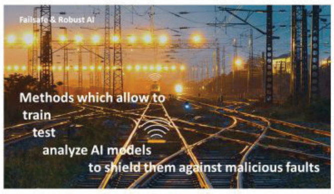
Causality

Explainable AI

Edge Analytics

Engineering for Distributed AI

Analytical User Guidance



Failsafe & Robust AI

AI for Sustainable Production

cide whether AI systems are used in real-time decision processes for industrial applications.

Tools for Guided Interactive Data Analysis: With **Analytical User Guidance**, it should become possible to elim-inate many frequently occurring bottlenecks in data- and visual data analysis and to quickly obtain essential insights in a timely manner even for users with limited knowledge in data analytics and visual interfaces. As a result, we expect that guided interactive data analysis can positively affect the production process and re-duce the workload of the involved employees. The guidance will be provided by e.g., suggesting the useful starting point for the analysis, highlighting particular data points, recommending certain views which may convey valuable insights better than the others, etc. The recommendations can be confirmed or rejected by the user which as result will improve the decisions of the system.

Reliable and Robust Models for Production Systems: Data collected during the industrial production processes contains highly important information that can be utilized for estimating the production parameters with the biggest influence on the quality and their causality. Based on these insights, it seems very likely that the final product quality can be improved, and the production efficiency increased.

When it comes to detecting anomalies, it is impossible to discover the true causalities for an anomaly as they cannot address confounders. For that reason, we will focus on con-founders by developing novel methods for time series data. Deep learning methods can both handle high dimensional data and can learn hidden representations with variational autoencoders (VAE), and accordingly approximate the hidden confounders that are the main drivers of the anomalies. Based on the criterion of the presence of a hidden confounder in the time series, we will propose novel deep learning algorithms based on VAE that can handle non-linear multivariate time series and can detect anoma-lies in the presence of hidden confounders.

Tools Supporting the Engineering of Distributed Industrial Edge Systems: The amendment topic edge analyt-ics aims for processing and analyzing data as close to its source as possible. Instead of transmitting data into a central data store (cloud) and processing it there (big data analytics), methods will be developed, which allow data to be directly accumulated, processed and analyzed at aggregator instances. The results of the amendment topic will demonstrate how intelligence can be brought closer to the product and production processes. In addition, it aims for the development and integration of frameworks and toolchains which al-low the easy deployment, management and concertation of dependable industrial grade edge solutions. Besides increased flexibility and robustness the application of edge analytics and computing will demonstrate how such a new form of analytics can give rise to new personalized service models (e.g. via high resolution monitoring) and opens up new business cases, which help to differentiate oneself on competitive markets.

Formal and Probabilistic Fault Safe Models: The expected results of this amendment topic are methods and tools which allow the training of Failsafe and Robust AI models for industrial graded automation solutions. This concerns the development, test and demonstration of methods which allow to train, test and analyse AI models to shield them against faults, the application of formal and probabilistic methods for a detailed state-space exploration, methods for the generation of use-case specific adversarial training data, as well as the development and application of frameworks for test case design and process guidelines in the context of model training.

Support for **Reduction of Energy Consumption and Stress Level**: The expected main results of AI for Sustain-able Production are the significant reductions in power demand and energy consumption of production sites and on the other hand, providing right information to the worker for decreasing the stress level, to the right level that maximize the per-formance of workers. In the cases for reducing stress level and energy consumption exploring hidden correla-tions and causalities are of critical importance gaining a deeper understanding of energy and human as a critical success factor in future production. This research is the basis for developing new methods for a greener and more sustainable production, addressing human as well as energy issues.

4

THE AREA STRUCTURE

A Joint Effort Towards Products and Production Systems of the Future

Pro²Future's Research Program is consolidating research results within two **core areas**, i.e. AREA 4.1 Cognitive Products and AREA 4.2 Cognitive Production Systems, **underpinned** with three major **scientific areas**, each taken from foundational and goal-oriented research disciplines related to cognitive systems, namely AREA 1 Perception and Aware Systems, AREA 2 Cognitive Robotics and Shop Floors and AREA 3 Cognitive Decision Making.

Visualisation of the overall research program of the Pro²Future initiative. Research efforts are structured into four main areas, whereby Areas 1 to 3 encompass foundational and goal-driven research. The accomplishments from these areas are transferred to Area 4, where exploitation and creation of cognitive industrial products and production systems take place.

In **Area 1 "Perception and Aware Systems"**, researchers focus on **simplification of interactions between humans and machines** in order to facilitate the implementation of **sophisticated cooperation and reasoning systems**. Beginning with mechatronics systems and spanning up to “Internet of Things”- and intelligent systems, Area 1 investigates and creates cognitive systems that are able to sense, reason, interact and cooperate to optimally solve problems and adapt themselves to changing contexts.

Area 1 works towards (i) **Human Aware Machines** (sensing, interpretation and understanding context-, activity-, attention-awareness), (ii) **Assistive Machines** (cognition-based assistance services for cognitive and decision making processes), (iii) **Self-aware Machines** (modeling self-description and self-management of production machines), and (iv) **Cooperative Machine Ensembles** (creation of stand-alone eco-systems of production machines, coordination in production ensembles).

Its projects aim specifically towards increasing **machine-machine cooperation** and the timely **adaptation of machines to human needs** and actions. Area 1 specifically contributes to Area 4.1 in terms of **integration of cognitive functionalities** into end-consumer products as well as to Area 4.2 regarding interaction processes enabling the realization of cognitive production systems.

Area 2 "Cognitive Robotics and Shop Floors" is directed at research on robotic systems and production systems to be incorporated into a fabric of cyber-physical industrial systems to drive the ongoing modernization of industry. Focus is set on the **reinvention of adaptable mechatronic and robotic production systems** and consequently the **adaptability of entire production processes** in shop floors by means of embodiment and respectively connecting physical entities with virtual representations.

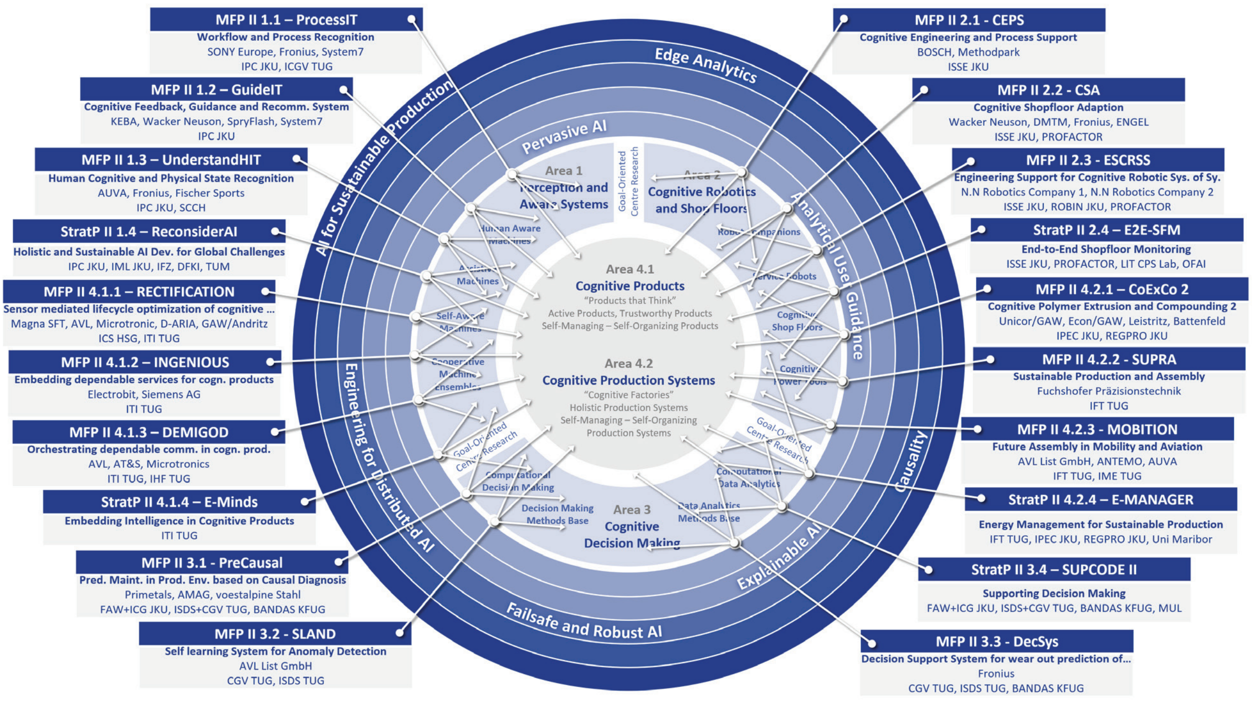
Area 2 works on (i) **Reasoning and Acting** (developing systems to manipulate and monitor industrial information and workflows and logistics), (ii) **Production Process Management** (interconnecting inventory management with shop floor logistics, QM-systems and serialization), (iii) **Multimodal Knowledge Transfer and Learning Support** (supporting tools that allow understanding human activities with respect to workflows and actions on the shop floor), and (iv) **Cognitive Shop Floors** (eco-systems of cognitive power tool entities, equipped with higher organizational abstraction layers for representation of complex production procedures, awareness and prosecution of general superior goals).

Area 2 mainly contributes to the realization of Cognitive Production Systems in Area 4.2, **integrating cognitive functions** like perception, self-awareness, user modeling and interaction modalities from Area 1 and **decision-making processes** from Area 3 **into automated production processes**. Furthermore, experience in the development of cognitive tools in the industrial field of application contributes to the **realization of cognitive end-user products** in Area 4.1.

Area 3 "Cognitive Decision Making" focuses on researching the aspect of **computational decision-making**, starting with the creation of **novel analysis techniques for large amounts of data**, via the development of **classification systems for industry**, reaching up to the development of industrial systems that **autonomously forecast** undesirable system states and **pre-emptively** take unobtrusive, **corrective action** on all granular system levels from single production actuator to ensembles or even control of complete shop floor entities.

Area 3 works on (i) **Data Analytics Method Bases** (general cognitive functions for base and reality mining, scientific, semantic visualization of data), (ii) **Computational Data Analytics** (providing cognition-based functions for handling of data under uncertainty), (iii) **Decision Making Method Bases** (models of cognitive functions for decision making including goal and plan representation, resource allocation and optimization of processes), and (iv) **Computational Decision Making** (transparent automatic multi-criteria, multi-resource decision making, choice modeling and heuristics).

Area 3 contributes the **identification of transparent and optimal solutions** under time, resource and strategy constraints, and processing of reliable as well as potentially unreliable data. These contributions represent fundamental components of any autonomous, cognitive production system or end-user product equipped with perception and self-awareness.



The results of Areas 1-3 enable the direct fusion of the respective contributions (perception, context interpretation, awareness, decision-making, learning, and executive behaviour) into cognitive systems headed by Area 4, with the subcategories of 4.1 Cognitive Products and 4.2 Cognitive Production Systems.

The focus of **Area 4.1 "Cognitive Products"** lies in the development of: (i) **Self-organizing Products** - products that manage their processes without need for interaction with centralized control units and are able to react to disturbances that limit their operability in a corrective manner), and (ii) **Active and Trustworthy Products** - products that communicate actively with other products and production lines to increase productivity by decreasing overheads. A trust system manages resource allocation to solve scheduling issues.

A separate yet related subject matter is investigated in **Area 4.2 "Cognitive Production Systems"**, focusing on: (i) **Cognitive Factories and Factory Floors** - by processing data generated by their individual subsystems and components, cognitive factories react under real-time constraints to situations occurring in industrial systems, both properly as defined in the production flow and unexpectedly and potentially impeding to productivity; (ii) **Holistic Production Systems** - design and development of entire industrial shop floors starting at each individual component and their interactions to subsystems. In this manner, decentralized systems can be conceived that can enact arbitrarily complex changes to the production chain. (iii) **Self-organizing Production Systems** - in effect entire industrial installations that communicate and cooperate to optimize productivity. Each of the components of such an installation generates shares and processes information in order to pre-emptively detect unexpected system states and take preventive measures.

Scientific advance, technological progress and changing industrial needs have led to enhance the research agenda of Pro²Future with **cross-area topics**. Among those are **Artificial Intelligence**, **Complexity Science** and **Safety** related **topics: PervasiveAI, Engineering for Distributed AI, ExplainableAI, Analytical User Guidance, Causality, Edge Analytics, Failsafe and Robust AI, AI for Sustainable Production.** So while Pro²Future **will continue** to **deepen** the **thematic focus** along the research goals **in the Areas 1, 2, 3, 4.1 and 4.2.**, the planned cross area research will be addressing the dynamics of industrial digital transformation during Funding Period 2.

Addressing the a foreseeable **“post digitalization” era** in industrial innovation, **Pro²Future** has coined the term **Tiny AI**, i.e. the **miniaturization** and **autonomization** of **seamlessly embedded AI technologies** fertilizing a ground breaking, rigorous and ubiquitous **“cognification” era of industrial systems**. Current trends include the **deployment** of **AI technology** in **industry**, involving **centralized**, **edge** and **cloud**-**based back**-**end AI**, with **very complex algorithmic machine learning** strategies, **massive computational effort** for model **training** and **inference** and **intricate generation** and **handling** of **huge data sets**. **Tiny AI**, in contrast, aims for a **radically miniaturized**, **radically dispersed, federated, resource-efficient, low power, low algorithmic complexity, live, online, human brain inspired, real-time AI** that operates **on-device,** and reliably even in **harsh environments.** The **size** of **Tiny AI target devices** ranges from **sub-millimeter** to a **few decimeters,** the **powering** from **mW** to **max 100W.**

The **Tiny AI research strategy** is aligned with the research topics **Tiny Machine Learning**, **Tiny Robots**, **Tiny Dependable Systems** and **Tiny Ensembles**, and is operatively implemented in four entangled projects (P1 **Live Learning**, P2 **Neuromorphic Control**, P3 **Dependable Miniatures** and P4 **Orchestration**).

Tiny AI strives towards **scientific foundations** and **technological breakthroughs** for **autonomic on-device AI,** and its amplification to **collective on-multiple-device AI.** The expected results include (i) the **miniaturization** of AI systems (hardware, algorithms, methods) into **Tiny AI**s, (ii) the **orchestration** of **dispersed tiny AIs**, (iii) the **opportunistic self-organization** of **limited resource ensemble AIs**, (iv) **reinforcement**-, **federated**- and **transfer**-**learning models** and **methods** to operate **tiny AI**s, (iv) **self-evolving tiny robotic brains**, **neuromorphic processing architectures** and **processor designs**, as well as (v) the **mapping** of all the related **findings** into the **cognification** of **products** and **production systems** of the future.

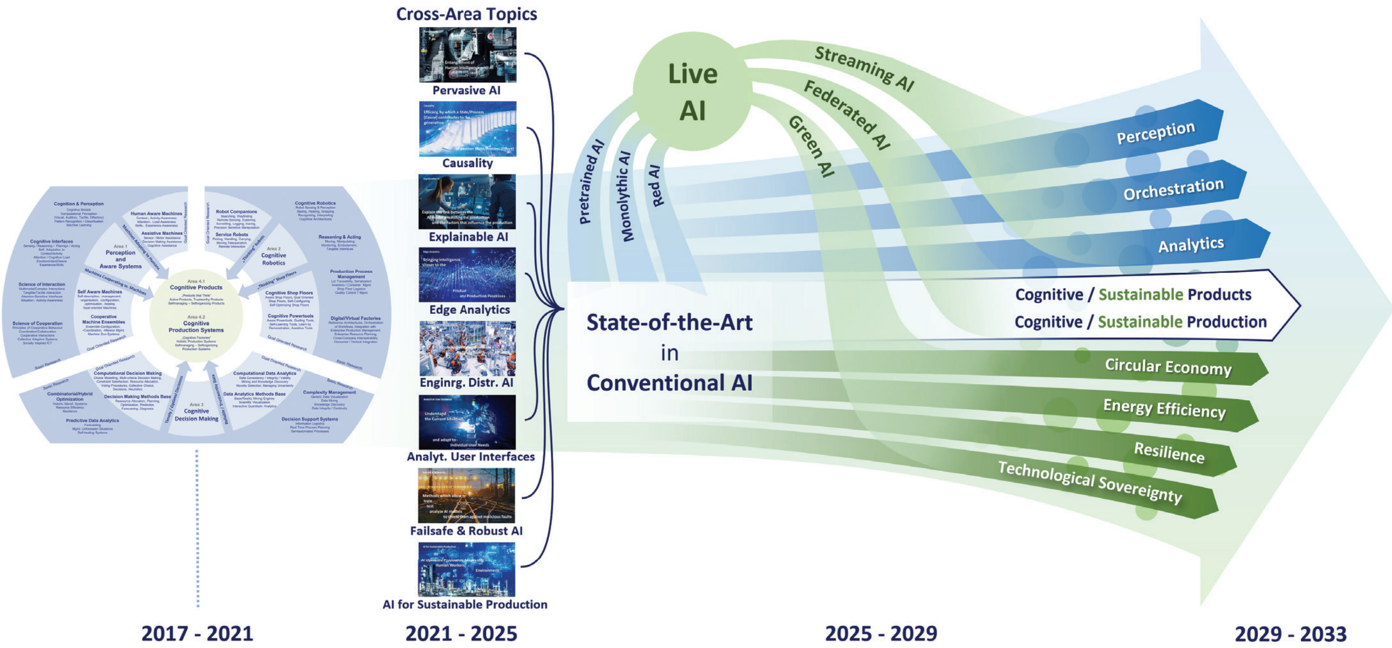
We have established a **unique composition** of **research expertise,** ranging from **cognitive systems**, **deep learning**, **human** and **computational perception**, **complex adaptive systems**, **pervasive AI, systems-of-systems**, **dependable systems**, **mechanics** and **robotic kinematics** from superlative institutions (**JKU Linz**, **TU Graz**, **DFKI**, **TU Munich**, **MIT Media Lab**) and **Pro²Future researchers.** The **academic scientists** are **complemented by industrial researchers** from Europe’s No 1 in **semiconductors** (**STMicroelectronics, Monza**), now envisioning the next generation of neuromorphic processor design, world’s No 5 in **welding technologies** (**Fronius, Wels**), the world No 1 in **Power Train** simulation and test technology (**AVL, Graz**), a world leader in **bending, power technologies** and **diodes** (**TRUMPF, Linz**), and a vibrant, agile and high potential **innovator SME** (**STTech, Munich**).

As an additional fundamental strategic research development, the research agenda for "**products-as-a-service**" and "**productions-as-a-service**" (**P²aaS**) was developed besides the **Tiny AI** research agenda are embedded in the existing Area structure and executed research direction.

P²aaS focuses on sustainable IPPSSs and servitization for a circular economy, **which are key to high quality products and sustainable production**. For this purpose, **P²aaS** conducts comprehensive, **interdisciplinary research into sustainable IPPSS (integrated product production service systems)/servitization**, both from a **technical and economic perspective**, resulting in deepened understanding and knowledge as well as innovative methods and tools. Using cognitive industrial technologies and considering the involvement of users/customers, these methods and tools **enable efficient and effective "fit-making" of products and (only partially digitised) production systems in the direction of "as a service"** as **well as the corresponding connection to existing services**.

From a scientific and technological perspective, **P²aaS will address the following key challenges** of sustainable IPPSSs and servitization in particular: (**i)** how to support **integration of legacy automation systems** in an envisioned servitization environment; **ii)** how to create and use **data shadows to manage production within and across plants especially considering the human factor**; **iii)** how **to manage the variability of products, production systems** and related services; **iv)** how to best use data to **understand impact and influencing factors throughout the lifecycle** to improve design, development, production, product and service (causal discovery); **v) prediction as a service (predictive analytics) to support recycling readiness and production planning** for recyclable materials; **vi) quality as a service** requiring the research of models **for the relationship between quality and sustainability of products**; **vii) business models and related innovations for circular economy**; **viii)** and **sustainability monitoring of IPPSS and a circular economy** within organisations and in surrounding ecosystems.

P²aaS will pave the way for the far-reaching, environmentally friendly, and economically successful establishment of sustainable IPPSSs and



servitization in a circular economy, opens a wealth of promising new research as well as business fields, and enables Austria to take a pioneering position here.

Today's applications of **AI technology** in **industry** involve **centralized**, **edge** and **cloud-based back-end AI**, with **very resource aggressive algorithmic machine learning** strategies **(processing power, memory, energy)**, **massive ecological impact (greenhouse gas emissions)** for model **training** and **inference**, and **intricate collection**, **generation** and **handling** of **huge training data sets**. Very recent advances in conversational AI (OpenAI GPT-4, Bard, LaMDA, Bedrock, etc.) have evidenced that the application of **AI** can **significantly harm the environment**.
Contrasting conventional (i) **pretrained**, (ii) **holistic** and (iii) **resource aggressive** AI, **Live AI** attempts to align AI technology and methodology with the industrial digital transformation reality, in that it introduces (i) **streaming AI**, i.e. **training** models **on-the-fly** while in operation, thus avoiding the need for mass data prior to commissioning, (ii) **federated on-device AI**, i.e. AI dispersed and distributed across different shopfloors, machines, appliances, processes and devices, thus avoiding bulky mass storage management and centralized server farms, and (iii) **green AI**, i.e. employing **spiking** deep learning techniques and **neuromorphic** processing principles, thus avoiding exponential training complexity growth induced by increasing model size.

Live AI research is structured along four topical research pillars **(i) Live Perception**, operatively implemented in the context of embedded brain-inspired perception in project P1 *Floating Perception*, **(ii) Live Federates**, addressing floating energy storage for e-mobility in project P2 *Liquid Federates*, **(iii) Live Learning**, to be approved in the context of renewable energy generation management in project P3 *On-line Learning* and **(iv) Live Dependability,** addressed with the creation of cognitive in project P4 *Dependable Embedded Machine Learning*.

Live AI brings together a unique aggregate of **complementary research expertise**, ranging from **cognitive systems**, **deep learning**, **human** and **computational perception**, **collective adaptive systems**, **dependable systems**, **cooperative** and **pervasive AI**, from internationally renowned research institutions (**JKU Linz**, **TU Graz**, **DFKI**, **TU Munich**) and **Pro²Future researchers.** The **academic scientists** are **complemented** by **industrial researchers** from Europe's No 1 in **semiconductors** (**STMicroelectronics**), now envisioning the next generation of neuromorphic processor design, world's No 5 in **welding technologies** (**Fronius**), the world No 1 in **Power Train** simulation and test technology (**AVL**), a world leader in **bending, power technologies** and **diodes** (**TRUMPF**), and a vibrant, agile and high potential **innovator in sustainable energy systems** (**eww**).

Live AI will interlink Pro²Future with (i) **world leading research** in **cognitive systems** (HBP – Human Brain Project) and **human empowerment** through **AI** (HumaneE AI Project), (ii) with **world leading industries** (STMicroelectronics, AVL, Fronius, TRUMPF), and (iii) embed Pro²Future into **European AI research networks** and **hubs** (ellis, CLAIRE, HumanE AI Net).

EXECUTIVE SUMMARY

Area 1

Perception and Aware Systems (FP1)

Area Leader: Prof. Alois Ferscha (JKU)
Area Manager: DI Michael Haslgrübler (Pro²Future)

Goals

The Perception and Aware Systems Area is devoted to apply state of the art research drawn from **cognition, perception**, **cognitive interfaces**, **interaction,** and **cooperation** to an industrial context. Thus, area 1 focusses on scenarios where machines (i) should **adapt to workers' limitations (Human Aware Machines),** (ii) support workers in their **strengths** (**Assistive Machines**), and (iii) **cooperate** with other **ICT systems**, thereby forming **collaborative industrial ensembles**, in order to achieve (i) and (ii).

For **Machines Cooperating with Machines,** we enabled true **autonomous collaboration** from **single machines** to complete **ensembles** based on (i) **self-awareness** and **self-organization** of individual entities (hard and software) and (ii) **goal-oriented entanglement of actors**, while still maintaining **traceability** and **transparency** of ongoing communication and **decision making** in these full-**automated processes** by providing **identification** and **communication** of the most important, critical, and decisive factors and meta data.

For **Machines Adapting to Humans,** we provide **safe** and **supportive interaction** between systems and human workers based on a fundamental **awareness** of **presence**, but enriched through understanding of **current context**, **ongoing activities** as well as an assessment of **higher-level cognitive states** of the human co-workers. This especially includes assessment of **orientation** and **intensity** of **attention** of the humans, estimation of **cognitive load** levels, as well as evaluation of **operator skill** levels to enable the selection and execution of appropriate supportive measures. These ambitions required us to develop a tight and encompassing **feedback loop between human behaviour** and system **reactions**, resembling human **perception and interpretation capabilities** of observed behaviour, often in the form of **nonverbal** and **implicit interaction patterns triggered by the system** steering human operators away from sub-optimal outcomes of their behaviour.

Approach

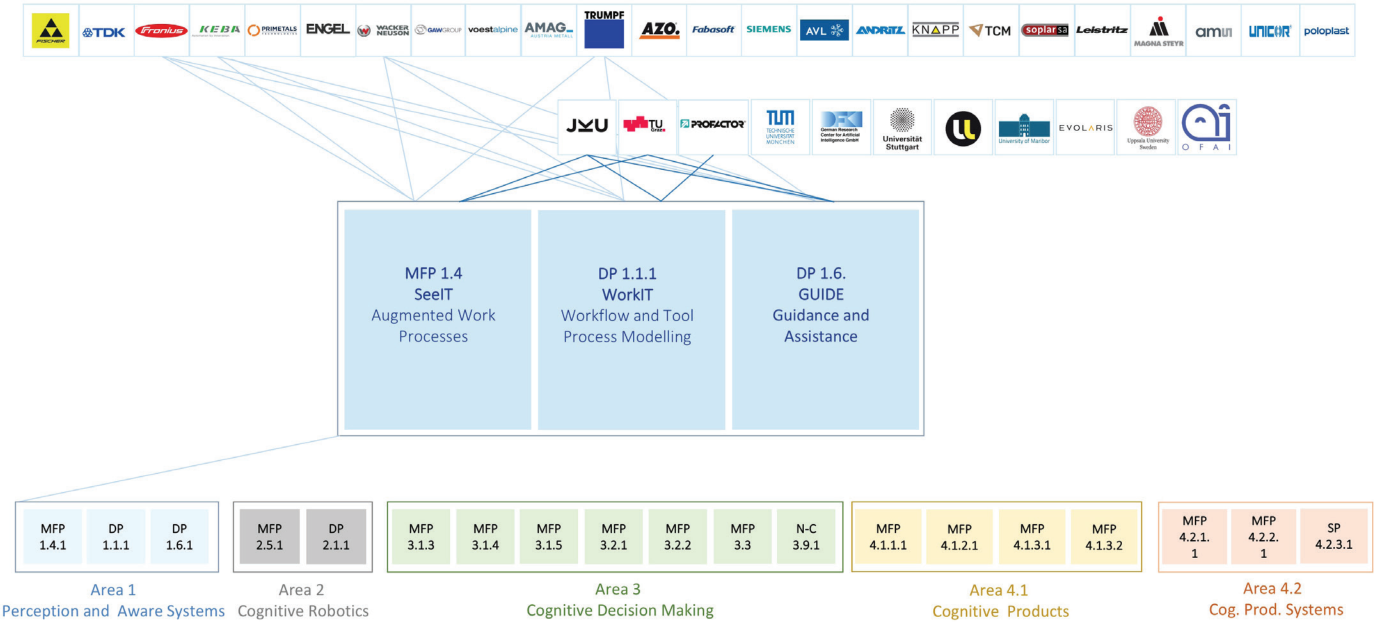
Area 1 mainly relies on **established methods** and **technologies** for the computational **recognition** of **context** and **modelling** of **self-awareness in embedded distributed systems** and **interaction design.** These methods are extended in three areas of our work: sensing, reasoning, and actuating and applied to solve needs of industrial partners and advance scientific understanding in these areas

Sensing – With tight cooperation with our lead contributors (JKU), who has a **long lasting experience** in this field, we implemented several sensing components and also fused heterogeneous sensor sources together in order to be able to perceive, abstract, interact, cooperate and learn of all the types of context and activities as well as **higher level cognitive derivatives.** We used (i) **visual sensors** (cameras for visual analysis, motion capturing) (ii) **infrared** (depth sensing, eye tracking) (iii) **auditory** (binaural micros) (iv) **tactile** (button, pressure sensors) (v) **motion** (Shimmer IMUs, Phidgets) for e.g. (I) **behaviour analysis** (activity tracking sensors) (II) **estimation of visual attention** (wearable eye gaze tracker) and (III) **measuring somatic indicators** of **attention** (skin conductance (GSR), pupil dilation, heart rate variability).

Reasoning – We implemented two lines of work, **reasoning about** the **worker** or the **environment**. For the first part we used **modelling techniques of human behaviour**. E.g. for Cognitive load detection we employed high-level cognitive models (e.g. SEEV attention model), by making use of **physiological indicators** such as heart rate and breathing, body posture and movements. We also investigated how behavioural data reveals operator skill levels, e.g. by interaction patterns with user interfaces or by the data captured by motion sensors during use.

For the second part, the reasoning about the environment we built e.g. a **Location awareness** – component by making use of **embedded computer vision** and **sensor fusion** techniques, combining multiple imaging modalities, such as RGB, depth and infrared but also inertial measurements to perform **simultaneous localization and mapping** to have **3D models** of the environments, which we use to annotate semantically and can be used to provide location specific information to users.

Actuating Having established computational awareness, of operators and users, based on sensing and reasoning, we used **neuro-physiological models**, e.g. Multiple Resource Theory, to create a new forms of interaction designs. We built hardware and software prototypes, e.g. in the form of wearables, which are able to **stimulate human operators subliminal** but effectively, providing a long-overdue change from today's attention-grabbing towards attentive-preserving computing devices. In addition, these devices are not only **designed to fit into processes** of their use, freeing users from adapting to the device, but are **adapting to operators** by assessing e.g. their skill level or the current cognitive load and **provide help if human need requires it,** e.g.



by providing explicit help, e.g. in the form of video snippets or limiting options on user interfaces to a necessary minimum, respectively.

Expected and achieved Results

We expected with our work to move beyond State of the Art **in Human-Aware, Assistive Machines** and **Cognitive Modelling**. A significant step beyond current state-of-the-art was made in the field of s**elf-aware, human aware and assistive, cooperative machines** by development of encompassing **perception**, **interpretation** and **understanding** of **human activities** and underlying **motivations** to enable true **collaborative cooperation** between human and machines in the industrial production process of several of our company partners. The **interpretation** of **cognitive states** of human workers requires the application and realization of complex computational models of (i) **perception**, (ii) **attention**, (iii) **motivation** and (iv) **executive behaviour** based on models from **cognitive** and **behavioural psychology**.
Based on the aforementioned three pillars of sensing, reasoning and actuating, we realised the following: (i) **Abstractions** and **models** of **industrial worker context** where effort (body pose, gestures, movement, etc.) is of constituent and essential significance; (ii) A **cooperation framework** for cognitive entities, forming a collective of devices to facilitate **user guidance** through complex workflows and assembly situations; (iii) A **recognition architecture** making use of heterogenous sensors for several recognition challenges; (iv) An **end-to-end framework** for capturing low-level visual sensor data and transforming it into high-level actions such as the active step in the manufacturing workflow and a users' **cognitive state** and **skill level**; (v) Providing the fundamental **basis for** future **self-aware system**, by following principles of **autonomous operation**, **self-adaptation,** and **self-improvement;** (iv) a pre-emptive quality assurance system with seamless integration of quality assurance data into existing quality management processes (vii) Provided insights to the scientific community and gathering feedback on our results in **18 peer-reviewed outlets: one Journal Publication and seventeen conference publications**

The aforementioned results were developed in **DP1.1 WorkIT - Workflow and Tool Process Modelling, DP1.6 Guide – Cognitive Assistance** and **MFP 1.4 SEE-IT Augmented Work Processes,** which were started together in January 2018, whereby all three projects are supported by the same Company Partners, namely Fronius, KEBA, Trumpf and Wacker Neuson and are interwoven to avoid duplicated developments and foster synergy effects. These projects are structured along three major axes: "**DP1.1 WorkIT**" deals with the recognition and perception of work situations and workflows (exemplary results: used tool detection from Ego-Centric View; Multi-Sensor Fusion Based Detection of Worker Activities based on IMU and Visual Data), and provide pre-processed sensor data streams to "**DP1.6 Guidance and Assistance"** (exemplary results: A welding helmet with an embedded an eye tracker computing Index of Pupillary Activity; Lightweight prototype for navigation and 3D reconstruction), which creates assistance systems and compute guidance triggers that are further communicated to "**MFP_1.4 SEE-IT**" (exemplary results: Head worn tactile navigation device; Wrist-Worn Embedded Visual/ Tactile Subliminal Stimulation Device), which investigates feedback- and actuator systems to communicate the formulated guidance to the worker. Throughout the funding period we deepened our work from "**DP1.6 Guidance and Assistance**" by adding three more partners, Fischer Sports, Sony Europe and System 7 to the MFP umbrella, with the partners strengthening already existing topics of **skill recognition**, **digitalisation of industrial environments** and **guidance based on unsupervised machine learning**.

Positioning of the Area within the Centre

The challenge for Area 1 is the investigation of **perception and computational awareness** in the domain of cognitive research, which represents a foundational research basis for the efforts of the other work areas. Especially the **focus on** and around system **operators**, is an essential factor in Area 1 and a pillar upon other Areas can build on. We, as well as other researchers, see **perception as a necessary precursor** (i) to give cognitive properties to systems (cognitive products), and (ii) for implementing cognitive systems (cognitive production). It is not enough to, as many companies do, making systems "smarter", but to design and implemented an **aware and human-centric approach** for the next generation of systems, i.e. making computing cognitive.
Our rigorous approach towards cognitive products and production systems is streamlined with activities in the other areas, providing additional value for our and other projects of all areas: E.g. we will integrate **dependable localisation approaches** developed for calculating viewpoint and distance between actuators and workers from Area 4.1; we will employ dependable **wireless communication facilities** from Area 4.1 or use novel production techniques of Area 4.2 for structuring functions of our cognitive headgear; we will use **interoperability techniques** for machine and robot interaction provided by Area 2. With Area 3 we have informal collaboration by exchanging ideas regarding **machine learning** and decision-making techniques.

EXECUTIVE SUMMARY

Area 1
Perception and Aware Systems (FP2)

Area Leader: Prof. Alois Ferscha (JKU), Prof. Alois Knoll (TUM)
Area Manager: DI Dr. Michael Haslgrübler (Pro²Future)

Vision and Strategy

In Area 1 “Perception and Aware Systems”, researchers focus on the simplification of interactions between humans and machines in order to facilitate the implementation of sophisticated cooperation and reasoning systems. Area 1 investigates and creates cognitive systems that are able to sense, reason, interact and cooperate to optimally solve problems and adapt themselves to changing contexts. The goal-oriented research addresses: (i) Human Aware Machines - sensing, interpretation and understanding context-, activity-, attention-awareness; (ii) Assistive Machines - cognition-based assistance services for cognitive and decision making processes; (iii) Self-Aware machines – Modelling self-description and self-management of production machines; (iv) Cooperative Machine Ensembles - Creation of standalone eco-systems of production machines, coordination in production ensembles.
Its projects aim specifically towards increasing machine-machine cooperation and the timely adaptation of machines to human needs and actions. To the core areas, Area 1 specifically contributes to Area 4.1 in terms of integration of cognitive functionalities into end-consumer products as well as to Area 4.2 regarding interaction processes enabling the realization of cognitive production systems.

Goals

The Perception and Aware Systems Area is devoted to applying state of the art research drawn from cognition, perception, cognitive interfaces, interaction, and cooperation to an industrial context. Thus, area 1 focusses on scenarios where machines (i) should adapt to workers’ limitations (Human Aware Machines), (ii) support workers in their strengths (Assistive Machines), and (iii) cooperate with other ICT systems, thereby forming collaborative industrial ensembles, in order to achieve (i) and (ii).
Machines Cooperating with Machines We enabled true autonomous collaboration from single machines to complete ensembles based on (i) self-awareness and self-organization of individual entities (hard and software) and (ii) goal-oriented entanglement, while still maintaining traceability and transparency of ongoing communication and decision making in these full-automated processes by providing identification and com-munication of most important, critical, and decisive factors.
Machines Adapting to Humans We provide safe and supportive interaction between systems and human workers on a fundamental awareness of presence, but through understanding of current context, ongoing activities as well as an assessment of higher-level cognitive states of the human co-workers. This especially includes assessment of orientation and intensity of attention of the humans, estimation of cognitive load levels, as well as evaluation of operator skill levels to enable the selection and execution of appropriate supportive measures. These ambitions required us to develop a tight and encompassing feedback loop between human behaviour and reactions, resembling human perception and interpretation capabilities of observed behaviour and often in the form of nonverbal and implicit interaction patterns.

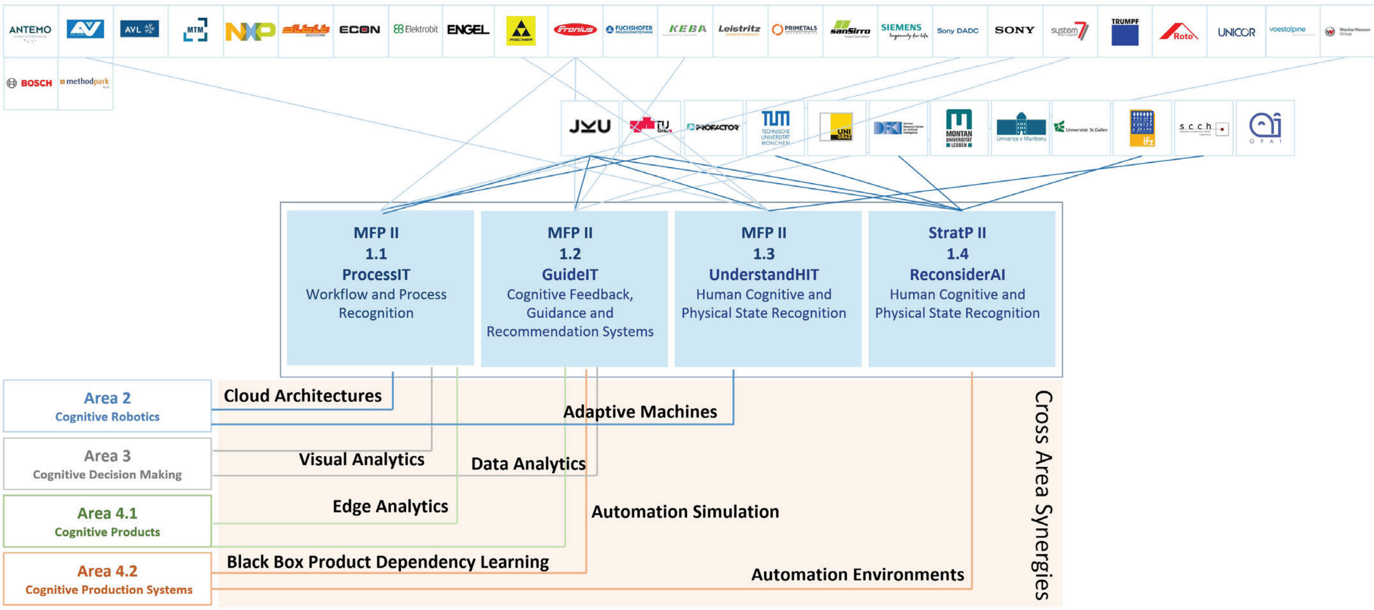
Beyond State of the Art

in Human-Aware, Assistive Machines and Cognitive Modelling A significant step beyond current state-of-the-art was made in the field of self-aware, human aware and assistive, cooperative machines by development of encompassing perception, interpretation and understanding of human activities and underlying motivations to enable true collaborative cooperation between human and machines in the industrial production process of several of our company partners. The interpretation of cognitive states of human workers requires the application and realization of complex computational models of (i) perception, (ii) attention, (iii) motivation and (iv) executive behaviour based on models from cognitive and behavioural psychology. The lack of reliable ground truths, metrics and boundary definition of the complex cognitive functions makes the field of cognitive modelling one of the most ambitious and risky goals of the our endeavour, yet by making use of developments in computational modelling of neuronal activities (Deep Learning, Neuronal Networks) we completed our goals in several of the four mentioned states.

Approach

Area 1 mainly relies on established methods and technologies for the computational recognition of context and modelling of self-awareness in embedded distributed systems and interaction design. These methods are extended in three areas of our work: sensing, reasoning, and actuating and applied to solve needs of industrial partners and advance scientific understanding in these areas.

Sensing – With tight cooperation with our lead contributors (JKU), who has a long lasting experience in this field, we implemented several sensing components and also fused heterogeneous sensor sources together in order to be able to perceive, abstract, interact, cooperate and learn of all the types of context and activities as well as higher



level cognitive derivatives. We used (i) visual sensors (cameras for visual analysis, motion capturing) (ii) infrared (Kinect, eye tracking) (iii) auditory (binaural micros) (iv) tactile (button, pressure sensors) (v) motion (Shimmer IMUs, Phidgets) for e.g. (I) behaviour analysis (activity tracking sensors) (II) estimation of visual attention (wearable eye gaze tracker) and (III) measuring somatic indicators of attention (skin conductance (GSR), pupil dilation, heart rate variability).
Reasoning – We implemented two lines of work, reasoning about the worker or the environment. For the first part we used modelling techniques of human behaviour. E.g. for Cognitive load detection we employed high-level cognitive models (e.g. SEEV attention model), by making use of physiological indicators such as heart rate and breathing, body posture and movements.
For the second part, the reasoning about the environment we built e.g. a Location awareness – component by making use of embedded computer vision and sensor fusion techniques, combining multiple imaging modalities, such as RGB, depth and infrared but also inertial measurements to perform simultaneous localization and mapping to have 3D models of the environments.
Actuating Having established computational awareness based on sensing and reasoning, we used neuro-physiological models, e.g. Multiple Resource Theory, to create a new forms of interaction designs. We built hardware and software prototypes, e.g. in the form of wearables, which are able to stimulate human operators subliminal but effectively, providing a long-overdue change from today's attention-grabbing devices. In addition, these devices are not only designed to fit into processes of their use, freeing users from adapting to the device, but are adapting to operators by assessing e.g. their skill level or the current cognitive load and provide help if human need requires it.

Achieved Results so far

• Abstractions and models of industrial worker context where effort (body pose, gestures, movement, etc.) is of constituent and essential significance
• A cooperation framework for cognitive entities, forming a collective of devices to facilitate user guidance through complex workflows and assembly situations
• A recognition architecture making use of heterogenous sensors for several recognition challenges
• An end-to-end framework for capturing low-level visual sensor data and transforming it into high-level actions such as the active step in the manufacturing workflow and a users' cognitive state and skill level
• Providing the fundamental basis for future self-aware system, by following principles of autonomous operation, self-adaptation, and self-improvement
• Providing insights to the scientific community and gathering feedback on our results in 18 peer-reviewed outlets: one Journal Publication and seventeen conference publications

Instead of perusing the strategic project Ethics (Ethical Machines) within the COMET frame, we opted for perusing, in conjunction with a strategic partner Interdisciplinary Research Centre for Technology, Work and Culture. Within the project started March 2020, we aim to developed guidelines and principles which can be adopted by policy makers, using-companies, tech-companies, labour organisations and workers, to create responsible embedding of AI technology into everyday life of workers.

Area 1's mission in FP2 is a bilateral effort of providing perception and awareness to humans and machines alike. We not only strive to enhance the capabilities of technical systems by embedding cognitive abilities and features into them. But also, to enhance perception and awareness of humans regarding their environment and their daily doing using technology. We foresee that through the pervasive embedding of AI in everyday objects, human existence can be enriched by gaining process understanding, by guiding them in complex situations or by seeing how their doing affects themselves and others in physical and mental aspects. Therefore Pervasive AI is a cross-cutting technological fabric found in all our projects. We will use it to build such systems and Sustainability - especially - in Production will be our guiding principle when realising such systems. Therefor we have setup three industrial and one strategic project to shape this vision. With ProcessIT we enable humans and machines to gain understanding to socio-technical processes, e.g. workflows by embedding AI into it. In GuideIT we ensure that humans are supported through technological means when interacting with complex processes or machines. In UnderstandHIT we enable machines to gain understanding of what affects human nature, such as temporary effects e.g. emotional state but also liked longer effects e.g. skill. In our strategic project, ReconsiderAI we want to extend our vision of sustainable AI in production to other areas outside of production, where we want to guide research by creating strategies, guidelines and showcasing of prototypes.

Positioning of the Area within the Centre: Area 1 is well connected with the topics addressed in other areas and influences their development, especially where human computer interaction is. A strong connection with Area 2 is the interaction of men and machine and distributed technology on the shop floor. With Area 3 we share goals of making what AIs do explainable and that operators need user guidance. A common goal of Area 1 and Area 4.1 is that analytics needs to be closer to the data sources and failsafe. With area 4.2 we share that vision for sustainable AI for production.

EXECUTIVE SUMMARY

Area 2

Cognitive Robotics and Shop Floors (FP1)

Area Leaders: Prof. Alexander Egyed (JKU), Dr. Andreas Pichler (PRO), Prof. Andreas Müller (JKU), Prof. Alois Knoll (TUM)
Area Manager: DI Michael Mayrhofer (Pro²Future), formerly Dr. Christoph Mayr-Dorn (JKU), Georg Weichhart (PROFACTOR)

Goals

Changing business environments and the dynamics of modern consumer markets requires flexible production systems capable of adapting to not only short term fluctuations in demand, but also long term flexibility with respect to evolving production systems towards new capabilities in the future.
"Thinking" Shop Floors - In Area 2 the technological basis for cognitive systems, able to adapt production machines (individual systems), entire shop floors (systems of systems), and even the product- and production design and engineering process (design for adaptability) is researched. The main cognitive function addressed is learning, supporting humans with the ability to teach new production processes to flexible machines and shop floors. The ultimate research goal for Area 2 is to enable change and learning at all levels from individual machines to shop floors – naturally supporting humans in contributing/intervening at any one of these levels (cognitive aspects).

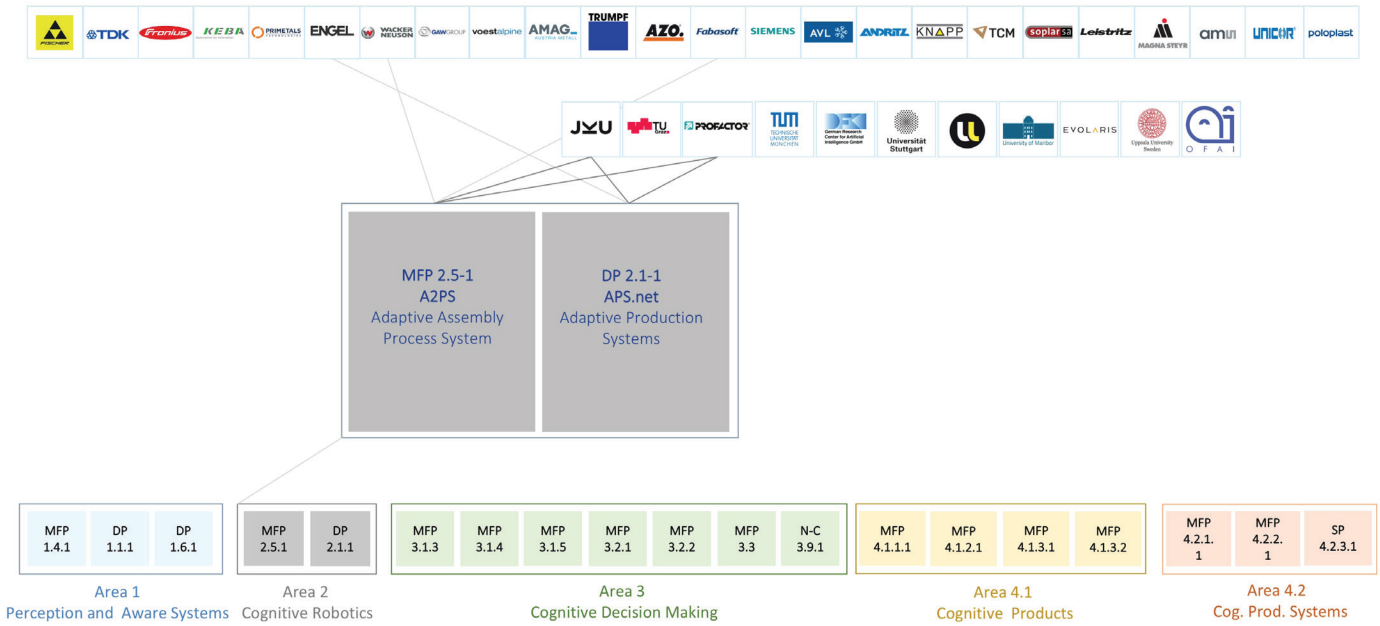
"Thinking" Robots - Another major goal of Pro²Future is equipping robots with human-like cognitive functions of (i) **self-awareness** (integration of sensing, perception, interpretation concepts from Area 1), (ii) **autonomous decision making** (integration of computational, multi-criteria decision making processes from Area 2), (iii) capabilities for **handling spatial tasks** (orientation, searching, wayfinding etc.) as well as (iv) **performing** object/workpiece **manipulation tasks** (identification, translation, handling of workpieces) to enable assistive actions (integration of decision making processes from Area 3)
.
Beyond State of the Art in Cognitive Robotics - Collaborative robotics, including robot-robot and robot-human collaboration, require approaches to create safer and more efficient production processes e.g. improved automatic perception of the human worker and the environment. However, these approaches hardly exceed presence detection for accident evasion. Pro²Future aims at enabling understanding of current human activities and cognitive load. This allows innovative kinds of interaction and learning, to support collaboration between robots/machines and between robots and humans.

To understand adaptation in cognitive robotics and shop floors, Area 2 established the following main goals: (i) realise **learning support for adaptation** (both as a means for better guiding adaptation and teaching new production), (ii) **support the humans** in the loop to set the goals for adaptation, and (iii) **design for adaptability** to support future adaptation goals.
Teaching Manufacturing and Learning How to Adapt is not just about changing the physical structure of a shop floor but it is also about changing its behaviour. This is where most of the "smartness" can be found and hence most of the cognitive aspects of adaptation are to be found in layer 3 as it embodies any form of complex behaviour: from a coordinated manufacturing step that requires synchronous machine behaviour (e.g., a stop action) to continuously changing manufacturing of a product.

Adapting shop floor behaviour is not only challenging but also requires a significant software engineering effort. We thus develop cognitive means for letting humans (e.g., a worker) change this behaviour in an intuitive manner: through teaching and learning, where humans demonstrate and machines repeat. On the most basic level, learning is about remembering past adaptations. If a shop floor existed (in part) then future adaptations may benefit from remembering it. For example, if a set of machines is adapted in a manner that is structurally identical to a previous shop floor adaptation then configuration parameters of these machines may be reusable. And even more significantly, so might be structural and behavioural aspects of their interaction on the shop floor level. Of course, on a more advanced level, "smartness" may also benefit from machine learning and other learning concepts. This should work well for repeatable patterns of interactions that can be demonstrated once and repeated indefinitely. However, it is tricky to understand when a pattern no longer applies (an exceptional situation) or when variations of patterns exist.

Therefore, scenario-driven approaches to teaching and learning are explored also. Moreover, teaching and learning at different levels of granularity: at the level of a machine and its manufacturing step(s) to the level of a shop floor and its structure and behaviour needs during manufacturing.

Human Guided Adaptation is the result of human interaction – from shop floor workers who may trigger adaptation because of a changing production need all the way to production processes where possible goal scenarios are articulated and transcribed by adaptation process engineers. Hence, it must be understood that the adaptation of machines and shop floors could be automated (controlled by a self-optimising software - Area 3) or manual (controlled by workers). However, we always expect a human decision maker to be involved. This human could be a supervisor, a smart contributor, or even a conflict resolver if there are multiple suitable alternatives. It is foreseeable that all four



layers in Figure 3.4.1 above impose different challenges onto cognitive guidance. Furthermore, it is clear that humans are a central actor in teaching and learning. They define adaptation goals, they guide/support the adaptation if it is not fully automated (likely the norm), they help decide/resolve adaptation constraints (e.g., you can have A, you can have B, but you cannot have both - what do you want?), they teach, and they design/engineer. These roles may overlap but are just as likely to involve different kinds of people with different skills and different cognitive needs and abilities.

Designing for adaptability and its evolution is necessary no matter how carefully a machine is designed for adaptation and no matter how many adaptation scenarios a shop floor is able to support. Designing for adaptability and its evolution is about engineering “change” into a machine or even a shop floor that is presently not configurable or teachable. Area 2 explores the continuous evolution of machines and shop floors, and how to better build adaptable machines and shop floors. In doing so, Area 2 also explores how to represent adaptation knowledge in a manner that can be acted upon and reasoned about – for example, by providing a means for defining configuration parameters and dependencies thereof. Here, an important part is to ensure safety and security during manufacturing to prevent harm to humans or machines. This imposes new levels of engineering complexity. Today, it is already hard to ensure the correctness of a single machine or a single shop floor (that is not configurable). In Pro2Future, the goal is to provide adaptation on machines and shop floors levels with a maximum of configurability and it must be assured that each possible adaptation scenario of its machines and the entire shop floor is correct.

Approach

In Area 2, the main goals are to provide the tools, infrastructure and methods to enable adaptive production systems. Production systems in this area consist of human systems and artificial systems that have a certain structure and show a certain behaviour, where the interaction of systems results in complex behaviour visible on a higher level. A shop floor can be adapted through a range of mechanisms: from reconfiguring individual machines to changing machine interaction. We distinguish the following four layers: (i) Adaptive Robotics/ Machines describe configuration parameters that provide means for changing individual machines. These configuration parameters reflect a machine’s built-in ability to change as was foreseen by the machine vendors (companies that manufacture machines). (ii) Adaptive Shop Floors describe how machines and other production resources are physically laid out within a shop floor and how this layout can be changed. We speak of the structure of a shop floor – a system of systems – where the structure understands how machines are configured and interact with each other. (iii) Adaptive Production Systems describe how machines interact in context of defined shop floor structure and how this interaction can be changed. We speak of the behaviour of a shop floor that can be changed with or without changing the structure of a shop floor (layer 2) and with or without changing the configuration parameters of its machines (layer 1). (iv) Adaptive Environment (environmental interactions) describes how shop floors and their machines may adapt to changing environment parameters.

Expected and Achieved Results

Area 2 delivered methods and tools to support the design of systems (of systems) capable for adaptation, tools to support flexible planning and execution of task within systems (of systems) capable of being adapted in structure and behaviour, and tools for adaptation of systems behaviours.

Due to changing company interests, Area 2 has changed dramatically from the initial plan (with only one former company remaining active in projects). This resulted in shifting the focus from robotics (for the initial projects) more towards adaptation and flexibilisation of shop floors as well as assembly floors.

Multiple prototypes of technical results are available. A central metamodel developed within the scope of the strategic project SP2.4 for use in MFPs across the area describes shop floor actors, organisational structure, processes, capabilities, parts, and resources (e.g., tools). The model is generic and extensible enough to cover both OPC-UA centric machine control as well as manual assembly floor activities. A cloud-based assembly progress tracking and deviation dashboard supports the monitoring of assembly processes and investigating deviations in scope of MFP 2.5. The metamodel serves, among other uses, as the basis for cognitive reasoning for scheduling and flexible adaptation plan: for example, to ensure rewiring (as conducted by the Wiring Editor) are correct and complete.

Concrete results include a framework for distributed execution of production processes, described in detail in scope of project DP 2.1 as well as a framework for (self) adaptation of human-intensive cyber-physical production systems of systems. Here the accurate monitoring of assembly progress based on incomplete observations of assembly workers conducting micro-adaptations is achieved.

Positioning of the Area within the Centre

Area 2 researches the science behind the physics and logics of adaptation and learning. As such, it does not concern itself with low-level man-machine interactions (Area 1) or decision support for humans (Area 3). Area 3 supports humans to understand the need and cope with the many variables that influence production, which enables humans to derive the goals. Using Area 1 man/machine interaction mechanisms, these goals are set for the machines. Area 2 thus complements Areas 1 and 3 in providing the mechanisms for adaptation, triggered by Area 1 and along dimensions and needs identified in Area 3.

EXECUTIVE SUMMARY

Area 2

Cognitive Robotics and Shop Floors (FP2)

Area Leaders: Prof. Alexander Egyed (JKU), Prof. Andreas Müller (JKU), Prof. Alois Knoll (TUM)
Area Manager: DI Dr. Ouijdane Guiza (Pro²Future), formerly DI Michael Mayrhofer (Pro²Future)

Vision and Strategy

Area 2 "Cognitive Robotics and Shop Floors" is directed at research on robotic systems and production systems to be incorporated into a fabric of cyber-physical industrial systems to drive the ongoing modernization of industry. The central focus is aimed at capitalizing on the flexibility and adaptability of mechatronic and robotic production systems, thereby extending this adaptability to encompass entire production processes on shop floors. This is achieved through the utilization of embodiment and the subsequent integration of physical entities with virtual representations, underscoring the overarching goal of enhancing system and process flexibility. The goal-oriented research addresses: (i) **Reasoning and Acting** - developing systems to manipulate and monitor industrial information and workflows and logistics; (ii) **Production Process Management** - seamlessly interconnecting all stages of production, ranging from initial planning through execution, culminating in quality assurance. This integration encompasses inventory management, shop floor logistics, Quality Management (QM) systems, and serialization, ensuring a cohesive and comprehensive approach to the entire production lifecycle; (iii) **Multimodal knowledge transfer and learning support** - supporting tools that allow understanding human activities with respect to workflows and actions on the shop floor; (iv) **Cognitive Shop Floors** - eco-system of cognitive power tool entities, equipped with higher organizational abstraction layers for representation of complex production procedures, awareness and prosecution of general superior goals. To the core areas, Area 2 mainly contributes to the realization of Cognitive Production Systems in Area 4.2, integrating cognitive functions like perception, self-awareness, user modelling and interaction modalities from Area 1 and decision-making processes from Area 3 into automated production processes. Furthermore, experience in the development of cognitive tools in the industrial field of application contributes to the realization of cognitive end-user products in Area 4.1.

Goals

Area 2 -The evolving landscape of business environments and the dynamic nature of modern consumer markets underscore the imperative for production systems characterized by exceptional flexibility and adaptability. These systems must not only swiftly respond to short-term demand fluctuations but also possess the capacity for long-term adaptability, enabling the seamless evolution of production capabilities to meet future requirements. **"Thinking" Shop Floors** - In Area 2 the technological basis for cognitive systems, able to adapt production machines (individual systems), entire shop floors (systems of systems), and even the product- and production design and engineering process (design for adaptability) is researched. The main cognitive function addressed is learning, supporting humans with the ability to teach new production processes to flexible machines and shop floors. The ultimate research goal for Area 2 was to enable change and learning at all levels from individual machines to shop floor – naturally supporting humans in contributing/ intervening at any one of these levels (cognitive aspects). **"Thinking" Robots** - Another major goal of the Pro²Future initiative is equipping robots with human-like cognitive functions of (i) **self-awareness** (integration of sensing, perception, interpretation concepts from Area 1), (ii) **autonomous decision making** (integration of computational, multi-criteria decision making processes from Area 2, as well as (iii) **performing object / workpiece manipulation tasks** (identification, translation, handling of workpieces) to enable assistive actions (integration of decision making processes from Area 3).

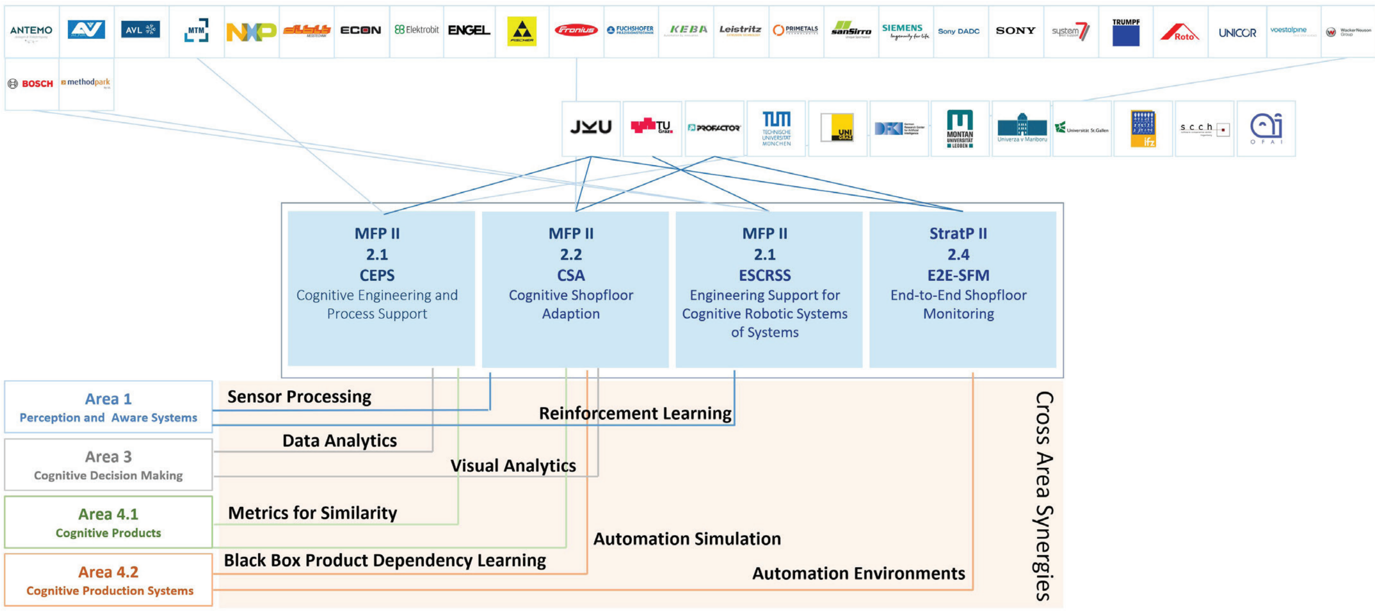
Beyond State of the Art

Cognitive Robotics - Collaborative robotics, including robot-robot and robot-human collaboration require approaches to create safer and more efficient production processes e.g. im-proved automatic perception of the human worker and the environment. However, these approaches hardly exceed presence detection for accident evasion. The Pro²Future initiative aims at enabling understanding of current human activities and cognitive load. Empowered by advanced perception skills including environmental perception, awareness of the workers and the ongoing processes, the collaborative robot (cobot) will facilitate more convenient and tailored assistance. This empowerment grants workers the much-needed flexibility to deviate from rigid processes, thus ensuring a more adaptive and accommodating operational approach. To understand adaptation in cognitive robotics and shop floors, Area 2 achieved the following main goals:

- realize learning support for adaptation (both as a means for better guiding adaptation and teaching new production)
- supporting the humans in the loop to set the goals for adaptation
- design for adaptability to support future adaptation goals

Teaching Manufacturing and Learning How to Adapt is not just about changing the physical structure of a shop floor, but it requires a more profound shift in its behavior. This is where most of the cognitive characteristics can be found as it embodies any form of complex behavior: from a coordinated manufacturing step that requires synchronous machine behavior (e.g., a stop action) to continuously changing manufacturing of a product.

Adapting shop floor behaviour is not only challenging but today it requires significant software engineering effort. We have thus developed cognitive means for letting humans (e.g., a worker) change this behavior in an intuitive manner: through teaching and learning



where humans demonstrate, and machines repeat. On the most basic level, learning is about remembering past adaptations. If a shop floor existed (in part) then future adaptations may benefit from remembering it. For example, if a set of machines are adapted in a manner that is structurally identical to a previous shop floor adaptation, then configuration parameters of these machines may be reusable. Of course, on a more advanced level, "smartness" may also benefit from machine learning and other learning concepts. This should work well for repeatable patterns of interactions that can be demonstrated once and repeated indefinitely.

Human Guided Adaptation is the result of human interaction – from shop floor workers who may trigger adaptation because of a changing production need all the way to production processes where possible goal scenarios are articulated and transcribed by adaptation process engineers. Hence, it must be understood that the adaptation of machines and shop floors could be automated (controlled by self-optimizing software - Area 3) or manual (controlled by workers). However, we always expect a human decision maker to be involved. This human could be a supervisor, a smart contributor, or even a conflict resolver if there are multiple suitable alternatives. Furthermore, it is clear that humans are a central actor in teaching and learning. They define adaptation goals, they guide/support the adaptation if it is not fully automated (likely the norm), they help decide/resolve adaptation constraints, they teach, and they design/engineer. These roles may overlap but are just as likely to involve different kinds of people with different skills and different cognitive needs and abilities.

Designing for Adaptability and its Evolution iis necessary no matter how carefully a machine is designed for adaptation and no matter how many adaptation scenarios a shop floor is able to support. Designing for adaptability and its evolution is about engineering "change" into a machine or even a shop floor that is presently not configurable or teachable. Area 2 has explored the continuous evolution of machines and shop floors and how to better build adaptable machines and shop floors. In doing so, Area 2 has also explored how to represent adaptation knowledge in a manner that can be acted upon and reasoned about – for example, by providing a means for defining configuration parameters and dependencies thereof. Here, an important part is to ensure safety and security during manufacturing to prevent harm to humans or machines. This imposes a new levels of engineering complexity. Today, it is already hard to ensure the correctness of a single machine or a single shop floor (that is not configurable). In Pro²Future, the goal is to provide adaptation on machines and shop floors levels with a maximum of configurability and it must be assured that each possible adaptation scenario of its machines and the entire shop floor is correct.

Approach

In Area 2 the main goals are to provide the tools, infrastructure and methods to enable adaptive production systems. Production systems in this area consist of human systems and artificial systems that have a certain structure and show a certain behavior, where the interaction of systems results in complex behavior visible on a higher level. A shop floor can be adapted through a range of mechanisms: from reconfiguring individual machines to changing machine interaction. We distinguish the following four layers: (i) **Adaptive Robotics/Machines** describe configuration parameters that provide means for changing individual machines. These configuration parameters reflect a machine's built-in ability to change as was foreseen by the machine vendors (companies that manufacture machines). (ii) **Adaptive Shop Floors** describe how machines and other production resources are physically laid out within a shop floor and how this layout can be changed. We speak of the structure of a shop floor – a system of system – where the structure understands how machines are configured and interact with each other. (iii) **Adaptive Production Systems** describes how machines interact in context of defined shop floor structure and how this interaction can be changed. We speak of the behavior of a shop floor that can be changed with or without changing the structure of a shop floor (layer 2) and with or without changing the configuration parameters of its machines (layer 1). (iv) **Adaptive Environment** (environmental interactions) describes how shop floors and their machines may adapt to changing environment parameters.

Expected and Achieved Results

Area 2 delivers methods and tools to support the design of systems (of systems) capable for adaptation, tools to support flexible planning and execution of task within systems (of systems) capable of being adapted in structure and behavior, and tools for adaptation of systems behaviors. Much effort has been devoted to reference projects, which resulted in attracting new Pro²Future partners (DMTM, Fabasoft, Engel). The second major effort was the interaction with- and detailed planning of the common research program (CRP)/DP2. Initial contributions to CRP and collective work involving researchers from Pro²Future, JKU and PROFACTOR is progressing as reflected in accepted publications. Furthermore, the Area has made noteworthy contributions to strategic research in the area of collaborative robots, working in tandem with Area 1. Notably, we have designed solutions for collaborative robot assistance for flexible manufacturing systems. This strategic initiative exemplifies the center inter-link and the collaborative aspect of Area 2. The Area 2 research vision has been contributed to and promoted at international research conferences as well as industrial events, and Area 2 is already getting very positive feedback on the conceptual work and research vision done in FP1 and FP2. In conclusion: (i) the conceptual work attracted new companies, and (ii) feedback from both industry and the scientific community is positive (researchers have provided direct feedback at conferences and during the review process for the scientific work that was very positive).

EXECUTIVE SUMMARY

Area 3

Cognitive Decision Making (FP1)

Area Leaders: Prof.^{in} Stefanie Lindstaedt (TU Graz), Prof. Marc Streit (JKU), Prof. Tobias Schreck (TU Graz), Prof. Josef Küng (JKU)
Area Manager: DI Dr. Belgin Mutlu (since Oct 2018, Pro²Future), Prof. Dr. Stefan Thalmann (until Sep. 2018, consulting until Sep. 2019)

Goals

Timely / Optimal Decisions - Highly complex systems often go beyond human perception and control capabilities. The Pro²Future initiative aims at supporting the handling of such complex systems via the realization of **cognitive, computational decision-making processes** to obtain optimal solutions, especially **in time sensitive situations** that overstrain the human system operator. Specifically, Pro²Future develops innovative choice modelling to enable **multi-criteria decision making**.

Beyond State of the Art in Computational Data Analytics: The crucial step beyond the current state of the art in data analytics is the requirement for **consistent analysis** and **interpretation** of **large scales** of not only **inhomogeneous data** but as well **data** of sometimes **questionable reliability** and **integrity**, which impedes **knowledge mining** as well as distinction of outliers from novelty. Hence, Pro²Future develops innovative methods for **analytic data analysis**, ranging from **visualization**, over **statistical measures** to opportunistic heuristics.

Beyond State of the Art in Computational Decision Making: The creation of choice modelling considering the multitude of decision criteria (implied sensors, actuators, resources and implications of taken actions, etc.) while still maintaining **traceability** and **transparency** of taken actions, holds a level of complexity previously unknown in the field of **industrial production control**. It is the ambition of the Pro²Future initiative to break new floors in the fields of **decision heuristics** (e.g., collective choice, voting procedures) based on **innovative decision-making methods** (Process Optimization, Prediction and Forecasting). To support human decision-making, Area 3 addresses the following two main objectives:

- combine **data-driven approaches** with configuration **management methods** and **simulation environments** in order to provide a reliable, trustworthy (data) basis for decision-making.

- Provide this objective basis for decision making to humans in such a way that it takes into account their **cognitive capabilities** (e.g., information filtering in stress situations) as well as the **situation/ context** in which the decision has to be made (e.g., within production process versus design process) in order to ensure **timely** and **optimal decisions**.

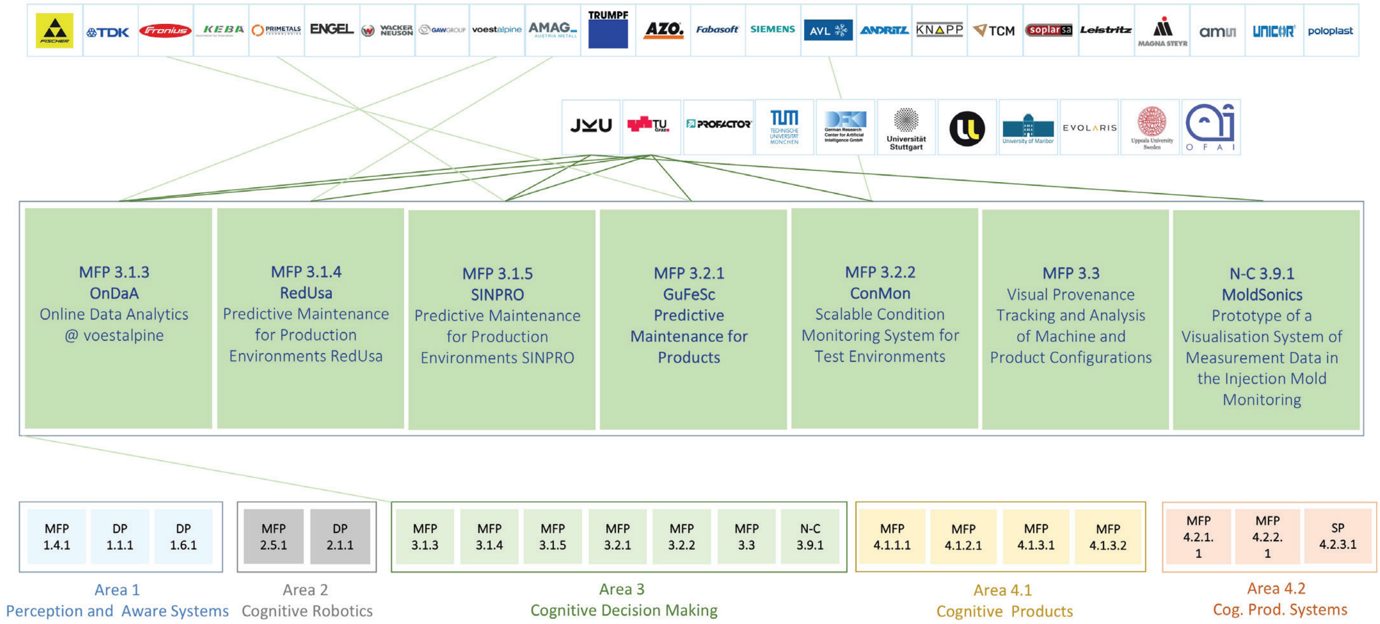
Approach

Area 3 focusses on four methodological pillars for supporting decision making of human actors: **(i) Planning**, **Scheduling** and **Supervision of Production Processes** and **Re-scheduling.** The latter can be interpreted as a re-configuration task due to dynamic requirements. **Challenges** include how to integrate **anytime aspects** into **(re-)scheduling algorithms** in order to allow **trade-offs** between **schedule quality** and **runtime performance**, and development of heuristics which allow the efficient retrieval of **personalized schedules** (i.e., schedules that take into account preferences in an optimized fashion) and how to learn them. We rely on **model-based diagnosis** to identify potentially minimal elements of a schedule that have to be adapted such that the new requirements are taken into account. **Learning algorithms** are applied for the derivation of heuristics based on a new language for the definition of **search heuristics** in the production context. A starting point to address supervision is **model-based reasoning**, which had been successfully applied to plan execution and diagnosis of automation systems.

(ii) Knowledge Management in Variability Management: The sophisticated challenges for knowledge management in industrial production of the future require further developments in the areas of **configuration knowledge representation**, **model-based diagnosis** and **testing**, **cognitive aspects of (configuration) knowledge base development** and **maintenance**, and **recommender systems**. Theories from **cognitive psychology** are analysed with regard to their applicability in the context of **configuration management**, **intelligent testing** and **debugging of knowledge bases**. Different **personalization** and **recommendation approaches** have been compared regarding their capability of **increasing** the **understandability of configuration knowledge for domain experts** (e.g., product development, marketing sales) and **knowledge engineers**.

(iii) Data-based Decision Support in Production Processes: To develop methods for efficient and effective **data acquisition**, **harmonization**, **transformation**, and **storage of data**, taking into account **security aspects and provenance information,** the work in this research topic builds heavily on methods, software frameworks, and analytics infrastructures developed in a joint undertaking with the KNOW-Center.

(iv) Visual Analytics in Production Processes To research **visual-interactive exploration methods** for p**roduction-related data (time-oriented, network-oriented data)**, tools for **visual analysis of large amounts of data** are beneficial to select appropriate data portions as input for **learning and process analysis modules** for **visual prediction tools** to be developed. To design and test visual-interactive approaches that make use of visual representations to incorporate **expert knowledge** directly into the **analysis and prediction process**,



we need to tightly integrate **automatic prediction models based,** e.g., on **time series analysis** or **classification**, with **visual-interactive data representations**.

Expected and Achieved Results

The four methodological pillars of Area 3 provide a **solid base** for implementing **predictive maintenance** and **decision making in product design** and **production processes**. It is expected that within the next 5 years the **number of sensory data** available will continue to increase significantly. Thus, it is of crucial importance that companies already explore novel ways in benefitting from this data and the insights which can be gained through its analysis. For this, it is not only important to set up the technical infrastructure to handle the data. Equally important is experimentation with the data to identify opportunities for **new or improved products** and **new services**. In order to make these **data-driven services** usable and useful for a wider user group (beyond data scientists), it is essential that the developed tools take the **cognitive strengths** and **weaknesses of humans** into account. The goal is to find an **effective division of labour** between **human** and **machine**, which synergizes the strengths of both into a productive team. In addition, we as a society have to ensure that workers (e.g., in production) have proper possibilities to build **"smart factory skills"**–to handle data and draw conclusions from it. Therefore, approaches for training and competence building interwoven with working processes appear very important.

Benefit for those applying the project results and the exploitation potential: The projects provide immediate benefit to our company partners. On the one hand, the **prototypes** can be directly **explored** and **evaluated in the work context**, thus providing valuable **feedback** both for the company as the researchers alike. Target users will be able to examine the impact from different perspectives. On the other hand, the prototypes can be developed further into specialized **decision-making tools for the industry** and thus can be exploited directly.

Area 3 contributes in two ways to the centre: (1) Development of a **methods base and computational prototypes** for providing a **reliable and trustworthy (data/facts)** basis on which decisions can be made; (2) Development of a methods base and computational prototypes for **supporting the decision making process** by taking into account **(personal) cognitive factors** of the **human, situation/context factors** of the decision making situation, and **application domain specificities** for embedding the decision-making process in the business processes.

The results we obtained have paved the way to define the preliminary **methods** for **data analytics**, and **visual data analytics** for our company partner. These methods have been developed further in the third year. To be appropriate, we have focused on **testing** and **investigating** different **AI algorithms** for (i) **forecasting** process quality, (ii) detecting **anomalies,** (iii) identifying **factors** with the **biggest influence** on the **production quality** and their **causal relations** on their applicability for predictive maintenance and decision making in production processes. For these methods we mostly used times series as input data which were **uni**- or **multivariate**. On top of that, we developed **visual analytics tools** to **monitor** the **production**- and **process data** and to **display** and **visually explore** the **AI results.** Together they defined the building blocks of intelligent decision support tools which support our company partner with maintenance tasks, monitoring the conditions of their machines and optimizing their production processes. The close **cooperation** with our **scientific advisors** from Graz University of Technology and JKU helped us to define research strategies and publish the results of the projects in peer-reviewed journals and conferences.

To stay **competitive** within the **age of AI** and at the same time to **benefit** from its **speed** and **accuracy,** our future work will focus on evaluating the applicability of **deep learning** and **reinforcement learning** algorithms in condition monitoring and predictive maintenance as well as **Bayesian networks** in analysing the root-cause of critical events in complex industrial processes. Although AI methods are increasingly being used, they are often seen as **black boxes**. For critical industrial applications with significant economic implications (e.g., predictive maintenance) this lack of transparency can be a key problem and may hinder that the AI methods are actively being used in real decision-making processes. To meet this challenge, we will further provide methods for making AI **explainable** and **understandable** to human. A special focus will be on the **explainability** of the deep-learning methods and on how to meet the constraints required for a **general application** of such methods in industry.

Positioning of the Area within the Centre

To realize cognitive products, the area utilizes concepts developed in the other areas and integrates them in the realization of cognitive product for realistic applications. A common goal of Area 1 and Area 4.1 is the development of pervasive AI, edge analytics and sensing methods. An integration of cognitive products in a shopfloor can only be achieve by integrating with efforts and methods developed in Area 2. The methods and technologies developed in Area 3, will allow Area 4.1 to realize cognition across all planned research activities and provide requirements for the development of the underlying building blocks. The cooperation with Area 4.2 allows us to establish and devise requirements for brown field integration and reasoning abilities within cognitive ensembles and combine developed technologies in the context of cognitive production systems.

EXECUTIVE SUMMARY

Area 3

Cognitive Decision Making (FP2)

Area Leaders: Prof.[in] Stefanie Lindstaedt (TU Graz) Prof. Marc Streit (JKU), Prof. Tobias Schreck (TU Graz)
Area Manager: DI Dr. Belgin Mutlu

Vision and Strategy

In Area 3 "Cognitive Decision Making", scientific and industrial partners focus on researching the aspect of computational decision making, starting with the creation of novel analysis techniques for large amounts of data, via the development of classification systems for industry, reaching up to the development of industrial systems that autonomously forecast undesirable system states and pre-emptively take unobtrusive, corrective action on all granular system levels from single production actuator to ensembles or even control of complete shop floor entities. The goal-oriented research addresses: (i) Data Analytics Method Bases - general cognitive functions for base- and reality-mining, scientific, semantic visualization of data; (ii) Computational Data Analytics - providing cognition-based functions for the handling of data under uncertainty (learning); (iii) Decision Making Method Bases - models of cognitive functions for decision making including goal and plan representation, resource allocation and optimization of processes; (iv) Computational Decision Making – transparent automatic multi-criteria, multi-resource decision making, choice modelling and heuristics.

Area 3 plays a crucial role in identifying transparent and efficient solutions within time, resource, and strategic limitations. It also handles the processing of both reliable and potentially unreliable data. These contributions serve as fundamental elements for any autonomous, cognitive production system, or end-user product that incorporates perception and self-awareness.

Goals

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- Provide this objective basis for decision making to humans in such a way that it takes into account their cognitive capabilities (e.g., information filtering in stress situations) as well as the situation/ context in which the decision has to be made (e.g., within production process versus design process) in order to ensure timely and optimal decisions.

Approach

Area 3 focusses on four methodological pillars for supporting decision making of human actors:

Planning, Scheduling and Supervision of Production Processes and Rescheduling. The latter can be interpreted as a re-configuration task due to dynamic requirements. Challenges include how to integrate anytime aspects into (re-)scheduling algorithms in order to allow trade-offs between schedule quality and runtime per-formance, and development of heuristics which allow the efficient retrieval of personalized schedules (i.e., schedules that take into account preferences in an optimized fashion) and how to learn them. We rely on model-based diagnosis to identify potentially minimal elements of a schedule that have to be adapted such that the new requirements are taken into account. Learning algorithms are applied for the derivation of heuristics based on a new language for the definition of search heuristics in the production context. A starting point to address supervision is model-based reasoning, which had been successfully applied to plan execution and diagnosis of automation systems.

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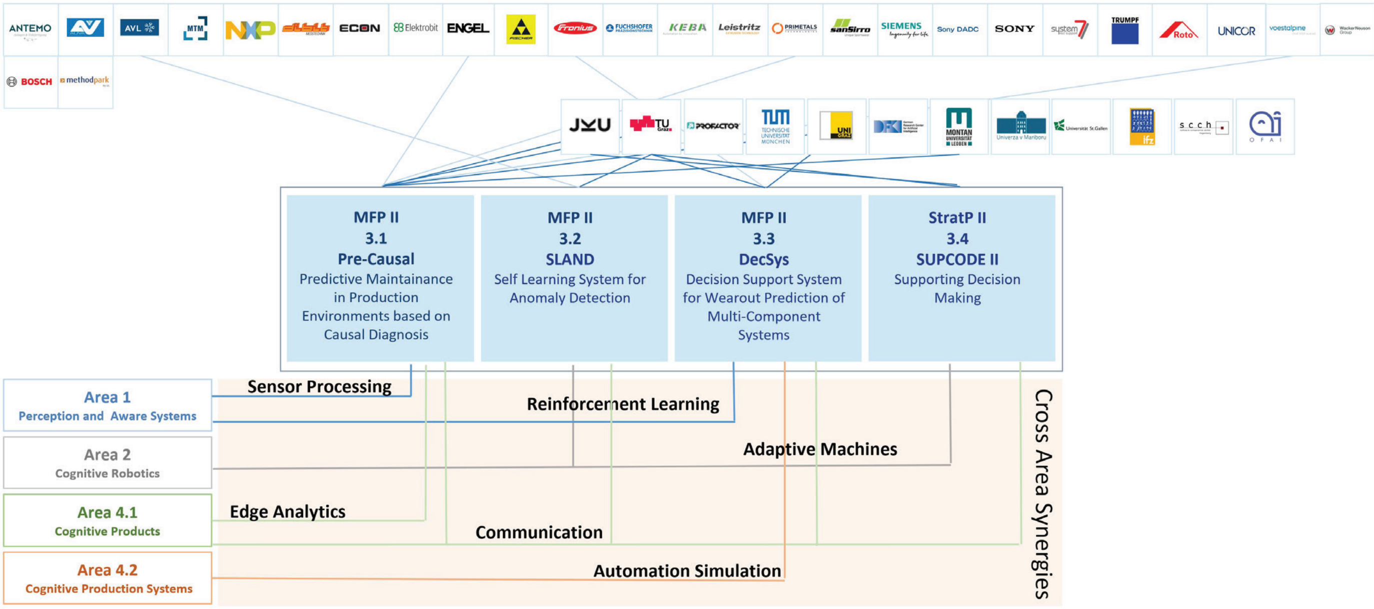


applicability in the context of configuration management, intelligent testing and debugging of knowledge bases. Different personalization and recommendation approaches have been compared regarding their capability of increasing the understandability of configuration knowledge for domain experts (e.g., product development, marketing sales) and knowledge engineers.

Data-based Decision Support in Production Processes: This research area focuses on developing approaches to optimise and streamline the process of acquiring, harmonising, transforming and storing data to ensure efficiency and effectiveness. It also considers the critical aspects of privacy and provenance information collection throughout the data lifecycle.

Visual Analytics in Production Processes: This research focuses on exploring visual-interactive methods for analyzing production-related data, particularly those with time-oriented and network-oriented characteristics. Utilizing tools for visual analysis becomes crucial, especially when dealing with large datasets. These tools aid in selecting relevant data subsets to serve as inputs for learning and processing modules, essential for developing visual prediction tools.
To achieve this, the goal is to design and test visual-interactive approaches that leverage visual representations to directly incorporate expert knowledge into the analysis and prediction process. This integration involves automatic prediction models based on techniques like time series analysis or classification, seamlessly merging with visual-interactive data representations. The ultimate aim is to enhance the analysis and prediction capabilities, allowing for better-informed decision-making in production-related domains.

Expected and Achieved Results

The four methodological pillars of Area 3 form a robust foundation for implementing predictive maintenance and decision-making in product design and production processes. As the volume of sensory data is expected to significantly increase in the next five years, companies must proactively explore innovative ways to leverage this data and extract valuable insights through analysis.
This exploration entails not only establishing the necessary technical infrastructure to handle the data but also conducting experiments to uncover opportunities for new or improved products and services. The ultimate aim is to create data-driven services that cater to a broader user base, extending beyond data scientists. To achieve this, it is vital for the developed tools to consider human cognitive strengths and weaknesses.
The overarching goal is to strike an effective balance between human and machine capabilities, enabling a productive collaboration that capitalizes on each other's strengths. Furthermore, as a society, we must ensure that workers, particularly those in production, are equipped with "smart factory skills" – the ability to handle data and derive meaningful conclusions from it. Consequently, approaches to training and competence building, seamlessly integrated with working processes, hold great significance.

Benefit for those applying the project results and the exploitation potential:
The project results deliver immediate benefits to our company partners in two significant ways. Firstly, the prototypes can be directly explored and evaluated in their work context, providing valuable feedback to both the companies and researchers. Target users can assess the prototypes' impact from various perspectives, ensuring their relevance and effectiveness. Moreover, these prototypes can be further developed into specialized decision-making tools for the industry, enabling direct exploitation.

Area 3's contributions to the center can be summarized in two key aspects. Firstly, the development of a robust methodological base and computational prototypes establishes a reliable and trustworthy data foundation for making informed decisions. Next, our prototypes are characterised by the seamless integration of human cognitive factors, situational and contextual elements and domain-specific considerations to support the decision-making process. This integration ensures that the decision-making process becomes an integral part of business processes, resulting in more effective and better-informed decisions.

Our future work will focus on applying advanced data analytics approaches to further increase the impact of our project. We will explore innovative techniques such as Generative Adversarial Networks (GANs), Graph Neural Networks (GNNs), as well as self-supervised learning and federated learning, which will allow us to utilise huge amounts of data from different sources while ensuring data privacy and security.

In addition, we plan to deepen our research into causal discovery and seek to understand and establish causal relationships within the data. This will lead to a deeper understanding of the factors that influence production quality and predictive maintenance, and enable more proactive decision-making.

In addition, we intend to harness the power of large language models and natural language processing (NLP) to extract valuable insights from unstructured text data. This will enable us to process large amounts of textual information, leading to more comprehensive and holistic analysis.
By integrating these cutting-edge techniques into our prototypes and methods, we aim to take our research to a new level and deliver even greater value to our corporate partners. With a focus on data-driven decision making, privacy protection and the integration of advanced data analytics, we aim to drive innovation and enable data-centric excellence in manufacturing processes and beyond.

EXECUTIVE SUMMARY

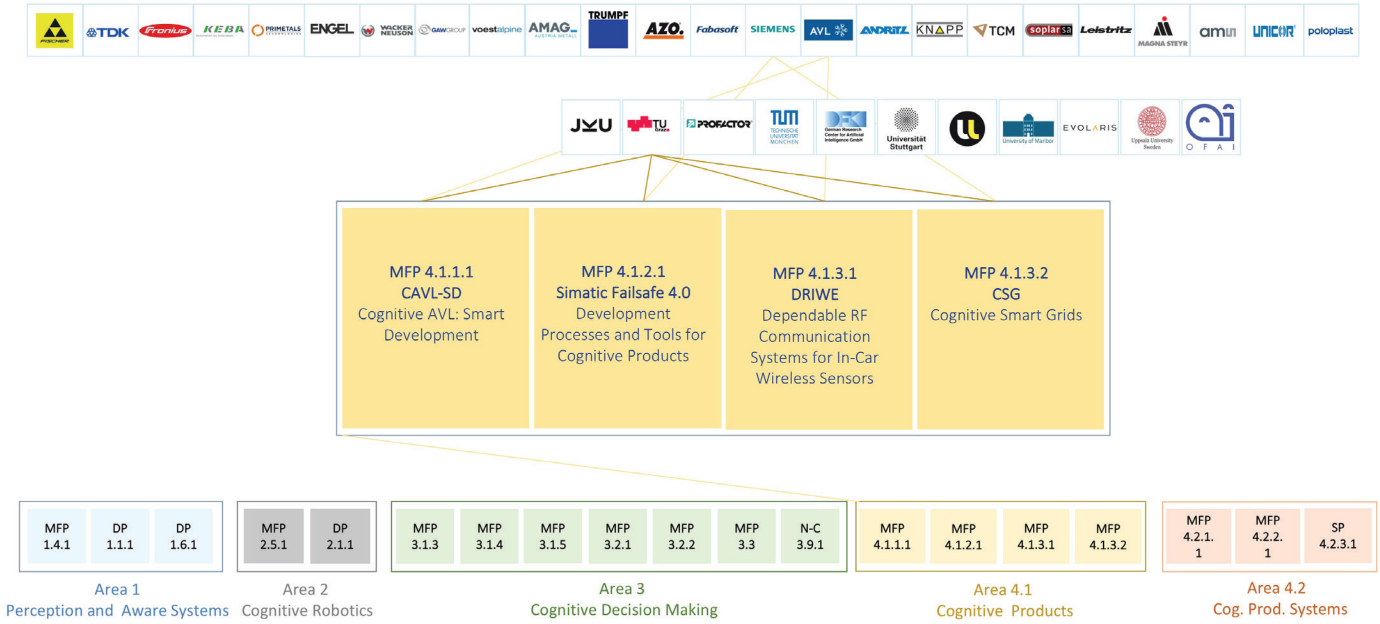
Area 4.1
Cognitive Products (FP1)

Area Leaders: Prof. Kay Römer (TU Graz), Ass.Prof.[in] Jasmin Grosinger (TU Graz)
Area Manager: Dr. Konrad Diwold (Pro²Future)

Goals
The overarching **goal** of this Area is to **develop case studies for cognitive products**. Here, "cognition" denotes a product's ability to adapt its functionality across the entire product lifecycle in order to maximize customer satisfaction, product quality and sustainability, and to minimize production overheads**. Cognification** of new and existing products **requires** several factors, namely: **sensing, networking, and software platforms**. These building blocks should be both **dependable** (as many products and their production are safety-critical) and **cost effective** (as the added value of cognition must be balanced with added hardware and development costs) and will allow the design and realization of cognitive products. In order to ensure the applicability and benefit of future cognitive products and their underlying frameworks, the design and development lifecycles are realised in close cooperation with industrial partners.
As previous research into cognitive products has mostly focused on selected application domains, there is a lack of generalized, domain-agnostic solutions. Likewise, there is currently a lack of solutions that consider the entire cognitive product lifecycle. Finally, existing sensing, networking, and software platforms for cognitive products currently do not meet both dependability and low-cost requirements. Research in Area 4.1 will close this gap, by co-designing unified, dependable sensing, localization, and networking solutions, all of which will be based on radio communication.

Approach
The ultimate goal of Area 4.1 is to realize **cognitive products** for **realistic applications** by **integrating concepts** from **Areas 1, 2, and 3** using novel sensing, networking, and software platforms. To achieve this overarching goal, the following objectives are addressed by the Area:
Objective 1: **Case studies of cognitive products**. The **industry partners** in the area **define case studies** in their **respective domains** in order to derive requirements on cognitive products. A **diverse set** of **application domains** are considered in order to ensure that the solutions developed in this Area are generic and can support a wide range of applications. **Prototypes** of cognitive products for the selected case studies have been realized, experimented with, and iteratively refined. The underlying methodology can be characterized by experimentally driven systems research. Previous research typically focusses on domain-specific solutions that do not generalize to other domains.
Objective 2: **Comprehensive optimization of cognitive products across their whole lifecycle.** A central benefit of "cognition" that drives the work in the Area are the comprehensive optimization of cognitive products across their whole lifecycle from **design**, **development**, and **validation**, over **production**, **use**, **service**, to **disposal** and **recycling**. Thereby, the production and use of cognitive products are **monitored** by **trustworthy embedded computers** in order to (semi)automatically optimize the hardware and the software of the products to maximize user satisfaction, to maximize product quality, to minimize the production overheads, and to maximize the sustainability of the products. Previous research focusses on selected phases of the product lifecycle and existing solutions typically cannot be extended to span the whole lifecycle.

Objective 3: **Dependable and low-cost sensing, networking, and software platforms for cognitive products.** In order to bring "cognition" into products, the latter need to be equipped with highly dependable and low-cost sensing, networking, and software solutions to realize the integrated concepts from Areas 1, 2, and 3. As many application domains of cognitive products have **safety-critical features** and the production of cognitive products is typically also a **safety-critical process**, the solutions for **sensing**, **networking**, and **embedded software** have to be **highly dependable** (i.e., reliable, available, safe, and secure) – otherwise we risk that cognitive products may fail and thereby hurt people or create economical losses. At the same time, the **extra total cost of ownership** resulting from the cognitive behaviour (e.g., additional hardware costs for sensing, networking, software; additional development costs) must be kept **low** to allow for **successful business models**. Offering dependability and low cost at the same time represents a profound research challenge, as especially the overheads for ensuring dependability result in significant costs. To this end, the Area will continue to research, among others, the co-design of unified dependable sensing, localization, and networking solutions all based on radio communication. Previous research typically focusses on individual wireless services and thus fails to exploit the potential of unified solutions.
Area 4.1 performs **experimentally driven systems research** to realize case studies of cognitive products in the application domains of our industry partners. The requirements derived from the case studies and the experience gained from experiments with the case studies drive the design of novel sensing, networking, and software platforms that **bring cognition into products** and enable their comprehensive optimization across their whole lifecycle. Specifically, three multi-firm projects (MFP) and one strategic project (SP) have been defined. **MFP 4.1.1 Comprehensive Optimization of the Cognitive Product Lifecycle** investigates novel architectures and solutions for comprehensive optimization of cognitive (Area 4.1 objectives 1 and 2). **MFP 4.1.2 Development Processes and Tools for Cognitive Products** investigates



software development processes and tools for cognitive products (Area 4.1 objectives 1 and 3). **MFP 4.1.3 Internet of Cognitive Products and Production Systems** focuses on (inter)networking cognitive products and production environments (Area 4.1 objective 1 and 3). **StratP 4.1.4 Unified Dependable Wireless Services for Cognitive Products** investigates co-design sensing, networking, and localization approaches all based on radio communication in order to maximize dependability of these wireless services while at the same time minimizing their cost.

Expected and Achieved Results

The area aims for prototypes of **cognitive products** for **realistic applications** realized on top of low-cost and highly dependable sensing, networking, and software platforms, integrating concepts from Areas 1-3. Specific technical results include a **trustworthy platforms** for **sensor data acquisition** from cognitive products; an **engine** for **mining sensor data** from cognitive products; **decision support tools** for the **human product designer**; **software development processes** and **tools** for cognitive products; **architectures** and **protocols** for an i**nteroperable** and **highly-dynamic Internet of products** and machines; **tools** for **automatically placing software functions** in the Internet of products and machines; and a **unified set** of **dependable wireless services** (sensing, networking, localization).

A **key benefit** is that the developed platforms for cognitive products will have a dependable performance even in **harsh industrial environments** and can thus be employed even **for safety-critical products** and their production. In addition, the performance of the resulting cognitive products will have to be **predictable before actually deploying** them. These are crucial prerequisites for realizing cognitive products in critical applications where **failures** may have disastrous consequences. A further key benefit is that the platforms will be **cost-efficient solutions**, such that employing the results of Area 4.1 will have a limited impact on the price tag of cognitive products. This is a crucial prerequisite for many business models involving cognitive products.

Area 4.1 has been substantiating the three MFPs that are associated with Cognitive Products and their life-cycle and have been pursuing basic research on enabling technologies for industrial integration scenarios on all levels of the networking stack as part of the strategic project. In the context of **MFP 4.1.1 Comprehensive Optimization of the Cognitive Product Lifecycle** a framework for the **semantic modelling of production development process** was developed which enables **reasoning** with our **Company Partners AVL List GmbH**. In addition, methods to **interface semantic web technology** with **machine learning** were developed to enable a semantically driven life cycle optimization with machine learning classification capabilities**.** Together with our company partner **Siemens AG Austria** we investigated in **MFP 4.1.2 Development Processes and Tools for Cognitive Products** how **functional safety, availability, and maintainability** can be **improved** in industrial environments. During the project, **a novel dynamic safety concept** which allows the dependable **cooperation of robots and machines in a production environment** was developed and demonstrated at the Austrian Village at the European ICT 2018. In addition, several **novel failsafe methods** have been **developed** and demonstrated, such as **two new soft-error mitigation strategies**. The MFP also demonstrated how **low-cost IoT** hardware can be used to **extend existing automation devices** with **cognitive features** (such as awareness), which allows the implementation of **novel cognitive services and features.**

Together with our company partner **Siemens AG Austria, AVL List GmbH and HMI Masters GmbH** we investigated in **MFP 4.1.3 Unified Dependable Wireless Services for Cognitive** Products dependable communication strategies for cognitive products and production systems. As a result, methods for the **simulation-based optimization of in-car communication systems** were developed, which utilize ray tracing in combination with link budget calculations to derive an **optimal setup** (antenna type and position) given a **specific target environment**. In addition, a recommender system was developed to identify optimal communication protocols to realize a particular use case. The project also demonstrated a concept for **BLE-based monitoring**, which requires **minimal engineering effort** and developed tools for the management of **communication in dynamic environments**, by assessing current **available link qualities (across multiple radios)** and **adjusting** the used communication channels and **payloads accordingly to achieve robust and dependable communication.**

Positioning of the Area within the Centre

Area 4.1 is one of the two application-oriented areas and thus forms a central integration point in the Centre. The Area integrates concepts from Areas 1-3 and applies them to the realization of cognitive products for real-world applications. Industry partners will provide these case studies. By carefully analysing and conforming to the requirements of these case studies and of the concepts from Areas 1-3, the sensing, networking, and software platforms will be tailor-made to enable in-product cognition appropriate to the case studies. At the same time, the multifaceted character of the case studies ensures that generalized solutions will be devised that suit a wide spectrum of cognitive products across their entire product lifecycle. The role of products in their production environment (which is the topic of Area 4.2) is also highly relevant and thus forms a cross-Area link.

EXECUTIVE SUMMARY

Area 4.1
Cognitive Products (FP2)

Area Leaders: Prof. Kay Römer (TU Graz), Ass.Prof.[in] Jasmin Grosinger (TU Graz)
Area Manager: DI Dr. Michael Krisper (Pro²Future), formerly Dr. Konrad Diwold (Pro²Future)

Vision and Strategy
The focus of Area 4.1 lies in the development of adaptive, trustworthy, and reliable products. Adaptive and self-organizing products manage their processes without the need for interaction with centralized control units and react to disturbances that would limit their operability in a corrective manner. Trustworthy and reliable products assure safety for humans and the environment and communicate actively with other products and production lines to increase productivity by decreasing overheads.

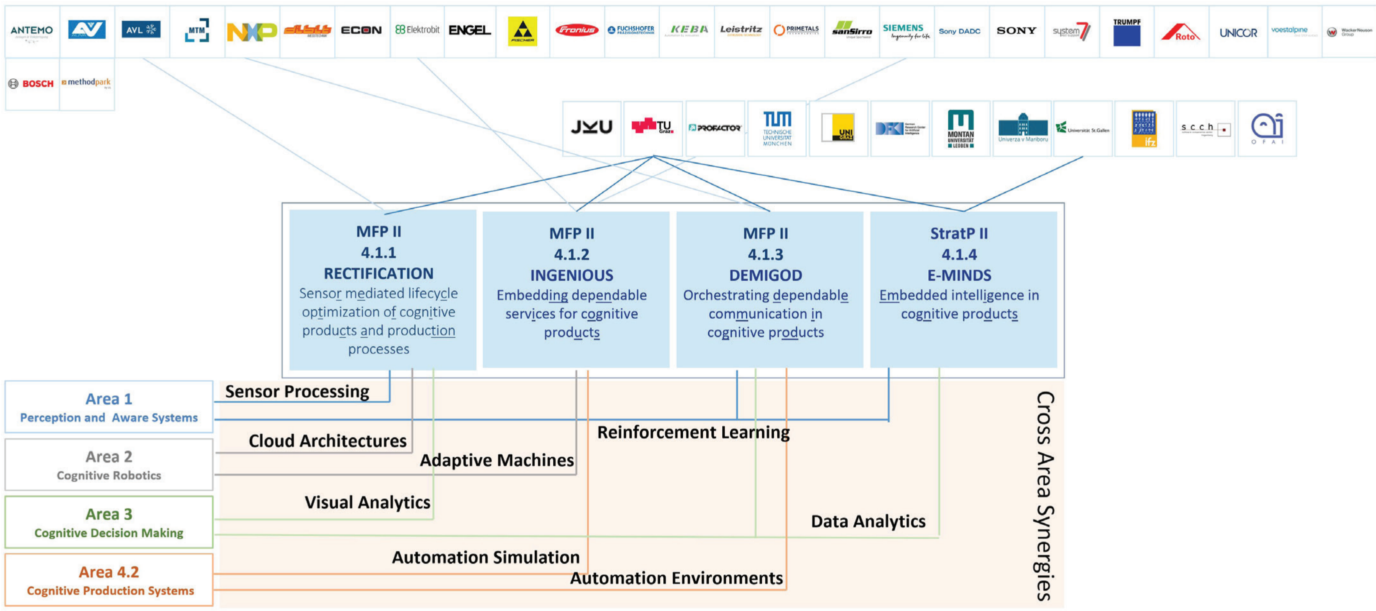
Goals
The overarching goal of the area is to do research on and realization of case studies for cognitive products. Specifically, we address cognition in the form of comprehensive optimization of cognitive products across their entire lifecycle and ecosystems. Bringing cognition into products requires dependable design and operation of all components and their communication with each other: sensing, networking, computing, and reacting (including all software and hardware aspects of the different platforms). The result manifests itself in concrete prototypes that are integrated within industrial environments from the physical layer (e.g., smart antennas) to the semantic layer (i.e., enabling systems to interoperate vertically). On the one hand, we create applicable prototypes that serve as feasibility studies within the projects, and on the other hand, we strive for generalized abstractions of the insights, ideas, and methods that can be published or patented.

Beyond State of the Art
Cognitive products: With their ability to self-adapt, interact, and integrate, cognitive products represent a significant step beyond the current state of the art, as they will be able to perceive external information (e.g., via sensing capabilities), process information, contextualize it, interpret and reason, learn and adapt models, derive actions, plan the future, and communicate and interact with other systems and system entities. As previous research in cognitive products mostly focused on selected application domains, there is a lack of generalized, domain-agnostic solutions, tools, and processes for the design of cognitive products. Likewise, there is a lack of solutions that consider the whole cognitive product lifecycle. To realize such products, dependable technological building blocks are required. Existing sensing, networking, and software platforms do not meet dependability and low-cost requirements at the same time as they are often conflicting with each other. Research in Area 4.1 will close this gap, by co-designing unified dependable sensing, localization, and networking solutions.

Approach
The ultimate goals of Area 4.1 are to realize cognitive products for realistic applications by integrating concepts from Areas 1, 2, and 3 using novel sensing, networking, and software platforms and also connect to Area 4.2 by sharing and applying the insights and tools to production systems. To achieve this overarching goal, the following objectives will be addressed by the Area:

Objective 1: **Case studies of cognitive products.** The industry partners in the area define case studies in their respective domains to derive requirements for cognitive products. Previous research typically focuses on domain-specific solutions that do not generalize to other domains. A diverse set of application domains are considered to ensure that the solutions developed in this Area are generic and can support a wide range of applications. Prototypes of cognitive products for the selected case studies will be realized, experimented with, and iteratively refined. The underlying methodology can be characterized by experimentally driven systems research.

Objective 2: Consideration of lifecycle aspects in the design and operation of cognitive products. Previous research focuses on selected phases of the product lifecycle and existing solutions typically cannot be extended to span the whole lifecycle. A central benefit of “cognition” that drives the work in the Area will be the comprehensive optimization of cognitive products across their whole lifecycle from design, development, and validation, through production, use, and service, to disposal and recycling. Thereby, the production and use of cognitive products will be monitored by trustworthy embedded computers to (semi)automatically optimize the hardware and the software of the products to maximize user satisfaction, maximize product quality, minimize production overheads, and maximize the sustainability of the products.



Objective 3: Dependable and low-cost sensing, networking, and software platforms for cognitive products. To bring "cognition" into products, the latter need to be equipped with highly dependable and low-cost sensing, networking, and software solutions to realize the integrated concepts from Areas 1, 2, and 3. As many application domains of cognitive products have safety-critical features and the production of cognitive products is typically also a safety-critical process, the solutions for sensing, networking, and embedded software have to be highly dependable (i.e., reliable, available, safe, and secure) – otherwise, we risk that cognitive products may fail and thereby hurt people or create economical losses. At the same time, the extra total cost of ownership resulting from the cognitive behavior (e.g., additional hardware costs for sensing, networking, software; additional development costs) must be kept low to allow for successful business models. Offering dependability and low cost at the same time represents a profound research challenge. Especially, the overheads for ensuring dependability result in significant costs. Previous research into radio communication typically focuses on individual wireless services and thus fails to exploit the potential of unified solutions. For this objective, the Area will research, among others, the co-design of unified dependable sensing, localization, and networking solutions all based on radio communication.

Area 4.1 conducts experimentally driven systems research to realize case studies of cognitive products in the application domains of our industry partners. Within the second funding period, Area 4.1 worked on three MFPs associated with cognitive products and their lifecycle, as well as several nonCOMET projects addressing specific aspects of industrial research (e.g. drones, recycling, digital twins in construction and buildings). Work was carried out with our industry partners AVL List GmbH, Siemens AG Austria, NXP Semiconductors Austria GmbH & Co KG, Infineon Technologies AG, and Elektrobit Automotive GmbH within COMET projects, as well as our project partners in nonCOMET projects (Austrian Power Grid AG, Siemens Energy AG, buildingSMART Austria, D-ARIA GmbH, Roto Frank Austria GmbH). Additionally, basic research on enabling technologies for industrial integration scenarios on all levels of the networking stack was pursued within the Area's strategic project.
The previously mentioned three multi-firm projects (MFP) and one strategic project (SP) are: MFP 4.1.1 Comprehensive Optimization of the Cognitive Product Lifecycle investigates novel architectures and solutions for the comprehensive optimization of cognitive products (Area 4.1 objectives 1 and 2). MFP 4.1.2 Development Processes and Tools for Cognitive Products investigates software development processes and tools for cognitive products (Area 4.1 objectives 1 and 3). MFP 4.1.3 Internet of Cognitive Products and Production Systems focuses on (inter)networking cognitive products and production environments (Area 4.1 objectives 1 and 3). StratP 4.1.4 Unified Dependable Wireless Services for Cognitive Products investigates the co-design of sensing, networking, and localization approaches based on radio communication to maximize the dependability of these wireless services while at the same time minimizing their cost (Area 4.1 objectives 2 and 3).
A key benefit of our research is that the developed platforms for cognitive products will have a dependable performance even in harsh industrial environments and can thus be employed even for safety-critical products and their production. In addition, the performance of the resulting cognitive products will be predictable before deploying them. These are crucial prerequisites for realizing cognitive products in critical applications where failures may have disastrous consequences. A further key benefit is that the platforms will be cost-efficient solutions, such that employing the results of Area 4.1 will have a limited impact on the price tag of cognitive products. This is a crucial prerequisite for many business models involving cognitive products.

Expected and Achieved Results

The area aims for prototypes of cognitive products for realistic applications (Area 4.1 objective 1) realized on top of low-cost and highly dependable sensing, networking, and software platforms, integrating concepts from Areas 1-3 and also porting it to Area 4.2 wherever it can bring a benefit. The points of common interest with other areas are: concepts for dependable sensing (Area 1), methods enabling shop-floor integration of the developed cognitive products (Area 2), and data analytics methods which enable optimization and reasoning within cognitive products (Area 3). Furthermore, the communication technologies, data exchange platforms, and methods for retrofitting and integration can be reused in Area 4.2 to implement use cases there. Specific expected technical results include a trustworthy platform for sensor data acquisition from cognitive products; an engine for mining sensor data from cognitive products; decision support tools for the human product designer; software development processes and tools for cognitive products; architectures and protocols for an interoperable and highly-dynamic Internet of products and machines; tools for automatically placing software functions in the Internet of products and machines; and a unified set of dependable wireless services (sensing, networking, localization).

EXECUTIVE SUMMARY

Area 4.2
Cognitive Production Systems (FP1)

Area Leaders: Prof. Kurt Schlacher (JKU), Prof. Franz Haas (TU Graz), Prof. Rudolf Pichler (TU Graz)
Area Manager: Dr. Markus Brillinger (Pro²Future), Mag. Bernhard Löw-Baselli (JKU)

Goals

Cognitive production systems represent a significant step beyond current state of the art due to their ability to self-adapt, interact and integrate with human-like flexibility, reliability, autonomy and robustness. Cognitive production systems will be able to reason from collected data; perceive, process, and interpret information to generate responses, actions and reactions, learn new models and self-adapt the existing ones; communicate and interact with other systems and humans, and be able to plan. In addition to this, the systems should behave adaptive to different production scenarios.

One import goal is for example to handle non steady state cases including the ramp up phase, which becomes dominant, whenever more diversified and fast changing product portfolios are required. One has to preserve tight quality tolerances, increased energy efficiency, as well as reduced waste and environmental impact under volatile energy and raw material prices.

A tight cooperation between the involved engineering sciences is necessary to succeed. A precise mathematical description of the processes allows already today monitoring beyond simple data processing. It is the indispensable tool toward awareness, process and product intelligence. This description must be extended such that the models become applicable to the problems caused by the new technologies. Basic algorithms like for control, monitoring etc. must be revised or replaced by new ones, such that distributed sensor and actuator fields can be handled, whereat the communication efforts are minimized, data security is granted and the current high level for services remains. This includes non-linear model predictive control, as well as smart data predictive control. All investigations must be performed with a strong view to application scenarios like the factory in the factory, as well as to the introduction of methods new for the application under consideration, like big data analysis, see Area 3.

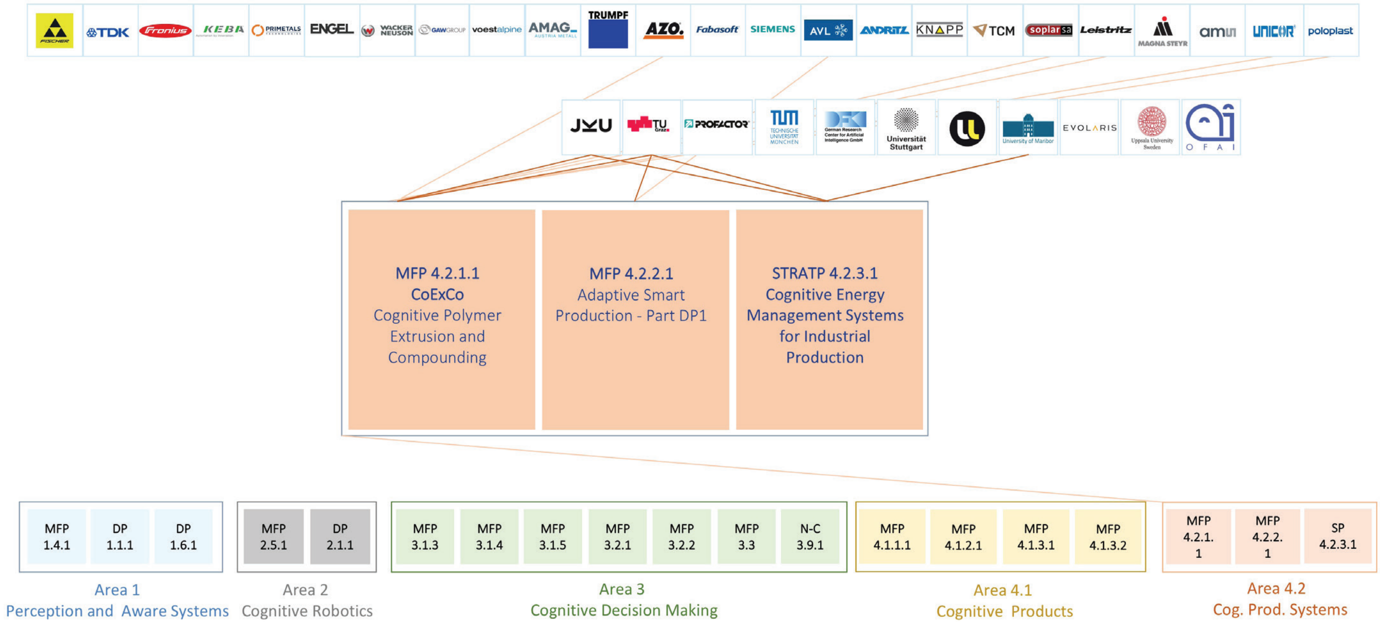
Approach

Area 4.2 investigates principles based modelling for analysis, system design and automatic control, like non-linear model predictive control technology including big data analysis driven optimisation of the overall plant dynamics, specific in-line process monitoring technology, as well as human-machine interaction with 3D motion tracking technology. The work program for batch production is the setup of a Smart Factory at Graz University of Technology and for continuous production is set up on Living Lab at Johannes Kepler University Linz. These will be the places, where defined topics of research and tests of all the new ideas mentioned before will be executed and evaluated. The pilot factories at Graz University of Technology and Johannes Kepler University in Linz will show the production of the future using emerging technologies, e.g. automatic guided vehicles (AGVs), 5G and cloud computing.

The management of complex situations (non-steady state cases) like change of operating points, (ad hoc) set-up and tracking of new trajectories, monitoring is a natural task of the cloud. The required mathematical models and tools, the algorithms and software systems will become available for the user, where the use of open software is preferred, such that monitoring, big data analysis, selective diagnosis etc., become possible beyond the current industrial standard. Cloud fog models of production processes lead to new business models because they break the current spatial connection between machines and control devices. Particular for control in the broader sense of guidance, on line optimisation, adaption etc. one will be to check proposed new models with respect to economic feasibility, but also to reliability, data security, and others.

Expected and Achieved Results

- Novel detection methods for human factors (vital state, skill, stress, peripheral interrupts) to reduce the workload and decrease the risk of incorrect operation.
- Novel concept for experimental and computational modelling of cognitive self-optimisation polymer extrusion and compounding production for increased production productivity and product quality.
- Novel meta-heuristic mathematical models of real time production including big data.



- Novel smart data and first principles based predictive control technologies.
- Enhanced on-line molecular mass control, in-line bulk material feeding and ramp up of working point.
- Implementation of a modular, opportunistic assistance recognition architecture making use of dedicated sensors.
- Smart batch production by modularization, simulation and virtualization.

In Area 4.2 two multi-firm projects (MFPs) were executed during funding period 1 until year 3 which started both in year one.
Cognitive Polymer Extrusion and Compounding CoExCo (MFP 4.2.1) has started as multi-firm project with the Company Partners AZO, Leistritz, and Poloplast but in difference to the proposal with Unicor (which has undertaken tasks of their company holding GAW) and Soplar instead of Tiger (which has retired before signing the contract). The project Adaptive Smart Production ASP (MFP 4.2.2) includes only a use case with AVL, because SFL technologies GmbH has also retired before signing the contract due to insolvency.

In the first year of the two projects, we were setting up network connections to our partners, as well as gathering and evaluating data. During the second year, we continued with data mining, deduced data-based models, and cognitive production systems for continuous (MFP 4.2.1) and discrete (MFP 4.2.2) flow of material. In the third year, we implemented the deduced data-driven models into both pilot factories, Linz and Graz. During the ongoing fourth year, we are testing, evaluating and refining these models.
On an employee level, in Area 4.2 currently 7 researchers are employed, named Markus Brillinger, Raffael Rathner, Muaaz Abdul Hadi, Maximilian Zacher, Marcel Wuwer, Hanny Albrecht and Johannes Diwold.

To sum up, we can conclude Area 4.2 achieved a good start. Due to some personnel changes up to highest level at JKU-ipec MFP 4.2.1 has had mayor disruptions at the end of 2018, but new highly skilled employees were found. However, one workpackage in project CoExCo with company Poloplast were under reconfiguration. Nevertheless, the positive feedback of the ongoing results of all other Company Partners contributing in Area 4.2 allows us to look favourably into the future.

Positioning of the Area within the Centre

The Area 4.2 “Cognitive Production Systems” deals with the central question of upgrading production systems, design of structures for information processing in terms of cognitive skills, as well as the deduction of new business models enabled by the approach of cognitive factories. Area 4.2 will strongly interact with the other areas and should finally demonstrate the performance potential of next generation production systems by means of (i) real pilot living labs, especially for continuous operating production processes like polymer extrusion and compounding as well as (ii) a real “smart factory” for batch production.

In contrast to the other areas the research core of Area 4.2 lies on the one hand in engineering science (the research results of Area 4.2 itself) and on the other hand in the symbiosis of computer science/mathematics (the research results of the other areas) with engineering science.

Engineering sciences of Area 4.2 are: (i) **automatic control**, which covers principles and methods to analyse and design software systems for complex network controlled feedback systems, including, monitoring, optimisation etc. (ii) **polymer processing technologies** which cover computational and experimental engineering activities concerned with operations carried out on polymeric materials or systems to increase their utility, the efficiency in production and to save resources as well as (iii) **flexible automation and robotics**, AGV, cloud computing and 5G - technologies and an open communication/interaction standard of all the participating specific machinery for realizing the framework for a highly flexible batch-size-one production.

EXECUTIVE SUMMARY

Area 4.2
Cognitive Production Systems (FP2)

Area Leaders: Prof. Kurt Schlacher (JKU), Prof. Franz Haas (TU Graz), Prof. Rudolf Pichler (TU Graz)
Area Manager: Dr. Markus Brillinger (Pro²Future), Mag. Bernhard Löw-Baselli (JKU), former Deputy Dr. Wolfgang Roland (JKU)

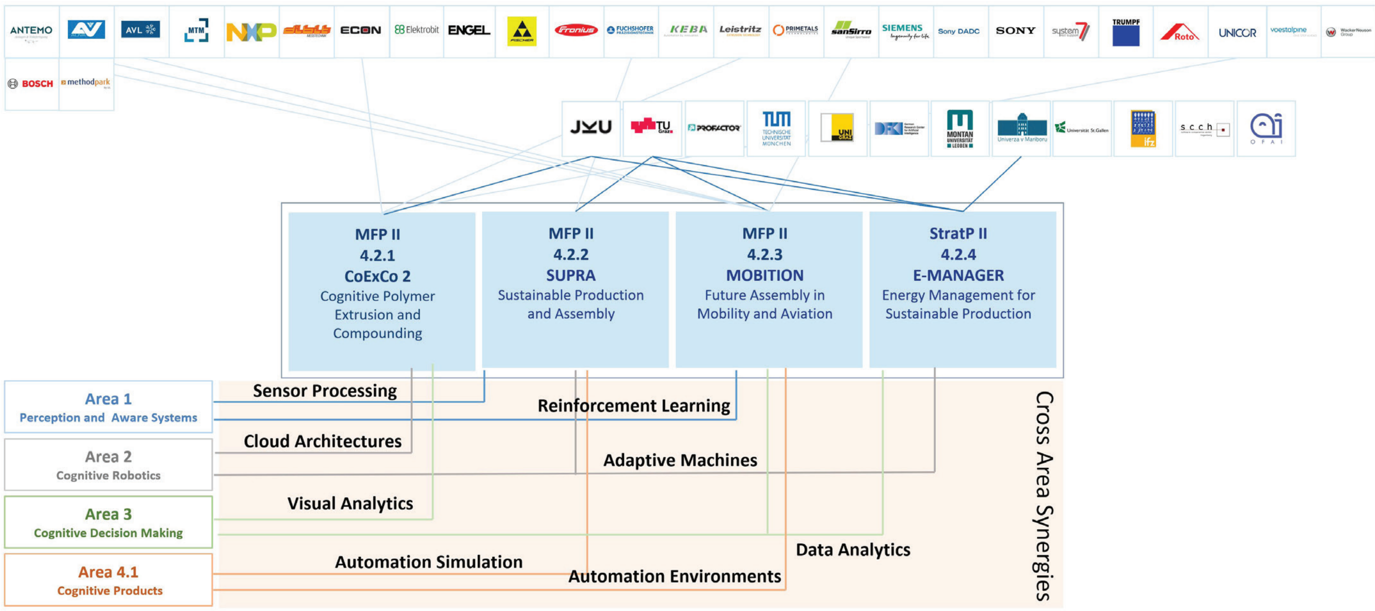
Vision and Strategy
A separate yet related subject matter is investigated in Area 4.2, focusing on: (i) Cognitive factories and factory floors - by processing data generated by their individual subsystems and components, cognitive factories react under real-time constraints to situations occurring in industrial systems, both properly as defined in the production flow and unexpectedly and potentially impeding to productivity; (ii) Holistic production systems - design and development of entire industrial shop floors starting at each individual component and their interactions to subsystems. In this manner, decentralized systems can be conceived that can enact arbitrarily complex changes to the production chain. (iii) Self-organizing production systems - in effect entire industrial installations that communicate and cooperate to optimize productivity. Each of the components of such an installation generates shares and processes information in order to pre-emptively detect unexpected system states and take preventive measures.

Goals
The goals of Area 4.2 are to enable and enhance flexibility and efficiency in continuous as well as batch production systems, by developing industrial systems which allow for novel control schemes, including smart data predictive control, first principles-based model predictive control, activity and behaviour detection, and human assistance. Furthermore, the feasibility of new flexible and efficient production paradigms, such as cobot-assisted manual assembling processes, is illustrated, and demonstrated under production conditions, by means of a Living Lab for continuous production and a Smart Factory for batch production.

Beyond State of the Art
Cognitive Production Systems: A classical production environment can be seen as a double-linked list, where the physical part of the environment (i.e., the machines) is connected to an information processing system. Interfacing between those elements is achieved via sets of sensors and actuators. The information processing system is connected by standard technology to an intranet, which is connected to the Internet, but protected by several security layers. This structure is mainly an outcome of current available technology. However, technological advances, in available computational power at automation device level as well as in communication technology (such as 5G based wireless networks), foster new production system structures, which offer greater degrees of freedom. The functional boundaries of the system blur, as the environment itself, including machines, sensors, actuator, (embedded) controllers, etc. form a computing environment (known as edge or fog), which is connected to the cloud via fast and reliable (wireless) networks. Considering modern continuous production processes, the utilization of data for control, as well as detecting faults and failures are state of the art for the stationary case. The cloud offers the capacity to add cognitive features like self-awareness and self-prediction to the system.
In addition to the stabilization of optimal points of operation in continuous production, condition monitoring and fault diagnosis, the systems should behave adaptively in different production scenarios. One import topic is to handle non steady state cases including the ramp-up phase, which becomes dominant, whenever more diversified and fast changing product portfolios are required. One has to preserve tight quality tolerances, increased energy efficiency, as well as reduced waste and environmental impact under volatile energy and raw material prices. A further goal is the reconstruction of the traditional multi-layer model to enable a mapping of an existing approach a fog cloud model. One observes opposing trends: security, determinism, and granularity increase by moving tasks to the fog, while flexibility, adaptivity and cognitivity increase by moving tasks to the cloud.

Cognitive production systems represent a significant step beyond the current state of the art due to their ability to self-adapt, interact, and integrate, with human-like flexibility, reliability, autonomy and robustness. Cognitive systems will be able to reason from collected data; perceive, process, and interpret information to generate responses, actions and reactions, learn new models and self-adapt the existing ones; communicate and interact with other systems and humans, and be able to plan for the future.

Approach
The methodology for creating an economic design of a future-oriented batch production (ideally batch size one production) will be to follow a modular concept of standard and new technology units that can be connected to the production demands of the current product in a very easy way (plug and produce). Within this modular and flexible arrangement of manufacturing hardware, there must be an inner



flexibility of the modules that will be obtained by means of intelligent automation.
Furthermore, Area 4.2 investigates principles-based modelling for analysis, system design and automatic control. This includes non-linear model predictive control technology and big data analysis driven optimization of the overall plant dynamics (specifically in-line process monitoring technology), as well as human-machine interaction with 3D motion tracking technology. The work program for batch production is the setup of a smart factory. This will be the test bed for defined topics of research and the new ideas mentioned earlier. This smart factory, a pilot plant at Graz University of Technology, will showcase the production of the future and should not be designed under the preconditions of using existing machine architecture and logistic devices. The field of “Cognitive Energy Management for Industrial Production” is planned to be realized in form of a fog cloud model.

Measures for technology transfer and industrial implementation of results: Technology transfer is quantified by publications in proceedings of peer reviewed conferences, by publications in peer-reviewed journals and by patents. The pilot plants of this area are a particularity, as they additionally allow to evaluate possible implementations at the plants of the industrial partners at laboratory size. Concrete goals, e.g., for the Living Lab for continuous production are the demonstration of a) an enhanced online molecular mass control, b) an enhanced inline bulk material feeding for a very wide dosing range and c) the enhanced ramp up of working point of a complete polymer extrusion line. A tight cooperation between the involved engineering sciences is necessary to succeed. A precise mathematical description of the processes already allows monitoring beyond simple data processing today and constitutes an indispensable tool toward awareness, process, and product intelligence. This description must be extended so that the models become applicable to the problems caused by the new technologies. Basic algorithms for control, monitoring, etc. must be revised, updated or replaced with new ones, such that distributed sensor and actuator fields can be handled, whereat the communication efforts are minimized, data security is granted and the current high level for services remains. This includes non-linear model predictive control, as well as smart data predictive control. All investigations must be performed with a strong view to application scenarios like the factory in the factory, as well as to the introduction of new methods, e.g. big data analysis.

The management of complex situations like change of operating points, (ad hoc) setup and tracking of new trajectories, monitoring is a natural task of the cloud. The required mathematical models and tools, the algorithms and software systems will become available for the user, where the use of open software is preferred, such that monitoring, big data analysis, selective diagnosis etc., become possible beyond the current industrial standard. Cloud fog models of production processes lead to new business models because they break the current spatial connection between machines and control devices. Particular for control in the broader sense of guidance, online optimization, adaption, etc. one will be to check proposed new models with respect to economic feasibility, but also to reliability, data security, and others.

All partners involved in Area 4.2 projects are contributing to the Living Lab for continuous production or the Smart Factory for batch production. This allows comparing ideas and proposals by experiments based on real data instead of simulations, such that new measures for effectiveness, reliability, etc. are gained. All these benefits together with a better understanding of modern process industries will not only have an impact on the industrial partners but also on the teaching in academic institutions. In addition, approved applications of integrated machinery are an important contribution to future production paradigm amongst industry 4.0. The use for the project partners lie in the generated know how of plant and machinery layout and the upgrade options, e.g. to outfit extrusion and compounding systems with cognitive skills. In the aforementioned case, this will be demonstrated by the above-mentioned three examples (enhanced online molecular mass control, in-line bulk material feeding and ramp up of complete co-extrusion lines).

Expected and Achieved Results

The achieved results in Area 4.2 are novel detection methods for human factors (vital state, skill, stress, peripheral interrupts) to reduce the workload and decrease the risk of incorrect operation as well as modularization, simulation and virtualization in smart batch production within the project Adaptive Smart Production.

In **continuous production** within the project Cognitive Polymer Extrusion and Compounding novel concepts for experimental and computational modelling of cognitive self-optimization polymer extrusion and compounding production for increased production productivity and product quality were developed. Novel mathematical meta-heuristic models of real time production including big data as well as novel smart data and first principles based predictive control technologies were implemented. The results were enhanced online molecular mass control, in-line bulk material feeding and ramp up of working point.

EXECUTIVE SUMMARY

Area X - CRP

Common Research Programme (CRP) on Cognitive Industrial Systems

Pro²Future has been collaborating with its sister COMET K1 Centre "Center for Digital Production" (CDP). This common research activities have been established in a more formal manner as a Common Research Programme (CRP). The CRP provides the frame for multiple demonstrator project(s) between Pro²Future and CDP. These demonstrator projects – for the period of the first two years – have to amount to a minimum volume of 2.4 Mio. EUR from each centre.

Pro²Future's main research and R&D emphasis is on **cognitive products** and **production systems**, and the **CDP** COMET K1 Centre is working on challenges posed by the fourth industrial revolution (Industry 4.0), requiring manufacturing companies to support a seamless integration of all process steps including automation, control and documentation. CDP covers process steps ranging from acquisition to delivery: (i) the **virtualisation of product and production systems** to allow for a comprehensive product specification and a reliable process planning, (ii) the **development of design automation** to not only accelerate the design process but also the work planning, (iii) **protocols for machine-to-machine communication** to support the implementation of flexible and reconfigurable automation systems, (iv) **digital platforms and networks for production** to allow for the dynamic formation of virtual smart factories enabling low tier manufacturers to provide a combined and therefore value-added service, and (v) the **ergonomic, legal and socioeconomic impacts** of digital production. **Their main R&D emphasis is on systems for digital production**.

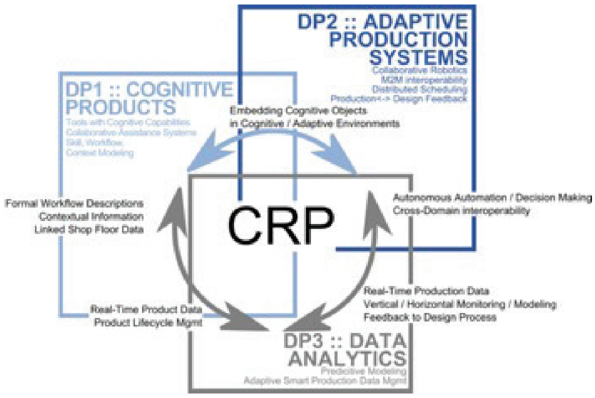
The **Common Research Programme (CRP) on Cognitive Industrial Systems** was developed in a structured solicitation process, including industrial partner of both consortia and moderated by the „Plattform Industrie 4.0 - Österreich" (https://plattformindustrie40.at/). In this process, significant technological and industry relevant problems were identified that will foreseeably challenge Austria's industry in near future and problem categories were shaped in line with the solution competencies coming from both consortia. The priorities that were deduced from topical industrial needs, aim at fostering innovation and competitiveness of Austria's Industrial Sector in international markets. In short, research priorities have been set towards (i) the **embedding of cognitive abilities** into products of the future, (ii) the **autonomous adaptation of modular production systems and supply chains** enabling manufacturing aiming at highly adaptive, and improved quality production processes, and (iii) **entangling product life cycles** and product use patterns **with processes and workflows** in adaptive and interoperable manufacturing systems based on **semantic and interoperable data flows and predictive analytics distributed on edge and cloud-based systems**. Industry 4.0 research at CDP in conjunction with the Cognitive Products and Production Systems research at Pro²Future paved the way towards a confluence of Industry 4.0 Systems and Cognitive Systems, suggesting headlining the Common Research Program (CRP) as Cognitive Industrial Systems.

The Common Research Programme has allowed to aggregate complementary approaches of Pro²Future and CDP into a joint, synergetic research initiative, extending the outreach for both centres, and stimulating research supporting Austria's manufacturing industry. For this purpose, three demonstrator projects have been developed, with prototypical realisations, demonstrating the potential and functionalities in the fields of (i) **assistive man-machine collaboration** (equipping machines with collaborative, cognitive capabilities to provide optimal worker support, as well as providing work tools and instruments with cognitive features to assist complex work processes with assistive guidance), (ii) **adaptive control and dynamic adaption of networked production** (enabling edge and cloud based intelligent cyber physical systems) as well as (iii) **integrated data analytics** (to allow for autonomous, sensor based data collection, mining and knowledge extraction, prediction and forecasting, planning, optimisation, autonomous decision-making and real-time control and steering).

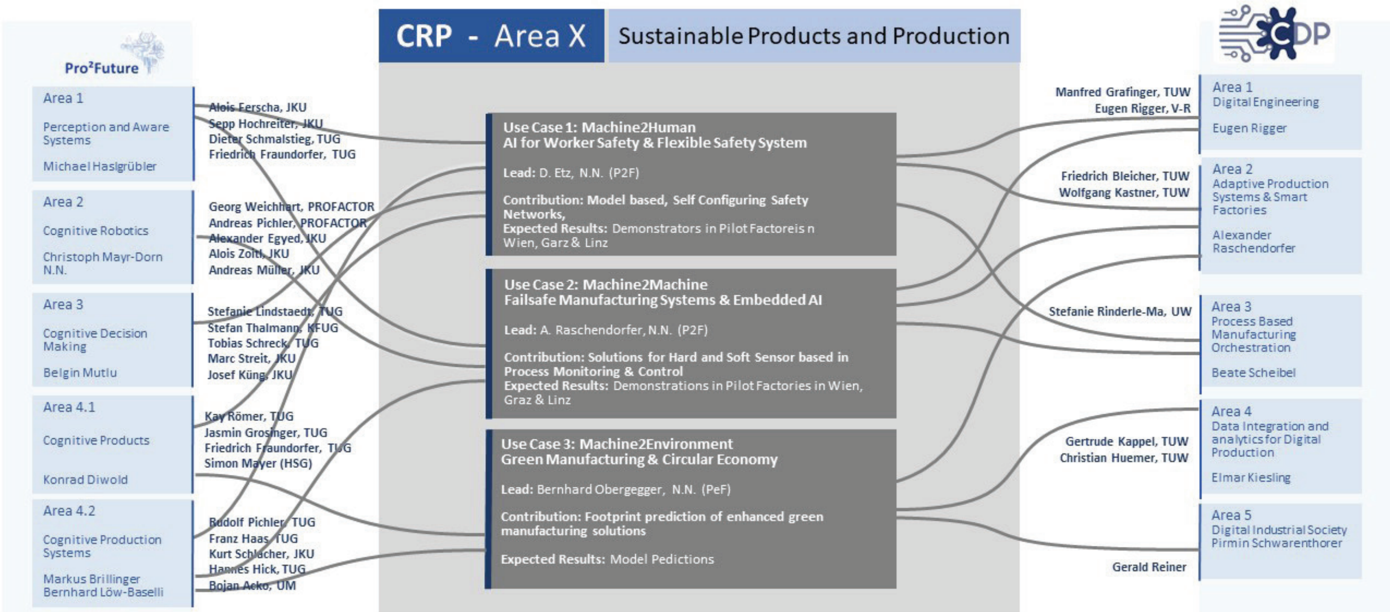
The Demonstrator Projects (DPs) are intended to demonstrate the potentials of online, real-time, interoperable, semantically structured **data and meta-data exchange** among **products**, **workflow systems** and physical **manufacturing systems**, so as to show-case adaptivity of product features and abilities, tools and work instruments, robotic equipment, manufacturing machinery, shop floors, from a continuous **feedback-loop among products and production systems**. It is considered ultimately important to exemplify projects that not only show how future and emerging industrial technologies impact the design, creation, use and life cycle of **products on their own**, and how these advances will excel how industry plans and sets-up production equipment and **manufacturing lines on their own**. CRP aims to clearly pose a case demonstrating **next generation products and production sys-**

tems. We shall demonstrate by example how cognitive product use impacts the next generation of tool designs by collecting, analysing and mining **product use data** , how tool-use intertwines with manufacturing processes that build on human-machine collaboration and enable higher levels of **adaptation in production**.

The Common Research Programme aims at exploring the potentials in the fields of (i) **physical cognitive products** in the realm of an intimate man-machine interaction which interact and correspond to workers and other cognitive systems in the direct environment, (ii) **adaptive machine-to-machine production systems** for optimized, synergetic organization of automatable tasks as well as (iii) **advancing required approaches for data analysis** which are capable of specifically contributing to improving production processes.



Entanglement and Overlap of the Demonstrator Projects (DPs) contributing to the Common Research Program (CRP)



The CRP is implemented in a **two-phase approach**. **Phase 1** (project years 1 and 2) will bring (according to the assessment of industrial partners very challenging, and very concrete) the demonstrator projects (DPs) **DP 1 - Cognitive Products, DP 2 - Adaptive Production Systems**, and **DP 3 - Data Analytics for Industrial Process Improvement** to a level of convincing "proof-of-concept" systems. In **Phase 2** (project years 3 and 4) they will be raised to fully functional, self-contained, highly elaborated, convincing demonstrators.

To approach the identified challenges, the consortia decided on **three representative demonstrator projects** that overlap in the data generated and exchanged for enabling the proposed functionalities as individual projects as well as an overall functioning single demonstrator, fusing the developments into an overall vision of future production systems.

DP1 - Cognitive Products addresses the aspects of realizing physical instances of direct, man-machine collaboration realising human-centred assistance systems.

DP2 - Adaptive Productions Systems aims at demonstrating solutions for self-adapting production systems and focusses on collaborative robotics, distributed scheduling of adaptive shop floors as well as feedback of production data into the design process.

DP3 - Data Analytics for Industrial Process Improvement will cover the fields of integration of processes, data analytics, and simulations and will build a toolset (set of algorithms, analytic machinery and visualisations) for industrial process improvements based on data analytics, to be evaluated by specific use cases in the Smart Factories in Austria. These three demonstrator projects overlap in the data generated and exchanged for enabling the proposed functionalities as individual projects as well as an overall functioning single demonstrator, fusing the developments into an **overall vision of future production systems**.

EXECUTIVE SUMMARY

DP 1

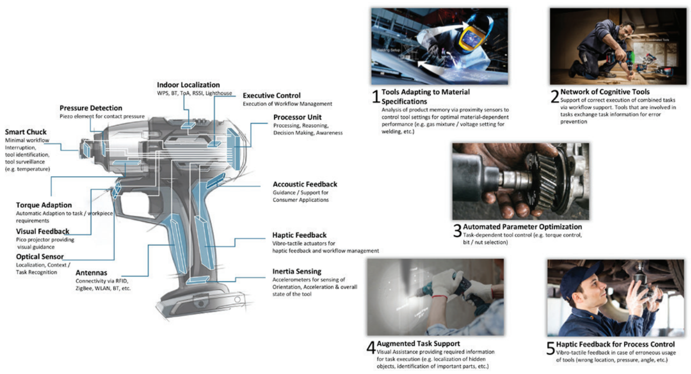
Cognitive Products

The current trend towards individualization of products is creating a dichotomy of automation and revival of manual labor in industrial production. Due to their **cognitive capabilities**, humans are better in adapting to changing, customized manufacturing processes than fully automated mass production systems. However, to maintain manufacturing efficiency, the **increasing specialization of products** and processes **requires guidance in task execution**. Furthermore, industrial companies nowadays recognize the benefits of a continuous, detailed assessment of current processes and their respective data for optimizing product specifications and production via digitalization of (semi) automated processes. DP1 attempts to advance the state of the art by digitizing **manufacturing processes that involve the human worker** and providing worker support with all associated complexities. The development of **cognitive manufacturing tools** (i.e. PowerTools) to enhance the performance of workers within a smart factory is hereby the chosen modality.

DP1 addresses these issues via the development of cognitive products, which are created by **embedding AI principles** into product hardware, and advanced machine learning and pattern recognition techniques into the software. These products thus **integrate cognitive functionality**, such as **perceiving** situations and the environment, **learning** and **reasoning** from knowledge models. The ultimate goal is to turn machines into ones that can reason using substantial amount of appropriately represented knowledge, learn from its past experiences in order to continuously improve performance, be aware of its own capabilities, reflect on its own behavior and respond robustly to surprise. Currently, we are witnessing an era in which the convergence of algorithmic advances, data proliferation, and tremendous increase in computing power and storage have propelled **Artificial Intelligence** (**AI**) from hype to reality. However, in order to develop truly cognitive learning and thinking machines there are open key challenges to address, i.e., (i) machine learning requires massive resources (computing power and training data), (ii) models do not generalize well, (iii) and processes of training and inference most likely differ from human learning and reasoning. Gaps we aim to reduce or even close with DP1.

Goals

DP1 has addressed key challenges towards this vision by **embedding cognitive capabilities,** such as perception, reasoning, learning and planning, into production tools in order to enable advanced (i) Worker **Guidance** and Support, (ii) **Automated Tool Configuration** and **Workflow-**adaptation, and (iii) **Data Collection** for Modeling and Documentation of Production Front- and Backend Processes by embedding

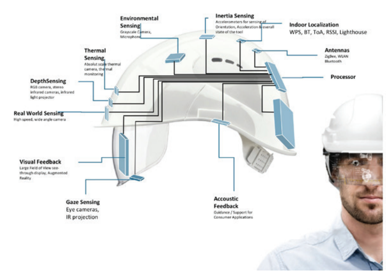


sensor, actuators and reasoning systems (e.g. machine learning) into tangible objects operating in the real world, in our case, particular in production environments.

The **selection of production tools as instances of Cognitive Products** (i.e. PowerTools) was driven by (i) their direct applicability to existing R&D environments in the industrial consortium, and (ii) due to their potential to bring a competitive advantage for industrial players: Cognitive Products provide key benefits, such as (i) **learning from past experience** to avoid repetition of errors and continuously improve quality and cost, (ii) production **task awareness** to enable flexible adaptation to variations within a single and across different tasks, (iii) **worker skill awareness** to enable compensation for lack of skill or attention, and (iv) **collaboration** between cognitive tools to provide resolution for deviations in earlier production steps. DP1 approaches these issues by means of visual/multi-sensor data analysis using deep learning and other modern (un)supervised classification, prediction and learning methods.

Thus, DP1 continuously aims at provisioning cognitive behaviors to industrial production processes as well as to end-user application scenarios. In particular, the project activities are focusing on the objectives of CRP: (i) develop new and enrich existing industrial **tools with cognitive capabilities,** (ii) optimize tool utilization and production processes based on **device state and contextual information** (iii) detect **cognitive load and attention** level and adapt the manufacturing process and (iv) identify **experience/skill level and workflow complexity** and adjust the worker's assistance appropriately.

We designed DP1 around 7 demo cases (DP1.1-DP1.7) show casing **solutions for cognitive products: DC 1.1:** Built upon state-of-the-art design tools enhanced and **novel realizations** interlinking existing production hardware with modern sensor and actuator hardware, and implemented **cognitive, (pro)active software modules** complying with the requirements of specific application scenarios, **DC 1.2:** Designed and developed a functional prototype of a **cognitive, head-mounted welding gear** and the associated design and implementation toolchain, demonstrated in a **digitalization scenario** of analog factories **DC 1.3:** Mobile eye-tracker based on fixations, saccades, blinks, pupils and smooth pursuit for detecting **cognitive load, skill and attention** level, **DC 1.4:** Multi-sensor fusion **framework** providing algorithms for **work-step and micro-action detection** aiming to provide appropriate worker guidance. **DC 1.5** (extending **DC 1.1**)**:** Develop manufacturing equipment, such as **cordless screwdrivers**, to be used in the production line of our industrial partners, where such equipment is used on a regular basis, **DC 1.6** (deepening **DC 1.1**)**:** Develop **unified dependable wireless services and communication platforms** enabling the respective products and tools to collaborate, and position themselves using batteryless radio frequency based sensing, **DC 1.7** (extending and specializing if **DC 1.3** and **DC 1.4**)**::** Develop **self-learning** adaptive control for **cognitive welding machines**.



The project results so far were demonstrated by means of a **Cognitive Welding Machine** as first instance of a dedicated CP showcase on the feasibility of the approach. The found principles were already extended to other domains, e.g. **power tools, heavy machinery**, or **assembly process** with respect to the company partners. Beyond this **refinement of the principles**, a particular focus will be to foster the **embedding** of **dependable wireless services**, and establish where **high bandwidth communication** and **low latency** is of concern. Additionally, **safety** and **security** will be embedded into the components to provide **content security**, **anonymization** and **privacy by design**.

Approach

Building upon the approach of opportunistic sensing, **cognitive components** will be made capable of **describing their capabilities** with respect to both sensing and actuating. They are able to find each other, form collective ensembles in a **self-organizing** manner and exchange structured data. **Collectively**, they will **sense the current contextual state**, in which they are used and adapt themselves accordingly, for example pre-emptively by suggesting usage strategies or best practices to the users, as well as reactively by setting operation parameters to suit the circumstance. Finally, the ensemble will be able to **learn from usage**/misuse of individual tools in the collective and take re-/proactive steps to increase their own life span or avoid hazard situations.
The consortium can build on rich experience from the fields of: advanced, opportunistic, **multi-sensor fusion** in embedded recognition architectures; **collective ensembles**, context- and activity recognition, attention recognition, behaviour prediction, **assistive multi-modal** systems; design of dependable wireless ICT platforms. Integration of the domain specific methods and tools for mechanical design, electrical/electronic engineering and software development is one main challenge in creating complex technical systems. For the development and engineering of the demonstrator within the project, latest **multi-disciplinary engineering design** methods will be applied. The methodical basis is set by VDI guideline 2206 but also **agile** approaches to **engineering design**, taken over from software development will be deployed.

Expected and Achieved Results

So far, an ensemble of cognitive components has been embedded into a three-folded welding gear, consisting of a welding shield, a welding torch and a power source and cognitive power drill, enabling the overall system to **present cognitive capabilities,** such as, perception, reasoning, learning and planning, towards its users. So far, the cognitive power tools are able to (i) support Worker **Guidance**, (ii) provide **Tool Configuration** based on the selected or detected step in a **workflow**, and (iii) provide **data recording capabilities** for documentation of overt and implicit production behavior.

Four **Demo Cases** have been accomplished so far in the executing **MFPs** WorkIT, GUIDE, SeeIT on the Pro²Future side, and **MFPs** MFP33, MFP11 on the CDP side: In **DP1-DC 1.1 :: Cognitive Product Design** three engineering design support features have been developed. The first one is a cognitive element library for SolidWorks enabling the re-use of common cognitive parts. The second is a CAD plugin facilitating the link of non-geometrical information (e.g., requirements) to CAD models that may be built with cognitive library elements. Thirdly an extraction tool supporting the creation of software configuration files, which include data originating from the model. For **DP1-DC 1.2 :: Digitalization of Industrial Environments** we saw that indoor localization based on infrastructure sensors was not feasible due to arbitrarily complex, large environments with mobile actors. In order to create and continously update point cloud models of arbitrary environments on-the-go, an image-based approach built upon a head-mounted RGBD camera and the RTAP-Map framework was used. For **DP1-DC 1.3 :: Gaze-based Skill-level Detection** a mobile eye-tracker was employed to create a labeled task-dependent training data set. The training samples were segmented, an extensive feature set based on fixations, saccades, blinks, pupils and smooth pursuits was extracted and used for model training. At runtime, the sensor data is again segmented and extracted features are classified by the trained model**. In DP1-DC 1.4 Work-Step Recognition** we built a dedicated software platform with capturing support for various sensing devices and supporting multiple operating systems and hardware platforms. Further, algorithms for multi-sensor fusion that are able to detect worksteps and micro-actions and that show the current state of the worker within a workflow model were developed. Based on the current workstep the system provides dedicated help to guide the user. For **MFPs** follow up results are in progress in the **Demo Cases DC 1.5** (extending **DC 1.1**)**: Develop manufacturing equipment**, **DC 1.6** (deepening **DC 1.1**)**: Develop unified dependable wireless services and communication platforms**, and **DC 1.7** (extending and specializing **DC 1.3** and **DC 1.4**) Develop **self-learning** adaptive control for **cognitive welding machines**.

As **overall DP1 achievement** (i) **quality control** has been digitalized & integrated into the assembly procedure (SeeIT; CP KEBA), (ii) well-defined **formal and visualizable workflows** established (WorkIT, SeeIT; ECB TRUMPF; ECB Fronius), (iii) **reduced cognitive strains on workers** induced by continuous and repetitive work processes (workIT, GUIDE; CP Fronius; CP TRUMPF), (iv) exploited **acceleration potentials by Just-in-time assistance** in cognitive product (power-tool) handling and lot-size-1 production (GUIDE; CP KEBA; CP Fronius), (v) aligned with cognitive power-tool features, by **providing cognitive guidance for workers** (GUIDE; CP TRUMPF; CP Fill; ECB ModelWorks), (vi) created **training** of human workers **at the workplace "on-the-fly"** (GUIDE; CP Wacker Neuson; CP: Trumpf/KEBA), (vii) practiced **Cognitive Welding Support** practiced with the HeadGear platform (presented at HANNOVER MESSE 2019). This resulted in **13 Peer-reviewed publications (2 co-authored Pro²Future / CDP, 1 co-authored with industry), 2 PhD approved (5+2 PhD in progress)** and **3 Masters (5 Masters in progress)**, and the international conference **IoT 2017 organized** and **hosted** at **JKU Linz.**

EXECUTIVE SUMMARY

DP 2

Adaptive Production Systems

(Not only) the 2020 pandemic has shown the importance of being able to have production systems in the heart of Europe. Physical Production around tangible goods is essential for jobs, welfare and social sustainability. In Europa competitive advantage is enables by agile production in a high mix, low volume environment. These requirements concern SMEs as well as large OEMs in Austria. Recent developments, subsumed under the headings of "Industrial Internet of Things" (IIoT), "Industry 4.0" (I4.0) and "Cyber Physical Production Systems" (CPPS), address the ability of machines to interact interoperable as a complex, adaptive network. While individual and isolated interface technologies and approaches exist, for a flexible network of production systems, several important elements are still missing and sustained research is necessary.

Through the incorporation of Industrial Internet of Things (IIoT), Cyber Physical Systems (CPS), collaborative robots (Co-Bots) and Edge/ Cloud-computing into the entire production process, small-lot-sizes, speed, efficiency, quality is addressed altogether through an adaptive production system. The adaptive production system combines conflicting paradigms of flexibility and efficiency amid high quality.

The goal of the demonstrator DP 2 is to realise proof-of-concept implementations and industrial application examples by incorporating results of the research activities into regular operations. Prototypes will be provided on a ready-to-use level of maturity in order to prove industrial relevance.

Specifically, in DP 2, Pro²Future is closely collaborating with DP 2-leader CDP (Pilotfabrik Aspern), to demonstrate IT technology in the context of the milling process, intelligent fixture, flexible milling process and adaptive robotic systems. Hence, the following describes the overall project, but the Pro²Future team contributes not to all of the following goals.

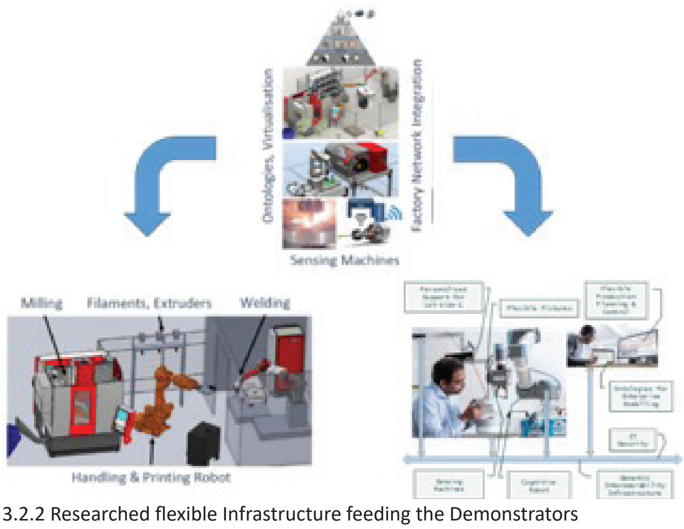
Goals

The overall objective is to demonstrate that adaptive production systems can be implemented by modern factory network and process control architectures for both fully automated process execution and manually assisted process execution.

For this purpose, the demonstrator DP 2 will implement a factory network based on OPC UA and workflow engines, in order to be able to implement plug and produce capabilities. This includes the composition of formerly distinct production units to a new, combined machining system.

The commonly developed flexible infrastructure enables multiple scenarios, which range from fully automated processes to collaborative robotics. In both cases, an infrastructure building on ontologies will provide a semantic layer that allows connecting multiple systems and processes. The figure below depicts this approach and it shows demonstrators that focuses on an automation scenario and a demonstrator that focuses on human worker support.

The figure separates the common research on the "middleware for the networked Production Systems" providing the input for demonstrators at different locations and where more specific research takes place. It is also the basis to feed production process data back to the design process.



3.2.2 Researched flexible Infrastructure feeding the Demonstrators

Approach

For design and implementation of OPC UA interfaces for demonstrator a systematic model driven approach is used. The main idea is to separate the design system from the implementation. The OPC UA interfaces will be described by using OPC UA modelling language, which is based on UML and afterwards code fragments for runnable applications will be generated automatically.

An OPC UA stack has to be developed in which TSN (Time Sensitive Networks) can be used concurrently with classical Ethernet as data link-layer. Based on the stack, both an appropriate OPC UA server and client implementation are required to meet the requirements of TSM. This approach allows making use of real-time communication while preserving compatibility with other OPC UA enabled manufacturing machines, and making these in an IT-friendly way interoperable with SCADA, MES and ERP environments. Transferring process data generated by sensing and tweeting machines back into the automated design process will enable product improvements in terms of, quality and cost through design for manufacturability.

For modelling an ontology for semantic interoperability, OWL will be made interoperable on the data-level with OPC UA Information models. Available interoperability tools will be analysed and a suitable tool will be chosen and adopted. Finally, the information models and queries will be implemented in OPC UA servers of the devices in the demonstrator.

Continuous adaptation requires interoperability of systems. Collaborative Robots require access to information from heterogeneous systems. This requires that the robot is aware of the above semantics of the information from the heterogeneous software environment and workflow. The robot requires its own interpretation engine. In addition to this general understanding of the work tasks, is it required to merge sensor data with the "static" knowledge-based models. This, includes, but is of course not limited to, the identification of product parts and the human operator manipulating parts. A basic understanding of critical situations with respect to inconsistencies of sensor data and the expected situation(s) is needed. A time critical enterprise as this concerns human safety. In addition, the detection and treatment of more general fault situations is essential. In collaborative situations, this requires common understanding of information exchange between human operator and robot. The possibility to handle also errors in human – robot interaction is critical. The safety aspect therefore does not only require semantic interoperability but also pragmatic interoperability.

For a fast reconfiguration of the whole production system enabled by modular fixtures, an interoperability layer and cognitive robots, the plug and produce philosophy has to be respected in all components. To do so, new interfaces and approaches to make systems (e.g. the fixtureing system with the robotic system and the control system) ad hoc interoperable in an instant way are required. These interfaces should provide data and energy exchange in combination with the plug and produce capability. To reach that goal a detailed specification analysis of information content, evaluation, and adoption of the relevant standards and models will be sequentially employed to formalise the target domain. Related to this, it is also required to have an understanding of the behaviour of all involved systems.

A knowledge-based enabling automated update based on sensed information needs to be developed. In order to make information from the manufacturing process interoperable, data of interest needs to be defined and methods for corresponding interpretation have to be identified (semantic alignment). In order to optimise acceptance of the developed solution, careful attention will be paid to the design of the data-structures (and their understandability) and the user interfaces for seamless human computer interaction.

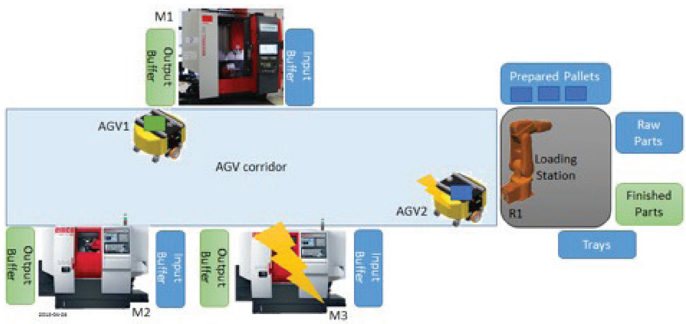
Expected and Achieved Results

Since its earliest days and up to now, production companies are able to compete successfully if they produce faster, cheaper or with better quality. Up to now, the majority of (process) innovations address these aspects separately. This project aims to demonstrate how these goals can be addressed in an integrated manner by means of manufacturing process adaption as well as design modifications. As a side effect, the manufacturing process will be more adaptive. Adaptive scheduling algorithms and automated adjustments of process parameters will be demonstrated. Key functions of adaptive production systems comprising the following aspects will be implemented within a demonstrator representing the major components of a typical shop floor.

Expected results

- adaptive process control: real-time determination of chatter
- predictive QA: the sensing machines - warning functions based on sensor data evaluation
- showcase learning possibilities for reconfiguration of manufacturing resources
- adaptive scheduling based on in-depth production monitoring
- teaching simple tasks to robots using natural interaction
- interactive human - robot message exchange in manual tasks
- job shop schedule optimisation
- tweeting machines – process and condition monitoring by machine-to-machine communication and platform connectivity

The demonstrator for milestone 1 brings together research along these many expected results. It consists of two interrelated use cases that demonstrate the joint integration. On the local-level, a robot solution (Pro²Future) picks unsorted raw parts and sorts them into pallets. These pallets are transported to machines for processing. The demonstrator shows the simple integration of robot human interaction and integration with the CDP centurio Workflow engine. The second use case is situated at the macro-level and focuses on integrating shop jobs with adaptive scheduling (Pro²Future). The novel aspects of the demonstrator include considering transport means as a limited resource and source of failure as well as integrating reliability information into the schedule for obtaining resilience: low impact of failing machines and transport means.



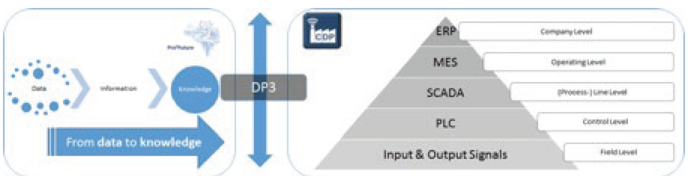
EXECUTIVE SUMMARY

DP 3

Data Analytics
for Industrial Process Improvement

Today, manufacturers are more and more able to collect and analyse data from sensors on manufacturing equipment, but also from other types of machinery, such as smart meters, pipelines, delivery trucks, etc. However, many manufacturers are not yet ready to use analytics beyond a tool to track historical performance. However, knowing what happened and why it happened is not sufficient anymore. Manufacturers need to know what happens next and what actions to take in order to get optimal results. It is a challenge to develop advanced analytics techniques including machine learning and predictive algorithms to transform data into relevant information for providing useful insights to take appropriate action. This project targets new analytical methods and tools that make insights not only more understandable but also actionable. The latter requires that the results of data analytics have an immediate effect on the processes of the manufacturer. Thereby, data analytics will improve industrial processes by reducing maintenance costs, avoiding equipment failures and improving business operations.

Accordingly, the **overall objective of this project is to develop a toolset (set of algorithms, analytic machinery and visualizations) for industrial process improvements based on data analytics**. This set of tools will not be bound to any sector of industry and will aim at specified goals, e.g., “prediction of failure”, “improvement of energy consumption”, “remaining number of future usages”, “correction of deviations and drift”. This tool set will be demonstrated within the setting of two smart factories (Vienna and Graz).



Goals

It follows that the ultimate goal of this project is to improve industrial processes by means of data analytics, which will be achieved, by a combination of data-driven knowledge generation and corresponding redesign and reconfiguration of processes. In order to support the decision makers (responsible for changing the processes) it is essential to visualize process designs, running process instances, recognized defects or inefficiencies, and possible changes. Furthermore, it is critical that the decision maker is aware of potential effects of process changes. Thus, this project will deliver a simulation tool to evaluate different alternative shop floor process changes. If a process is changed, the corresponding effects may be local to a specific level of the automation pyramid or it may have cascading effects on other levels of the pyramid that will be supported by this project. In addition, this project will provide a secure data communication protocol which will enable the communication of data to be analysed e.g. between production sites. Eventually, it is the goal to evaluate the framework by a common use case, which is independently demonstrated at two different smart factories (in Vienna and in Graz).

In summary, this project aims towards six main goals: (i) process redesign and reconfigurations by means of data analytics, (ii) visualization of processes and process changes, (iii) simulation of data and process alternatives, (iv) support of cascading process changes, (v) secure data connections, and (vi) use case based evaluation in smart factories.
This joint project aims towards creating new knowledge for improving/adapting already existing processes by use of data analytics and its means of visualization. The simultaneous and systematic examination of data and processes will support production at all levels.

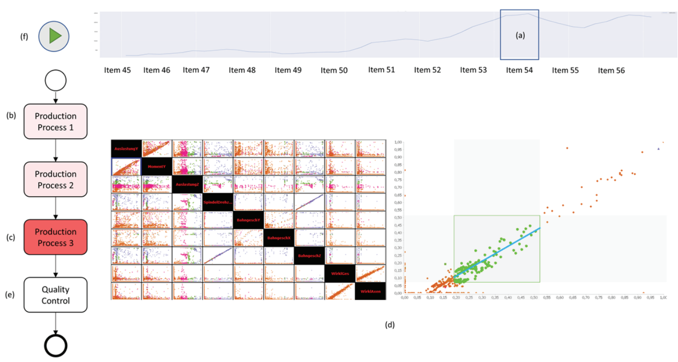
Approach

This project investigates on applying the data analytics concepts (as envisioned by Pro²Future) to the process-oriented view (as envisioned by CDP). Accordingly, the project envisions flexible production processes that benefit from data analytics. In this joined project we will gather and analyse (including visualizing) production data, interpret it in the context of production processes in order to support the decisions on process design and execution as well as for delivering the corresponding process enactment.
CDP follows a process-oriented view in order to facilitate production processes. It is envisioned that the necessary process steps are (semi-automatically) derived from the product design, although manual process design is also supported to give the process owner a complete set of design choices. The P2F approach is to (1) monitor horizontal and

vertical (production) activities and to make the (production) progress visible, (2) develop predictive models based on the collected data, (3) analyse data across automation pyramid levels in order to generate data-based models and knowledge.
In a joint collaboration, this project identifies potential functionalities in improving production processes by means of data analytics. In a subsequent process the conceptual approaches and methodologies to deliver these functionalities are to be developed. These conceptual approaches and methodologies are supported by fully functional research prototypes. These prototypes should be used in case studies that serve both as a proof-of-concept evaluation and as demonstrators that facilitate the technology transfer.
In order to reach these goals, the academic partners have to collaborate with both IT providers and manufacturing companies. The Smart Factories in Graz and Vienna will provide requirements, uses cases and data for different tasks in various work packages. They will support data & process knowledge collection as well as testing for models and evaluation of tools. Evidently, the manufacturing companies serve as demonstration partners in the real-world case studies. The IT providers will not only serve as critical reviewers in the development of the conceptual approaches and methodologies, but also as implementation partners to develop the prototypes.
This project will be implemented in close coordination with the other two DPs. Specifically, DP 2 will provide production data across the automation pyramid (potentially across the secure data connection) to DP 3. In turn, parts of the DP 3 toolset can be applied within the Smart Factories. It is envisaged that data concerning the production process of one specific product will be provided to DP 1. Requirement analysis and use case definition have to be closely aligned with the needs of smart products and production systems.

Expected and Achieved Results

This project delivers a reference architecture, tools and demonstrator for production process analytics, covering the following components:
Integration of data and processes. To gather a fully integrated view on data and processes we define three core tasks: (i) **Data Analytics Aware Processes**, that allows the integration of data analytics as regular steps of a production process that provide relevant context information for production steps, (ii) **Data Driven Process Design Improvement** that analyse production processes in the past in order to improve the production process design, and (iii) **Data-Driven Process Reconfiguration** to provide self-healing capabilities for production processes on basis of live data analysis of production data streams.
Tools for Visual Data Analytics. This component allows the interactive visualization of processes based on process definitions and historic and (near) real-time measurement data obtained from nodes of the processes (i.e., machines in a production line). To this end, a set of tools to appropriately visualize the data at hand will be realised. The toolset will support a process expert to monitor processes in (near) real time and hence support the decision-making process, based on



interactive data visualization.

Data & Process Simulation. This component supports cognitive decision making by the simulation of data in production systems. The effects of possible decisions on the various process levels will be shown and can be evaluated by the end-users.

Secure Data Connection Framework for Cross-Level Process Optimization. This component supports cascading effects of changed process designs or process instances at different levels (of the automation pyramid). It consists of a technological infrastructure, which allows for a highly secure transmission of data in a distributed production environment, and respective data integration tools for efficiently handling design changes over multiple process levels.

Smart Factories as a testbed for model verification. A common use case for both Smart Factories is going to be elaborated and defined. According to the common goal of this use case, both locations will capture large amount of data from various sources. On basis of both data silos data analytics will be implemented and evaluated. These tools will find their validation again on the more specific processes at both locations of the Smart Factories.
The final result will be a **two-staged demonstrator** in each Smart Factory. These will provide local small and medium sized companies the opportunity to gather new ideas for their digital transformation and define new projects.

Results
Integration of data and processes: We integrated data analytics into process management by making the data analytics results part of the process logic**.** The **data analytics component** allows analysing data from the production systems and making recommendations for adapting production processes during run-time of the process engine. The **process engine** is responsible for storing and executing the process models and to coordinate the data collection. The component is also able to integrate new insights from the analytics component as well as from the simulation component during runtime. Additionally, the process engine can integrate new insights from the visual analytics component during design time.

Visual Data Analytics: The **visual data analytics component** allows the interactive exploration of big data streams based on a visualisation of the process model. Thus, the deciders are able to conduct a root cause analysis and to identify process improvements quickly during design time.

Data & Process Simulation: The **simulation component** evaluates alternatives of process execution during the runtime and recommends process adaptations.

Secure Data Connection Framework for Cross-Level Process Optimization: The **secure data connection** allows for a highly secure transmission of data to the process engine as well as between all other involved components.

All the components have been developed based on a first set of use cases in the Pilot Factory in Vienna/Aspern.

Smart Factories as a testbed for model verification: Concept for smart production solution for small and medium sized companies has been defined and will be evaluated by the end of 2020.

EXECUTIVE SUMMARY

Area X - CRP II

Common Research Programme (CRP II) on Sustainable Products and Production

Pro²Future (**Pro**ducts and **Pro**duction Systems of the **Future**) and **CDP** (Austrian **C**enter for **D**igital **P**roduction) are Austrian Research and **COMET Competence Centre for Excellent Technologies** funded by the **Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology**, the **Federal Ministry** for **Digital and Economic Affairs**. Both centres have **applied** in the **K1-Centres 4th Call** 2015, have been proposed for funding after fulfilling a **jury requirement before contract** to pool their complementary competencies in a **Common Research Programme** (**CRP I**), are in operation since **April 1, 201**, and are preparing for the **Mid-Term Evaluation** after the first funding period (**FP1**, 2017-2021).

The **jury requirement** for FP1 requested **Pro²Future** and **CDP** to implement the **Common Research Programme** (**CRP I**) in the form of **demonstrator projects**, having to amount to a minimum volume of 2,4 Mio. EUR from each centre every two years (**total 9.6 Mio. EUR**) and having to be approved via a **stop-or-go decision** after project year 2. **24** (**Pro²Future**) and **27 (CDP)** researchers have worked on CRP I, successfully delivering **proofs of concepts** for **new solutions** to **technologically significant** and **industrially relevant** problems of **digitalization in industry**, in **3 demonstrator projects** (**DP1 - Cognitive Products, DP2 - Adaptive Production Systems**, and **DP3 - Data Analytics for Industrial Process Improvement**), exhibiting **12 demo cases**. After submitting a **two-year CRP evaluation report** on June 27, 2019, and a **panel hearing** on September 26, 2019, CRP I has been very positively evaluated by an **international evaluation jury**. This jury in its final statement **recommended** to **continue** this **cross-centre collaboration** also in the upcoming funding period FP2 (2021-2025).

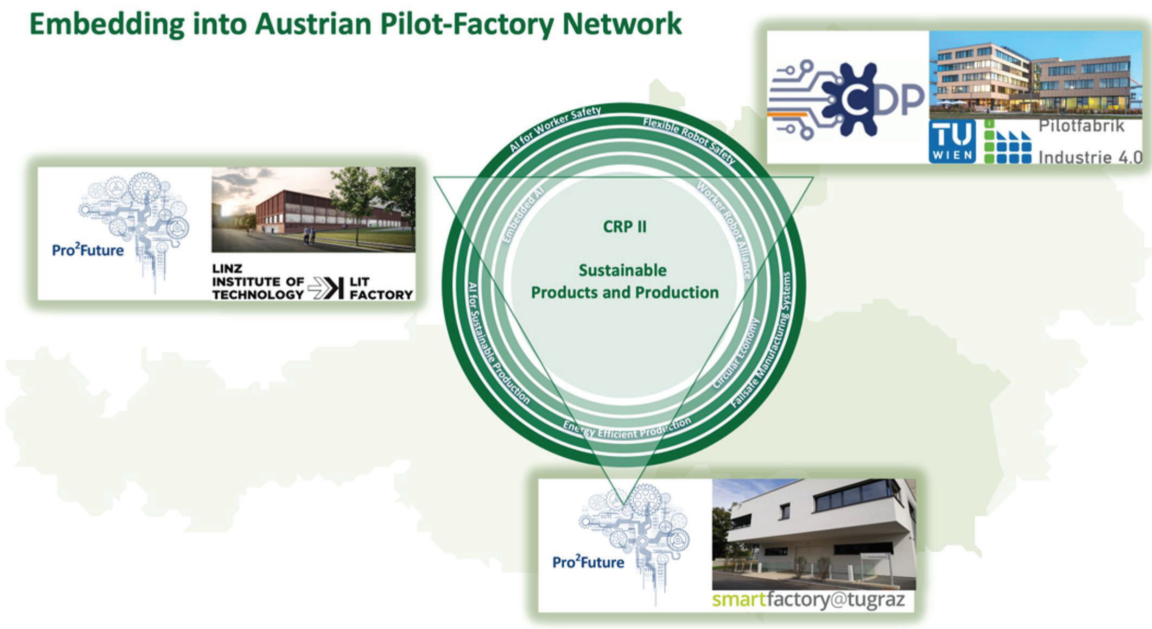
The research programme for this **follow-up cross-centre CRP** is presented in this proposal (**CRP II**).
This **CRP II** proposes a **next step** in **industrial digitalization**, emphasizing (i) **human workers**, (ii) mostly **AI operated machines** in manufacturing, and (iii) the **environment** as the very critical production resources for a sustainable development in industry, i.e. the creation of **sustainable products** with **sustainable production processes**. **CRP II** is driven by the **hypothesis,** that (i) according to the observed advance in underpinning industrial production with technologies like **AI** (**Artificial Intelligence**), (ii) according to the dramatic **impact** of **aggressive energy use** and **uncontrolled creation** of **waste**, and (iii) to the emerging need for a **prosper co-existence** of **human intelligence, sustainability** in **products and production** will be the dominating concerns of **economic growth** and **social welfare** in the **very near future**.

CRP II in **one project** comprising **3 use cases** will addresses sustainability in the interdependencies among **Machines** (information and communication technologies, mechanical and electrical engineering, advanced manufacturing), **Human Workers** (cognitive sciences, welfare, social sciences) and the **Environment** (ecology, global warming, circular economy, waste management). **CRP II** will investigate scenarios emerging from the interplay of these resources, and **develop solutions** in the small, potentially effective to **prevent** from **sustainability hazards** in the large, exploiting the **Austrian Network of Pilot Factories** (**LIT-Factory**, Linz, **smartfactory** Graz, and **Pilotfabrik Industrie** 4b, Vienna). It is aligned with **The European Green Deal roadmap** towards a **sustainable European economy** by leveraging the potential of digital technologies, the **United Nations Sustainable Development Goal G12** to ensure sustainable consumption and production patterns, and the priorities of Austria's **Federal Ministry bmk** in **Innovation & Technology**, **Energy**, and **Climate & Environment.**

The **budget share** and the respective split among **Pro²Future** and **CDP** **2.5 M€ per Centre** for all **4 years** in **FP2**. **Budget matters** follow a clear and strict separation of concerns at the contributing task level ("**Twin Model**"), securing the COMET rules of financial management.

Allocating the R&D of CDP and Pro²Future in the Austrian research and industrial landscape **reveals a perfect geographical balance** of endeavor across the whole nation (**Upper Austria** and **Styria** with Pro²Future; and **Vienna**, **Burgenland**, **Lower Austria**, **Salzburg**, **Vorarlberg** with CDP).

Motivation
Climate change and environmental degradation are an existential threat to Europe and the world. In order to address these challenges, the EU proposed a strategy, called "**The European Green Deal**", which aims to **transform** our **society** into a **modern** and **resource**-**efficient** one, while at the same time protecting and/or increasing its competitiveness. The European Green Deal is a roadmap towards **sustainable European economy**. (European Green Deal, 2019)



Sustainability as Pervasive Megatrend
Sustainability is a holistic approach not excluded to current megatrends: With population becoming elder (silver society), governments are trying to find answers how to involve this generation in the economy. Approaches for involving the silver society in a sustainable and profitable way include new working time models and age-based workplace design.

Individualization is another megatrend in industrialized countries, emerging from the need for a single and unique lifestyle, expressed e.g. in individualized transportation behavior and customer-designed goods, while keeping costs low. Well established production strategies are not capable of providing customized goods at low cost. For mitigating such disparities, the industry has implemented a new production paradigm, called mass customization, supported by the digitalization megatrend.

Sustainability as Critical Success Factor for Future
Sustainable products and production systems increasingly appear on legislation agendas and will inevitably become an indispensable business imperative. This will lay the foundations for sustainable manufacturing, which will minimize waste and pollution, reduce energy demands and manage operations in an environmentally and socially responsible manner. In a nutshell, it will minimize the diverse business risks inherent in manufacturing operations while maximizing the new opportunities that arise from improving processes and products. This progressive transition to a sustainable economic system is an indispensable part of the new EU industrial strategy for a sustainable future.

A key cornerstone of a sustainable future is the circular economy in which resources are kept in use for as long as possible while maximum value is obtained from their usage, and at the end of their life-cycles constituent materials are recovered and regenerated (ISPT, 2020).

Sustainable Products and Production
New advanced technologies, sustainable solutions and disruptive innovations are critical to achieve the objectives of the European Green Deal (European Green Deal, 2020).
Digital Europe states, that the European manufacturing sector can reinforce its innovative and sustainable leadership position by combining digital and clean technologies (Digital Europe, 2020).

Digital technologies, such as artificial intelligence, 5G, cloud and edge computing and the Internet of Things, are a critical enabler for attaining the sustainability goals of the Green deal in a multitude of sectors. Digitalization also presents new opportunities for remote monitoring of air and water pollution, and for monitoring and optimization of energy and natural resources utilization, e.g. for products and production systems. All actions, concerning products and production systems and targeting the Green Deal, require a scientific and holistic approach and critical scrutiny of impact assessments (European Green Deal Communication, 2019).

With this **Common Research Programme** we propose to attempt for a **next step** in **industrial digitalization**, considering aside the classical factors of production (land, labor, capital, and entrepreneurship) with specific emphasize also the factor of "**human**" workers, and the environment. In the course of this research we will specifically address these production resources as critical for a sustainable development in industry. We must assume, that (i) according to the observed advance in technologies like **AI** (**Artificial Intelligence**) and the rigorous provision of machinery in industries that is AI operated, and (ii) according to the dramatic **impact** of **aggressive energy use** and **uncontrolled creation** of **waste**, **sustainability** in **manufacturing** and a **prosper co-existence** of **human** and **artificial intelligence** will be the dominating concerns of **economic growth** and **social welfare**.

The research proposed herewith hence picks up on cross-domain topics rooted in **Machines** (i.e. **technology** like information and communication technologies, mechanical and electrical engineering, advanced manufacturing) and **Human Workers** (i.e. **humanities** like cognitive sciences, welfare, social sciences) and the **Environment** (i.e. **environmental sciences** like e.g. ecology, physics, circular economy, waste management, global warming). Specifically, will we investigate scenarios emerging from the interplay of these resource pillars in the context of products of the future and the process of their manufacturing. We will attempt on **concrete problematic mutual interdependencies** of these factors, and **develop solutions** and practices in the small, potentially effective to **avoid** and **circumvent sustainability hazards** in the large.

EXECUTIVE SUMMARY

Area X - CRP II Use Cases

Common Research Programme (CRP II) on Sustainable Products and Production

Cases of investigation have been identified at the entanglement of **AI for Worker Safety** and **Failsafe Manufacturing Systems**, **Embedded AI** and **Flexible Safety Systems**, and **Green Manufacturing** and **Circular Economies**.
The two partnering Austrian COMET K1 competence centers **Pro²Future** (Products and Production Systems of the Future) and **CDP** (Austrian Center for Digital Production) are attempting with a science-based approach to evolve new digital technologies for Austria's manufacturing sector: While Pro²Future is addressing **cognitive products** and **production systems** with the **embedding** of **cognitive capabilities** into **products** and **manufacturing systems** so as to enable them to **perceive**, **understand**, **comprehend**, **interpret**, **learn**, **reason** and **deduce,** and **act** in an **autonomous, self-organized** way - together **with humans**, CDP is focusing on **automatization** and **Cyber-Physical-Production-Systems**. The two Centres have been successfully working together on a C**ommon Research Programme (CRP)** in funding period 1 (FP1, 2017-2021) after a jury recommendation to **pool** the respective **complementary competencies** to develop reference projects and demo-cases to **demonstrate novel digital industries solutions** for **problems** of **technological significance** and **industrial relevance**.

Throughout this **CRP** (**CRP I**) research alliance of **Pro²Future** and **CDP** the respective consortia have been very active to create a network of **Pilot-Factory sites in Austria**, by the foundation of pilot two factories in Linz (**JKU LIT Factory, Pro²Future**) and Graz (**SmartFactory@TUGraz, Pro²Future**), and interlinking them with the then already existing **Pilot Factory of TU-Wien (CDP).**

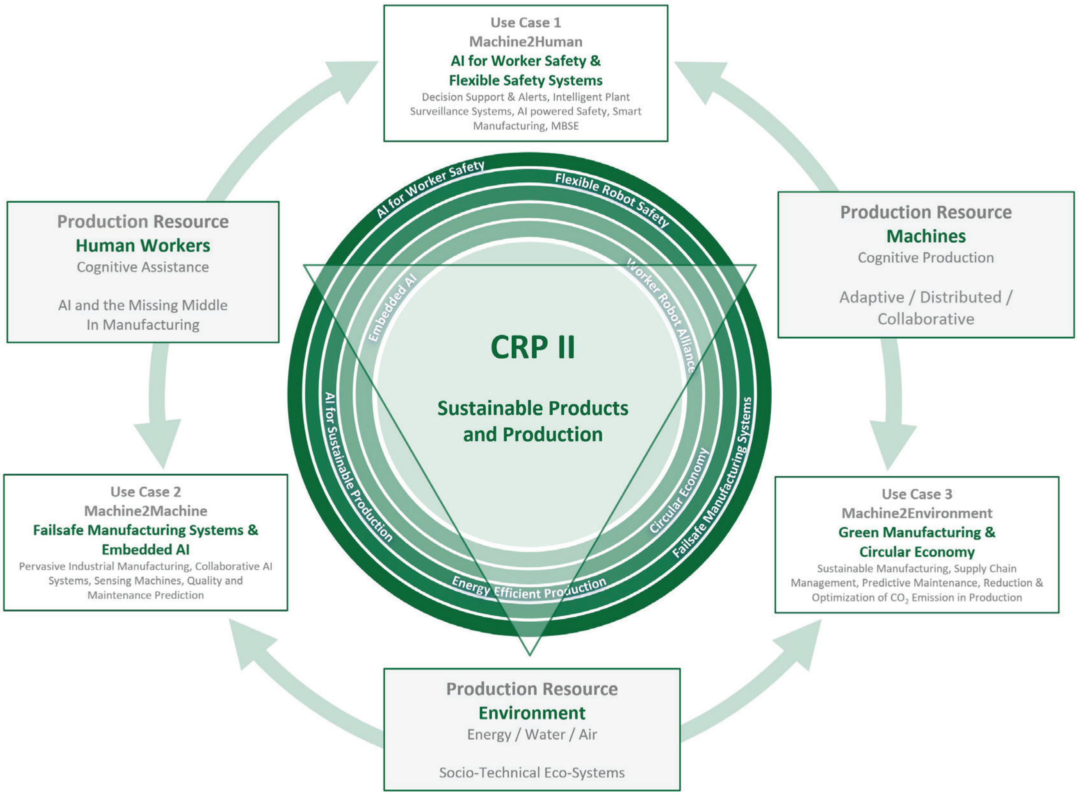
Both the **experience** gained from jointly engaging and **cooperatively sharing** their respective unique strengths in CRP, as well as the **exploitation** of the **shared resources** of the pilot-factory network gives an **excellent starting condition** towards fostering **future** and **emerging technologies** for **sustainable products** and **production systems**. It encourages, supports and promotes the collaborative vision of a **sustainable future** for **industries** by **combining digital** and **clean technologies** in this follow-up **Common Research Programme (CRP II)**. The planned **CRP II** will set a milestone in Austria's industrial research and will have a strong impact on the **European community for sustainability**. Specifically, the potential of the involvement of all Austrian Pilot-Factories will leverage the impact of the CRP on a national, and in further on an international scale.

Embedded AI
Embedded AI technology is increasingly becoming pervasive in industrial manufacturing. Pervasive AI thus aims for effective ways for collaboration between humans and AI systems, and exploiting the strengths of both humans and machines while keeping the human in control. The key challenge is confluent distributed cooperation between AI-aware industry workers and AI-operated machines.

AI for Worker Safety
Intelligent plant surveillance systems, automating the process of monitoring and protecting plant operations, are increasingly based on computer vision and deep learning. AI-powered safety in the industrial workplace is a major step forward for improving workplace safety and productivity. Based on real-world data collection and analytics capabilities AI is now able to target safety awareness initiatives far more effectively using data-driven insights from actual operations in various ways: e.g., decreasing human error; undertaking dangerous tasks; tracking worker location, etc.

Green Manufacturing
Increasing adoption of AI/ML technologies promotes sustainable manufacturing in all areas, ranging from the supply chain management to quality control, predictive maintenance, and energy consumption. AI systems are used in process and operational controls to optimize energy-efficient process planning and energy-efficient scheduling by reducing excessive use of certain materials and redundant production scrap waste, and improving inefficient supply chain management, logistics, and unequal distribution of energy resources. By expanding the scope of the contextualized data collection framework being developed in the first phase of the CRP, Energy and resource consumption can be attributed down each intermediate step of the value stream.

The transformation required to become a green manufacturer entails many aspects, from better production design, to alteration of existing processes, to facilitation of part replacement and increased durability. Through embracing all aspects, companies, SMEs and large corporations alike, will be able to renew and modernize their manufacturing processes and contribute to 'closing the loop' of a circular economy (European Green Manufacturing, 2018).
In an ever-changing and adapting world, one common issue affects a multitude of industries: sustainability and environmental awareness. The solution to this issue is known as green manufacturing, which re-



fers to production processes creating less overall production waste and emitting less pollutants. In this scope are process accommodations for utilizing fewer resources, e.g. production techniques using less water or producing more durable products with replaceable parts, i.e. products fitting into the circular economy. (European Green Manufacturing, 2018).

Circular Economy
The ex-ante attribution of CO2-Emission and resource consumption along the overall supply chain in the production network planning enables to identify optimization approaches before the actual start of production. Especially the aspect of re-use and recycling needs to be considered in the planning phase of a supply chain, as later changes may affect the product specification and may be difficult to implement given the tight cost and delivery conditions. Comprehensive Supply Chain Modelling techniques allow to predict the effect of network planning decisions on carbon emissions and material flows as a decisions support tool for entrepreneurs and policy makers.

Flexible Safety Systems
Smart manufacturing production facilities that dynamically adapt to changing production demands bring along completely new challenges to functional safety systems. The research will address these challenges by applying a Model-Based Systems Engineering (MBSE) approach. It will utilize communication technologies that support interoperability and Real-Time capabilities to design a self-organizing safety system. This assistive system would support engineers and help smart manufacturing facilities to leverage their full potential.

Failsafe Manufacturing Systems
“Sensing Machines”, Workflow, Quality and Maintenance Prediction combined with instant feedback to local or remote operators allows a “round the clock” usage of production infrastructures, reducing the environmental footprint and improving the competitive position of companies applying this set of technologies.

Goals and Expected Results
The overall goals and expected achievements of the hereby proposed research can be summarized as follows:

(i) **Tracing** and **monitoring** of **energy consumption** in **production processes** will help identify energy utilization and wasted energy, which will ensure that appropriate measures for energy savings are applied. A reduced production energy consumption reduces the energy costs. Furthermore, the product’s own energy requirements need to be decreased as well. Minimizing product’s energy demands will reduce the cost of use, can make products more appealing, and at the same time will adhere to future standards and regulatory requirements. Moreover, a reduction of hazardous substances in products and production systems will lower the cost of monitoring, treatment, and disposal of such substances. Hence, such products will be considered generally as safer and more attractive.

(ii) The **reduction** of **material waste generation** and **emissions** will have a positive impact on the **cost** of **monitoring**, **treatment**, and **disposal**, and will reduce the loss of economic value of utilized materials and material costs of produced goods. High material utilization can also be achieved by replacing or upgrading equipment and/or production lines, especially in continuous production systems, which will improve efficiency of operations.

(iii) Considering the **entire product lifecycle**, **reprocessing**, and **remanufacturing** of **end-of-life materials** will increase the **value** of **material inputs**. These materials can be used as substitute (recycled/renewable) materials for non-renewables, which will save material costs and will create more attractive products. Moreover, an improved recyclability or biodegradability of products will enhance the value of material inputs and will reduce costs associated with disposal. Improved product durability will diminish the need for non-renewable materials and will increase product value (OECD Sustainable Manufacturing Toolkit, 2011).

5

PROJECTS

WORKING TOWARDS COGNITIVE AND SUSTAINABLE PRODUCTS AND PRODUCTION SYSTEMS OF THE FUTURE

Pro^{2}Future

Products and Production Systems of the Future

PROJECTS COCKPIT

ID	Name	Partner	Duration
MFP 1.3	3D-RECON I - Cognitive Assistance	SONY, TU Graz	01.04.2019 - 31.03.2020
MFP 1.4.1	SeeIT - Augmeted Work Processes	KEBA, Wacker Neuson, Trumpf, Fronius, TU Graz, JKU	01.01.2018 - 31.12.2020
DP 1.1.1	WorkIT - Workflow and Tool Process Modelling	KEBA, Wacker Neuson, Trumpf, Fronius, TU Graz, JKU	01.01.2018 - 31.03.2021
DP 1.2.1	Fischer4You - Cognitive Skiing Products	Fischer, JKU	01.01.2019 - 31.03.2021
DP 1.2.3	RTEAS - Cognitive Rail Track Error Analysis Support	system 7, JKU	15.11.2019 - 14.11.2020
DP 1.6.1	GUIDE - Guidance and Assistance	KEBA, Wacker Neuson, Trumpf, Fronius, TU Graz, JKU	01.04.2018 - 31.12.2020
DP 1.6.2	HumanAI - Human Focused AI for occupational safety and accident prev.	AUVA, JKU	01.11.2020 - 31.03.2021
StratP 1.5	AssE - Opportunistic Awareness in Assistive Environments	TUM, JKU	01.04.2020 - 31.03.2021
MFP II 1.1.1	3D-RECON III - Novel Methods for 3D models from camera shoots	SONY, TU Graz	01.04.2021 - 31.03.2022
MFP II 1.1.2	DERELE - Deep Learning Based Reconstruction for Linear Edifices	dibit, Joanneum Research, JKU	01.10.2021 - 30.09.2022
MFP II 1.2.1	APECGR - Artificial Personality for Cognitive Guidance and Recom. Systems	Fronius, JKU	01.04.2021 - 31.03.2024
MFP II 1.2.1	RTEL - Cognitive Rail Track Error Learning	system 7, JKU	01.04.2021 - 31.03.2024
MFP II 1.2.3	GAP - Cognitive Guidance for Assembly Processes	KEBA, JKU	01.04.2021 - 31.03.2022
MFP II 1.3.1	Fischer4You2 - Active Learning for Cognitive Skiing Products	Fischer, JKU	01.04.2021 - 31.03.2022
MFP II 1.3.2	AI2Human - Using AI for occupational safety and accident prevention	AUVA, JKU	01.10.2021 - 31.03.2025
DP 2.1.1	APS.net - Adaptive Production Systems	ENGEL, PROFACTOR, JKU	01.01.2018 - 31.03.2021
MFP 2.5.1	A2PS - Adaptive Assembly Process Systems	Fabasoft, PROFACTOR, Wacker Neuson, JKU	01.04.2018 - 30.10.2019
MFP 2.5	LineTACT - Cognitive Line Tacting Support	Wacker Neuson, MTM, JKU	01.03.2020 - 31.03.2021
StratP 2.4.1	HOP-ON - Cognitive Shopfloor Monitoring	PROFACTOR, JKU	01.04.2020 - 31.03.2021
MFP II 2.1.1	CEPS - Cognitive Engineering Process Support	Bosch, methodpark, JKU	01.01.2022 - 31.12.2024
MFP II 2.2.1.1	LineTACT II - Cognitive Line Tacting Support	Wacker Neuson, MTM, JKU	01.04.2021 - 30.04.2022
MFP II 2.2.1.2	CoSma - Product and Production Cosimulation for Smart Manufacturing	Fronius, PROFACTOR, JKU	01.04.2021 - 31.12.2023
StratP II 2.4.1	DEVINE - Deviation in Evidence	JKU	01.05.2022 - 30.04.2023
MFP 3.1.1	EPCOS 1 - Maintenance 4.0@EPCOS OHG Preparation and Ex-Post Analysis	TDK, EPCOS, TU Graz	01.07.2017 - 30.06.2018
MFP 3.1.2	DEFCLAS - Advanced Defect Classification	TDK, EPCOS, TU Graz	01.11.2017 - 31.05.2018
MFP 3.1.3	OnDaA - Online Data Analytics @ voestalpine	voestalpine, TU Graz	01.10.2017 - 30.09.2019
MFP 3.1.4	RedUsa - Predictive Maintenance for Production Environments	AMAG, TU Graz	01.01.2018 - 31.12.2021
MFP 3.1.5	SINPRO - Predictive Maintenance for Production Environments	Primetals, TU Graz, JKU	01.04.2018 - 30.06.2020
MFP 3.2.1	GuFeSc - Predictive Maintenance for Products	Fronius, TU Graz	01.01.2018 - 31.03.2021
MFP 3.2.2	ConMon - Scalable Condition Monitoring Systems for Test Environments	AVL, TU Graz	01.01.2018 - 31.12.2020

ID	Name	Partner	Duration
StratP 3.4	SUPCODE - Supporting Cognitive Decision Making	EVOLARIS, PROFACTOR, JKU, TU Graz	01.04.2019 - 31.03.2021
MFP II 3.1.1	VAPS - Visual Analytics for Production Systems	voestalpine, JKU, TU Graz	01.04.2021 - 31.03.2025
MFP II 3.1.2	PreMoBAF - Data-driven methods for predicting and monitoring	PRIMETALS Technologies, JKU, Uni Graz	01.04.2021 - 31.03.2025
MFP II 3.1.3	PREMAC - Predictive Maintenance für Krankomponenten	voestalpine, Montanuniversität, TU Graz	01.04.2021 - 30.09.2023
MFP II 3.1.4	KAL-GISS - Klassifizierung der Spritzgießverfahren	ENGEL, JKU, TU Graz	01.10.2021 - 31.03.2025
MFP II 3.3.1	ZEWAS - Zeitreihenanalyse zur Erk. von Wartungsarb. an Schweißgeräten	Fronius, Know Center, Uni Graz	01.04.2021 - 28.02.2022
StratP II 3.4.1	SERAM - Supporting users in exploring & reasoning in multivariate timeseries	JKU, TU Graz	01.07.2021 - 30.09.2023
StratP II 3.4.2	UNSUDET - Understanding and Supporting Users in Decision-Making Tasks	JKU	01.07.2021 - 30.06.2023
MFP 4.1.1.1	CAVL-SD - Cognitive AVL: Smart Development	AVL, Universität St.Gallen, TU Graz	01.04.2018 - 31.03.2022
MFP 4.1.1.2	SAFE-TRACK - Failsafe Autonomous drone-based warehouse check	Roto, D'ARIA, TU Graz	01.09.2020 - 31.03.2021
MFP 4.1.2.1	Simatic Failsafe 4.0 - Development Processes and Tools for Cogn. Products	SIEMENS, TU Graz	01.12.2017 - 31.11.2019
MFP 4.1.3.1	DRIWE - Dependable RF Communication Systems for In-Car Wireless Sensors	AVL, TU Graz	01.03.2018 - 28.02.2021
MFP 4.1.3.2	CSG - Cognitive Smart Grids	SIEMENS, TU Graz	01.04.2018 - 31.03.2020
MFP 4.1.3.3	CONVENIENCE - Cognitive building automation infrastructure and services	hmi, TU Graz	16.04.2020 - 31.03.2021
StratP 4.1.4	PREDISCOVER - Unified Dependable Wireless Services for Cognitive Products	TU Graz	01.03.2018 - 28.02.2021
MFP II 4.1.1.1	CORVETTE - Cognitive Sensing for Vehicle Fleet Driven Data Services	AVL, TU Graz	01.05.2021 - 31.04.2024
MFP II 4.1.2.1	CompEAS-BSW - Compositional Embed. Automative Systems - Basic Software	Elektrobit, TU Graz	01.04.2021 - 31.03.2025
MFP II 4.1.2.2	TWIN-SOLUTION - DigitalTwin enabled comm. & testing of failsafe autom.	SIEMENS, TU Graz	01.04.2021 - 31.03.2025
MFP II 4.1.2.3	CompEAS-HW - Compositional Embed. Automative Systems - Hardware	Infineon, TU Graz	01.07.2021 - 31.03.2025
MFP II 4.1.3.1	Enhance UWB - Benchmarking and adv. local. and comm. perform. UWB	NXP, TU Graz	01.07.2021 - 30.03.2024
StratP II 4.1.4.1	E-Minds-1 - Embedded Intelligence for Wireless Communication Services	Universität St.Gallen, TU Graz	01.09.2022 - 31.03.2025
MFP 4.2.1.1	CoExCo - Cognitive Polymer Extrusion and Compounding	GAW Group, Leistritz, soplar sa, AZO, poloplast, TU Graz, JKU	01.04.2017 - 31.03.2021
MFP 4.2.2.1	ASP - Adaptive Smart Production	AVL, TU Graz	01.01.2018 - 31.12.2019
MFP 4.2.2.2	ASP 2 - Adaptive Smart Production 2	AVL, TU Graz	01.04.2020 - 31.03.2023
StratP 4.2.3	ENERMAN-1 - Cognitive Energy Management Systems for Industrial Prod.	TU Graz, Univerza v Mariboru, JKU	01.01.2019 - 31.03.2021
MFP II 4.2.1.1	AI-Gran 2 - AI based smart optimization of underwater granulation	ECON, JKU	01.04.2021 - 31.03.2023
MFP II 4.2.1.2	SmartCom - Smart Compounding	Leistritz, JKU	01.04.2021 - 31.03.2025
MFP II 4.2.1.3	SmartCoEx - Smart extrusion blow molding	soplar sa, JKU	01.04.2021 - 31.03.2025
MFP II 4.2.1.4	SmartWell - Smart corrugated pipe production	UNICOR, JKU	01.04.2021 - 31.03.2025
MFP II 4.2.2.1	SUPRA-1 - Sustainable Production and Assembly 1	FUCHSHOFER Präzisionstechnik, TU Graz	01.04.2020 - 31.03.2023
MFP II 4.2.2.12	QA-HEdge-2 - Quality Assurance using High-Frequent Edge Technology	SIEMENS, TU Graz	01.02.2023 - 30.09.2023
MFP II 4.2.2.13	SUPRA-2 - Sustainable Production and Assembly 2	AVL, TU Graz	01.04.2023 - 31.03.2025
MFP II 4.2.3.1	ACTION II - Adaptive Cobot Integration 2	sanSirro, ANTEMO, TU Graz	01.04.2021 - 30.09.2023
MFP II 4.2.3.2	ASP 2 II - Adaptive Smart Production 2 II	AVL, TU Graz	01.04.2020 - 31.03.2023
StratP II 4.2.4	E-Manager - Energy Management for Batch and Continuous Production	TU Graz, Univerza v Mariboru, JKU	01.04.2021 - 30.09.2023
nonCOMET	REWAI - Reduced Energy and Waste using AI	Lenzing, TU Graz, JKU	01.04.2022 - 31.03.2025
nonCOMET	X-AMINOR - Cross sensor Platform for lifecycle-monitoring of Transformers	Siemens Energy, SIEMENS, APG, Joanneum Research	01.02.2021 - 01.01.2024
nonCOMET	recAIcle - Recycling-oriented coll. waste sorting by continual learning	SIEMENS, Montanuniversität	01.09.2022 - 31.08.2025
nonCOMET	TWIN - Digitale Zwillinge für zukunftsfähige Gebäude	SIEMENS, AIT, buildingSMART Austria, TU Graz	01.03.2022 - 31.05.2023
nonCOMET	AI-Flight - AI-Enabled autonomous flight of indoor drones	D'ARIA, Roto, TU Graz	01.09.2021 - 31.10.2022

AREA 1

MFP 1.2-2 3D-RECON I

Cognitive Assistance

Area 1 - Perception and Aware Systems	
Project ID:	MFP 1.2
Project Title:	3D-RECON Guidance and Assistance
Project Lead:	DI Michael Haslgrübler Pro2Future GmbH
Duration:	12 Months, 01.04.2019 - 31.03.2020
Strategic Volume:	10 %

Work Packages

WP 1: Projektspezifikation und Datengenerierung

WP 2: Data driven Multi-View Stereo

WP 3: Data driven Structure-From-Motion

WP 4: Test und Evaluierung

WP 5: Dissemination

WP 6: Projektmanagement

Company Partners

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Academic Partners

TU Graz, Institut für Maschinelles Sehen und Darstellen (ICG)
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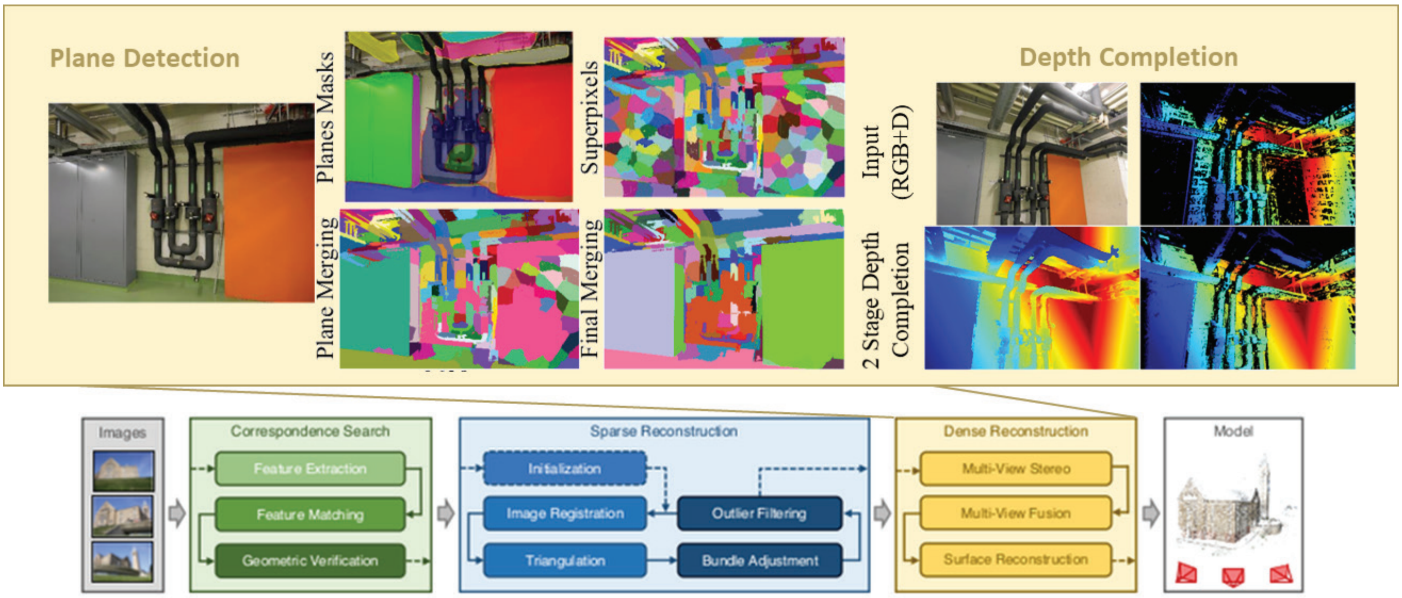
The aim of 3D-Recon is the research and development of methods for high quality 3D reconstruction from images in two dimensions: (i) making use of deep neural networks for higher precision and accuracy on camera positioning and (ii) making use of deep learning and computer vision in 3D reconstruction. In a first step the project will focus only on reconstruction of static scenes, i.e. rooms and not on dynamic scenes which e.g. include moving humans. The fundamental goal of the project is to provide improvement on existing benchmarking data from the scientific community as well as company partner Sony.

The project team believes that Deep Neural Networks (DNNs) have the potential to improve the quality of image-based 3D reconstructions, which could be at a very later stage be used by millions of users equipped with cameras in there smartphones, while e.g. laser based solutions will never be a commodity good.
In order to leverage this benefit, in a first step the project team aims to improve 3D reconstructions, using neural networks on high-resolution image datasets as available by the ETH3D benchmark and using them for geometric image-based 3D reconstruction. With this approach, we foresee that especially in areas where traditional methods fall short, e.g. surfaces like large walls, ceilings or floors a substantial improvement beyond the state of the art can be made.

The improvement will be made in two areas of multi-view stereo (MVS) pipelines, which are like classical two-view stereo methods, which build up a cost volume by matching image patches along the epipolar line. MVS however construct a cost volume by computing costs for a set of given plane hypothesis. The first area of improvement will be confidence prediction which is an inherent part of MVS methods. It calculates costs by local patch comparison based on metrics like e.g. Normalized Cross Correlation. The second area of improvement will be depth refinement, since there MVS methods tends to fall short in untextured areas, e.g. walls, where the matching becomes ambiguous. Here most 3D reconstruction pipelines include a refinement step meant to remove depth outliers or even estimate missing depth areas. Often these methods rely on a confidence map, as it is critical to understand which depth map areas are reliable and which need to be extended.

Overall, we aim to compare our improvements on the multi-view stereo reconstruction methods with existing approaches on scientific benchmarking sets like COLMAP or ACMM.



Goals

3D-Recon has the goal to advance 3D Reconstruction in two dimensions (i) making use of deep neural networks for higher precision and accuracy on camera positioning and (ii) making use of deep learning and computer vision in 3D reconstruction. In a first step the project team aims to improve in these areas, using high-resolution image datasets as available by the ETH3D benchmark and using them for geometric image-based 3D reconstruction. With this approach, we foresee that especially in areas where traditional methods fall short, e.g. surfaces like large walls, ceilings or floors a substantial improvement beyond the state of the art can be made. The project will focus at this stage solely on static scenes where there are no dynamic objects moving in front of the camera. Advancing image-based 3D reconstructions, has the benefit, in comparison to laser-based solutions, that they could be used at a very later stage by millions of users equipped with cameras in their smartphones.

Approach

3D-Recon will build on- and advance over state-of-the-art methods for multi-view stereo pipelines.
The first area of improvement will be confidence prediction which is an inherent part of these pipelines. It calculates costs by local patch comparison based on metrics like e.g. Normalized Cross Correlation. Here we use pixel-wise estimation of the expected noise in the 3D space based on trained data from a neural network. The second area of improvement will be depth Refinement, since there MVS methods tend to fall short in untextured areas, e.g. walls, where the matching becomes ambiguous. Like most 3D reconstruction pipelines we include a refinement step meant to remove depth outliers or even estimate missing depth areas. Here build upon a pretrained plane detection neural network and super pixels to estimate the true planes in a 3D space.

Expected and Achieved Results

We aimed to establish a large improvement on accuracy and precision by estimation the camera position in a structure from motion system, with the ultimate goal to enable improved and comprehensive reconstruction of indoor rooms, with large quantities of low textured planes like walls, ceilings, or floors in contrast to existing state of the art solutions.
This new approach was developed in a software pipeline and applied to various kind of benchmarking datasets of the scientific community and demonstrate the feasibility of image based 3d Reconstruction. The areas of improvement in our multi-view stereo approach are in confidence prediction and depth refinement, two steps which are crucial to 3D reconstruction from images. In both areas we made use of deep neural network to advance our overall method.
This was achieved by confidence prediction networks which have been adapted to the Multi-View Stereo (MVS) case and are trained on automatically generated ground truth established by geometric error propagation. We demonstrated the utility of the confidence predictions for the two above mentioned steps in outlier clustering and filtering and additionally in the depth refinement step, shown in the Figure.

Status / Progress

This project officially started in April 2019 and finished in March 2020. In this project, Pro²Future worked with our Company Partners Sony and the Institute of Computer Vision and Graphics at TU Graz towards the creation of a multi view stereo pipeline useable for 3D Reconstruction from images. Various projects meetings were conducted with company partners either at TU Graz or in Stuttgart. In addition to senior staff, a student researcher Tarek Boamer and junior researcher Christian Sormann were assigned to the project.
Within the frame of the project Tarek Boamer, started and finished his master thesis, named “Machine Learning for Image Based 3D Reconstruction” focusing on depth refinement using plane CNN and superpixels. Together the project team finished the pipeline and evaluated it against benchmark datasets in the scientific community. The evaluation showed an improvement in relation to the start of the art in various scenes from the dataset. The approach and evaluation results was compiled into a paper named “DeepC-MVS: Deep Confidence Prediction for Multi-View Stereo Reconstruction” and is currently under review. Overall the goals of the project were achieved and it was a success for all partners and will continue with a follow up project on the same topic.

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AREA 1

MFP 1.4-1 SeeIT
Augmented Work Processes

Area 1 - Perception and Aware Systems

Project ID:	MFP 1.4-1
Project Title:	SeeIT - Augmented Work Processes
Project Lead:	Univ.-Prof. Dr. Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	36 Months, 01.01.2018 - 31.12.2020
Strategic Volume:	10 %

Work Packages

WP1: Actuator Technology
WP2: Software Platform Development
WP3: Interaction Modalities
WP4: Integration
WP5: Evaluation
WP6: Project Management

Company Partners

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Academic Partners

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TU Graz, Institut of Technical Informatics (ITI)
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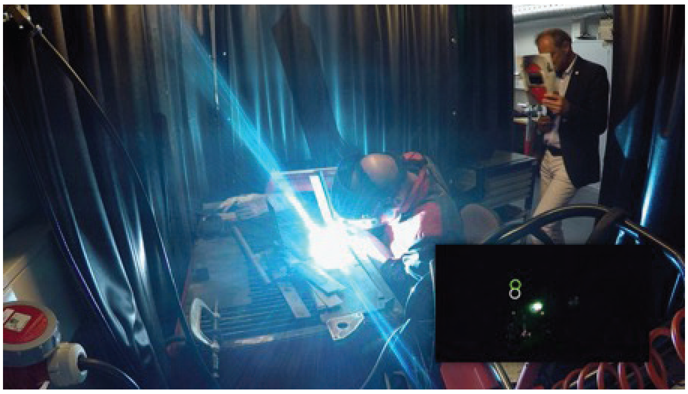
Harsh industrial environments, where workers interact with machines, tools or other entities (such as robots or other workers) provide a difficult terrain for human computer interaction. It is the aim of SeeIT to provide workers with digital augmentation using different forms of deployment, body worn/mobile or infrastructure based different fidelity of transmitted content, e.g. manuals or video snippets and different sensory targets, such as visual, auditory or tactile channels. The aim is to create a holistic human-in-the-loop system as pluggable interaction component, which can be used by sibling projects, Guide and WorkIT.

Due to the complex needs of industrial reality and the harshness found there, e.g. noise pollution or changing lighting conditions, perception capabilities of workers are limited and need to be considered carefully, especially when critical information needs to be received by a worker. The interaction design is therefore three folded based on general suitability, information flow (unidirectional vs. bidirectional) and content perception. SeeIT considers therefore several factors when providing augmentation: (i) environment factors like noise pollution or changing lightning conditions, (ii) actuator availability such as distance, viewpoint or powered off, (iii) content availability like media available for a specific sense or device, (iv) worker preferences and (v) worker applicability such as sensorial load for a given sense. In addition to that the system will provide the user with a way to interact with the presented information, either implicitly, e.g. by behavior change, or explicitly, by providing input via devices. The major focus will however be on implicit interaction, such as capturing the response of a worker, i.e. in terms of behavior change, to a system triggered information display. We are therefore particular interested in observing overt behavior changes, such as turning the head towards the audio source or avoiding to get closer to a dangerous machine. But we will also investigate intrinsic behavior changes, such as a reduction of cognitive load measured by eye tracking devices or GSR wrist bands. Finally, we aim to use sensory channels which are not already highly engaged, as proposed by Wickens' Multiple Resource Theory. In addition, we strive to not bind a huge amount of attention for long periods of time but aim to make use of subliminal stimuli, such as vibration or ambient lightning, and to provide brief information exchanges, e.g. through video snippets. These three categories, general suitability, information flow, and content perception, will be used to select the best suitable modality in case the system, e.g. Guide or WorkIT wants to exchange information with a worker.

Goals
The project goal is to communicate digital information on different modalities (visual, haptic, auditory), whereas the content is prepared independently of a specific device at the information source, e.g. WorkIT' workflow recognition module, but tailored to a specific device at the information sink. E.g. an attention capturing notification, will be sent by the source and will be translated by the system into a specific modality, the best suitable at this point in time, which then at the receiving device node will be translated into e.g. the exact PWM frequency for the vibration motor to raise the attention. The translation processes considers various factors such as environmental limitations, e.g. ambient noise, or worker limitations, e.g. viewpoint towards a screen or prior engagement/load of a sensory channel but also contextual information, such as the current workstep in a workflow.
In addition, the presented information can be acted upon both explicitly by using input devices, such as eye trackers or implicitly by changing or not changing of current behaviour, be it overt -- e.g. body pose -- or intrinsic -- e.g. decrease of cognitive load. The interaction response again will be used to manipulate or stimulate further feedback but also to train the system into learning how successful feedback is given not only on a general basis (i.e. pretrained) but for the system to learn how to provide feedback for a specific user individually.

Approach
The system will be designed based on previous work and make use of a message oriented architecture. Trigged by components of other project, i.e. Guide and WorkIT, rather generic feedback, e.g. alert, will be processed in two stages. The first stage will select the best suitable modality, where several factors are considered: (i) environment factors, (ii) actuator availability, (iii) content availability, (iv) worker preferences and (v) worker applicability such as sensorial load for a given sense. In a second stage the selected modality and content will be transformed on a device node into an actuator specific format, e.g. a vibration message will be converted into the corresponding PWM sequence. The feedback can be interacted with both explicitly with dedicated devices or implicitly by observing overt and intrinsic behaviour (changes). In addition, the system will use the response of the user to learn and self-optimise how to best provide feedback in future interactions.

Expected and Achieved Results
The project should result in a multimodal hardware and corresponding software prototype, which is able to provide feedback using infrastructure and mobile/wearable devices, which are able to stimulate visually, auditory or haptic. We plan to have each output device fully connected via an IP network. A central controller acts as mediator between the information source, e.g. a workflow recognition module, and information sink, an output device node. This controller receives generic feedback mechanism, e.g. alerts, and first derives by sensor data from the network which modality: (i) visual, (ii) auditory or (iii) haptic is best suited based on the following: (i) environment factors like noise pollution or changing lightning conditions, (ii) actuator availability such as distance, viewpoint or powered off, (iii) content availability like media available for a specific sense or device (iv) worker preferences and (v) worker applicability such as sensorial load for a given sense. Secondly, based on the selected sensory modality the now selected content will be send to a dedicated output device node, which may translate or adapt the content for a specific actuator, e.g. a vibration pattern is converted into a pwm sequence.
After the feedback is provided by the system, it waits either for explicit interaction using dedicated devices, such as eye trackers, or observes both overt behaviour, like body pose, and intrinsic behaviour, like cognitive load. Hence, through this machine perception of how feedback is affecting a worker, we aim to close the loop and provide that again as an input for both selection of modality but also about when and how to interact with a user. Therefore, the system will optimise itself to best fit its user. We foresee that, in conjunction with Guide and WorkIT, we will be able to provide work step relevant information such as position in workflow, work step instructions, material and tool parameters, while at the same time decreasing information overload by ensuring that cognitive load is within expected values.



Status/Progress
This project officially started in January 2018. In it, Pro²Future is working with our Company Partners Fronius, KEBA, Wacker Neuson, Trumpf, and the Institute of Technical Informatics Technology at TU Graz towards the creation of the cognitive feedback engine. The project kick off has been held in conjunction with the sibling projects Guide and WorkIT. Afterwards initial inspections took place at each company partner individually to (i) investigate environmental perception limitations, such as ambient noise, (ii) examine already existing actuators present at the resulting workplaces and (iii) available content to be used by workers for their tasks. In parallel, as the project aim is to capture human reaction and perception of feedback, work started into integrating an eye tracker as a rich source of information. Based on eye tracking data we aim to primarily monitor cognitive load as intrinsic behaviour indicator for feedback reception, but also to capture, if feedback has been perceived, e.g. primarily visually but secondly, also auditory or haptic as users tend to focus on information sources.

Furthermore, an investigation was launched into which actuator technologies, both infrastructure or mobile/wearable and which types of modality was already investigated and deployed by other researchers into harsh industrial environments. Based on this survey, promising ready-to-use technologies were integrated as device nodes, such as tablets or wristbands, each of which can be used to provide all types of modalities. The tablet being used as an infrastructure device whereas the wristband as a wearable. In addition to off-the-shelf components, we implemented also an embeddable tactor component, which can be driven by any I2C device such as an NVIDIA Jetson/Xavior or a Raspberry PI. As the tactor is used as subliminal vibration stimulation device, we also wanted to provide a subliminal visual stimulus device, therefore we implemented another embeddable component, which drives either a single RGB LED or a whole group of RGB LEDs. Here, the idea is to use colour-coded feedback in the peripheral vision of a user to trigger behaviour changes or make him aware of something in the environment. The next step will be to create the reinforcement algorithm, which is used for the feedback optimisation mechanism.

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AREA 1

DP1.1-1 WorkIT
Workflow and Tool Process Modelling

Area 1 - Perception and Aware Systems

Project ID:	DP 1.1-1
Project Title:	WorkIT - Workflow and Tool Process Modelling
Project Lead:	Univ.-Prof. Dr. Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	39 Months, 01.01.2018 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP1: Workflow and Awareness Modelling

WP2: Framework for Assembly Tasks

WP3: Industrial Workflow and Awareness Analysis

WP4: Use Case Analysis and Prototype Design

WP5: Integration

WP6: Strategic: Supporting Workflow Recognition

WP7: Project Management

Company Partners

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The vision of WorkIT is to establish cognitive capabilities in today's conventional products (e.g. power tools or machines). To achieve this, anything surrounding the worker in an industrial context, be it product, robot or machine, needs to be self-aware and possesses self-organisation capabilities to orchestrate the recognition of workflow and tool processes with others. In addition, the self-organisation approach needs to have the worker in the loop. Overall a collective behaviour of humans and machines needs to be formed, as (i) machines actively adapt to users behaviours and needs by (ii) algorithms and systems which facilitate coordination and collaboration and (iii) exploiting worker and machines strengths (HABA/MABA). WorkIT along with sibling projects SeeIT and Guide is a component of and targets the creation of a general cognitive assistance system.

However, establishing cognitive abilities in product components, tools or machinery requires three levels of awareness: context-, activity- and self-awareness. Specifically for context awareness, we are interested in recognizing the state in the underlying workflow, composed of activities, i.e. work steps, which are performed in sequence or parallel by humans and machines. For activity awareness, we are interested in the recognition of atomic tasks executed by workers, e.g. grab/place a workpiece, which together form a work step. Finally, we are integrating machine/robot states and tool and material parameters, e.g. selected or measured torque in a dynamometric key or detection of metal sheet size, to formulate self-awareness of devices.

The main focus of WorkIT will therefore be centred on recognition of explicit human behaviour, i.e. recognition of the work tasks but also by combing that information with implicit human behaviour, e.g. cognitive load, to formulate an overall cognitive state of an industrial worker. For these recognition tasks, WorkIT will deploy both infrastructure-embedded and mobile-wearable sensors, which either solely or collectively can be used to deduce the worker state. For explicit behaviour recognition, we target to recognize activities, which are of large value in the industrial field of manufacturing, such as screwing in complex assembly tasks or assessing quantitatively quality values of metal working tasks, like welding or metal bending. For implicit behaviour, we aim to leverage existing advances in detection of cognitive state, e.g. using GSR or Pupil Dilation, and aligning them with work tasks to estimate task complexity.
WorkIT's deduced cognitive state of the collective of worker, machines and tools will be used as input for sibling project Guide, e.g. to deduce action plans, or SeeIT, e.g. to provide what the next task is.

Goals

The goal of the project is to provide awareness of three kinds: context-, activity- and self-awareness for cognitive machines and tools or as a pluggable embeddable component, which could even be part of robots or stand-alone. While the second form of awareness, activity awareness, is targeting industrial workers, the last form, self-awareness, is targeting machines or tools, the first form, context-awareness is concerned with underlying processes, i.e. workflows, where men and machine need to cooperate to achieve a particular -- e.g. manufacturing -- goal. Vice versa, in order to understand context, i.e. recognize workflows, one needs to recognize human behaviour, both explicit and implicit, and machine behaviour on a shop floor.
With the industrial setting provided by the company partners, the project will support workflow recognition for assembly processes, metal forming and joining by leveraging information from embedded-infrastructure and wearable-mobile sensing devices. The goal is to combine various information sources making it not only feasible to do workflow recognition but also to provide a high level of reliability by providing redundant, overlapping or disjoint sensor data either of the same or different kind, such as e.g. multiple camera image sensing onto the same viewpoint, depth sensing from multiple angles, or combing data from IMUs and head-worn cameras. Additionally, we aim to recognize task complexity by also incorporating physiological data indicative for the cognitive state.

Approach

The system will be designed around a self-description approach and publish-subscribe principle of sensors and their data. High-level awareness modules, i.e. context-, activity-, and self-awareness, harness this approach by potentially combing data from various sources. We aim to receive data from tools, e.g. welding pistols, machines, e.g. bending machines, and from human-focused dedicated sensors either attached to a worker or embedded in the environment of the shop floor. Based on this self-awareness of machines and tools, and the activity-awareness of dedicated sensor software/hardware modules, we aim to implement a high-level context awareness, in the form of workflow recognition. A particular focus of the project will be to fuse together various data sources into a multi-layered recognition chain for a high level of reliability.

Expected and Achieved Results

The project aims to develop a recognition and awareness architecture, capable of combing and processing multi-sensor data streams from various information sources, such as machines, tools or human behaviour sensing devices, in near real time to correctly and reliable recognize industrial workflows. To his end the project recorded collect multi-modal sensor streams of sensors embedded into products (e.g. welding torch), machines (e.g. bending machine) or the industrial environment (e.g. top down RGB-D cameras), or worn by workers themselves (e.g. eye tracker), which recorded internal states for products or machines, implicit and explicit behaviour, biometric and physiological, but cognitive indicative, data from humans on the shop floor. We implemented various established (e.g. message queues), but also create novel, pre-processing (tree based reactive streams) mechanisms for this huge and frequent volume of data, to deal with redundant, overlapping and disjoined data by either same or different sensor sources. Based on the raw or pre-processed data, we deployed machine learning algorithms to check for the alignment with workflow specifications and report progress or deviations, by a mechanism, which supports correct task execution, provided by sibling projects Guide and SeeIT.
Additionally we still aim to provide knowledge to ensure correct execution of task order, performance and result, but also aim to distinguish between attentional and systematic errors in manual assembly processes by making use of strategic knowledge, which is created on the fly by repeated work task executions and stored for analysis in a workflow database. This database is also what we used to capture data for classification on the shop floors of our industrial partners. Additionally, we already we able to identify bottlenecks by implementing quantitative assessment methods within the production procedure, such as inefficiencies in single work step, erroneous operation of industrial tools and machines.

Status / Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partners Fronius, KEBA, Wacker Neuson, Trumpf, and scientific partner Profactor in Steyr towards the creation of the multi-layered multi-sensor recognition architecture. The project kick off has been held in conjunction with the sibling projects Guide and WorkIT. We started with individual inspections on the premises of each company partner to (i) investigate shop floors, workflow and task executions, (ii) examine already existing specifications and documentations of workflows, and (iii) collect typical or frequent error or mistakes which may happen.

At the same time, we established an ontology map for workflow recognition systems to categorize prior work of fellow researchers. Based on that data we selected promising, both wearable and infrastructure-based, sensors to be used for the collection of multi-modal data streams. We already integrated wrist-worn IMUs, i.e. Shimmer, infrastructure depth sensors, i.e. Intel Realsense, i.e. eye trackers, i.e. Pupil Labs Pupil and off the shelf webcams, by providing sensor description and subscribable sensor data streams.
In parallel, we already implemented workflow modelling tools capable of representing arbitrary industrial workflows with parallel or in sequence executions of work tasks.

Further, we already recorded large multi-modal data streams of all industrial partners, which even includes machines data from bending machine and welding unit, at their shop floors. On this data we applied several state-of-the-art feature extraction and selections mechanisms. Whereas the outcome was fed into both an un-supervised and a supervised, machine learning approach and evaluated against each other with the target to detect atomic activities. Although unsupervised ML looked promising in our laboratory studies, it failed to deliver results in the diversity of shop floor experiments. So far, we are able to detect various low-level shop floor activities like different types of screwing (e.g. wrenching, screwdriver), welding direction or various tasks during bending (e.g. measuring, looking for workpiece) or attaching hoses. The detection was not only performed posthumous in our offices but also on the shop floor, where we looked specifically for weaknesses of the classification algorithms, which we are investigating and addressing.

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AREA 1

DP 1.2-1 Fischer4You
Cognitive Skiing Prodcuts

Area 1 - Perception and Aware Systems

Project ID:	DP 1.2-1
Project Title:	Cognitive Skiing Products
Project Lead:	Univ.-Prof. Dr. Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	27 Months, 01.01.2019 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 1: Skier Skill Recognition

WP 2: Device Selection and Data Acquisition

WP 3: Cognitive Product Recommender

WP 4: Dissemination

WP 5: Project Management

Company Partners

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Academic Partners

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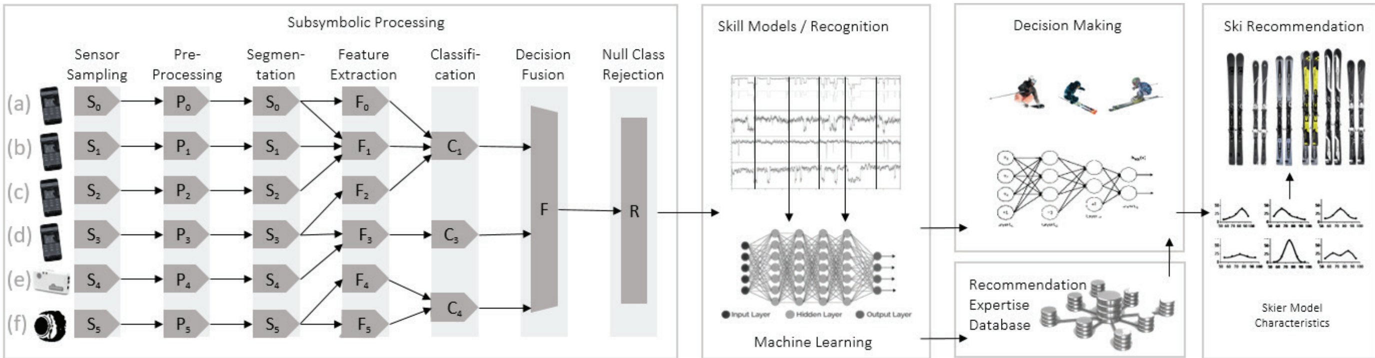
Fischer4you will study skier's behavior to find their skill level of skiing, therefore provide them with an appropriate range of equipment and ski skill recommendation. This project is motivated by the fact that every group of skiers need skiing equipment not only based on their general profile but also their technical profile. Fischer4you will try to assess the skill level and performance of skiers in driving different skiing techniques upon a data driven model and therefor is related to fundamental research in the interdisciplinary fields of sport science, computer science, biomechanics and kinesiology. In addition, Fischer4you is not limited to performance analysis, as it goes beyond this by also using the data to recommend users products and suggestion to improve their skills according to their assessment.

Alpine skiing techniques are defined by the Austrian skiing teaching union as the following: Glide, Schuss, Wedging, Snowplough, Drift, Parallel Short Swing, Parallel Long Swing, Carving Long Swing and Carving Short Swing. Each Techniques varies in several regards, like speed or turn rate and they also need to be adapted towards the state of the piste. This makes it hard for unexperienced users to have a consistent behavior in driving different techniques and control speed at each turn. Thus they often lose their control at turns and are not able to manage their speed and body angle to make a good curve, resulting in a lot of severe accidents with other skiers. Moreover, there is a correlation between the behavior at each turn, created curve and its radius, and proper equipment specification. Often users tend to use equipment which doesn't fit their profile or driving style resulting in both a bad experience at skiing as well as endangering others as they cannot fully control their skis.

Therefore, Fischer4you aims to get qualitative data insights into the process of skiing using multi sensor setup and also test the feasibility of using just a single sensor smartphone system for broad usage. These insights should deliver where best to place the smartphone to get the best out of the collected data while skiing. In the end the goal is to provision a data preprocessing and machine learning pipeline to be executed on data sent by a smartphone app. This pipeline detect patterns and insights from accelerometer, gyroscope, magnetometer and GPS signals, as well as derived data such as altitude, such as the skier's skill from the generated patterns during skiing, make a skier profile and assist them by a feedback in form of product and ski recommendations and technique guiding.



Goals

Fischer4you goal is to recommend the most suitable ski equipment to each ski driver according to their performance profile and making them aware of their skill level and the level of consistency they have during skiing. Fischer4you will monitor (i) user activities occurring during a skiing day using body worn sensors embedded into everyday smartphones, (ii) user behavior while skiing such as speed control and consistency in driving several different techniques (according to the specification of the Austrian ski teaching union), (ii) user motions such as stability at each turn and acceleration/deceleration after/before each turn, to build a skill assessment model and a skier performance profile. Ultimately, this system, provides users their skiing profile, supports them to access their own driving quality and choose a proper product and to improve their skiing skills. Further the goal is that this system runs on a central server and its assessment can triggered by just using data coming from a mobile phone, which is also used for information users about their skill level and an appropriate product recommendation.

Approach

Fischer4you will build on and advance over state-of-the-start methods for performance and motion analysis, activity identification and skill level recognition relying on machine learning models. Fischer4you will acquire data via IMU sensors and GPS sensors, preprocess the received signals, make a skier profile according to the generated patterns and skiing performance, and derive measures of skill level through a data driven model which compares each user with expert users' behavior, i.e. users which are teaching skiing instructors. Subsequently, skill level fused with the other general information sources, e.g. demographic information, form input to the recommendation system to get both ski product and improvement recommendations.

Expected and Achieved Results

Fischer4you aims to develop a smartphone application to be used by everyone with any level of skill. This recognition pipeline consists of the following components: (i) a sensor fusion module used to create viable sensor ensembles in an opportunistic manner as a basis for motion analysis and activity recognition, (ii) performance analysis and activity recognition models to know what each skier does and how well he is performing each technique, (iii) a data driven model based on expert users profile to be used as a reference for skill assessment (iv) a recommendation module, able to offer the most appropriate equipment to each user, and (v) a feedback trigger module, which will formulate a ski recommendation and potentially also areas of improvements, e.g. like recommending seldomly driving techniques. This framework is to be developed as distributed application, with a sensing and actuating component, e.g. an app on a smartphone, a reasoning component, e.g. implemented as a machine learning server component for recognition, as part of the demonstrator project 1. For demonstration purposes, the produced application on a smartphone along with the skill assessment framework and recommendation system will provide state of the art user assistance to form a stand-alone, visual support- and guidance system for a targeted personas study and for a bigger audience of skiers in the long run.

Status / Progress

This project officially started in January 2019 and will continue till March 2021. In it, Pro²Future is working with our Company Partner Fischer and the Institute of Pervasive Computing at JKU Linz towards the creation of recommendation systems based on skier driving skills. Several projects meeting provided a discussion platform for the overall approach and additionally several data recording session took place not only in winter but also in summer on glaciers. With the current preliminary data investigation is in progress and, in parallel, consortium members have completed the initial system models for the performance analysis, activity recognition and skill assessment architectures. The models have been presented to the consortium partner during the WIP meeting and were discussed in brief, with a more detailed discussion to be held during each individual bilateral partner meeting.

Fischer4you by itself will utilize the created models and learning approaches to enhance product recommendation as planned in the project outline. To this end, a machine learning software framework is being created and interfaces set up according to the models and guidelines set forth by the consortium - the focus at this point being the abstraction of skier's skill level based on generated patterns and performance. In the mid-term, machine learning models will be trained for activity recognition, skill assessment and recommendation system. These developed tools and components will determine the need for adaptive feedback to users, increase performance and skill, and return usage information towards a product recommendation. The key investigators aim to achieve this by integrating the developed machine learning pipelines with the multi-sensor fusion framework developed as part of the WorkIT project. In the long term, the devised classification pipeline will be investigated during live studies on snow with a large group of skiers. This is being created right now by splitting several part of the analysis pipeline into dedicated modules, which are either deployed on a central server or the smartphone. Where the former provides the analysis part and the later provides that data gathering and feedback part.

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AREA 1

DP 1.2-3 RTEAS
Cognitive Rail Track Error Analysis Support

Area 1 - Perception and Aware Systems

Project ID:	DP 1.2-3
Project Title:	Cognitive Rail Track Error Analysis Support
Project Lead:	DI Michael Haslgrübler Pro2Future GmbH
Duration:	12 Months, 15.11.2019 - 14.11.2020
Strategic Volume:	10 %

Work Packages

WP 1: Domain Knowledge Establishment

WP 2: Statistical Data Analysis

WP 3: Visualization

WP 4: Recommendation System

WP 5: Dissemination

WP 6: Project Management

Company Partners

System 7 - Railtechnology GmbH
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Academic Partners

JKU, Institut für Pervasive Computing (IPC)
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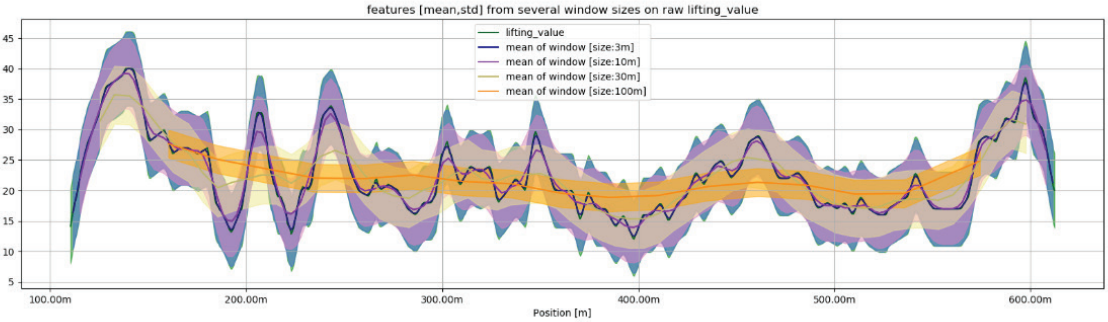
RTEAS will provide support in rail track error analysis based on the data from rail track machines. Along with company partner System7 which builds this kind of machines, the analysis support will be used by System7 customers in the form of reporting and suggestion the maintenance of the rail tracks. E.g. in Europe alone over 200000 kilometers of rail road need to be maintained, whereas a repair job for 500 meters takes several hours. Especially with providing a green alternative to flying, the maintenance of rail tracks is crucial when driving with very high speed, e.g. over 200KM/h. Deterioration of the tracks is not only governed by use but also by bad weather conditions, e.g.strong rain or very low or high temperatures.

Typical rail track maintenance is costly and done with automated inspection of the rail tracks which records errors in several regards, such as longitudinal, directional, or superelevation errors, which can if not mitigated are sources for derailment. These errors occur typically when the underlying ballast bed cannot absorb the force by driving. The errors are fixed using semi-automatic tamping machines, which press together ballast. This process can be repeated on several occasions till a point where the gravel is destroyed by the tamping process and the ballast bed needs to be replaced. In order not to over-tamping areas which don't need tamping as well as finding out when to replace the ballast, RTEAS aims to leverage data coming from the hydraulic units of these machines.

Therefore with both historical measurements and maintenance data along with the (i) Rail Road Geometry (Hight shift, direction, Height Variance), (ii) Ballast Measurement (compaction force, Adjustment travel, Regulating time) and the (iii) Position (odometer, GPS, IMU), rail road tracker managers as well as tamping machine operators should get insights into data and also derive action suggestion. Based on a unsupervised machine learning pipeline built in Guide and WorkIT, along with further descriptive data analysis measures, the project team aims to improve the quality of track maintenance and reduce the cost of unnecessary track maintenance.
Additionally, based on the data analysis and the insights gathered from it, RTEAS also will build a reporting engine, which prepares this data into persuasive reports for both tamping machine operators as well as rail road track maintenance managers.



Goals

RTEAS has the goal to to provide decision support for manager and tamping machine operators, suggesting the scheduling of maintenance operations and replacement of ballast bed by monitoring and analyzing the (i) Rail Road Geometry (Hight shift, direction, Height Variance), (ii) Ballast Measurement (compaction force, Adjustment travel, Regulating time) and the (iii) Position (odometer, GPS, IMU). Based on machine learning, e.g. outlier detection, and descriptive statistics, e.g. variance analysis, correlations should be found between errors and data, which guide decisions whether or not to make the correction to the railroads in order prevent failures. RTEAS aims to use the specifically coming from system7 tamping machines sensors, i.e. the hydraulic unit, and will develop the anomaly detection mechanisms able to predict and generate suggestions for further correction in a railroad.

Approach

RTEAS will (i) build on over state-of-art methods for data analysis and correlation in the data for anomaly detections, (ii) Conventional machine learning and recognition architectures tailored to the railroad and temping session data processes, (iii) and powered by an existing data collecting architectures from the system 7 tamping machines. RTEAS will find the correlations, plot, and calculate the wear and tear of the rail track. Subsequently, different anomaly classes are matched to the models derived from domain-specific expert knowledge, thereby supporting prediction, and suggesting the maintenance of the track and guiding decision makers by providing appropriate persuasive reports to either take action in various direction, e.g. not scheduling maintenance for several months or immediate replacement of ballast bed.

Expected and Achieved Results

RTEAS aims at two developments within the project frame: (i) a data analysis pipeline which will be powered by data coming from rail track tamping machines; (ii) a report engine which delivers high quality reports and charts to guide decision makers into appropriate actions. Of course, the main deliverable of this project is the Data analysis pipeline and prediction of the rail track maintenance status. As for this data analysis, we already implemented various expected outputs such as an (i) In-Depth Report on Distribution of Data and Correlation between Problems and Data (ii) Interactive Visualization, which is not yet embedded in System7 Inframe Platform. As for the data analysis company partner System7 expects to find correlation between several relevant data classes, namely geometry data (longitudinal error, directional error and superelevation), ballast bed measurements provided by the hydraulic units (compaction force, compaction path length and time) and position (odometer and GPS data) and to be provided with scientific visualization results clearly indicating underlying problems.
Further in the Recommendation part of the project, the main outputs are (i) the implementation of deriving appropriate actions in reporting Engine (ii) and the preparation of reports on Decision Making by providing necessary visualization and outlining circumstances for actions. Additionally persuasion techniques typically found in HCI sustainability projects should be applied to these reports.

Status / Progress

This project officially started in November 2019 and will end in November 2020. In it, Pro²Future is working with our Company Partners System7, with a delayed kick off held in December 2019 due to organizational incapacities at the company partners side. Various meeting till December 2019 were held for the team to establish the necessary domain knowledge needed for the data analysis. Preliminary data investigation was done in January 2020 and, in parallel, responsible members have completed the initial data analysis approaches and the methodologies which will are now the foundation to build the RTEAS projects. The analysis reports have been presented to the partner during monthly meeting and were discussed in detail. Along with further acquisition of domain knowledge and improvements in System7 data acquisition on their tamping machines work has been done on providing Statistical data analysis and visualizations (Distribution analysis, correlation analysis). By now the machine learning and descriptive statistics pipeline is ready for the anomaly detection and can provide the automatic reports, based on data coming from temping session.

Ongoing work is to stabilize the development of this pipeline regarding data anomaly found in sensor output of the hydraulic units. In the second half of the project the Data analysis framework will be further extended by the engine, which recommends the track maintenance operations and provides persuasive material for the both track maintenance managers and operators alike.

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AREA 1

DP 1.6-1 GUIDE

Guidance and Assistance

Area 1 - Perception and Aware Systems

Project ID:	DP 1.6-1
Project Title:	Guidance and Assistance
Project Lead:	Univ.-Prof. Dr. Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	33 Months, 01.04.2018 - 31.12.2020
Strategic Volume:	10 %

Work Packages

WP 1: Models and Knowledge Representation

WP 2: Recognition System and User Classification

WP 3: Guidance and Assistance

WP 4: Use Case and Prototyp Design

WP 5: Integration

WP 6: Strategic: Supporting Worker Guidance

Company Partners

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Academic Partners

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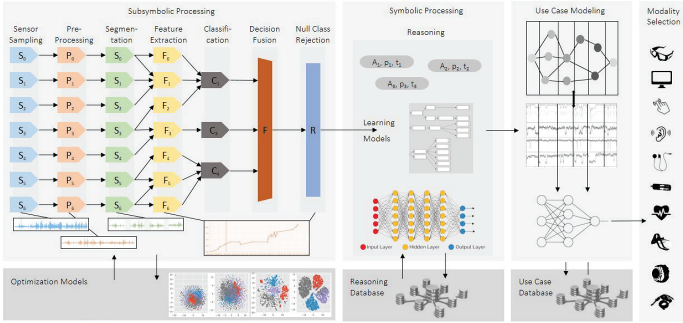
GUIDE will investigate novel worker context recognition, assistance and guidance technologies for use in the manufacturing- and production setting. The project is motivated by the fact that suboptimal outcomes of interactions between man and machine (measured via product quality and manufacturing efficiency) are correlated with (i) the cognitive load and level of attention of the factory worker, (ii) the frequency and degree of disruptions during the manufacturing workflow, as well as (iii) misalignments between the worker's skill and the task complexity. GUIDE will attempt to model the level of cognitive load of human workers in the execution of tasks and is thus related to fundamental research in the interdisciplinary fields of cognitive science, computer science, industrial research, and behaviorism. Further, GUIDE will extend beyond current interactive assistance systems that are mainly restricted to presence detection and collision avoidance by not only recognizing production step, but as well interpreting underlying motivation, level of engagement and goal for optimal activity support and guidance. Finally, GUIDE aims at triggering context-sensitive, multi-modal feedback and instructions, depending on the respective current workflow task, adaptable in sensory channel modality as well as with respect to the workers current skill level and wish for guidance.

Typical industrial work processes involve information from a variety of sources, usually spread out over a multitude of locations. Inexperienced workers are thus often forced to divide their attention between performing the manufacturing tasks and seeking information from different sources – a task that has been shown to adversely affect cognitive load and ultimately result in decreased productivity. As part of DP1, GUIDE will contribute towards the development of a prototype cognitive head gear (HMD) that aims at providing all necessary guidance information directly to the worker at the time of need. Specifically, GUIDE will provision a data preprocessing and machine learning pipeline to be executed on the HMD's mobile processing unit. The key investigators aim to achieve this by utilizing an already previously developed framework for opportunistic, multi-sensor fusion in the domain of embedded activity recognition and optimizing it for the requirements of mobile execution in conjunction with the created HMD. This pipeline will be able to utilize low-level sensor data and transform it into high-level classification results related to (i) industrial workflow steps or the (ii) current cognitive state of the user. The produced HMD along with the context recognition framework will be integrated with state of the art industrial work equipment.

Goals

GUIDE has as its goal the detection and reaction to threats for desirable interaction outcomes, thereby preventing the degradation of product quality and manufacturing efficiency. Specifically, GUIDE will monitor (i) human factors such as the vital state (fatigue, fitness), skill and experience, cognitive load (stress), ongoing social interactions, distractions and peripheral interrupts (background noise), (ii) workflow complexity and state with respect to activities, processes, timeliness, exception handling, robustness, and quality assurance, (iii) apparatus complexity and worker skill, especially when interacting with complex manufacturing tools, (iv) support human decision making with respect to complex information (machine- or workflow related), unreliable or uncertain situations, and achieving transparency concerning offered assistance, and (v) minimize cognitive load. In that, GUIDE aims at a modular, opportunistic worker state recognition architecture, that makes use of dedicated mobile sensors (eye-trackers, body pose, and hand movements) and actuators (visual, vibro-tactile, auditory), and at the development of feedback trigger mechanisms, able to support, warn and sense workers during manufacturing, assembly and production tasks.



Approach

GUIDE will (i) **build on- and advance over state-of-the-art methods for cognitive load estimation**, (ii) **machine learning and recognition architectures** tailored to industrial machines and workflow processes, (iii) **build on existing opportunistic sensing architectures**, and (iv) **formulate triggers for worker feedback mechanisms**. To this end, GUIDE will derive a measure of cognitive load and human attention and incorporating the same into a user-centric and redesigned version of the context recognition chain, extended by high-level reasoning and recognition architectures. Subsequently, fused decision classes are matched to workflow process models derived from domain-specific expert knowledge, thereby supporting prediction and support.

Expected and Achieved Results

GUIDE aims at the development of a holistic framework to be used in multiple industrial manufacturing and production use cases as agreed upon with our respective industrial partners. This framework will encompass and consist of the following components: (i) a sensor fusion module used to create viable sensor ensembles in an opportunistic manner.

This will go beyond the results of the WorkIT project and be integrated with the context recognition chain as implemented by the GUIDE project, (ii) purpose-build models of human attention and cognitive load, each based on existing research from the fields of psychology and cognition. (iii) a modelling methodology for the abstraction of workflow processes, encompassing expert domain knowledge, activity recognition, context recognition and forecasting, (iv) a skill and experience module, able to infer worker skill and to model experience gain, and (v) a feedback trigger module, which will determine the need for feedback and formulate a recommendation for the feedback modality to be used by the SeeIT project. This framework was integrated and exemplified in a head mounted display prototype developed as part of the demonstrator project 1.

For demonstration purposes, the produced HMD along with the context recognition framework provides state of the art industrial work equipment to form a stand-alone, visual support- and guidance system, which we deployed e.g. during shop floor studies at company Fronius. In cooperation with sibling project WorkIT project, and sophisticated machine learning pipelines were developed especially for supervised methods, we developed both a classical feature based machine learning pipeline as well as multi layered deep neural networks, based on state-of-the-art paradigms like CNN (e.g. UNet or Inception) and RNNs in form of LSTMs. Further we also investigated the cognitive state of workers by building a gaze analytics pipeline or using data from a wrist-worn GSR unit, which we to this end used to investigate cognitive load during welding or for skill recognition during welding.

Status / Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partners Fronius, KEBA, Wacker Neuson, Trumpf, the Institute of Computer Engineering and the Institute of High Frequency Technology at TU Graz towards the creation of Industrial Worker Guide and Assistance systems. We have held the project Kick-Off, and conducted meetings with all Company Partners at their respective locations to gauge the possibilities and most promising approaches on site. Preliminary data investigation was used to define the initial system models for the guidance and assistance architectures. To this day they are extended using data collected in the WorkIT project, and by results with respect to feedback triggers to the SeeIT project.

So far the machine learning software framework created, in conjunction with sibling project WorkIT, features a classical featured based machine learning pipeline as well as a deep neural network based one additionally the overall toolkit also features interfaces and implementation for abstraction of a workers' cognitive state. The trained machine learning models have been trained for each industrial application of our company partners and extends on all steps of the context recognition chain. The developed tools and components still need to be extended for detecting the need for adaptive feedback to industry workers, however so far, they were able to spot task inefficiency, performance variations and return usage information towards product optimization.

Further we also implemented a gaze analytics pipeline used for creating features from a mobile eye tracking unit, which are examined for detecting the workers cognitive state, i.e. skill level or cognitive load. So far, we investigated skill level for company partner Trumpf during bending and cognitive load for Fronius during welding. Additionally, in conjunction with the machine learning and multi-sensor fusion pipeline from WorkIT and the feedback system from SeeIT, we already implemented a new guiding interface for novices helping them during metal bending bending. The work will be extended by the key investigators to all the use cases and showcases the cognitive reasoning capacity of GUIDE.

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AREA 1

DP 1.6.2 HumanAI
Human Focused AI for occupational safety and accident prevention

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.6.2
Project Title:	HumanAI - Human Focused AI for occupational safety and accident prevention
Project Lead:	DI Michael Haslgrübler Pro2Future GmbH
Duration:	5 Months, 01.11.2020 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 1: Human Focused AI for occupational safety and accident prevention

WP 2: Dissemination

WP 3: Project Management

Company Partners

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Academic Partners

JKU Linz, Institute of Pervasive Computing (IPC)
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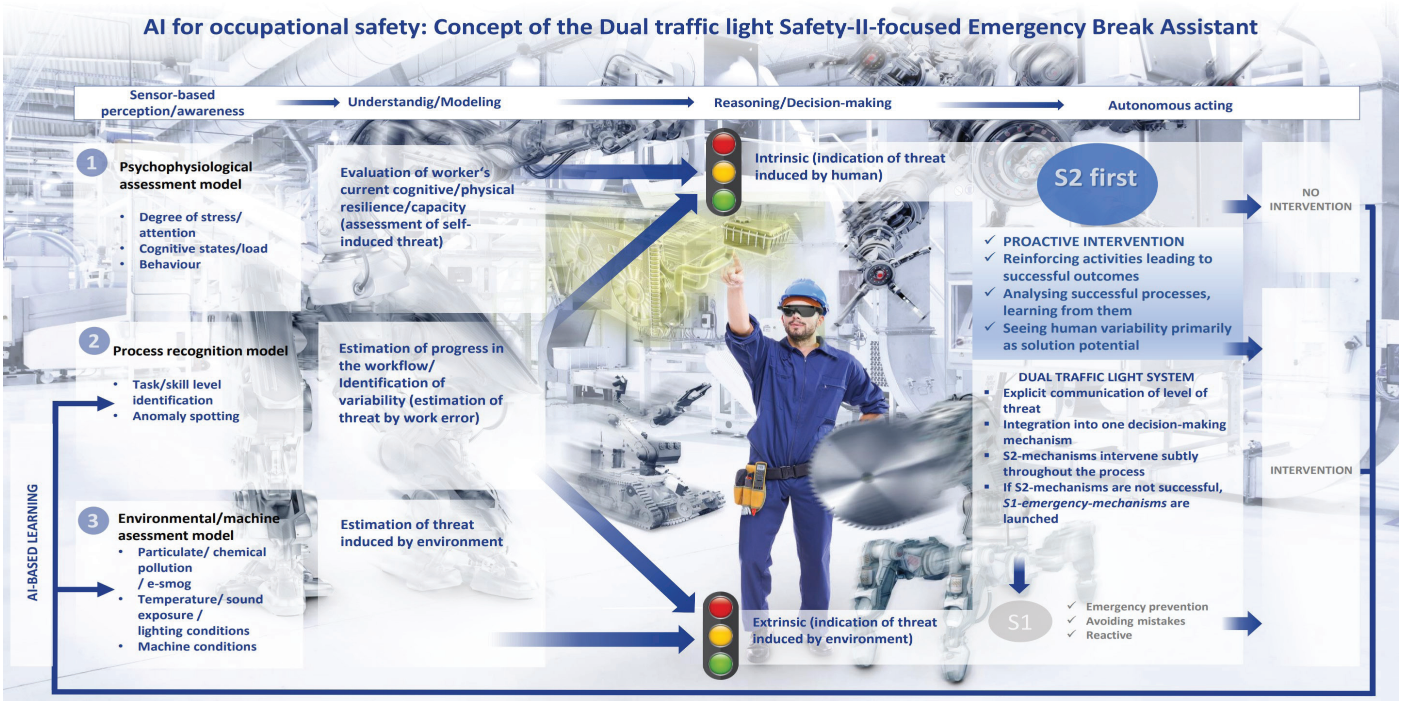
Work environments, particularly within the industrial sector, are undergoing swift and dynamic technological transformations. Employees are increasingly confronted with new challenges, notably the integration of highly efficient, semi-autonomous machinery that necessitates seamless human collaboration. Presently, computer-driven methodologies and AI-based systems (centered around human interaction) in the realms of industrial research and machine advancement have been harnessed to enhance productivity and adaptability. Regrettably, the well-being of workers often takes a back seat, occasionally even being completely disregarded.
The core objective of this endeavor is to reconceptualize this paradigm and embark on an extensive research initiative aimed at exploring how the next generation of AI-based systems can significantly enhance occupational safety and prevent the occurrence of accidents.
As part of this initial design study, preceding the main project, we are shaping a conceptual and technical framework for an AI cognitive system that prioritizes human safety at work and prevents accidents. This system is named the "Safety-II Emergency Break Assistant." It brings together three interconnected models: firstly, it evaluates the worker's state; secondly, it tracks the progress of the tasks; and thirdly, it analyses the working environment.
The system intelligently assesses potential risks, encompassing both those originating from human errors (intrinsic threats) and those arising from the environment or machine malfunctions (extrinsic threats). Subsequently, it employs appropriate guidance and support measures to facilitate a smooth collaboration between human operators and machines. This includes the ability to provide support and guidance to workers without disrupting their essential duties but is also able to shut down the system by means of an emergency brake if necessary.
The system is designed to continuously learn and improve its accuracy over time. This iterative process ensures that it offers practical and effective assistance while maintaining its trustworthiness. The underlying conceptual framework, combined with a systematic exploration of various sensor data collection and presentation devices aimed at enhancing occupational safety, are documented and described in a position paper, which will serve as the foundation for subsequent research.

Goals

This project initiates a broader study into how AI-powered, human-centered systems can enhance occupational safety and accident prevention, particularly in industrial settings. Our project partners' data highlights that most accidents occur in the domain of manufacturing. Therefore, we are envisioning AI solutions which address existing threats to worker safety but also additional challenges that are brought into the domain by means of constantly increasing automation.
Our primary goal is to firmly establish the concept of “HumanAI for occupational safety” in the domain of industrial research. Proposing a solution, we envisioned a comprehensive and technical framework of a holistic, multisensory, and multimodal interconnected mechanism



that gathers data from workers and their environment and provides feedback not just for enhancing productivity, but mostly, safety. Our system aims to seamlessly assist workers as needed, without disrupting their workflow, and only intervenes in real-time if it detects potential dangers. The goal is to recognize workflows that lead to dangerous outcomes before accidents occur. Especially experienced workers may circumvent safety measures seen as unnecessary. Thus, we intend to design the system in such a way workers will not feel compelled to bypass the mechanisms, a common issue in real-world situations.

After anchoring the topic in the research field, we intend to use the framework as a base for the follow up project, where the concepts discussed are planned to be materialized as demonstrators.

Approach

The sensory framework consists of three models, which analyze the threats initiating from those areas: (i) psychophysiological analysis, (ii) workflow recognition, and (iii) environment and machine assessment. Mobile and stationary sensors, unobtrusively deployed in the infrastructure and on the workers bodies, collect the necessary data. Model 1 monitors health and wellbeing, the attention state and stress levels. Model 2 monitors the workflow. Model 3 evaluates the environment and the machines. A dual traffic light system informs the workers of danger levels adding to the system's transparency. An emergency brake engages only in cases of acute danger, otherwise, the system is serving with assistance. Notably, the system learns from past workflows to enhance precision.

Expected and Achieved Results

Cognitive assistance systems are most useful when based upon adequate sensors, actuators, and data processing devices. Therefore, one of the results of our work was a broad literature exploration and description of these components. We assessed their suitability for worker safety and practicality in real-world scenarios. An eye-opening takeaway was a critical underrepresentation of work safety aspects in general, as well as a lack of potential applicability of the devices for worker safety at that time, revealing a critical gap that spurred our subsequent project. Therefore, with the conceptualization of the technical framework we created an outline of the mechanism we would like to build, which we were able to use for further research and exchange with future company partners. Our emphasis here was on designing a system that does not only regard separate aspects and immediately shuts down whenever a "wrong" work step happened but can see the "whole" picture. The hypothesis behind was that dangerous situations might not arise when one aspect goes wrong, it is rather a combination of factors that might lead to unlucky outcomes. Also, there is not only one way of doing things right, but many ways that can lead to successful outcomes – considering human creativity instead of trying to eliminate it was one of our motivations. Another focus of research has been the mechanisms' practicality and efficiency, later also trust, making it potentially useful in real-world settings. The results have been summarized and published in form of a position paper (Addressing worker safety and accident prevention with AI, Huber et al.) and presented at a conference (IoT 2023).

Status / Progress

The project is now completed and has transitioned into the main project, AI2Human, which is currently ongoing. While the main project concentrates on real-world industrial applications, analyzing existing norms and guidelines, developing risk evaluations, and designing prototypes, it was the HumanAI phase that effectively explored the domain of AI for worker safety for the first time, attracting significant interest and receiving approval within the research community.

However, sharing the proposed system with the wider community and potential stakeholders expanded our outlook, exposing us to diverse and at times, intricate perspectives, along with possible limitations. The perception and reasoning abilities of a holistic, intelligent system within an industrial context hinge on sensor-driven human activity and workflow recognition, going along with diligent monitoring of the industrial scene. This goes hand in hand with concerns about privacy and supervision. Even if the system is designed in the best possible way to avoid being perceived as intrusive into the private sphere, establishing real trust, openness and acceptance among the workers requires a significant investment of effort by the developers and, in case of a real-world implementation, by the employers. To sum up, significant technical progress cannot materialize without a concurrent improvement in both knowledge and mindset.

Another concern emerges when AI components intervene into the machine control system. While AI-driven assistance systems offer guidance and information, a more intricate scenario unfolds when AI is granted the capability to initiate or cease machine operations. Should this be the case, the machine requires reevaluation and recertification by the manufacturer, as it introduces additional vulnerabilities (considering scenarios where AI malfunctions could hinder proper shutdown). While global regulations for systems incorporating AI elements (e.g., the AI Act of the European Parliament) are currently in development, we must deal with much uncertainty. However, in the domain of AI systems, rigid guidelines prove inadequate due to the highly contextual nature of most use cases. We confront the challenges ahead with enthusiasm, motivated by the understanding that this project will make a lasting contribution to improving worker safety.

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AREA 1

StratP 1.5 AssE

Opportunistic Awareness in Assistive Environments

Area 1 - Perception and Aware Systems	
Project ID:	StratP II 1.5
Project Title:	AssE - Opportunistic Awareness in Assistive Environments
Project Lead:	Univ.-Prof. Dr. Alois Ferscha JKU, Institute of Pervasive Computing
Duration:	12 Months, 01.04.2020 - 31.03.2021
Strategic Volume:	100 %

Work Packages

WP 1: Feedback and Guidance Systems

WP 2: Embedded AI and Cognitive Products

WP 3: Workflow Recognition

WP 4: Future AI

Academic Partners

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The purpose of "Opportunistic Awareness in Assistive Environments" was to support scientific work on the following topics:

- **Feedback and Guidance Systems** Industrial ICT systems that are designed to provide feedback or guidance to humans have been shown to fail if the provided assistance information is not suitable to the worker and situation in question. AssE aims to further the state of the art in this aspect via provisioning of skill sensitive feedback, i.e. feedback that is designed for- and adapted to the worker's skill and experience. Part of this approach is to guarantee that provided guidance information to industrial workers is explainable and reconstructable.

- **Embedded AI and Cognitive Products** Embedded AI is expected to be a major future driver in industries. Waiving the need for large scale data centers and achieving decentralized artificial intelligence would open new applications for AI, removing restrictions imposed by the ongoing "data silo-fication" in many domains. AssE aims to further the state of the art by proposing a research endeavor in this field. This effort will be co-organized with research proposals on advancing neuromorphic architectures of cognitive products – a field that is still very young and in need of more research.

- **Workflow Recognition** An important puzzle piece for many industrial ICT applications involving human workers is the correct detection of their current work tasks. Applications are for example the construction of quality assurance logs, or the detection of human oversights and manufacturing errors. AssE will focus on advancing the state of the art in micro- and macro work step detection, as well as activity recognition using overhead cameras.

- **Future AI** AssE aimed at identifying long term- and short-term future application domains for AI systems and provided text blocks and state of the art reviews for research grants proposals on both time scales: For the long term, human-like intelligence informed AI systems and neuro-robotics are investigated, whereas on the short term, cognitive systems for green technologies are researched.

Goals

The goal of the project was to further strategic developments in terms of scientific output. The following areas of research were investigated:

- Sensor-based recognition of the state of (i) machines (system state), (ii) humans (skill level, cognitive state, vital state), and (iii) processes (workflow recognition).
- Display of- and interaction with digital content, such as (i) video snippets for documentation purposes, and (ii) haptic signals for unobtrusive notifications.
- Aspects of AI and its applications, such as (i) human-informed AI, (ii) green tech and sustainability, (iii) neurorobotics.

The achievement of goals was demonstrated through (i) scientific publications, (ii) demonstrators and videos, (iii) reviews and summaries of the state of the art, and (iv) text blocks for research grant proposals.

Approach

To achieve the target scientific output, the project was built on a strong scientific consortium, involving partners from the JKU and TUM, where Pro²Future focused on research related to (i) feedback and guidance systems, (ii) cognitive products, and (iii) workflow recognition, JKU focused on (i) embedded AI, (ii) human state recognition, and (iii) greentech AI, and TUM focused on (i) robotics, (ii) neuromorphic architectures of cognitive products, and human-like intelligence informed AI.

Expected and Achieved Results

The project resulted in **1 journal paper and 4 conference papers** that were submitted to the MDPI-Applied Science journal, as well as the PETRA and IOT conferences.

Micro Activities Recognition in Uncontrolled Environments (A. Abbas, M Haslgrübler, AM Dogar, A Ferscha; Applied Sciences 11 (21))

Determining Best Hardware, Software and Data Structures for Worker Guidance during a Complex Assembly Task (B Anzengruber-Tanase, G Sopidis, M Haslgrübler, A Ferscha; Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments)

Micro-activity recognition in industrial assembly process with IMU data and deep learning (Georgios Sopidis, Michael Haslgrübler, Behrooze Azadi, Bernhard Anzengruber-Tánase, Abdelrahman Ahmad, Alois Ferscha, Martin Baresch; Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments)

Skill Level Detection in Arc Welding towards an Assistance System for Workers (M Laube, M Haslgrübler, B Azadi, B Anzengruber-Tánase, A Ferscha; Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments)

Privacy Preserving Workflow Detection for Manufacturing Using Neural Networks based Object Detection (A. Ahmad, M Haslgrübler, G Sopidis, B Azadi, A Ferscha; Proceedings of the 11th International Conference on the Internet of Things)

Status / Progress

Further, contributions to Tiny AI were made within AssE. TinyAI aimed at developing scientific foundations and technological breakthroughs for autonomic on-device AI, and its amplification to collective on-multiple-device AI. The expected results included (i) the miniaturization of AI systems (hardware, algorithms, methods), (ii) the orchestration of dispersed AIs, (iii) the opportunistic self-organization of limited resource ensemble AIs, (iv) reinforcement-, federated- and transfer-learning models and methods to operate AIs, (iv) self-evolving tiny robotic brains, neuromorphic processing architectures and processor designs, as well as (v) the mapping of all the related findings into the cognification of products and production systems of the future.

Tiny AI aimed at novel algorithmic strategies for:

- small-scale machine learning techniques on resource-constrained, yet autonomous devices, including the mass deployment of human perception like ML across multiple devices, the integration of ML into embedded and real-time systems, and the live (on-the-fly) processing of multimodal data streams from multiple sensor sources. This would answer the research question “How to fit ML into resource-constrained embedded devices?” by substantially improving the training efficiency (few shot learning) and inference efficiency of reinforcement learning.
- dependable systems addressing reliability, energy efficiency, real-time processing, and cognitive wireless communication (providing dependable performance even in harsh environments), answering the research question “How to assure dependability guarantees for tiny ML?”.
- device ensembles to answer the research question “How to manage the complexity of tiny dynamic ML ensembles?” by devising engineering principles to build dynamically networked, spontaneously configured groups of Tiny AI entities and making the complex AI ensemble behavior explainable to humans.
- robotics to answer the research question “How to realize tiny thinking robotic ensembles?” by co-designing tiny mechatronic mechanisms, tiny neuromorphic control and tiny brains that employ tiny dependable ML ensembles.

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AREA 1

MFP II 1.1.1 3D-RECON III

Novel methods for 3D models from camera shoots

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.1.1
Project Title:	3D-RECON III - Novel methods for 3D models from camera shoots
Project Lead:	Dr. Michael Haslgrübler Pro2Future GmbH
Duration:	12 Months, 01.04.2021 - 31.03.2022
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Data driven Multi-View Stereo

WP 4: Data driven Structure-From-Motion

WP 5: Test und Evaluierung

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Academic Partners

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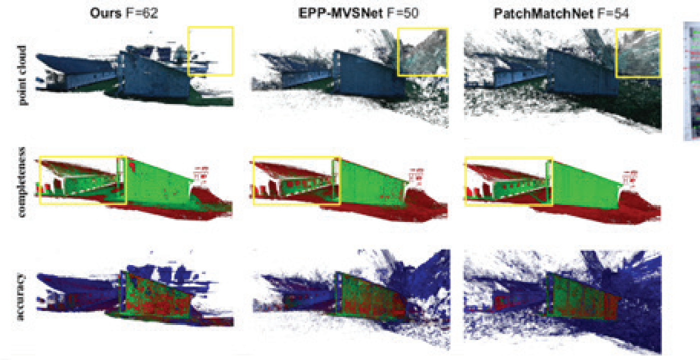
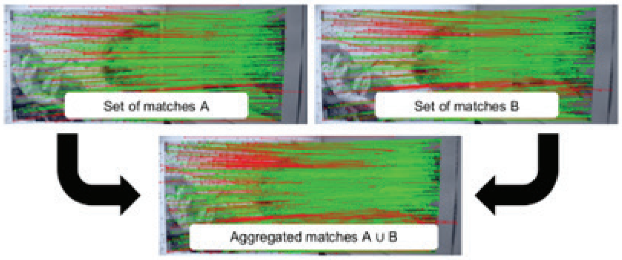
The focus of this research initiative is to advance the field of multi-view stereo (MVS) by addressing key challenges and introducing innovative solutions. One core goal is the generation of more complete 3D reconstructions for datasets characterized by a scarcity of captured camera poses. To achieve this, the approach involves generating additional virtual camera poses alongside existing ones. Depth maps corresponding to these new poses are then refined using a depth completion algorithm. This refinement process significantly enhances the density of the resultant 3D reconstructions, enabling a more accurate representation of the scene's geometry.
One of the novel directions within this research area is the exploration of MVS techniques without relying on traditional cost-volume approaches. The aim is to devise a more adaptable architecture that can generalize effectively across a wide range of data types and scenarios. Building on recent advancements in binary mask-based depth estimation from classical stereo, the project will implement a similar strategy within the MVS context, thereby innovating over the state of the art.
Furthermore, the research delves into the incorporation of semantic information, particularly for planar surfaces, to enhance depth map completion. By leveraging the inherent structure of certain scene elements like walls and floors, incomplete regions of the depth map can be intelligently filled, resulting in more coherent and realistic 3D reconstructions.

The optimization of correspondence search, a computationally intensive step in the MVS pipeline, is another vital aspect of this project. A hierarchical approach is being developed to reduce the computational burden of this process. This involves the exploration of hierarchical descriptor vectors and the formulation of an appropriate cost function for the neural network responsible for descriptor computation.
Lastly, the project addresses the fusion of RGB color and depth (RGBD) data for improved feature extraction. By tailoring neural network architectures originally designed for color data to accommodate the additional depth dimension, the goal is to leverage the synergies between color and depth information to extract more informative and discriminative features.

In essence, this research initiative aims to revolutionize the field of multi-view stereo by tackling critical challenges in depth estimation, reconstruction completeness, efficiency, and feature extraction. The culmination of these efforts promises to significantly enhance the quality and accuracy of 3D reconstructions, opening up new possibilities for applications in computer vision, robotics, and augmented reality.

Example Scenes acquired by the pipeline





Goals

This project's objective is to push the boundaries of 3D reconstruction by investigating, developing, and evaluating methods that exceed current technological capabilities. The primary focus lies in incorporating semantic insights and contemporary machine learning techniques.
Two key domains are under scrutiny:

- The deployment of machine learning, driven by data, to enhance the precision and dependability of camera pose determination.
- The integration of machine learning, powered by data, into the realm of 3D data creation via multi-view stereo methodologies.

The project's achievement will be evident in various ways:

- The successful validation of these novel techniques on pertinent benchmarks, including the notable ETH 3D dataset, as well as Sony's provided datasets.
- Tangible improvements that become apparent through subjective and qualitative assessments.
- The dissemination of successful methodologies through scientific publications and potential consideration for patenting.

In essence, this initiative is driven by the ambition to not only achieve advanced 3D reconstructions but also to rigorously validate their effectiveness. By harnessing machine learning and semantic insights, this project strives to leave a notable mark on the landscape of 3D reconstruction methodologies. The project will not initially focus on reconstructing static environments such as rooms and places and will put less emphasis on capturing dynamic scenes or objects like humans.

Approach

The project approaches the given tasks by utilizing artificial environments and scenes derived from Unreal Engine 4, to increase the availability of data for training. In this way, dataset generation was streamlined using the large number of available scenes in the associated online store. Using the EasySynth plugin, it is possible to export (i) rgb images, (ii) camera poses (in COLMAP format), (iii) depth maps (in floating point format, (iv) normal vector maps (in floating point format), and (v) GT point cloud (reconstructed from the extracted depth maps and poses). Using this synthetic data, existing MVS algorithms will be refined and a multi-detector for local feature extraction, based on a retrained deep-matcher on top of the MD-net structure, developed.

Expected and Achieved Results

The project expects the following results: (i) enhancing the accuracy and robustness of estimating camera positions within a structure-from-motion (SFM) system; (ii) improving reconstruction of indoor spaces, specifically flat surfaces such as walls, ceilings, and floors, surpassing the capabilities of current leading methods; (iii) achieving both qualitative and quantitative assessments of the newly developed techniques; (iv) creating software implementations of these novel methods, and (v) finally showcasing the extended practicality of 3D reconstruction methods, highlighting their efficacy in generating higher quality results. The project has been concluded and achieved its expected results.

Status / Progress

After having achieved, implemented and demonstrated (i) improved camera position estimation within a structure-from-motion (SFM) system, and improved reconstruction of indoor spaces, the project will be renewed and continued. In 3D-Recon-IV we are continuing to still further enhance 3D reconstruction with deep learning techniques. As such we focused on two data driven multi-view stereo and structure from motion. For the first a new architecture was implemented which optimizes epipolar line search with deep learning. Results were published in IEEE WACV. For the second part, structure from motion, the project team worked on deep learning-based feature extraction of key points of images, a task very common in computer vision pipelines. Noteworthy is that the training process works fully unsupervised and achieves competitive results on established benchmarks, published in IEEE ICPR.

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AREA 1

MFP II 1.1.2 DERELE

Deep Learning Based Reconstruction for Linear Edifices

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.1.2
Project Title:	DERELE - Deep Learning Based Reconstruction for Linear Edifices
Project Lead:	Dr. Michael Haslgrübler Pro2Future GmbH
Duration:	12 Months, 01.10.2021 - 30.09.2022
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Lineation and Longitudinal Edge Course Detection for Point Clouds/Meshes

WP 4: Section Plane Detection for Point Clouds/Meshes

Company Partners

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Academic Partners

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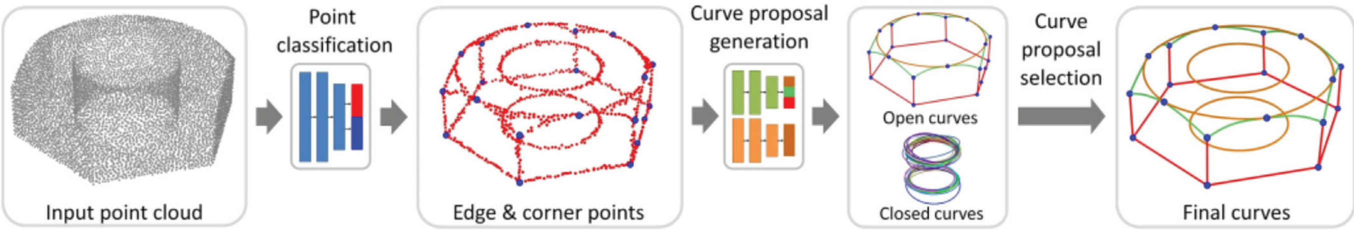
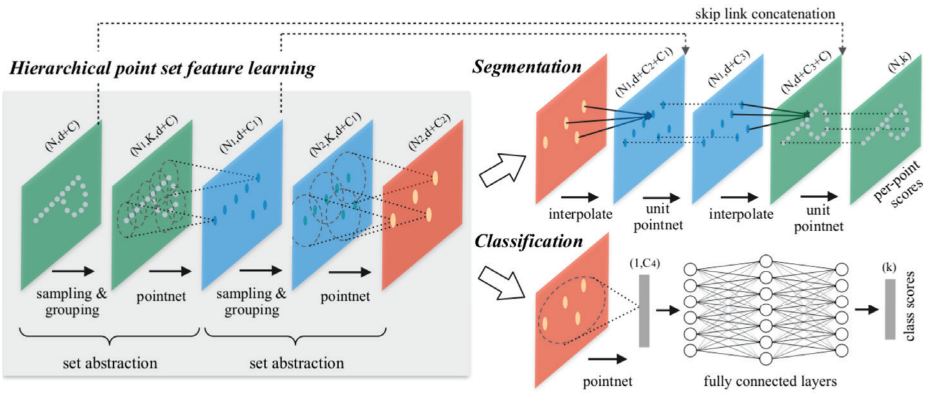
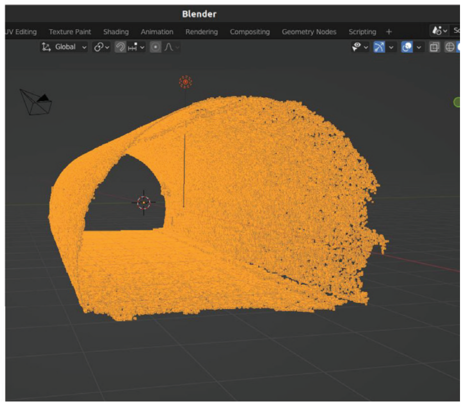
Machine learning-based detection of geometric shapes has emerged as a rapidly expanding research field, with significant attention currently directed towards external, outside geometries. This project investigated methods to achieve this for large-scale interior geometries while leveraging RGB-based data - a novel and intriguing challenge. At the heart of this project lies the development of a prototype machine learning algorithm, specifically designed for the recognition of longitudinal edges and cross-sections. The primary objective was to provide valuable support to surveyors involved in the complex task of geometry creation for 3D tunnel models. By automating the detection of longitudinal edges and cross-sections, this machine learning approach aimed to streamline and expedite the process, ultimately enhancing the efficiency and accuracy of 3D tunnel model processing and analysis.
This project extended the boundaries of the existing state-of-the-art methodologies in the domain of transforming 3D models into comprehensive 3D tunnel geometries. By building upon the foundations laid by prior research, this project advanced handling of large interior geometries within the context of tunnel models. The inclusion of RGB-based data further added a novel dimension, as it opened new possibilities for richer and more detailed geometric analyses and texturing. Throughout the project, rigorous experimentation and prototyping was conducted to refine the machine learning model continuously. The focus was on optimizing the accuracy and reliability of the longitudinal edge and cross-section recognition. Additionally, the research team collaborated closely with surveying experts, gathering valuable feedback to ensure the practical applicability and effectiveness of the developed algorithm.
This project represented a step forward in the field of machine learning-based geometric shape detection. By expanding its applications to encompass large-scale interior geometries and incorporating RGB-based data, it opened doors to novel opportunities in the realm of 3D tunnel model processing and analysis. The successful implementation of this prototype provided a valuable tool to surveyors when creating indoor geometry and the project contributed to advancements in the transformation of 3D models into comprehensive 3D tunnel geometries.

Goals

The primary objective of this project was to facilitate the data transformation process of 3D point clouds into an actual 3D geometry, here instantiated at the example of a road tunnel. The point cloud was collected in advance and outside of the project by a vehicle dedicated for the task. Previously, achieving the task of transforming point clouds into geometries relied on manually defining the underlying reference geometry to fit to the point cloud. The project aimed at leveraging machine learning techniques to automate this process at least partially, thereby streamlining the workflow. The project targeted the following







key areas of investigation: (i) machine learning-based recognition of fracture edges or longitudinal edges (potentially extending to include the identification of vertical and plan view axes), and (ii) machine learning-based cross-section computation and recognition.

Approach

To implement the recognition of longitudinal edges, cross-sections, and section planes for point clouds and meshes using parametric, open curves, the following approach was adopted:
(i) PointNet++ was used to perform point cloud segmentation. PointNet++ is a deep learning architecture that can effectively handle unordered point clouds. By dividing the point cloud into segments, it was possible to isolate distinct regions that are relevant to specific edge and cross-section detection tasks.
(ii) For precise identification of corners and edges in the segmented point cloud, PIE-Net was used. PIE-Net is designed to detect features like corners and edges with high accuracy.
(iii) Prior to applying the deep learning methods, the point cloud and mesh data was processed using open-source tools such as Blender.
(iv) Section planes in the 3D models were identified using standard geometric algorithms, and parametric curves that represent longitudinal edges and cross-sections were constructed using mathematical techniques like B-spline interpolation or fitting polynomial curves to capture the intricate details of the detected features.

Expected and Achieved Results

The project is now concluded. To inform the project's approach, a comprehensive analysis of the state-of-the-art in transforming 3D models into descriptive 3D geometries was conducted and a corresponding report generated. Additionally, the team developed prototypes to showcase the effectiveness of machine learning-based fracture edge- or longitudinal edge recognition (with potential extensions) and machine learning-based cross-section recognition. These prototypes featured a complex processing pipeline, made up partially of established deep learning networks for processing and segmentation of point clouds (PointNET++, PIE-NET), as well as purpose-built aspects of generating section planes and parametric curves. This pipeline was initially devised and prototyped using open-source data sets of object point clouds, and subsequently adapted and optimized to be used with a pre-existing point cloud data set provided by consortium partners. The final system was demonstrated successfully within the frame of the project. The achieved advancements enhanced the efficiency and accuracy of the 3D tunnel creation process from raw point cloud data, using an approach based on lineation and longitudinal edge course detection, as well as section plane recognition, thereby contributing to the field of 3D modeling and beyond.

Status / Progress

This project tackled the challenge of lineation and longitudinal edge course detection for point clouds and meshes. To achieve this, several essential blocks were addressed. Firstly, a thorough analysis of state-of-the-art techniques in lineation and edge detection was conducted. This step involved (i) understanding key point detection, (ii) lineation/edge detection, and (iii) the intricacies of longitudinal edge course detection. Based on this analysis, further steps and methods were determined. The selected reference architecture was validated using a public dataset. This implementation involved adapting the chosen reference architecture to suit the specific requirements of the project. The reference architecture was trained first using published and publicly available data sets, enabling it to learn and recognize patterns relevant to lineation and edge course detection. The results obtained from these early training steps were compared with the state-of-the-art to gauge the effectiveness of the selected approach. After this initial validation, the focus shifted towards adapting the architecture to a different dataset, specific to the selected use case of tunnel surface recreation. This adaptation involved verifying the suitability of the dataset and making any necessary modifications to the implementation to ensure it functions seamlessly with the new data. Following this phase, a comprehensive hyperparameter study was conducted to fine-tune the model's performance, with further refinement and optimization undertaken subsequently based on the results of the conducted study. Hyperparameter optimization was conducted iteratively, striving to achieve the best possible results. The architecture was adapted to the problem domain, leveraging insights gained from previous stages. Additionally, runtime optimization was explored, streamlining the model for efficient deployment.
The same basic process was followed in order to develop a machine learning-based system to implement section plane detection for point clouds and meshes, involving the computation of cross-sections of the tunnel profile. This was made necessary due to the fact that cross sections of tunnels are not necessarily shaped the same. Road tunnels include safety areas to the side of the tunnel, where cars may park in case of emergency, as well as access points for escape routes. These structures break the usual shape of the tunnel, complicating the task of detecting section planes, and further of generating 3d models of the tunnel structure. This issue was specific to the investigated tunnel dataset, and it was thus necessary to develop a purpose-built recreation pipeline for this task.

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AREA 1

MFP II 1.2 APECGR

Artificial Personality for Cognitive Guidance and Recommendadtion Systems

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.2
Project Title:	APECGR - Artificial Personality for Cognitive Guidance and Recommendadtion Systems
Project Lead:	Dr. Bernhard Anzengruber-Tanase Pro2Future GmbH
Duration:	36 Months, 01.04.2021 - 31.03.2024
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Process Recognition

WP 4: Cognitive State Recognition

WP 5: Infrastructure for Reinforcement Machine Learning

WP 6: Interaction Design

Company Partners

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Academic Partners

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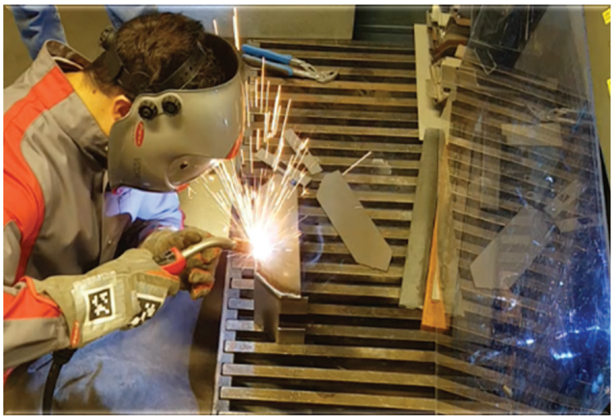
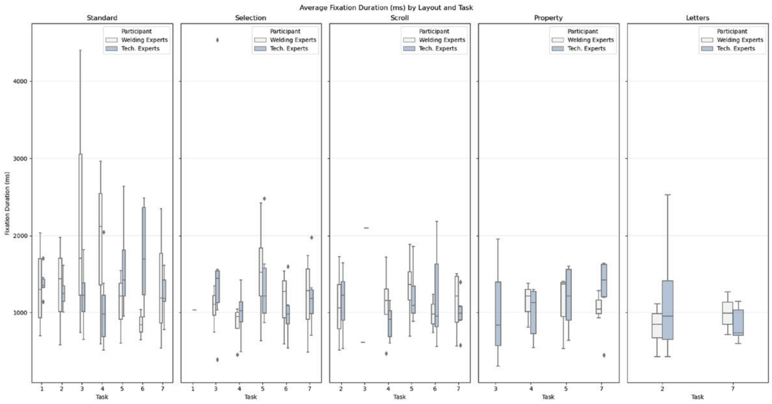
This project researches user experience design based on emotive triggers in the industrial domain, with the goal of increasing tool life by decreasing instances of negligent handling of industrial tools, reified using manual welding torches. Usually, in the industrial domain, good user experience design is not a significant focus. Don Norman argued that, while human-centered (interface) design processes in theory represent the ideal, in practice they are commonly untenable. He goes on to iterate that in his experience, market-driven pressures plus an engineering-driven company yield ever-increasing features, complexity, and confusion. But even companies that do intend to search for human needs are thwarted by the severe challenges of the product development process, in particular, the challenges of insufficient time and insufficient money. Norman anecdotally postulates that there are only two actual drivers of new product designs: (i) adding features to match the competition, and (ii) adding some features driven by a new technology.

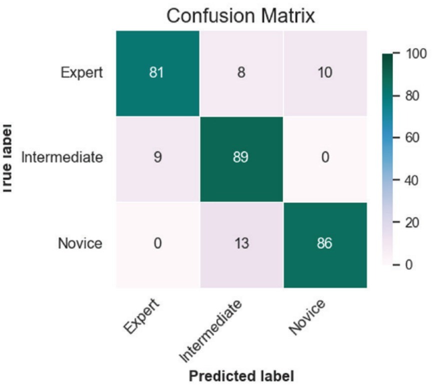
In an attempt to break this mold, APECGR puts the user at the center of the design process, investigating ways to make the user want to interact with “their” product, and caring for it, thereby reducing the chance the device will be treated roughly and negligently. The project will firstly investigate ways to accurately determine instances of rough use to initiate an interaction with the user, and further investigate ways to identify states of heightened user affect. This is done, to provide either calming or informative interaction to reduce potential mishandling of the product. If successful, the project will further investigate ways to impact the users emotional state using interactions. The project will further investigate ways to design user interfaces, manually and using reinforcement learning, which aim to minimize frustration and optimize interaction efficiency.

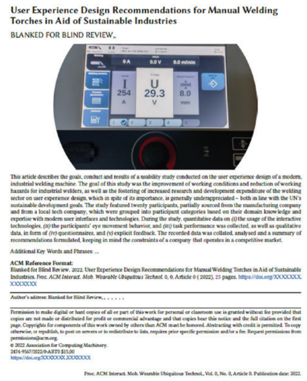
Finally, the project will investigate ways to determine the skill level of users, in order to provide tailored interactions based on the users actual need and profile, thereby avoiding annoying and negative interaction experiences.

The project will implement and test the developed system in the domain of manual arc welding using both novices and experts at welding. The results will be demonstrated via multiple independent studies of the individual parts of the overall system in industrial environments and encompass the development of a final prototype.









Goals

The goal of this project is to investigate ways to trigger emotional responses in welders, ultimately to reduce device damage induced by inappropriate handling of welding torches. These goals will be achieved by development of an assistance system for welders, that detects whenever a welding device is being treated roughly, thereby reducing its life expectancy, and prompts the user in an emotive way to not do so in the future. The system should be engaging to interact with and reduce the need for device maintenance due to inappropriate handling. Part of this system is the development of a cognitive state recognition engine, that measures the users emotional affect as well as skill level, and provides suitable feedback, as created via statically designed- and reinforcement learning approaches. The interactions should provide methods of self-improvement for the welders, as well as demonstrate problems and offer avenues of improvement. The project will demonstrate its result in form of a prototype for the envisioned user guidance system, using available sensors integrated in the welding torch.

Approach

The project will implement the given goals using a sensor-data driven approach. A purpose-built data collection system will be created, consisting of (i) the welding torch itself as a data source, (ii) an eye tracker as indicator for affect, intent and interface quality, (iii) body-physiological wrist-worn sensors, (iv) as well as in-ear microphones. In this way, the project will attempt to find indicators for affect and skill in the welding domain, based on established research, and be able to investigate the impact of user experience design choices on the emotional state of welders.

Expected and Achieved Results

The project will yield multiple systems that coordinate in order to provide user focused feedback regarding the mindful handling of a manual welding torch. Specifically, the project will result in (i) a system that recognizes impacts to the welding torch that are outside the accepted safe parameters using the IMU included within the welding torch (achieved), (ii) a system to determine the skill level of a welder based on their welding movements (partially achieved), (iii) a study on sensors and derived indicators for affect that are suitable for the welding environment (in progress), (iv) an evaluation of the graphical interface of the welding device with the purpose of enhancing user experience (achieved), and (v) methods of automatically generating useful UI designs based on welding tasks (in progress). This system will optimize itself for known, re-occurring interactions during welding.

Status / Progress

The project has already achieved a large amount of its work. A comprehensive user experience study of the welding interface was conducted and has been published as an internal report. Based on the study and based on global usage statistics, a reinforcement learning approach to automatically optimize the UI design is currently in progress. An initial study to evaluate the viability of known indicators for affect (pupil dilation, galvanic skin response, blood volume pulse etc), has been conducted and will be utilized to formulate design recommendations for future user interfaces with the goal of increasing positive welder affect towards the welding tool. A system to detect rough handling of welding torches was implemented. Further, the description of work was extended in this regard to attempt to determine exact welding patterns purely based on IMU data. Finally, a study to determine the skill level of welders is currently ongoing.

Next steps involve finalizing the identification of indicators for affect and providing ground truth by establishing a system that aims to detect situations of high negative affect and positively impacts them, thereby avoiding mistreatment of the welding torch. Further, the skill level detection system will be extended and finalized. This process currently involves the investigation of new features and data processing pipelines, as well as a step back from categorical skill classifications due to limited ground truth and data. Finally, a reinforcement learning approach for self-adaptive interfaces will be finalized. The system currently encompasses eight psychological and user task efficiency-related systems for evaluating a user interface. A large-scale grid-search study will be conducted to find the best set of parameters and weights.

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AREA 1

MFP II 1.2 RTEL
Cognitive Rail Track Error Learning

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.2
Project Title:	RTEL - Cognitive Rail Track Error Learning
Project Lead:	Dr. Michael Haslgrübler Pro2Future GmbH
Duration:	36 Months, 01.04.2021-31.03.2024
Strategic Volume:	18 %

Work Packages

WP 1: Project Management

WP 2: Dissemination and Exploitation

WP 3: Infrastructure for Active/Reinforcement Machine Learning

WP 4: Machine Learning for Usage Recommendation

Company Partners

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Academic Partners

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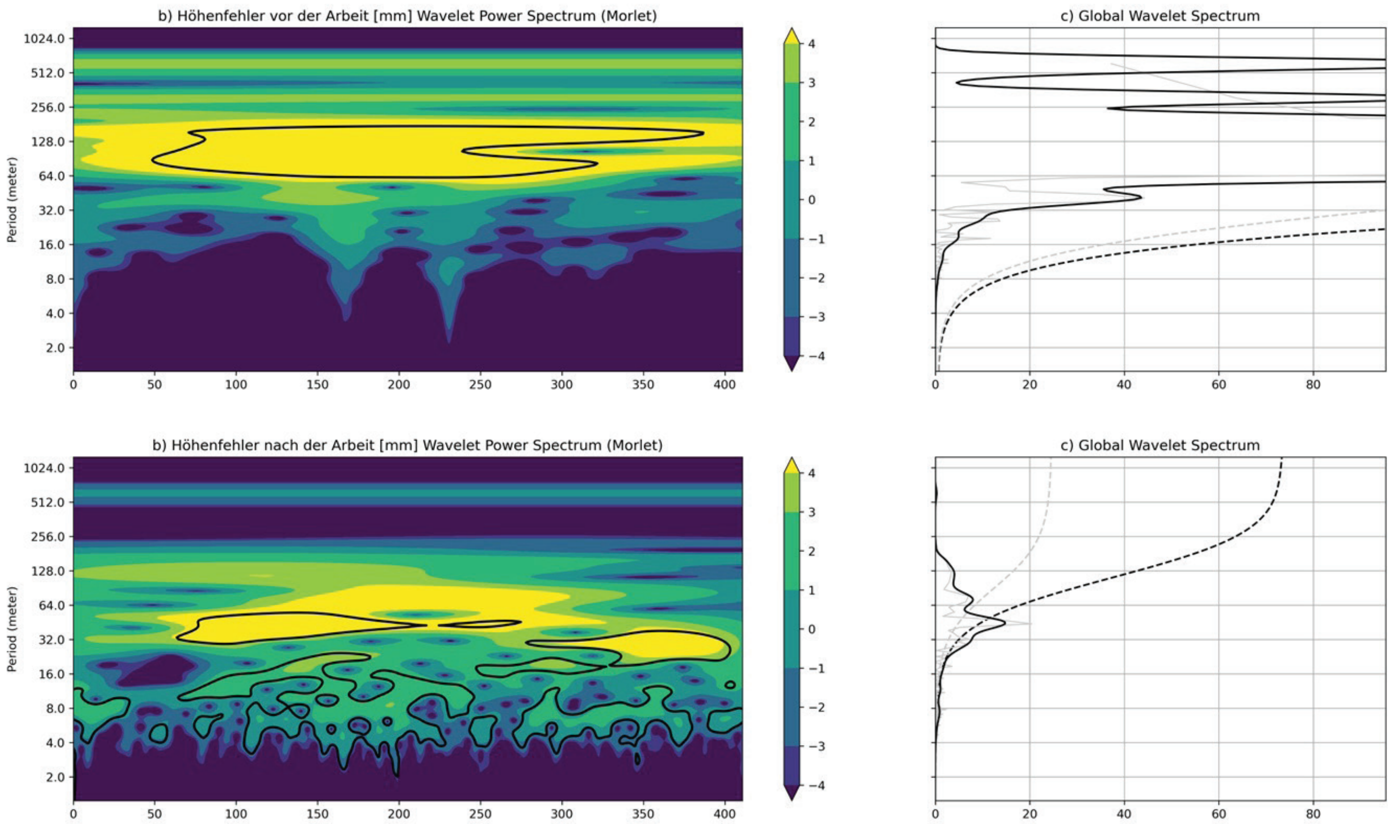
RTEL is an innovative Rail Track Error Learning AI system where in collaboration with System 7, we will analyze railroad maintenance signals prior to and after the tamping work, embed machine learning algorithms in track bed analysis, and assess the tamping work quality. Such a system will spot anomalies in the rail track prior to tamping using signal processing and provide findings on the fly to the machine operator, e.g., suspected dirty ballast. Additionally, after tamping work, the system evaluates maintenance jobs and recommends maintenance actions such as ballast replacement due to low quality.

The railway is a highly energy-efficient and environmentally friendly mode of transportation, emitting considerably fewer greenhouse gases per passenger kilometer compared to planes and cars. Therefore, it's crucial to have a high-quality maintenance system in place to maintain railway infrastructure in good condition and ensure service continuity. The most recognized rail track maintenance job is tamping the ballast, which is also necessary for the newly built tracks. Our Company partner, System7, not only does build such a machine but also offers maintenance work. The maintenance task using ballast tampers takes several hours for every kilometer of the railroad. Although the maintenance of railways using ballast tampers is well established, the tamping result is not easy to evaluate. Tamping work is the most important and expensive part of the maintenance process. Therefore, it's essential to have high-quality tamping work to fix errors and reduce costs. However, current tamping quality evaluation methods are limited. To bridge this gap, we're examining track geometry and tamping data to research all informative signals. We'll feed these signals, collected before, during, and after tamping, into machine learning models to formulate the tamping work behavior. In collaboration with System 7, our focus is on tamping result evaluation. To develop a tamping assessment system, we're going to study tamping data and investigate several machine learning models to find the best one for assessing tamping work quality.

Goals
The goal of the RTEL is to spot anomalies in railway tracks, provide online information to the operator, assess the tamping work in dealing with track errors, and recommend actions. RTEL aims to study signals before tamping and while tamping from System 7 machines sensors, i.e., the hydraulic unit, and will develop the anomaly detection mechanisms to predict and generate suggestions for further correction in a railroad. Additionally, knowing failures in the track infrastructure helps with assessing maintenance work and formulating machine behavior in addressing rail track failures.



Approach

The approach in the RTEL project is to build an AI system upon existing data collection architectures from the System 7 tamping machines. This system consists of an anomaly detection model that spots the position of the error on the railroad using signal processing, a deep Autoencoder which can learn tamping data, compress, and reconstruct them, and a deep learning model that can model tamping machine behavior and predict after tamping signals. Therefore, RTEL will find failures, locate and plot them, predict how they will be addressed, and evaluate the tamping work. This system can support decision makers to take appropriate maintenance actions or adjust the maintenance plan ranging from, e.g., not scheduling maintenance for several months or immediate replacement of ballast bed.

Expected and Achieved Results

In the scope of the RTEL project, we expect to have a pipeline implemented that can detect anomalies and assess how well tamping work fixes these failures. Therefore, we must develop two main models upon data from tamping machine sensors. The first model is anomaly detection, and the second is machine behavior. We employed wavelet transform to study recorded data in the frequency domain. The output of wavelet analysis spots failures on the track before tamping and helps to identify the source of error. Then, wavelets will be fed into a deep model to learn the machine behavior in tamping. So far, we have implemented the wavelet transform report, where it is possible to compare signals before and after tamping in the frequency domain and see changes due to tamping work. System 7 has already embedded this analysis in its reporting platform. As for the data analysis, company partner System7 expects to identify the source of the error and its position based on the dominant frequencies and to be provided with scientific visualization results indicating underlying problems.

Moreover, by formulating the machine behavior, System 7 will predict the expected result of the tamping work and can evaluate the maintenance jobs. To train such a model, raw signals before and after tamping and their wavelet transformations will be fed into a deep-learning model. As a part of this model, we have already developed an Autoencoder to compress and reconstruct the prior-to-tamping signals and their related frequency bands. Such a model will facilitate the comparison between signals in their latent space. We have trained such an Autoencoder model to reconstruct tamping signals.

Status / Progress

This project officially started on the first of April 2021 and will last till the end of March 2024. Pro2Future cooperates closely with System 7 and has held regular discussions to report the work in progress and exchange information and ideas. During monthly meetings, we have presented the analyses to the partner and discussed them in detail. Along with the further acquisition of domain knowledge and improvements in System7 data acquisition on their tamping machines, we have worked on providing data analysis and visualizations (e.g., wavelet analysis). So far, anomaly detection using wavelet transform is ready and integrated into the System 7 reporting platform where every dominant frequency is connected to a group of error sources. Moreover, the machine learning pipeline is under development, and the signal reconstruction module is delivered to the company partner.

For the rest of the project, the focus is on developing a machine behavior model based on wavelet results to become an accurate engine, which formulates tamping work, evaluates the maintenance job, and recommends the track maintenance operations. Therefore, the model provides online suggestions and information during the tamping to the operator and feedback to take appropriate actions to the experts.

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AREA 1

MFP II 1.2. GAP

Cognitive Guidance for Assembly Processes

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.2
Project Title:	GAP - Cognitive Guidance for Assembly Processes
Project Lead:	Dr. Michael Haslgrübler Pro2Future GmbH
Duration:	12 Months, 01.04.2021 - 31.03.2022
Strategic Volume:	18 %

Work Packages

WP1: Project management

WP2: Dissemination and Exploitation

WP3: Micro-Workstep-Detection

WP4: Macro-Workstep-Detection

WP5: Interaction Design

Company Partners

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Academic Partners

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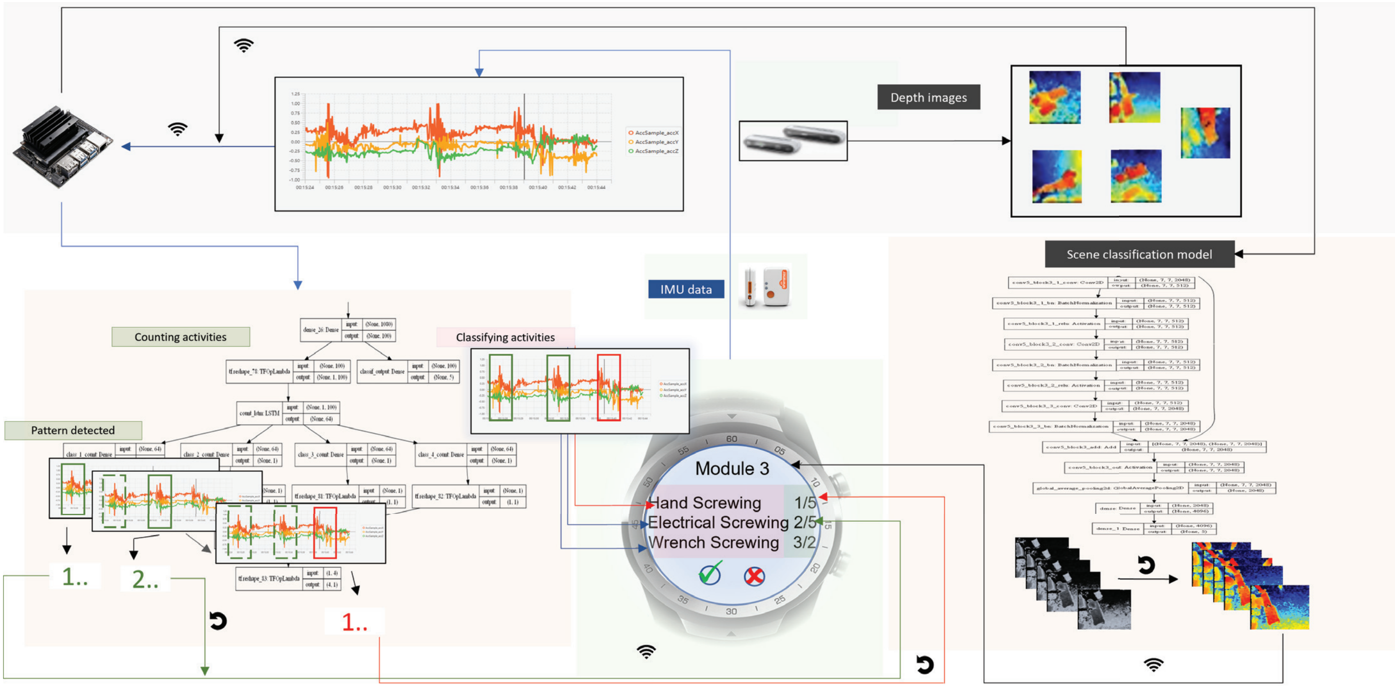
Human Activity Recognition (HAR) holds immense significance in computer vision, offering benefits in diverse scenarios. In industrial settings, manufacturing assembly steps are categorized into macro and micro tasks. Macro steps involve attaching or inserting components, while micro steps encompass swift actions like screwing. Detailed research has been conducted on HAR for screwing tasks, considering architecture, window size, sliding rate, weighting methods, and model development. The focus is to differentiate between short-duration activities (e.g., screwing) and continuous movements (e.g., walking). The ATM assembly involves numerous steps, each containing specific screwing actions vital for completion. Tracking these actions helps compare with requirements, aiding error reduction, faster detection, and lowers costs. Additionally, human-machine collaboration could enhance worker confidence and shorten training periods.
Automated understanding of work steps in industrial assembly work is important for assistive guidance technologies in employee-machine collaboration and for industrial environments. Our aim is to identify macro work steps using depth images and micro activities of employees during the assembly of ATM machines for auxiliary purposes in their daily complex tasks using hand-operated tools.

Due to the advance of inertial measurement unit (IMU) technologies and pattern recognition IMU based sensing together with machine learning has gained momentum on work step recognition and was selected for this study in combination with a depth camera sensor which is mounted on a ceiling with a top-down angle. In this work, the focus is on a seamless embedding of non-impeding body-worn IMUs or their integration into smart devices, and the depth sensor ensures the privacy of the operators, allowing for unobstructed monitoring of tools' usage patterns and thus assembly work step recognition.
The results of this study are evidenced by empirical observations of assembly work step executions by (i) hand screwing, (ii) screwdriver screwing, (iii) machine screwing, (iv) wrench screwing, with the null class being disproportionally dominant in the data set. Deep Learning models including LSTM, Temporal Convolutional Networks (TCN), and CNN architectures are proposed for the detection of micro activities and macro work steps and the identification of the current work step which is beneficial also for the recognition of the transition between each two consecutive macro work steps. A sophisticated counting mechanism of the classified activities is recognized as the next research challenge, that utilizes features from each IMU sensor with weak labels and the temporal information from the depth sensor.

Goals

This project investigates further development of cognitive assistance systems in the assembly area by incorporating new machine learning-based mechanisms for macro and micro work step detection, as well as the embedding of weakly annotated data to improve the data anno-



A road-map for the system proposed in this study showing the micro activity recognition in steps along with the macro work step classification.

tation process and the quality of the recognition results. Furthermore, it assists the worker by recognizing the work step and work activities, allowing them to complete complex tasks without errors.
The initial phase involves adapting the project's approach based on insights gained from the previous period. This entails transitioning to smartwatches while reducing the reliance on shimmer sensors and enhancing user usability. However, this transition prompts a necessary adjustment in machine learning algorithms due to the altered input parameter configuration. Simultaneously, user management becomes a priority, enabling personalized utilization of project tools. Additionally, the project explores the implementation of automatic work step identification. Complementing the user's ability to navigate work segments through a smartwatch, this algorithm is refined using privacy-friendly image processing techniques.
The aim of the project is to investigate personalized Machine learning algorithms that can operate on weakly annotated data for micro-work step detection algorithms and privacy-friendly image processing algorithms for macro-work step detection.

Approach

The system detects micro and macro work steps during an industrial assembly process shown in the figure. The process begins with the initialization of the application on the smartwatch that enables the collection of the IMU and depth data as it is visible in the upper part of the image. The collected data is then sent to a CPU via Bluetooth and used as input to the deep learning models, which will have to predict the number of activities that constitute each module (left side of the watch in the image) and the correct module of the workflow in which the employees currently are (right side of the watch in the image).
Individual deep models are trained to recognize similar patterns and additionally perform scene classification to provide feedback through a wrist-worn smartwatch. Weakly annotated data is used for the deep learning models to count the activities.

Expected and Achieved Results

In the final stage, the user will be able to have the complete system working in a smartwatch. Each node transmits data to the IoT system, where the data from the IMUs are processed and the activity is counted while the new work step is classified based on depth images. The system will detect the activities, classify them, and enumerate them to determine the stage of the process. Finally, it will provide online visual feedback in its built-in monitor combined with vibrations for delivering messages. Information on the smartwatch includes how many micro activities are completed at each timestamp, how many activities are yet to be done and what is the current macro work-step.
Currently, the system is deployed in an industrial environment where the collected data is used to train and fine-tune the models. LSTM and CNN architectures are implemented to identify the activities and the work steps for this supervised problem. The classification and recognition of the activities are already achieved while the work step recognition yields promising results. The counting part of the problem as shown below is tested successfully in a public dataset related to industrial activities.

Status / Progress

The provided model architecture exemplifies its application in activity counting using IMU data. This process involves dividing the IMU data into sequences of varying lengths, which serve as inputs for the model. Each sequence is associated with a weak label indicating the number of activities within it.
Visualizing the data input, distinct examples showcase time-series data divided into sequences of segmented acceleration data. These sequences vary in duration, sample count, and weak label range of activities (number of activities/sequence). The weak label is generated by the number of spotted endings (red arrow) inside each individual sequence.
As of the current project status, the model architecture is designed for activity counting employing IMU data. The utilization of ragged tensors caters to variable-sized input data, enhancing its adaptability. Sequential processing, involving Timedistributed dense layers and an LSTM layer, allows the model to capture temporal patterns and generate per-time-step outputs to discern transitions between activities. The model exhibits the capability to differentiate between these steps even with limited data, indicating its promising potential. Enhancing the results is feasible with increased data acquisition in subsequent endeavors.

However, it's worth noting that the project is subject to further refinement using real-world IMU data. In conclusion, the project has reached a stage where a model architecture for activity counting using IMU data has been established with data from public datasets. The architecture's unique features, such as the handling of variable-sized input using ragged tensors and the utilization of square-shaped data representations for edge detection, contribute to its effectiveness. The macro work step detection is performed with the available data. Ongoing efforts are focused on refining and evaluating the model's performance to ensure its viability for real-world applications.

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AREA 1

MFP II 1.3 Fischer4You2

Active Learning for Cognitive Skiing PRoducts

Area 1 - Perception and Aware Systems	
Project ID:	MFP II 1.3
Project Title:	Fischer4You2 - Active Learning for Cognitive Skiing Products
Project Lead:	Dr. Michael Haslgrübler Pro2Future GmbH
Duration:	12 Months, 01.04.2021 - 31.03.2022
Strategic Volume:	18 %

Work Packages

WP 1: Projectmanagement

WP 2: Dissemination and Exploitation

WP 3: Data Integrity

WP 4: Active Learning for Understanding Human Activities

Company Partners

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Academic Partners

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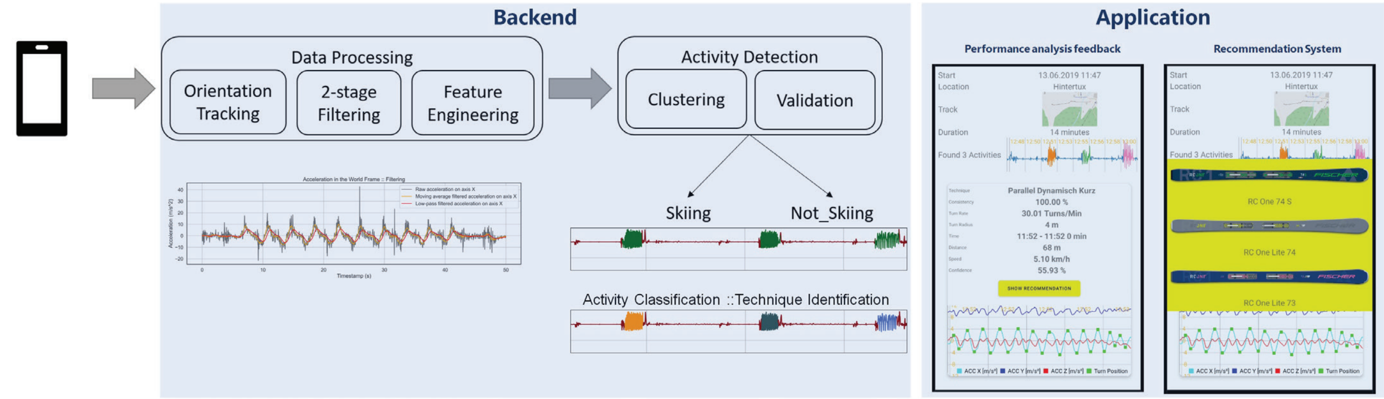
Fischer4You2 aims to assess recreational alpine skiers to find their skill level of skiing, therefore providing them with an appropriate range of alpine skiing equipment and skill recommendations. The primary motivation of this study is that alpine skiing equipment recommendations not only must be based on the general profile of skiers but also their skill level of skiing. Through this project, we will try to build a data-driven model that can evaluate skiers' skills in driving different alpine skiing techniques. Thus, Fischer4You II needs to research the interdisciplinary fields of sports science, computer science, biomechanics, and kinesiology. Further, the ultimate goal of Fischer4You II is to go beyond alpine skiing activity recognition and performance analysis and offer product and coaching recommendations based on skiers' profiles to improve their skiing experience and safety.

Austrian Skiing Association defines alpine skiing techniques as follows: Glide, Schuss, Wedging, Snowplow, Drift, Parallel Short Swing, Parallel Long Swing, Carving Long Swing, and Carving Short Swing. These techniques differ in speed, turn rate, etc. Moreover, they must be adapted depending on the skiing piste condition, which makes it hard for novice skiers to ski comfortably while performing different styles and controlling their speed at each turn. Therefore, inexperienced users are often unable to maintain their pace and body angle to make a smooth curve at turns and, as a result, lose control which causes severe injuries and accidents with other skiers. In addition, there is a direct relationship between the skiing behavior at turns, created curves, turn radius, and appropriate skiing equipment. The problem is that skiers often choose the wrong equipment, which does not fit their skiing profile. As a result, they will have a bad experience at alpine skiing and may endanger others as they cannot fully control their skis. To avoid such problems, there should be an easy-to-use system that can evaluate skiers and offer them the right skis and bindings based on their expertise. Therefore, there is a need to have an easy-to-use system that can evaluate skiers and offer them the right skis and bindings based on their expertise to prevent such problems.

Goals

Fischer4You2 aims to recommend appropriate alpine skiing equipment based on the skill level of alpine skiers and make them aware of their expertise and level of consistency in performing different alpine



skiing techniques. During the Fischer4You project, we will implement a pipeline that collects skiers' data via body-worn sensors embedded into their smartphones, processes the recorded signals to detect their skiing activities, classifies those activities into alpine skiing techniques, monitor user behavior while performing different skiing styles such as speed control and consistency and stability at each turn and acceleration/deceleration after/before each turn, and scores them to provide a level of expertise. This pipeline processes the accelerometer, gyroscope, magnetometer, and GPS signals and detects alpine skiing patterns and insights to build a skill assessment model. The model recognizes the skier's skill from the generated patterns during skiing using machine learning algorithms, creates a skier performance profile, and assists them with feedback in the form of product and skis recommendations and technique guides.
Ultimately, this system provides users with their skiing profile, supports them to access their own driving quality and choose a proper product, and improves their skiing skills. Further, the goal is that this system runs on a central server and its assessment can be triggered by just using data coming from a mobile phone, which is also used for informing users about their skill level and an appropriate product recommendation.

Approach

The Fischer4You2's approach is to build a model based on state-of-the-art methods in sports activity detection, performance and motion analysis, activity identification/classification, and skill level recognition relying on machine learning algorithms. The Fischer4You II pipeline will gather data using IMU and GPS sensors embedded in the smartphone, preprocess recorded signals, detects and analyze alpine skiing activities, and creates a skier profile based on generated patterns. Finally, it will score skiers through a data-driven model that compares each skier with expert users' behavior and their consistency in reproducing similar patterns at consecutive turns. Subsequently, recognized skill levels fused with other general information sources, e.g., demographic information, form an input to the recommendation system to get both ski product and coaching recommendations.

Expected and Achieved Results

The main goal of the Fischer4You II is to develop a smartphone application to be used by every recreational alpine skier with any level of skiing skill. This recognition pipeline consists of the following components: (i) a sensor fusion module used to create viable sensor ensembles opportunistically as a basis for motion analysis and activity recognition, (ii) performance analysis and activity recognition models to know what each skier does and how well he is performing each technique, (iii) a data-driven model based on expert users profile to be used as a reference for skill assessment (iv) a recommendation module, able to offer the most appropriate equipment to each user, and (v) a feedback trigger module, which will formulate a ski recommendation and potentially also areas of improvements, e.g., like recommending seldom driving techniques. This framework is developed as a distributed application, with a sensing and actuating component, e.g., an application on a smartphone, and a reasoning component, e.g., implemented as a machine learning server component for recognition. For demonstration purposes, the produced application on a smartphone along with the skill assessment framework and recommendation system provides state-of-the-art user assistance to form a standalone, visual support- and guidance system for a targeted personas study and a bigger audience of skiers in the long run.

Status / Progress

This project officially started in April 2021 and finished in March 2023. Through Fischer4You II, Pro²Future has collaborated with Fischer Sports as the partner and the Institute of Pervasive Computing at JKU Linz towards the development of recommendation systems based on skier driving skills. Several projects meeting provided a discussion platform for the overall approach. Additionally, several data recording sessions took place not only in winter but also in summer on glaciers. The preliminary data investigation was successful, and consortium members have completed the initial system models for the performance analysis, activity recognition, and skill assessment architectures. The models have been implemented and presented to the consortium partner during the WIP meeting and discussed in detail. Fischer4You II utilizes the created models and learning approaches to enhance product recommendation as planned in the project outline.
To this end, we have deployed a machine-learning software framework for activity recognition, skill assessment, and recommendation system. In addition, we have set up interfaces according to the models and guidelines set forth by the consortium. Moreover, we have published a paper on Alpine Skiing Activity Detection using Smartphone IMUs. The Fischer4You application is already operating within the Fischer Sport community. The mobile application runs on the skier's smartphone, records IMU and GPS signals, and sends them to the server for analysis. On the server side, the backend software preprocesses signals, detects alpine skiing activities, classifies them into techniques, evaluates them, and compares the skier with experts to score the skier. Based on the result, the model creates a skier profile to recommend appropriate equipment and coaching recommendations.

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AREA 1

MFP II 1.3.1 AI2Human
Using AI for occupational safety and accident prevention

Area 1 - Perception and Aware Systems

Project ID:	MFP II 1.3.1
Project Title:	AI2Human - Using AI for occupational safety and accident prevention
Project Lead:	Dr. Bernhard Anzengruber-Tanase Pro2Future GmbH
Duration:	42 Months, 01.10.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Safely Applying AI in Production Systems

WP 4: Company Projects I-III

WP 5: Demo Case

Company Partners

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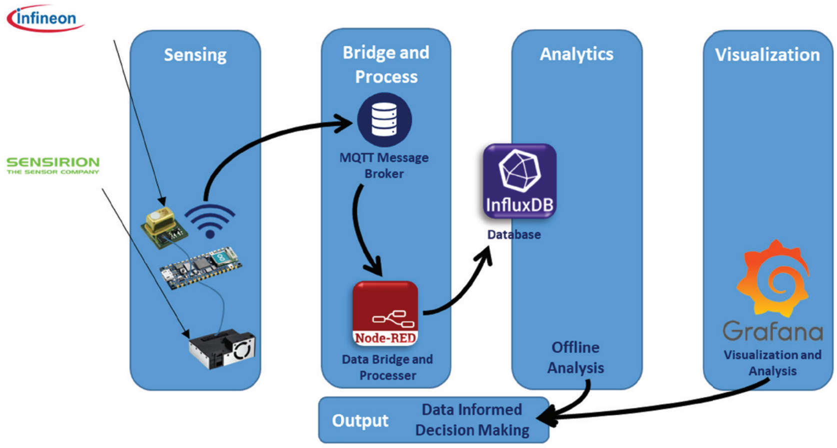
The technological revolution is rapidly transforming the work environment, subjecting workers to new challenges, such as collaborating with highly efficient and partially autonomous machines. Currently, computer-assisted techniques and AI systems (human-centered artificial intelligence) are utilized in production research and machine development to enhance productivity and flexibility. However, occupational safety is often overlooked or given low priority in these advancements. This project aims to leverage the emerging generation of AI-based production systems to promote occupational safety and accident prevention.
The project will focus on investigating the following areas: (i) hazard assessment and robustness analysis for safety-relevant AI systems, (ii) building trust and enabling transparent communication with safety-relevant AI systems, (iii) preemptive testing of safety-relevant AI systems, (iv) feedback and intervention measures, with a focus on Safety 2 approaches, and (v) analysis and implementation recommendations for EU regulations related to AI and machine safety, and safe AI in the workplace with or without machines.
The achievement of the project's objectives will be demonstrated through (i) sensor and algorithm-based hazard assessment, (ii) visualization of intrinsic (human-caused) and extrinsic (environmental) hazards, (iii) the development of an intervention and feedback system, and a (iv) final report on affiliated industrial projects, including an assessment of state-of-the-art practices, an evaluation of occupational safety and accident prevention, and a critical examination of how the elements of the EU AI Directive were implemented in to ensure safe AI.
In summary, this project seeks to harness the potential of AI-based production systems to prioritize and enhance occupational safety and accident prevention. By addressing key aspects like hazard assessment, transparency, preemptive testing, and feedback systems, the project aims to contribute to the realization of a safer work environment and promote compliance with relevant EU regulations related to AI and machine safety. Through the integration of human-centered artificial intelligence, this endeavor holds the potential to create a transformative impact on workplace safety and worker well-being in the face of evolving technological advancements.

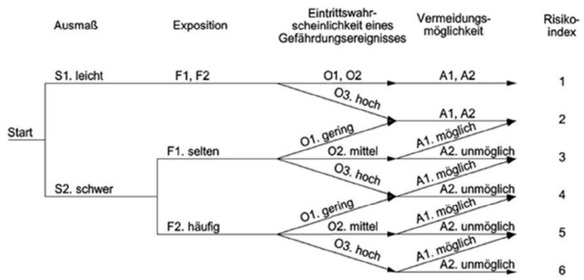
Goals
The project aims to implement the following goals:
(i) developing a comprehensive survey of the current research landscape concerning aspects of AI systems, such as robustness, transparency, trust, risk assessment, and evaluation. The focus is on understanding the methods and tools used in previous studies and analyzing existing norms while proposing new ones to enhance safety in AI systems,



Air quality

	category	System part	Danger zone	Description of danger	details
1.1	Fairness	Sensors, decision algorithm	Whole shopfloor	Threshold values and their effects on respiratory system can vary from person to person. If particular individuals or groups of individuals are not sufficiently represented in the data, system can use incorrect benchmarks	Individuals with underlying health conditions can suffer even when pollution values are low, warnings coming late

Mod	Risk estimation (before)					Risk mitigation measures	Risk estimation (after)					Sufficient ?
	S	F	O	A	RI		S	F	O	A	RI	
1.1	S 1	F 1	O 3	A 1	RI 2	Qualitative feedback (individual devices), define personal threshold values	S 1	F 1	O 1	A 1	RI 1	yes



(ii) develop a risk assessment of AI systems in affiliated industrial projects, beginning with identifying potential hazards and their locations, followed by the evaluation of risks and the implementation of measures to mitigate them. The importance of trust and transparency should be emphasized, focusing on identifying monitoring interfaces and communication methods to build user trust,
(iii) implementation of a demonstration case within a controlled factory environment. The demonstrator should showcase successful implementations of robustness, transparency, trust, risk assessment, and evaluation principles in AI systems.

Approach

The project addresses its goals using a threefold approach. By joining- and participating in meetings of (inter)national standardization committees, an understanding of issues and planned solutions for worker safety and AI systems is being created and decisions influenced. By cooperating with affiliated companies outside the project consortium, real world issues regarding AI systems and worker safety are identified and investigated. This process will involve performing risk analyses of potential application use cases for AI systems in the industrial domain. Finally, a prototype of a safe integration of an AI system into a production process will be developed and demonstrated within a safe industrial environment. To this end, a guideline of necessary steps for this integration process will be developed and published.

Expected and Achieved Results

The project will identify national- and EU norms regarding AI systems and worker safety and determine the state-of-the-art in developing and using sensor technology and algorithms for hazard assessment. It focuses on pinpointing weaknesses in existing norms and practices and proposing enhancements and test processes for safety-relevant AI systems. This effort will result in a final report that includes use case descriptions, risk assessments, and recommendations for measures, while ensuring compliance with AI regulations. Ultimately, this line of work will act as a resource for safely applying AI in production environments to be used by industries and related stakeholders.
Further, the project will yield risk assessments of three affiliated industrial projects, to be used as input for the prototype development of a worker safety system within a safe industrial environment. The system will be able to monitor safety relevant parameters within the environment, while fulfilling predetermined requirements in case of safety-critical applications.

At this point, much of the target project work has been achieved. A report on the safe integration of AI system into production processes was developed and distributed. A first risk assessment of an affiliated industrial project was developed and served as basis for the development of a prototype system that aims to demonstrate how safety-aware AI applications could be designed, deployed and function. The prototype will be deployed for demonstration- and data collection purposes in a safe industrial environment within the year. The system consists of a selection of appropriate sensors and feedback mechanisms to enhance safety measures.

Status / Progress

The project work currently centers around the initial deployment of the safety-aware AI prototype within the LIT factory – an industrial environment created for scientific study. The developed system consists of multiple small, autonomous sensor units, that collect environmental parameters such as air quality, and warn workers in case of danger. The development of the AI system is informed by a recently completed report on necessary steps and guidelines to integrate AI applications into production environments developed within work package 2. The individual parts of the prototype are currently operating in a stand-alone fashion but could be integrated into production machines in case of non-safety critical applications. In case the system detects a potentially hazardous situation, a warning will be communicated to the surrounding, affected workers in the spirit of a Safety II system, meaning that a warning is communicated proactively once a hazard is detected. The central focus is on creating a secure demo AI system that meets safety requirements. The implementation will be followed by an in-depth analysis and safety assessments to ensure compliance with safety standards and regulations. An analysis of the safety aspects of affiliated, potential company projects will be conducted subsequently.

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AREA 2

DP 2.1-1 APS.net

Adaptive Production Systems

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	DP 2.1-1
Project Title:	Adaptive Production Systems
Project Lead:	Dr. Christoph Mayr-Dorn Pro2Future GmbH
Duration:	39 Months, 01.01.2018 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 2.7: Interoperability and Consistency

WP 2.10: Showcase Integration

WP 2.11: Project Management

WP 2.12: Strategic Research

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PROFACTOR, Flexible Production Systems
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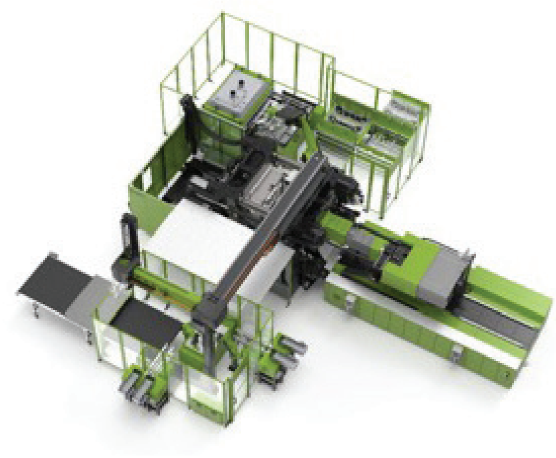
This SFP investigates models, architectures, techniques, and algorithms for increasing the flexibility and adaptability of industrial production systems. Software, and specifically, software architecture plays a central role in achieving these goals. The general capabilities of a production plant depend on its physical layout. Yet, which capabilities are invoked, in which order and under which conditions is controlled mostly by software or human operators. Thus, fast and cheap reconfiguration can only happen through software designed to allow for adaptability and flexibility. In these systems, physical aspects such as material flow, manipulation of physical objects, and physical layout of machines and humans, play a major role.
In this SFP, we borrow concepts, approaches, and ideas from software Architecture to guide the design of Cyber-Physical Production Systems (CPPS). Adaptability in CPPS comes in two main categories: **adaptation of the software** (i.e., machine configuration, process configuration etc.) and **adaptation of the physical layout** (i.e., relocating machine, mobile robots, autonomous guided vehicles). Both categories imply software adaptability.
Traditionally, with little or no product change, engineers custom tailor the software for the machines/robots/production cells specifically for a particular product. With increasing demand for adaptability, two orthogonal adaptation dimensions emerge. On the one hand, we distinguish between the **levels of adaptation**, and on the other hand, we differentiate according to the **locality of adaptation**. The former describes adaptation of product-specific vs machine-specific code, while the latter separates adaptation within a machine, invisible to the outside (local), from adaptations affecting multiple machines (distributed).

APS.net investigates models for achieving interoperability on multiple levels. We aim to achieve this by ensuring
such a model will allow **hierarchical/self-similar modeling** of shop floors down to individual software components within a machine. From the point of view of a single component, interoperability can then occur on the same level as well as with components on lower levels and higher levels, while exposing capabilities, allowing discovery and monitoring regardless of hierarchy.
Such a model allows to define blue prints for (i) which **capabilities** are needed in a production processes, (ii) describe **collaboration** among production cells, machines, robots – hence supporting the cognitive reasoning on a component's surroundings and its role within, (iii) allow reasoning on optimally **distribute control and dataflow**, for (iv) ultimately achieve distributed process execution.

Goals

The overall applied research-centric goal is to **investigate a new middleware** for the shop floor that enables semantic interoperability and flexible adaptation of machines and shop floor configuration. In particular, the focus is on the question of how machines, robots, and increasing demand for adaptability, two orthogonal adaptation dimensions emerge. On the one hand, we distinguish between the levels of adaptation, and on the other hand, we differentiate according to the locality of adaptation. The former describes adaptation technical interoperability through **interface standards**, (ii) achieving semantic interoperability through the use of **data standards**, (iii) support for programmatic interoperability through **infrastructure & central services**, and (iv) support of engineering, development, deployment, operations of modular and adaptive systems. The ultimate goal is having a framework that allows the discovery of production entities, composition of their capabilities, distribution for decentralized execution, monitoring of that execution, and continuous adaptation thereof.



Approach

The approach is based on **"Design Thinking". Stage1 Empathize:** Interviews and workshops with company partners showed the current limits of flexibility of machines and processes at the shop floor. **Stage 2 Definition**: Based on this, specific objectives of flexibilisati on were defined and use cases were developed in which target attainment was to be measured (e.g. relocation of a production process from one production cell to a non-identical one). **Stage 3 Ideate:** Based on a study of the state of the art and research, several architectural solutions have been identified. **Stage 4 Prototype:** Simple/ advanced prototypes focused on the basics and iterative enhanced prototypes allow fast implementation of ideas. A first simulation of flexible machines and OPC-UA was realised. **Stage 5 test:** Scientists and engineers at the industrial partner evaluate the prototype and thereby generate feedback for the previous four stages. The whole process is highly iterative and non-linear; feedback from each stage to previous ones is not only possible but also explicitly desired.

Expected and Achieved Results

This project has two main expected results: **(i) a framework for modeling capability-based production processes**, **and (ii) a framework for distributed/adaptive execution of production processes**. Along the lines of the former expected result, an extensible meta-model provides the basis for modeling actors (humans, machines, robots), processes (work steps including control and data fl ow), parts (the physically input and output of work steps), and resources (such as tools). A key aspect are "**capabilities**" which describe abilities that humans, robots, machines provide **without having a tight coupling** to the providing actor. A first version of such a meta-model is complete. This model serves as the basis for an algorithm to semi-automati cally **match discovered capabilities** (from machines etc.) **to abstract processes** (i.e., based on capabilities only).

Model and algorithm are available in an editor. The second main expected results, where preliminary aspects are complete, is an algorithm for **analysing the control and data flow among process steps** to allow optimally allocating not only capabilities but also control logic to actors in a distributed fashion, thus enabling decentralized process execution. The distribution procedure involves directly linking up actors that need close collaboration such as machine-robot synchronized actions, dynamically generating and deploying code, as well as dynamically interpreting and executing subprocesses on machines and robots. Production step distribution and execution is only one aspect. Scheduling multiple process across the same machine is an equally relevant, orthogonal challenge. The expected result is creating a **scheduling algorithm** (based on prior project results) that **considers failing transport mechanisms** (e.g., AGVs) as well as machine failure likelihood to produce resilient plans. Such **resilient plans** may be less optimal in terms of throughput, but require less costly, less impactful, changes in the event of failures, which is especially relevant during ghost shifts.

Status / Progress

APS.net officially started in January 2018. The industrial partners in this project is ENGEL Austria, a manufacturer of high precision, high quality, and high variant injection moulding machines used in domains such as automotive, teletronics, medical, packaging, and many others. The scientific partners include the Institute for Software Systems Engineering (ISSE) at the Johannes Kepler University Linz (JKU), and the Group for Flexible Production Systems at PROFACTOR, Steyr. Given the highly iterative approach based on Design Thinking, regular on-site meetings at ENGEL with weekly conference calls are necessary and welcome to align industry needs and research approach.
The initial task was to collect the technical, organisational and non-functional requirements of the industrial partner and the state of the art. First investigations showed that existing approaches and models insufficiently covered the distributed and modular nature of Cyber Physical Production Systems. The core of a novel model was developed within the strategic project in Area 2, with extensions for shop floor and machine/robot interactions developed within APS.net. An accompanying process editor allows to design abstract processes, discovery of machine capabilities from the shop floor and allocate abstract processes to a discovered setup of machines.

Together with the ISSE a demonstrator, the „Factory in a box" was developed, consisting of independent plotting stations and conveyor belts. The different systems were structured in a modular way, inspired by the Actor Model of Computation by Hewitt. This leads to a reconfigurable production plant that allows to add, remove and reposition systems without need of reprogramming the individual systems. Each system hosts ist own controller, created in different programming languages, showcasing distributed control and interoperability.

Current work focuses on support and guidance for workers to track error sources in such modular production cells.
Part of this project focused on the joint demonstration with the Austrian Center for Digital Production (CDP) in Vienna. To this end, this project jointly established a demonstrator that exemplifies how, on the one hand, robots, AGVs, and imaging systems can be integrated for ghost shift production, and, on the other hand, how to achieve resilient, adaptive scheduling of jobs.

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AREA 2

MFP 2.5-1 A2PS

Adaptive Assembly Process System

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	MFP 2.5-1
Project Title:	Engineering Collaborative Machines
Project Lead:	Christoph Mayr-Dorn Pro2Future GmbH
Duration:	19 Months, 01.04.2018 - 30.10.2019
Strategic Volume:	14.5 %

Work Packages

WP 0: Project Management

WP 1: Interoperable and Adaptive Process-oriented Systems

WP 2: Digitalisation and Design Support for Assembly Systems

WP 3: Security & Safety

WP 4: System Evaluation

WP 5: Strategic Research

Company Partners

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This MFP investigates models, architectures, techniques, and algorithms for increasing the flexibility and adaptability of cyber-physical production systems, specifically here adaptive assembly process systems (A2PS).
A primary concern in assembly production systems is increasing the flexibility and adaptability as companies move towards producing highly customizable products in small lot sizes at the costs of mass production. A2PS exhibits **tight dependencies** between work steps, their duration, input, required machines/tools/skills, product variants, product mix, and production cells/stations. Any **disturbance** such as missing work input, delays, or degraded resources will **cascade and grow**, potentially bringing production to a standstill when left unmitigated. Hence self-adaptation is a key concept to managing such complexity.

The desired **flexibility often limits the applicability for full automation**. On the one hand cognitive capabilities required for adaptation to unforeseen situations can (so far) only be achieved by human operators. On the other hand, programming and configuring all the necessary automation steps for each and every product variant (e.g., gripping positions and movement for robots) takes an excessive amount of time and needs to be updated often. From an economic point of view, human workers are more efficient for such tasks. Self-adaptation approaches in A2PS have to explicitly account for **humans participating in the adaptation loop**: not only as part of the adaptation control logic but also as the entities subject to adaptation.
In assembly lines, workers are learning and optimizing their activities from experience or from their peers. Regularly, mitigation actions become necessary to overcome micro-deviations locally. Experienced workers help out novices (e.g. an expert jumps in where ever s/he notices delays about to happen, workers reorder their tasks while they wait for a late input part to arrive). Such **local optimizations** by human workers are a natural way of **self-adaptation at the lowest, local level**. Such behavior prevents basic deviations to grow but cannot guarantee that deviations won’t cascade.

At the same time, these deviations make monitoring more difficult, as even with perfect observations available, these would not match the expected behavior. The **challenge**, hence, becomes obtaining an **accurate picture of the current production** that is robust to the above micro-deviations while remaining able to detect ‘’serious`` deviations early. Specifically, in this project we address the challenge of obtaining a reliable view on the assembly progress through modeling of prescribed assembly processes, monitoring **heuristics** that are **robust to incomplete observations**, followed by deviation detection algorithms that highlight impact of deviations.

Goals

The overall applied research-centric goal is investigating a novel approach for supporting of networks and flexible shop floors with dedicated focus on assembly processes. Concrete goals focus on **(i) modeling of human-intensive assembly processes** and **(ii) monitoring of human-intensive assembly processes**. The former aspires to obtain a model of the organizational units carrying out the assembly work (i.e., assembly stations and human workers) flexibly integrated with the assembly process steps, assembly part structures, and required tools. The requirement is to **go beyond rigid, control-flow driven processes** as these limit the workers' flexibility to react to unforeseen circumstances. At the same time the goal is to allow constraints among work tasks to allow reasoning upon the assembly progress in the presence of incomplete and deviating observations. A key element in modeling and monitoring assembly work is the **high amount of variability** within the assembly products which needs dedicated modelling support. The later concrete goal addresses the need to establish an accurate view of the assembly line without complete, fine-grained observations.

The industry partner specific goal for Wacker Neuson and Fabasoft are **obtaining a live/continuous picture of the assembly progress**, respectively show case how assembly processes, product orders, and assembly progress can be managed in the cloud.

Approach

The approach is based on **"Design Thinking". Stage1 Empathize:** Interviews and workshops with company partners showed the current complexity of monitoring progress on the assembly floor and involved intra-organizational logistics. **Stage 2 Definition**: Based on this, specific objectives of monitoring were defined and use cases were developed in which target attainment was to be measured (e.g., detecting deviations and notifying logistics department). **Stage 3 Ideate:** Based on a study of the state of the art and research, several architectural solutions have been identified. **Stage 4 Prototype:** Simple / advanced prototypes focused on the basics and iterative enhanced prototypes allow fast implementation of ideas. A first simulation of assembly processes was realized. **Stage 5 test:** Scientists and engineers at the industrial partner evaluate the prototype and thereby generate feedback for the previous 4 stages. The whole process is highly iterative and non-linear, feedback from each stage to previous ones is not only possible but explicitly desired.

Expected and Achieved Results

This project has two main expected results: **(i) a framework for assembly process modeling**, and **(ii) a framework for assembly line monitoring and deviation detection**. Along the lines of the former expected result, an **extensible meta-model** provides the basis for modeling actors (humans, stations, assembly line layout), processes (work steps and dependencies among steps), parts (the physically input of an assembly step), and resources (such as tools). A key aspect is modeling dependencies of assembly steps that are specific to a particular product feature. A first model version including cloud-based editor has been achieved. The second main expected result consists of an assembly-floor sensor integration with a cloud-based assembly tracking tool, heuristics that are able to **infer from incomplete and indirect (privacy-respecting) data** to the overall assembly progress (within specified boundaries), a **deviation detection mechanism**, and algorithm for inferring the **impact of deviations** in one part of the assembly process onto upcoming assembly steps as well as on subsequent process instances. A set of heuristics have been implemented that apply constraints among work steps and stations to infer additional progress information. Detecting deviations in a timely manner is of uttermost importance. One potential application of the deviation analysis and impact estimation is notifying logistic about (upcoming) changes such as delays or steps reordering. This allows to deliver **the right parts at the right time to the right station even in the presence of assembly deviations**. The deviation analysis can also serve as input for supporting the redesign of the assembly line by highlighting which products in their particular feature configuration and assembly production sequence were prone to deviations, thus identifying loci of improvement, ultimately making the production sequence more **resilient to deviations**. To attain this goal, a weekly/daily assembly dashboard has been implemented in the Fabasoft cloud updating the progress of stations and processes in a near-real-time manner and summarizing the detected deviations in different categories.

Status / Progress

A2PS officially started in April 2018. The industrial partners in this project are Wacker Neuson, a manufacturer of high-customizable construction machines such as digger, dumpers, excavators, and compaction devices, and Fabasoft, a provider of cloud services for the digital control of documents, electronic assets, processes and record management. The scientific partners include the Institute for Software Systems Engineering at the Johannes Kepler University Linz (JKU), and the Group for Flexible Production Systems at PROFACTOR, Steyr. Given the highly iterative approach based on Design Thinking, regular on-site meetings at Wacker Neuson and Fabasoft with two-weekly conference calls are necessary and welcome to align industry needs and research approach.

We started by defining an Assembly Process Model (based on the core model devised as part of strategic research in Area 2) that allows to link stations and worker (roles) to process steps, parts, and tools. Specific care was given to the ability to represent within an assembly process description all possible variants of a particular product (i.e., the 150% bill of process). Constraints amongst steps are also modeled representing the assembly work dependencies. We show-cased how the real assembly processes at Wacker Neuson can be modeled using APM, and highlighted details and relations not yet captured by the existing IT infrastructure. We further prototyped the management and visualization of process specifications and process instances in the document-centric Fabasoft cloud.

The next steps included capturing observations on the assembly floor. Manual observations of several product instances with varying features provided timestamps for part picking and work step execution activities as a baseline dataset to test monitoring heuristics against as well as to obtain insights which and how many observations are required for a particular level of progress accuracy, respectively, timeliness. This analysis also informs the decisions where to place sensors and what their sensing frequency needs to be. A set of monitoring heuristics were defined for the tracking of assembly steps progress. We then applied these heuristics to obtain an accurate process view of the assembly floor. Subsequently, comparing the actual work status with the prescribed one allowed us to determine the expected impact such as how delays may cascade down several stations, or what mitigation actions can be set to mitigate the impact, respectively get the assembly work back in 'tact'. Different types of deviations are detectable with our approach including (i) steps executed in longer time than expected, (ii) stations exceeding the allocated tact time and (iii) altered assembly sequences. The approach requires merely standard sensory infrastructure on the assembly floor such as weight-sensitive part boxes or pick-by-light systems. Shopfloor progress information and deviation analysis is provided back in near real-time via a cloud-based dashboard solution hosted by Fabasoft.

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AREA 2

MFP 2.5-2 LineTACT

Cognitive Line Tacting Support

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	MFP 2.5-2
Project Title:	Cognitive Line Tacting Support
Project Lead:	Dr. Christoph Mayr-Dorn Pro2Future GmbH
Duration:	24 Months, 01.03.2020 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 0: Projekt Management
WP 1: Takterstellungsprozess - Kontextanalyse
WP 2: Analyse bestehender Modelle, Ansätze & Verarbeitungsalgor.
WP 3: Alg. & Services für Abhängigkeitserstellung, Ableitung, und Verfeinerung
WP 4: Algorithmen und Services für Line Tacting
WP 5: Prototypen Architektur und Implementierung (Klick-dummy)
WP 6: Prototype Evaluation
WP 7: Strategic Research Dissemination

Company Partners

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Academic Partners

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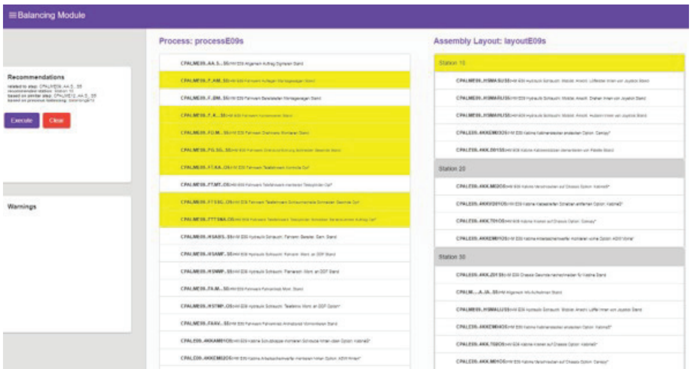
This MFP investigates models, architectures, techniques, and algorithms for reducing the time to rebalance a manual assembly line. A primary concern in assembly production systems is increasing the flexibility and adaptability as companies move towards producing highly customizable products in small lot sizes at the costs of mass production. Manual assembly processes exhibit **tight dependencies** between work steps, their duration, input, required machines/tools/ skills, product variants, product mix, and production cells/stations.
Optimally balancing the assembly steps across the available assembly stations requires a **multi-objective optimization**: ensuring that all workers have equally much to do, don't sit idle within a assembly tact, but also are not constantly stressed to meet the tact time, have all parts nearby to avoid non-productive activities such as fetching parts from their (temporary) storage location, achieving this for every station (so that all station consist of roughly equally long work steps, a necessity for a fixed tact), and achieve this over all products on a line as well as all product variants. The result of balancing is a set of assembly processes, one for each product that describes exactly which step is done at which station by which worker using which parts.

One aspect in generating such a distribution of tasks is the **dependencies amongst task** (some task might need another task done earlier such as mounting the tracks requires the prior mounting of the wheels). Hence obtaining a usable assembly process upon introducing a new product or new variant **requires several rounds of design and feedback** from the line before all errors (e.g., impossible task sequences, suboptimal task sequences) are removed. Most often the knowledge to do this is available only as **tacit knowledge among the assembly workers**, station leaders, and line leaders. **Explicitly modelling** all dependencies is not only a **very costly** (because time consuming) task but also **quickly outdated** as smaller and larger adjustments are made in the product design or line layout. Constantly checking and improving the dependencies quickly becomes infeasible.

Instead, this project aims at **reusing data from past** processes, line layout, and parts to find similar situations, extract dependencies from this and produce a baseline line balance. This **reduces the effort required for engineers** to come up with a first balance while having the advantage that the approach and algorithm learns over time from an increasing data set and also encourages thus the exchange of tacit knowledge across production sites. **The challenge** is to derive at suitable similarity algorithms that can distinguish between generally valid dependencies and variant or product specific peculiarities that might not be found in past data. The approach thus has to provide **accurate results even in the presence of incomplete and inconsistent data** (e.g., dependencies in one product are not found in another, and vice versa).



Goals

The overall project goal is - in the sense of applied research – the investigation of a new approach to support the planning of the timing of an assembly line. The primary approach **to reduce the effort for deriving a configuration** is to automate it as much as possible, to generate it at least partially automatically, and thus to have provided a usable basis for manual refinement and expansion.

The specific goal is to **continuously improve the priority graph** (the graph that defines assembly dependencies) without aiming for a perfect graph. Creating a perfect graph is too lengthy and time-consuming and potentially changes again and again. Instead, it should be possible to continuously improve it and to **model how precise / inaccurate certain dependencies** are, hence introducing the concept of the partial fuzzy priority graph.

Approach

The approach is based on **"Design Thinking". Stage1 Empathize:** Interviews and workshops with company partners showed the current complexity of modeling the assembly process and the balancing procedure. **Stage 2 Definition**: Based on this, specific objectives of reducing the time for balancing were defined and use cases were developed in which target attainment was to be measured (e.g., amount of automatically, correctly allocated steps to stations). **Stage 3 Ideate:** Based on a study of the state of the art and research, several architectural solutions and allocation strategies have been identified. **Stage 4 Prototype:** Simple / advanced prototypes focused on the basics and iterative enhanced prototypes allow fast implementation of ideas. A first step similarity measurement algorithm was implemented. **Stage 5 test:** Scientists and engineers at the industrial partner will evaluate the prototype and thereby generate feedback for the previous 4 stages. The whole process is highly iterative and non-linear, feedback from each stage to previous ones is not only possible but explicitly desired.

Expected and Achieved Results

This project has two main expected results: (i) a set of similarity metrics and step-to-station allocation algorithms building on top as well as (ii) a prototype integrating these metrics and algorithms to evaluate the performance of the algorithms and, more importantly, enable the reduction of the time needed for line balancing.

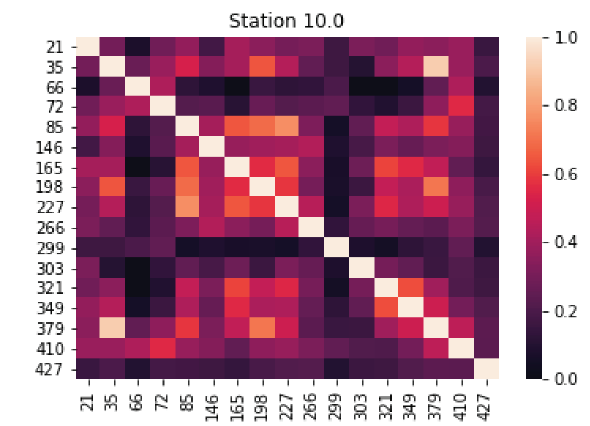
The prototype will be fed with previous line balancing configurations, line layout, list of current steps to be balanced (i.e., allocated across the stations), and each step's involved part (where applicable). The line balancing engineer then has the option to request **step to station allocations** at various levels of accuracy, **obtain rationale why a particular allocation** has occurred, may refine the allocation, and while doing so, will **receive warnings if the new allocation appears to violate** some implicitly learned step dependency. The engineer can always choose to ignore the warnings.

The step similarity metrics help to identify where previously unseen steps (e.g., new steps of a new product) may best be allocated to and what other steps need to come before and may follow thereafter.

Status / Progress

This project officially started in March 2020. Alongside with our partners Wacker Neuson and DMTM, Pro²Future is working towards the cognitive support for assembly line balancing based on step similarity metrics and prior balancing data. We started investigating different similarity metrics to determine the most similar assembly activity based on previous balancing solutions. Then a prototype was developed integrating different functionalities for assembly balancing support. Previous balancing solutions, assembly layouts and the assembly process to be balanced serve as input for the prototype. An upfront automatic balancing will automatically allocate the maximum number of assembly steps to stations based on similarity measures and prior balancing solutions available. Further step-by-step assistance is also possible. The user can request station recommendations or related steps recommendations for individual assembly steps. Alerts are displayed if an allocation violates the drawn assembly constraints. These alerts can then be acknowledged or dismissed. Balancing experts at our industry partner Wacker Neuson evaluated the functionalities of the prototype useful for the balancing process.

The manual assembly processes involve common categories of activities that are repeated in multiple steps and stations. These activities are not very informative of the steps and can affect the similarity measures. We therefore accorded different weights to assembly activities based on their usage within a step or a station. Activities that are not common and are detected in a specific type of steps are very informative and therefore accorded a higher weight value. This helps identify more similar steps based on the core activities of each step. We are further investigating ways to make the balancing process more efficient as a large number of similarity calculations need to be executed depending on the number of steps and the number of available previous balancing solutions. We do not need to compute the similarity of every pair of steps. We only need to locate the most similar step amongst those that are more likely to be similar. In the long term, additional resources (such as tools or parts) can be used as inputs for the similarity measures.



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AREA 2

StratP 2.4-1 HOP-ON

Cognitive Shopfloor Monitoring

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	StratP 2.4-1
Project Title:	Adaptability and Interoperability of Complex Adaptive Systems
Project Lead:	Dr. Christoph Mayr-Dorn Pro2Future GmbH
Duration:	12 Months, 01.04.2020 - 31.03.2021
Strategic Volume:	100 %

Work Packages

WP 0: Projektmanagement

WP 1: Monitoring - Kontextanalyse

WP 2: Analyse von bestehenden Modellen, Ansätzen und Algorithmen

WP 3: Infrastruktur und Services für Kommunikationsmonitoring

WP 4: Prototype Implementation and Evaluation

WP 5: Research Dissemination

Academic Partners

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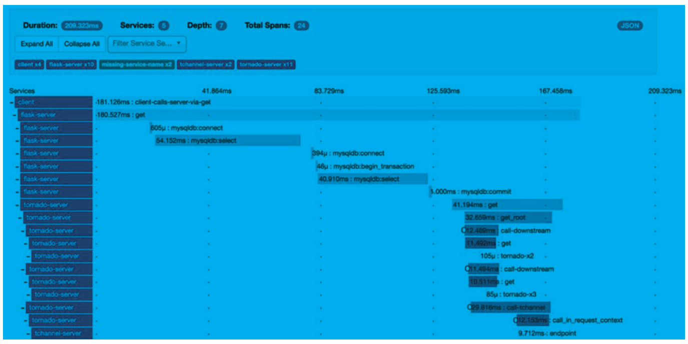
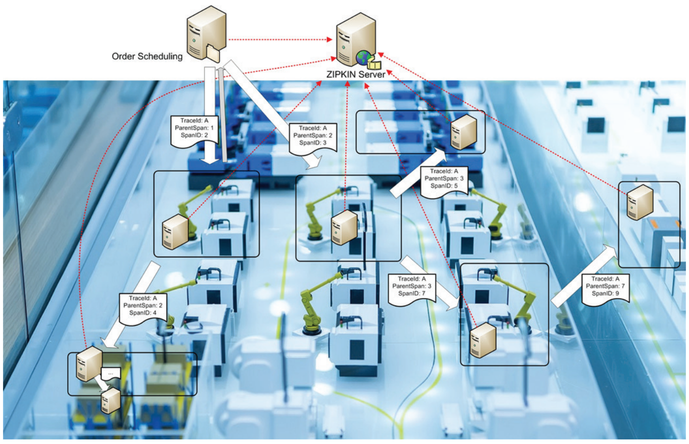
Production Systems are systems-of-systems and very specific and unique systems. Here Production Systems address machines composed of mechatronic systems and also shop floors that are composed out of machines. In order to control, adapt, and achieve interoperability among machines, a common communication infrastructure is envisioned that targets the peculiarities of shop-floors and robotics. Dynamics in the production environments require the system elements (machines, sensors, etc) to be adapted to changing needs. However, this flexibility of adapting a system based on changing behaviour and / or structure of systems that form the system under consideration comes not for free, but needs to be designed in order to be available and hence needs a middleware that support such adaptivity.

The basis of any such adaptativity is awareness what is going on the shopfloor and how interactions among shopfloor participants can be traced back to particular orders, respectively, products.

Goals

The overall project goal is - in the sense of applied strategic research - to enable a new approach to support the monitoring of work processes, orders, implementation on the shop floor / assembly floor between machines, robots, and humans. Approaches from applied software engineering to systems of systems monitoring are to be researched. These approaches are primarily evaluated in laboratory environments, but it is also possible / planned to prototype them with industrial partners (up to Technology Readiness Level 4). This exploration is carried out using software prototypes.





Approach

The project’s approach is based on "Design Thinking".

- Stage1 Empathize: Insights into the problems of existing Pro2Future partners and other industrial companies in the context of existing collaboration describe the current challenges and processes in monitoring system-of-systems in the industrial sector. These insights help to make realistic assumptions in the algorithms and prototypes.
- Stage 2 Definition: Building on this, the goals of system-of-system monitoring are adjusted based on new knowledge (stage 1) and use cases are refined, which allow the achievement of the goals of the project to be measured more precisely. Feedback from stage 5 (test) enables iterative adjustments and objectives of the ideal phase (e.g., which model / information sources, i.e. algorithms, were promising, which were not and in which direction the next idea (state 3) and prototype phase (stage 4) should go.
- Stage 3 Ideate: Based on the study of the state of the art and research, existing fuzzy information description models and information merging algorithms are identified for their applicability, expandability, modifiability or their shortcomings.
- Stage 4 Prototype: Simple / iterative improved prototypes focused on the basic concepts allow quick implementation of the ideas. The prototype implementation is based on the prevailing conditions on the shop floors of the industrial partners. Prototypes range from demonstration of individual algorithms, to scenario walkthroughs on paper, to manual simulation of production situations, and use in laboratory environments.
- Stage 5 Test: Scientists (and indirectly reviewers as part of submission reviews) evaluate the respective prototype and thereby generate feedback for the previous 4 stages.

The chosen technical approach basically consists of the following components:

- Enrich communication channels / messages / events / calls with context information: this is planned to be based on X-B3 http headers and Zipkin tracing infrastructure, whereby the header formats are adapted to the respective transport / communication technologies: ie OPC UA header, MQTT message meta information, Akka Actor Message meta information, etc.
- Pass through context information such as order id, iteration ids, batch ids, process step ids, etc. through the individual systems: this means that any reaction to signals (messages, calls, parameter read / writes) can be assigned to a very specific order and can be precisely tracked in what condition and, consequently, why the individual shop floor participants reacted to this order.

Expected and Achieved Results

This project is of high strategic relevance: Accurate monitoring what goes on on the shopfloor and enabling all shopfloor participant to better perceive their usage context is fundamental to adaptation at across all levels. Hence this project investigated following key aspects:

- Tracking processes / orders / activities through a complex production environment (system-of-system) requires the observation of control / data flow, correlation of events / messages across system boundaries and the merging of model information about the individual systems. Due to the different processing speeds (near-realtime machine control, slower human workers) and participants (machine, robot, humans, logistics), this is a significant problem that has not yet been adequately solved.
- A new approach is control / data flow, the correlation of events / messages is not tracked top-down (e.g. in MES) but bottom-up, directly via the effective individual communications, control and data connections.
- As a side effect, the participants were able to experience their work context directly instead of being provided incompletely and with a delay from “above” (i.e., the MES).

Concretely, the expected output of this project are prototypes and accompanying methodology how to incorporate cross shop floor tracing information in communication channels and how to set correlation and sub interactions appropriately.

Status / Progress

This project started 1 April 2020, thus only a few results are available. The first steps focused on analyzing the extensibility and entry point of OPC UA frameworks for integration of tracing headers. In this respect, we have identified ZIPKIN X-B3 headers (as applied in web-based systems) as a suitable mechanism to convey correlation information between machines. We have then identified in the Eclipse Milo Framework the classes, methods, and datastructure in the OPC UA client and server stack where such information can be passed in and out.

The figure below displays the conceptual flow of trace correlation information among shopfloor participants. The trace information is passed on between every participant, even between subsystem within a cell or even a single machine. Upon receiving a reply, respectively completion feedback in the scope of Machine-2-Machine communication, participants send trace information such as start and end to the Zipkin server.

Future steps focus now on the instrumentation of running OPC UA clients and servers in an industrial setting, using the Factory in a Box demonstrator (a collaboration with JKU) as a first proof-of-concept implementation playgroud. This first proof-of-concept will show how trace identifies can be transmitted across OPCUA enabled machines and how the captured trace information can be made available for shopfloor monitoring. The figure below (taken from a web based system) describes how such a monitoring interface will look like. Instead of web services and server instances, the various entries will represent machines and their subcomponents (including logistics and robotic equipment) that are responsible for processing a shopfloor order. One can thus quickly obtain insights into which processing steps where able to be completed in parallel, which steps have taken long, where has been time spent for synchonization or waiting for resources to become available.

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AREA 2

MFP II 2.1 CEPS
Cognitive Engineering Process Support

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	MFP II 2.1
Project Title:	CEPS - Cognitive Engineering Process Support
Project Lead:	DI Michael Mayrhofer Pro2Future GmbH
Duration:	36 Months, 01.01.2022 - 31.12.2024
Strategic Volume:	18 %

Work Packages

WP 0: Project Management
WP 1: Dissemination and Exploitation
WP 2: Engineering Process – Context Analysis
WP 3: Process Support Architecture and Connectors
WP 4: Process and Constraint Modelling Support
WP 5: Runtime Process and Constraint Support
WP 6: Prototype Evaluation

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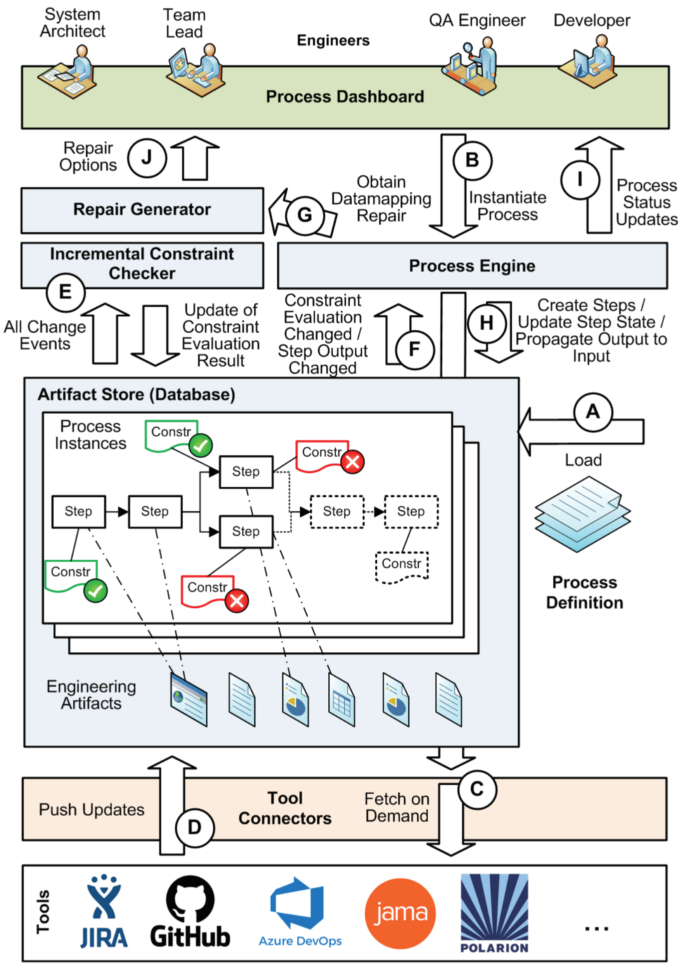
The automotive industry is developing complex, interdisciplinary systems, containing a multitude of software and hardware components that have to work together as a unified product. In order to achieve this, multiple teams with different specialty backgrounds need to develop each of these components separately, while also collaborating tightly to assure the flawless and safe integration of these pieces into a whole. To ensure this collaboration and the thoroughness and safety of the development, each team must follow a process, which specifies the steps to be performed.
However, in the context of engineering processes and interdisciplinary products, the process contains innumerable use cases and decision points. All these use cases have to be captured by the process model, which is then to be followed by the engineers. As a result, the level of complexity of this process model can easily become overwhelming, leading to process deviations, or frustration for the engineers.

To address this complexity, we are proposing an approach and tool support that supports the specification of such complex process models. Also, we are assisting the engineers in following this process, through customized guidance and suggestions that help simplify the task of following the correct use case of the process. Additionally, we are developing the basis for a new type of process constraints, called temporal process constraints. These are rules applied on a process step, which capture and check that the order of the operations performed on the system is correct. These rules allow the process modelers to more accurately describe the process to be followed and the relationships between the operations, while also improving the guidance given to the engineers.

At the current state of the project, we have developed some prototypical implementations of the approach suggested and the temporal constraints, as well as a tool connector linking the approach to the production environment. We have also conducted a user study and a series of interviews to capture the main open challenges and feedback for our approach. In the next steps, we are improving the prototypes, as well as planning additional user studies and tool integrations.

Goals
As previously stated, the main goal of this project is to support the engineering process through tool integration and guidance. In this regard, the approach targets the two most important components of the engineering process.

On the one hand, we are aiming at supporting the modelling of engineering processes through tool integration and constraint specification. In this regard, we are researching the modelling and use of temporally-aware constraints, which react to each engineer's progress through the process at runtime. As such, our goal is to enable process modelers in defining complex and collaborative processes.



On the other hand, our approach also targets the engineers working through these complex processes. With the ever-increasing number of use cases and corner situations, the tool support and approach designed assist the engineers in navigating the process and finding which tasks are pending at each step. Additionally, in contrast with other existing approaches, we are allowing process deviations where they occur, and assist the engineers with repair suggestions to get back on track.

Therefore, the aim of our constraints is to balance the need for ordered tasks, resulted from safety constraints and standards, with the flexibility and creativity that is intrinsic to engineering processes.

Approach

In order to achieve this goal, we are developing a process engine which can observe at runtime the artifacts created and manipulated through the process. Firstly, tool support solutions will enable the process engine to view these artifacts and the changes that occur. Then, the constraint checker integrated into the process engine evaluates whether the artifacts and their links fulfill the specified process constraints for the current process step. Finally, based on this evaluation, the process engine determines the required repairs, when a process deviation is detected, or the next step to be performed in the process. The result of this determination is then transmitted back to the engineers in the form of guidance.

Expected and Achieved Results

With the aim of the project being the support of engineers and process modelers in working with and through the processes and their constraints, our first concern is the integration of tool support into their current working environment. Thus, they will not have to change the toolset they already have experience using. Instead, our approach will enhance their use of these tools with in-tool guidance and suggestions. Also, the process modeling task was extended to capture the traceability links between related artifacts in different components, and a more accurate and fine-grained view of the status of development for each such artifact and component.

Additionally, we are aiming to provide a proof-of-concept that will cover the approach proposed, as well as a proof-of-concept solution to the problem of integration. Through these, we can evaluate our chosen approach in user studies and experiments, and iteratively improve the process modelling, as well as the guidance and repair suggestions visible to the engineers.

Finally, in terms of temporal constraints, we are developing a novel solution that addresses the unique features of such constraints in the context of engineering processes. Namely, these constraints need to support a balance of fulfilling the required standards, as well as allowing and supporting the engineers in case of process deviations. Additionally, in order to provide adequate and relevant guidance, we are investigating how violations of these constraints can be repaired.

Status / Progress

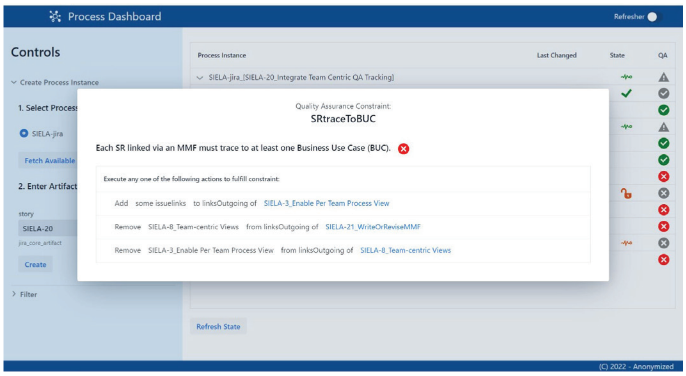
Currently, all the expected results are in development, with iterative proofs of concept being evaluated and improved. We are also in constant communication with our industry partners to ensure the developed approach matches the open challenges in their industry and can be applied in their specific context.

For the integration of our approach with the existing tool environment, we have started by developing a plug-in connection into Azure DevOps. Through this, the process engine prototype could access the information of the artifacts stored in this tool, including their inter-connections and changes. We then expanded the integration to STAGES, where the process constraints can be defined and checked. We also expanded the traceability and status information captured in STAGES. This information can be used in the specification, checking and repair suggestions for process constraints.

The temporal constraints are also in progress, with the first working prototype available. Through this first iteration, the temporal aspect is captured through special operators and evaluated iteratively, resulting in a fast and highly scalable solution. The prototype also offers a first iteration of simple repairs specific to the temporal constraints, that will be further improved in future prototypes.

These prototypical implementations have been extensively evaluated on process benchmarks and specific use cases of interest. We started the project with a series of interviews with the stakeholders involved in our approach, highlighting the open challenges that we needed to address. Our first prototype was evaluated in a user study with Bosch software engineers. The results of this user study show that our approach makes the process easier to follow. Additionally, the engineers found that determining the completion criteria at each process step was much clearer using our approach. Since then, we have carried out multiple workshops and are currently putting the basis for another series of user studies to evaluate both the progress of the approach, and the usability of the temporal constraints prototype.

Below, we have attached a capture of the guidance provided by the first working prototype of our approach. This prototype already uses the Azure DevOps integration and was used in the first user study. In the following development iterations, we have integrated the temporal constraints prototype and improved the main aspects the engineers suggested during the user study.



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AREA 2

MFP II 2.5.2 LineTACT II

Cognitive Line Tacting Support

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	MFP II 2.5.2
Project Title:	LineTACT II
Project Lead:	Dr. Christoph Mayr-Dorn Institute of Software Systems Engineering, JKU
Duration:	13 Months, 01.04.2021 - 30.04.2022
Strategic Volume:	10 %

Work Packages

WP 0: Project Management
WP 1: Balancing Process – Context Analysis
WP 2: Analysis of Existing Models, Approaches & Balancing Algorithms
WP 3: Algorithms and Services for the Creation and Refinement of the Dependency Graph

WP 4: Algorithms and Services for Line Balancing
WP 5: Prototype Architecture and Implementation
WP 6: Prototype Evaluation
WP 7: Strategic Research Dissemination

Company Partners

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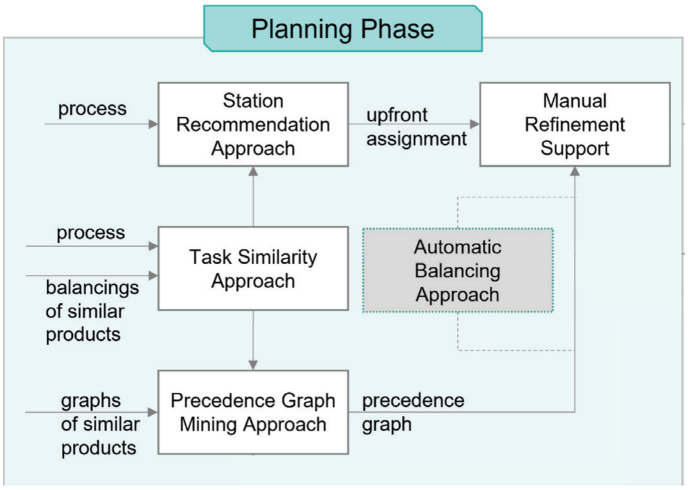
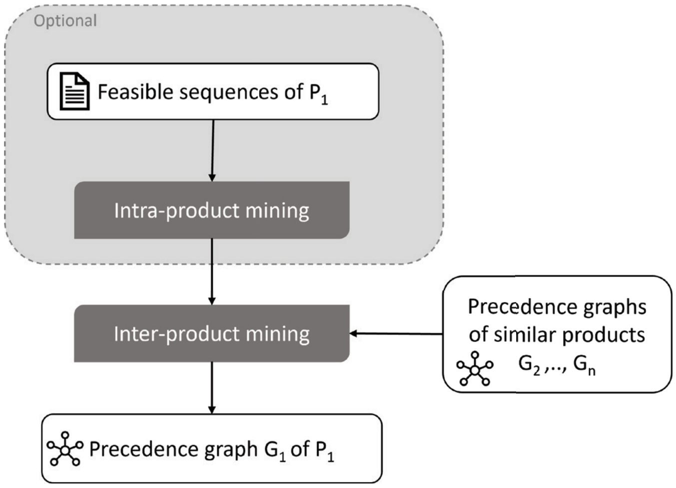
To participate in a highly competitive market, manufacturing companies today offer a wide range of product variants accommodating the increasing customer demand for customization. To this end, manufacturing companies pursue producing highly customizable products, in small lot sizes, at the costs of mass production. Different uncertainties, such as the volatility of the market demand, abrupt disruptions of supply chains, production errors, etc. may arise threatening various stages of production. This gives an advantage to flexible manufacturing systems for their ability to cope with these unforeseen situations.

To ensure assembly planning flexibility towards internal and external disturbances, prompt planning and configuration of the assembly process are necessary. This includes the balancing of the assembly line. The Assembly Line Balancing Problem (ALBP) is the partitioning of assembly work among stations with respect to prioritized objectives. These objectives are cost or profit-oriented and aim to minimize the number of stations and/or maximize the line efficiency. The ALBP has drawn considerable attention from the academic and industrial communities for decades. The formerly presented solutions, however, are not always feasible in real-world assembly systems where we notice a gap between the effort invested in solving the ALBP within the research community and its applications in industrial settings. This is often due to the lack of input data, namely the assembly precedence graph. Experts in different industries rely on their tacit knowledge of precedence relations and other constraints to deliver a feasible assembly line balancing. The process of manual assembly balancing is tedious, error-prone, and time-consuming. It limits the rapid responsiveness of the assembly system, making it more vulnerable to disturbances.

Goals

This Project aims to support the prompt balancing of new products while addressing the lack of vital data in real-world assembly systems, namely the assembly precedence graph. Additionally, we plan to support the re-balancing of already existing products allowing efficient re-





sponses to market changes and supply chain disruptions. To this end, we attempt to learn the missing precedence graph allowing the application of several prominent automated assembly balancing solutions in real-world assembly systems.

Approach

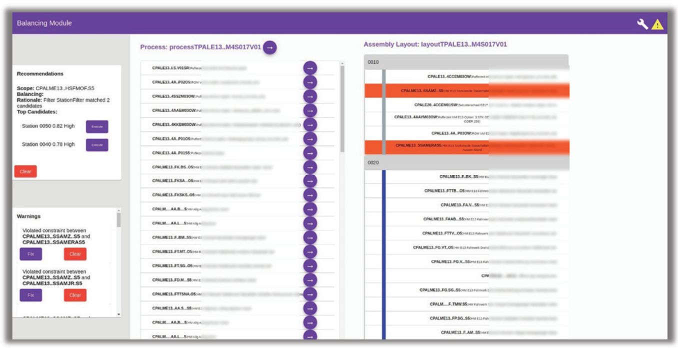
We proposed a novel approach for the support of the flexibility of assembly systems during the planning phase. For the first case, entailing the planning of new products, we propose an approach providing station assignment recommendations for each task of the process. These recommendations are based on similarities calculated to tasks of previous balancings of similar products. The output of this step is an upfront task to station assignment. At this stage, not all tasks have been assigned (for some tasks, no recommendations are provided) and the assignment is not properly balanced. A planning expert then manually refines the assignments. We also provide support for the manual refinement step through (i) recommendations for alternative stations where a task can be shifted and (ii) warnings for violations of precedence constraints based on the learned precedence graph. In the case of new products, where no past feasible sequences are available, the learning is based on graphs of similar products. The precedence graphs of similar products can be already available at the manufacturing company or generated using our approach. Using the learned precedence graph, an automatic balancing approach can also be used. There are several solutions available that can be applied depending on the assembly conditions and balancing objectives. Manual refinement is still required after using automatic balancing solutions as well.

The second case entails the re-balancing of already existing products in order to adjust the line throughput or to modify the line tact for example. We proposed a two-step graph mining approach. The first step is the intra-product graph mining approach using past feasible sequences if available. The second step is the inter-product graph mining approach, in which the initial learned graph from the previous step can be improved by learning additional independencies from the graphs of similar products. Using the learned precedence graph, automatic assembly balancing approaches can be used before a manual refinement step is performed.

Expected and Achieved Results

We evaluated the recommendation approach using real assembly data of excavator assembly and by calculating 2 metrics, namely the coverage and precision.
Our approach is able to provide station assignment recommendations for 91% of the total of tasks with a precision of 82%. We also presented a dynamic threshold approach that improves the approach coverage as compared to a standard static threshold. We conclude that task similarities can indeed be used to derive task assignment information from other products. It is critical, however, to select a sensible reference product, which is typically a straightforward task for a user familiar with the product portfolio.

We also investigated to what extent can task similarities to other products be used to derive precedence constraints. To this extent, we evaluate our precedence graph mining approach based on real industry data of construction machine assembly. We conclude that graphs of similar products can be used to derive task independencies. Our approach specifically addresses the lack of feasible sequences in the case of new products. We have also evaluated the results of a user study conducted with balancing experts, who corroborated the usability and usefulness of a prototype implementing our approach for manual balancing support, including warnings based on the mined graphs.



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AREA 2

MFP II 2.2 CoSma

Cosimulation for Smart Manufacturing

Area 2 - Cognitive Robotics and Shop Floors

Project ID: MFP II 2.2
Project Title: CoSma - Cosimulation for Smart Manufacturing
Project Lead: DI Michael Mayrhofer
Pro2Future GmbH

Duration: 33 Months, 01.04.2021 - 31.12.2023
Strategic Volume: 18 %

Work Packages

WP 1: Project Management
WP 2: Dissemination and Exploitation
WP 3: Current System Analysis
WP 4: Highly Flexible Production System Design Ideation
WP 5: Highly Flexible Production System Architecture Design
WP 6: Highly Flexible Production System Simulation Model Implementation
WP 7: Virtual Testing
WP 8: Systems Integration
WP 9: System Verification and Validation

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Predicting quality in production systems is an open field of research, especially for discontinuous production like assembly.
In manufacturing of safety critical systems the final products have to undergo rigorous testing. These testing schemes can cause a bottleck in the overall production line. In addition, if a broken product is detected at the end of the line, whilst the error has been caused in an early stage of production, many work steps are in vain, even have to be undone in case of repairs.

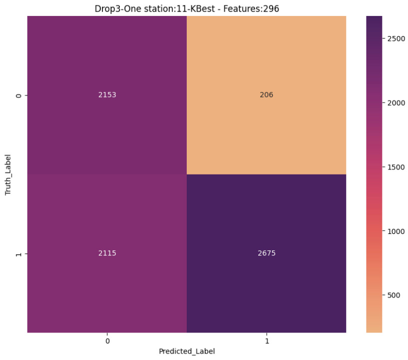
In many production lines, a great number of production parameters are recorded. This MFP investigates, which methods are beneficial to predict the outcome of such a final test. Second, we aim to determine, to which extent the prediction is reliable and whether it is possible to give a detailed estimate of which specific test in the whole testing scheme will fail. Finally, we apply an ablation study to determine an optimal station in the production line, that balances the prediction quality against the repair costs.

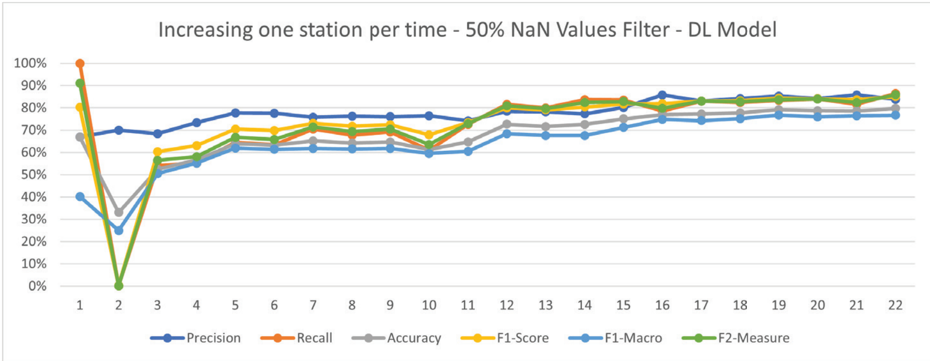
The problem was tackled by training several machine learning models. The developed approach was tested in an assembly line for electric inverters. Special focus was put on data preprocessing and feature selection. This posed a great challenge, as even after rigorous filtering during preprocessing, roughly ten thousand features remained for training of the model. Several methods were employed to narrow down the number of features.

The trained models allow accurate predictions of failing products already after only half of the assembly steps have been performed. Further work will be done to improve the accuracy when predicting individual errors. The developed approach will be running in a virtual environment to evaluate its usefulness without interfering with the actual production.

Goals

The goal of this multi firm project is the creation of an environment, that allows to use real time data from the production line to predict the product quality. Target of prediction is the probability, that a product will fail in the end-of-line test. The quality of the predicition will be measured in comparison with the real results of the end of line tests.





The multi firm project will investigate in detail the structure and capabilities of the existing assembly line. Based on this initial analysis, requirements are developed for the system to create. After a first functional system architecture is agreed upon, models are built, trained on measurement data and integrated with the system architecture.

Verification and validation of the developed models will first be done backwards, thus by comparing model predictions based on recorded data with the corresponding test results, and later in-line: manufacturing data is mirrored into a live digital twin of the manufacturing line, allowing to investigate the prediction quality over an extended period of time.

Approach

Machine learning models and neural networks have been employed in a manifold of use cases. The focus of this project does not lie on the creation of new machine learning algorithms, but rather on their incorporation into an automated framework that continuously learns from new results in the manufacturing line and retrains its models on the fly. Especially the selection of features can benefit from reliable automated tool support, as no specialist has the time, or is maybe not even capable of deciding for every variable whether it will be an important feature, or what its meaning is.

Expected and Achieved Results

The architecture to retrieve measurement data live from the production line has been implemented by partner Fronius and is already in use to prepare the datasets that serve to train the classifiers. Failure prediction models have been created and trained based on classical machine learning algorithms and neural networks. A stacked model of these prediction models will be integrated in the architecture. Verification and evaluation of the classifier will be carried out until the end of the project. The results from the evaluation will be used to estimate the potential for optimization through changing the order of test cases.

Future work will include the feedback of assembly actions and components that might cause failing products in-line. This requires yet more rigorous data collection in the production of preproducts and clear tracking of those until the assembly station. Another activity for future investigation is the implementation of a variable testing scheme, whose order reacts on the estimated frequency of errors occurring.

Status / Progress

The multi firm project CoSma started officially in April 2021. As common with other machine learning projects, the exploration and preparation of the recorded data took substantial time. This first project phase, together with first experiments, used roughly the first year. The insights from this phase were used to define the relevant features for freshly recorded datasets containing measurements for a bigger set of entities of a specific product type. This dataset was then used to train classification models and allowed to achieve impressive results.

By the time of writing, 92.85% of products predicted to have an error were predicted correctly, translating into less than 8% false positives – see also left figure: false positives are in the top right corner, and correctly predicted faulty products in the right bottom corner. At the same time it could be shown with an ablation study, that already in the middle of the production line, after half the production steps – see right figure, and note the rapid increase of F2-measure from station 10 – 12.

We expect, that the prediction quality can still be improved through the use of stacked classifiers, thus training individual models for different error causes – or at least the most frequent error codes among the ~400 present in the data – and use aggregation strategies to result in a more accurate classifier.

The remaining four months will be used to employ the models in a live environment that mirrors the measurements recorded in production, to verify and validate the models and estimate the benefits of correctly predicting errors.

So far, one conference publication is currently under review at the International Conference on Industry and Smart Manufacturing (ISM 2023), where the ablation study that was employed to determine the point in time to predict faulty products was published.

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AREA 2

StratP II 2.4.1 DEVINE
Deviation in Evidence

Area 2 - Cognitive Robotics and Shop Floors

Project ID:	StratP II 2.4.1
Project Title:	DEVINE - Deviation in Evidence
Project Lead:	Dr. Ouijdane Guiza Pro2Future GmbH
Duration:	12 Months, 01.05.2022 - 30.04.2023
Strategic Volume:	100 %

Work Packages

WP 1: Project Management

WP 2: Dissemination und Exploitation

WP 3: Training Embedded Intelligence

WP 4: Verification of Embedded Intelligence

WP 5: Deployment of Embedded Intelligence

WP 6: Case Studies

Academic Partners

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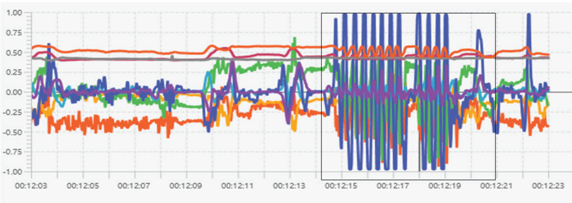
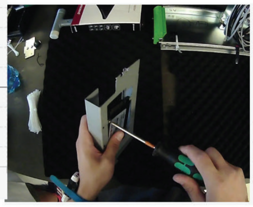
In the dynamic landscape of modern industry, the integration of robotic systems into manufacturing processes has become increasingly ubiquitous. This project seeks to redefine the conventional notion of human-robot collaboration by introducing a paradigm shift towards flexibility and adaptability. Unlike traditional robotic setups that adhere strictly to preprogrammed processes, our initiative capitalizes on cutting-edge perception technologies, including cameras and wearable sensors, to enable robots to comprehend and respond to human actions and progress in real-time. This heightened perceptual awareness forms the bedrock for a novel approach to collaborative work, where the robot's interventions are contextually aligned with the human operator's evolving needs.

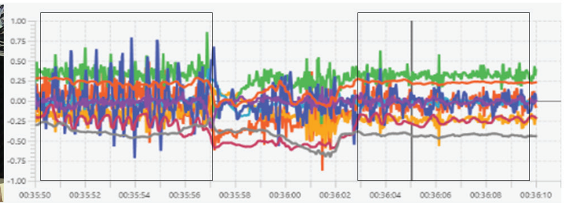
The central tenet of this endeavor lies in the transformation of robots from rigid tools into intelligent and responsive collaborators. Conventional industrial robots have been constrained by their inability to navigate unexpected deviations, often necessitating human intervention to address unforeseen challenges. In contrast, our framework empowers robots with the capacity to assess and react to unpredicted events. By employing advanced data fusion techniques and machine learning algorithms, the robot becomes adept at identifying patterns, anomalies, and potential disruptions, allowing it to dynamically adapt its actions to match the demands of the task at hand.

At the core of this project is the vision of a harmonious human-robot partnership that thrives on mutual strengths. By leveraging the human operator's creativity and adaptability alongside the robot's precision and speed, we aim to create a synergy that is exceptionally suited to tackling uncertainty. The fusion of human ingenuity and machine precision holds the promise of revolutionizing manufacturing practices and ensuring continuous operations, even in the face of the unexpected.

In summation, this project endeavors to transcend the boundaries of conventional human-robot collaboration by embracing adaptability and responsiveness. By infusing robots with the ability to comprehend human actions, progress, and situational context, we aspire to forge a new era of manufacturing efficiency, where flexibility reigns supreme. The outcome of this initiative holds the potential to unlock innovative avenues for industry, propelling human-robot collaboration to unprecedented levels of productivity and resilience.







Goals

This project aims to redefine human-robot collaboration in flexible manufacturing systems. The focal point is enhancing collaborative robots (cobots) with advanced perception capabilities by integrating data from cameras and wearable sensors. This amalgamation of inputs empowers the Manufacturing Execution System (MES) to intricately gauge assembly progress, enabling informed decision-making.

Furthermore, the MES leverages this real-time progress assessment to tactically assign support tasks to available robots. This dynamic choreography between MES-guided assignments and cobot-driven actions amplifies manufacturing efficacy. The symphony of human intellect and robotic precision unfolds, revolutionizing the adaptive potential and productivity of modern manufacturing.

In essence, this initiative molds a new era of synergy between humans and robots. The cobots, equipped with perceptive faculties, act as collaborators attuned to real-world dynamics. The MES orchestrates this harmony by harnessing assembly insights to distribute tasks adeptly. The result is an ecosystem where adaptability, productivity, and precision converge to shape the future of manufacturing.

Approach

The system is equipped with a range of inputs, including cameras and IMUs, that work together to detect and track the progress of human workers during the assembly process. The current state of the art deep learning models in Human Activity Recognition (HAR) are utilized for our supervised classification challenge. These include variations from simple RNN (Bi-dir LSTM) and CNN to complex attention models. This approach targets the detection of basic assembly micro activities like wrenching and screwing, leveraging data from wrist-worn wearable sensors. Furthermore, diverse models are employed for object detection via stationary cameras. These models detect distinct assembly components, thereby enabling traceability to specific assembly tasks.
These different inputs are combined and fed into a rules engine that combines the data and uses a pre-defined precedence graph to determine which task the workers are currently performing. Based on the progress detected, the Manufacturing Execution System (MES) triggers any available robots to perform assistive tasks that have been modeled for the current stage of the assembly process. The robots are equipped with cameras that help them determine the location of parts, where to weld, and which screws to use. The MES is also capable of scheduling robots to provide assistance to multiple human workers, which is detected through cameras and other sensors. As the environment changes and progress is made, the process of robots is dynamically adapted to ensure that they are always working effectively and efficiently.

Expected and Achieved Results

We have designed a controlled lab environment to meticulously test and assess the practicality and efficacy of our proposed methodologies. It's crucial to emphasize the generalizability and scalability of this evaluation setup, which can readily be extended to accommodate real industrial settings for the assembly of more complex products and including more complex robotic responsibilities.

Our designed environment is a dedicated assembly station tailored for the assembly of a compact bicycle, with the collaboration of a robot. In this context, the robot's role entails the precision picking of small assembly components like screws and nuts, subsequently handing them to the worker to facilitate the relevant task.

The assembly's progress is deduced through the combination of micro activity detection (such as screwing, wrenching) and the detection of the picked bike parts. This composite insight is then used by the Manufacturing Execution System (MES), which then allocates the robot the task of picking the screw or washer relevant for the ongoing assembly step. Notably, the robot's skill to identify and grasp the small components is facilitated by its dedicated camera, enabling autonomous recognition and retrieval. These components' positions are not fixed on the assembly station, thereby increasing flexibility. Additionally, we have implemented a failsafe mechanism involving hand gesture commands as a means of communication between the worker and the robot. This contingency approach serves as a vital approach for scenarios like faulty parts (e.g., broken screws).

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AREA 3

MFP 3.1-1 EPCOS 1

Maintenance 4.0 @EPCOS OHG, Preparation & Ex-Post Analysis

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-1
Project Title:	Maintenance 4.0 @ EPCOS TDK
Project Lead:	Dr. Stefan Thalmann Pro2Future GmbH
Duration:	12 Months, 01.07.2017 - 30.06.2018
Strategic Volume:	0 %

Work Packages

WP 1: Automatic Suggestion of Troubleshooting

WP 2: Ex-Post Analysis

Company Partners

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Academic Partners

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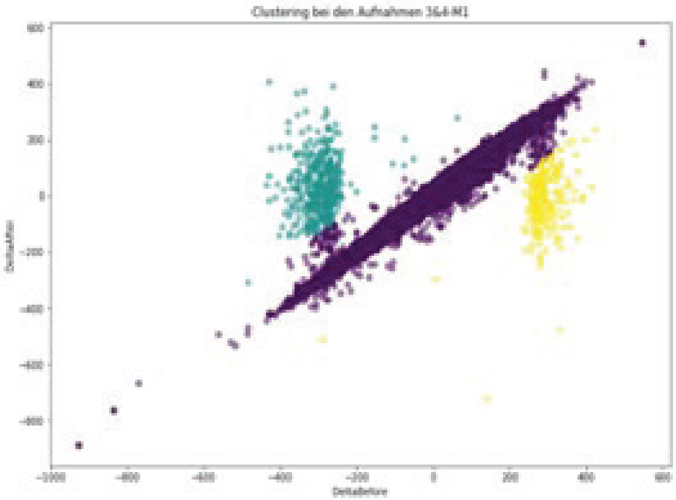
The predictive maintenance systems are built upon is a clear definition of defects and the corresponding approaches to address them. First, the different types of defects should be identified and ranked considering to what extend they may affect the system. The next step is about defining possible methods and strategies that can be used to deal with these defects. Basically, the outcomes of these methods are (i) **predictions** about which kind of error may appear, and (ii) **recommendations** about how to deal with them.

Approach

In order to classify the defects, we analyzed two important features, **DeltaBefore** and **DeltaAfter**. This features where identified using visualization approaches like scatterplot, boxplot, etc. and through the discussion with the domain experts from EPCOS. Finally, we structured and processed the data so that they could be readily interpreted from various clustering methods.

We performed different clustering methods (e.g., K-means clustering, GaussianMixture, etc.) over the data. The results showed that the GaussianMixture performed better as it could cluster the defective parts successfully (see Figure below). The green and the yellow clusters represents the defects, and the purple cluster represents the normal behaviors.



Much effort has been put on collecting high quality event data (EASTGATE data). Analyzing this information together with the Log data and ISPRO data, we were able to deploy a classification model based on Random Forest.

Expected and Achieved Results

The goal of the defined model was to classify the defects in advance. Therefore, we defined various prediction horizon (e.g., 2, 5, 19, 20 and 60 minutes), which represented the prediction time before the defects happened. Next, we defined various time ranges (windows) (e.g., 10, 20, 30 minutes) each representing a period in which we observed the data to generate predictions. The following table shows the results.

		Vorhersagehorizont				
		2 Min	5 Min	10 Min	20 Min	60 Min
Analysewindow/Minutes – **10 minutes**	Accuracy	0.74	0.83	0.81	0.77	0.82

Status / Progress

This project officially started in May 2018 and successfully ended in September 2018. In it, Pro²Future worked with our Company Partners EPCOS, TU Graz Institute of Interactive Systems and Data Science towards the creation of models to classify defects on produced chips. From the start of the project, we had several meetings with the company partner where we defined the requirements, discussed the data quality and presented the preliminary results for the classification models. During these meetings, we obtained constructive feedback which we could use to adapt the models with regard to the requirements of the company partner. The final prototype has been delivered to the partner on the 28th of September 2018.

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AREA 3

MFP 3.1-2 DEFCLAS
Advanced Defect Classification

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-2
Project Title:	DEFCLAS - Advanced Defect Classification
Project Lead:	Stefan Thalmann Pro2Future GmbH
Duration:	07 Months, 01.11.2017 - 31.05.2018
Strategic Volume:	10 %

Work Packages

WP 1: Classification of Defects

WP 2: Best Practice Guideline

WP 3: Literature and Conceptual Framework

WP 4: Project Management

WP 5: Preparation of Training Data and Performance Improvement

Company Partners

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Academic Partners

TU Graz, Institute of Interactive Systems and Data Science (ISDS)
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Automatic optical inspection (AOI) in the semiconductor industry is considered an extremely important and demanding task for detecting significant errors on the wafer fab process within the Quality Process Control pipeline. During this step, yield deviations can more seamlessly identified and engage the engineers to locate the exact source of error with the numerous complex process steps. With the advent of advanced analytic techniques (e.g. Deep Learning) as well as parallel computing (deployment of GPU servers) is now possible to classify and label the errors on the chip surface by feeding large images datasets to Neural Networks.

Goals

The goal of the project is to define models that should help to identify and classify the errors which might occur while producing chips. The outcome of the project should be a best-practice guide on what to consider when defining such models. This mainly comprises the methods that have been successfully applied to address the challenges we faced during this project: export and postprocessing the data from the plant, processing of the trainings data, defining of the classification model for error detection on the chip surface etc. With this guide we aim to support the experts who might face the same challenges in future projects.

Approach

The first challenge is to identify the relevant part of the images. A too large picture can distract and thus reduce the quality of the classification. Further, larger images increase the complexity of the data processing and the performance of the approach. Too small images on the other hand could hide relevant structures and thus reduce the classification quality as well. Chip images which are used for training a classification model should first contain the appropriate context in terms of defect structure. This means characteristics should be as distinguishable and intense as possible from the remaining complex chip architecture so not to raise any confusion to the later prediction process. As it's possible from the automated inspection system (AOI) to extract the images with the defect centered, that can facilitate for building a more reliable and accurate model.

Expected and Achieved Results

In cases where entire chip images are provided with the four soldering joints (Lötstellen) an initial classifier model (CascadeClassifier) is trained so to extract automatically the areas of interest, namely the four soldering positions. A separate classification model (Haar Cascade Classifier) was first trained on 100 images. Inside these instances, the four soldering regions were manually defined by defining rectangles, enclosing the joints, of certain width-to-height ratio (256x256px) with their location coordinates. The extracted images of the soldering joints are fused with the labelling information regarding the fact that is defect or not.

All defect images should have a constant size which need to be fed into the neural network model initially for training. After interviews and first wafer data we concluded to an image size of 90x90 px so that to achieve a trade-off between algorithm performance (final model size) and classification accuracy. Experiments have been conducted for the initial classification problem of the 3 defect classes ("Druckstelle", "Verschmutzung", "PR-Fehler") so to benchmark the utilized image size. Images with sizes greater than 90px (e.g. 128x128) were also tested and findings showed that complexity was increased and thus classification performance decreased.
Convolutional Neural Networks (CNN) with its many architectural variations can fit very well for demanding applications of image recognition tasks. Across the internet there many available datasets (see CIFAR-10 and CIFAR-100 [1], MNIST [2] or also ILSVRC 201* [3, 4]) which are mainly used for benchmarking novel models as well as to mark overall dataset specifications.

We conducted an experiment to examine the effect of the training data size on the classification accuracy. We deployed the model with the five defect classes from the WB-AOI, as images from within these classes are more homogeneous and stable. It is essential that testing images to evaluate are coming from the same distribution (similar image context within classes), otherwise the outcome will be biased. Also, this is a strong indication that the model should be updated by training with the novel images, that the model failed to classify correctly. By above 1200 images per class the classification accuracy is converging and thus providing sufficient evidence for the adequacy of the training data size.

Status / Progress

This project officially started in August 2017 and successfully ended in September 2018. In it, Pro²Future worked with our Company Partners EPCOS, TU Graz Institute of Interactive Systems and Data Science towards the creation of models to classify defects on produced chips. From the start of the project, we had several meetings with the company partner where we defined the requirements, discussed the data quality and presented the preliminary results for the classification models. During these meetings, we obtained constructive feedback which we could use to adapt the models with regard to the requirements of the company partner. The final prototype has been delivered to the partner on the 28th of September 2018.

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AREA 3

MFP 3.1-3 OnDaA
Online Data Analytics @ voestalpine

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-3 OnDaA
Project Title:	Online Data Analytics @ voestalpine
Project Lead:	Dr. Heimo Gursch Know-Center GmbH
Duration:	24 Months, 01.10.2017 - 30.09.2019
Strategic Volume:	20 %

Work Packages

WP 1: Data Analysis and Identification of Correlations in Use Case Bramme

WP 2: Building Prediction Model for the Use Case Bramme

WP 3: Visual Analytics Tools for Monitoring Tasks for the Use Case Bramme

WP 4: Prediction Model for Anode Change

WP 6: Strategic: Data Analytics Methods Base

Company Partners

voestalpine Stahl GmbH
Dr. Markus Brummayer, MSc

Academic Partners

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Know-Center GmbH
Research Center for Data-Driven Business & Big Data Analytics
Heimo Gursch, hgursch@know-center.at

This project focuses on data analytics and visualisation for the continuous casting process in large-scale steel production. In modern steel production, sensor and process data are recorded to observe and control the continuous casting process and the resulting product quality. Monitoring this data directly is cumbersome yet demanding for process engineers. Hence, the monitoring is labour intensive, often only done on sample basis or to investigate particular events observed in the finished product, the so-called slabs. To improve the monitoring the sensor and process data, the data is processed by machine learning algorithms. The objective is to create a prototype for a monitoring solution highlighting the right information about the current steel production to the process engineers and limit unneeded or distracting aspects to a minimum.

As a preparatory work, a comprehensive data analysis was required highlighting characteristics of the data and establishing coherences with the steel production process. In the next step, a detailed feature engineering was conducted, where relevant features were derived from the process and data understanding. These features capture the important insights hidden in the raw data and abstract from shortcomings of the raw data like noise. The extracted features are the basis for the machine learning algorithms trained and applied on them. These algorithms recognise and categorise phenomena about the produced steel in the prepared features. Hence, the algorithms provide an estimation about the expected product quality and about the state of affairs in the ongoing process. An important part of the project is the visualisation of the data and the results, so that the process engineers get an ideal overview about the current production state and got informed about potential critical developments. The visualisation is the necessary tool to handle large amount of data in a comprehensible manner by providing different views with varying levels of detail. Hence, the process engineers can choose from different views depending on their task; high-level views to monitor the ongoing processes were also available alongside detailed views to drill down and investigate particular events.

Goals
The objective of the project was to conduct research into feature extraction, machine learning and visualisation applications for sensor and process monitoring in continuous casting. The feature extraction defines quantifiable and reliable characteristics of the raw data by modelling aspects of the continuous casting process influencing the

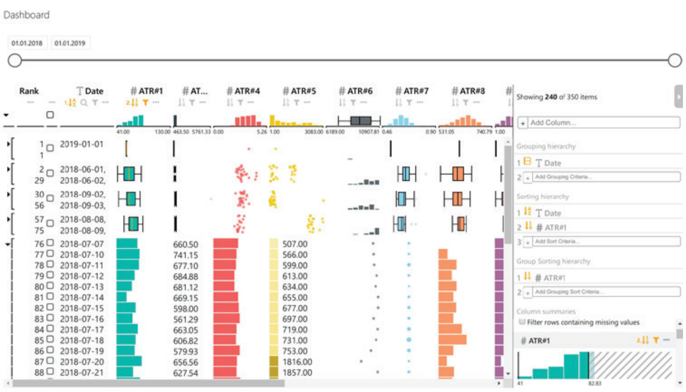
output quality. The extracted features needed to be reproducible and robust against noise or variations in the process. The machine learning builds on said features to categorise relevant casting phenomenon in the slabs. This categorised phenomenon helps the process engineers to identify potential issues in the produced slabs and the underlying production process. The visualisation provides these extracted insights in a neat and user-friendly graphical interface to the process engineers. The interface offers different levels of detail giving each process engineer the right amount of information for a given task. On the one hand, a high level of abstraction caters for fast and easy to comprehend overviews. On the other hand, the user process engineer can select high levels of detail if this is required for a detailed investigation of a particular issue.

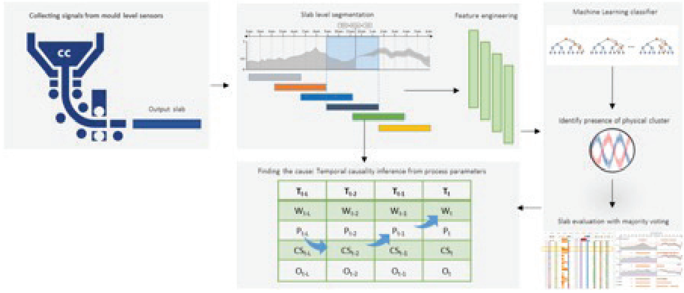
Approach

The centre of the project are machine-learning models. The models are trained to detect relevant characteristics of the produced slabs. In this training and on the subsequent usage of the model, the model relies on features extracted for the raw data. The construction of these features was most important for the success of the project since they capture all relevant aspects in the data, are low in dimension and also robust against noise and variations. While these features are the key success factor for the machine learning, the visualisation was clearly focused on human understanding. The data is presented in a way that is comprehensible for the engineers and shows them the important aspects they need to judge the current products. Hence, the focus is the underlying sensor and process data.

Expected and Achieved Results

In this work, the feature extraction for bivariate time series was investigated. The construction and definition of the features is designed to the specific physical phenomena described by the customer and observed in the sensor and process data of the steel production. The features are the basis for the identification of critical physical phenomena by means of machine learning. The machine learning is conducted in two stages. In the first stage, a multiclass approach was taken to determine if a single dominating phenomenon can be identified for a produced slab. In the second stage, a multi-label approach was chosen to allow the identification of more than one relevant phenomenon occurring in a single slab. The expected outcome was a list of identified phenomena and their influence on each slab. Regarding the visualisation, a visual analytics application prototype was developed. This prototype allows for a general overview and also a detailed drill-down of the underlying time series data. This is facilitated by a customisable ranking including grouping and aggregation of the underlying data. Moreover, a Microsoft Power BI custom visual was developed to explore rankings of items based on a set of heterogeneous attributes. It also supports hierarchical sorting and interactive (nested) grouping as well as provides a variety of visualisations for group aggregations, cells, and summaries of the underlying data.





Status / Progress

This project officially started in October 2017 and went on for 24 months until September 2019. A cost-neutral elongation until the end of 2019 took place to finalise the visual analytics part. The project was conducted with voestalpine AG as industrial partner, JKU Linz and TU Graz as scientific partners, and the Know-Center as implementation partner. The first phase in the project was dominated by a strong knowledge exchange between the partners. In this phase the continuous casting process with its properties and features had to be understood by all project partners.

This understanding was created by a walkthrough of the production plant and several data exchanges. The exchanged data was also the foundation of the remainder of the project. In the second phase, this data was analysed and the coherences and correlations between process phenomena and the data were identified. In this phase of the project, additional data transfers took place when shortcomings in the first data were found or new interesting insights needing deeper investigations discovered.

This phase then led to the feature engineering, where the insights and phenomena, which should be extracted, were defined. All these phases before were the basis for the current implementation and evaluation of the machine learning and visualisation prototypes. The prototypes were evaluated and enhanced in several iterations. In each iteration the prototypes were verified and enhanced. A particularly close cooperation with the industry partner was found in the coordination of the dashboards to find outliers and patterns over time in data by means of three use cases.

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AREA 3

MFP 3.1-4 RedUsa

Predictive Maintenance for Production Environments RedUsa

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-4
Project Title:	Predictive Maintenance for Production Environments
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	36+3 Months, 01.01.2018 - 31.12.2021
Strategic Volume:	15 %

Work Packages

WP 1: Data- and Infrastructure Preparation

WP 2: Data Analytics for Quality Improvements

WP 3: Advanced Visual Analytics for Quality Improvements

WP 4: Concept for Introducing/Establishing Data Analytics

WP 5: “Strategic Project” - Data Analytics Methods Base

Company Partners

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Academic Partners

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The power of the predictive maintenance lies on providing immediate assistance in situations where human judgment disregards the reactions times or when human beings do not possess the required skills. This is considered as highly important particularly in uncertain conditions where making a poor selection might cause high consequences for the production process. This MFP will investigate methods and tools to identify factors that might affects the quality of production and in turn to allow maintenance to be planned before the failure occurs. This project is motivated by the fact that while producing aluminum plates in Austria Metall GmbH (AMAG) and in the affiliated companies (with regard to § 189 a UGB), there might be not-metallic indications in the produced items caused by unknown factors. To be appropriate, these indications have an enormous effect on the quality of the produced plate. In order to tackle this issue, this project should provide methods that can be used to identify the influencing factors and to reveal relationships among these parameters and production quality. Furthermore, the gained insights should be applied to forecast the production. Finally, a visual analytics tool should be provided, which shows the end user (engineers from AMAG CAST) the influencing parameters visually and allows to interact with them.

The data being used in this project are production and quality data.

Goals

The goal of this project is to define visual methods, which can reveal the relationships among production parameters and the production quality. Sensors at various production steps deliver a stream of production data, which is time-dependent and typically, high-dimensional. While the data is continuously captured, its preprocessing and analysis are a challenge, due to the size and heterogeneity of data. The main challenge, however, is to map the time-dependent production data to the run length of the cast aluminum. An interactive visualization tool should therefore provide means to visually inspect the possible influences of production parameters on product quality and promote a better understanding of parameters in production. On the top of that, the tool should be defined in a way that it can be used by the users (engineers from AMAG CAST) that have little or no expert knowledge in visualizations but possess the required domain knowledge about production aluminum plates.

Even with an interactive visual analysis tool that offers users several functions for exploring their data, the users can still be overwhelmed by the huge amount of data and may have difficulties to identify critical patterns in their data sets. With our visual analysis tool, we also want to provide various methods for the detection of specific ultrasonic patterns and thus try to help users to identify possible critical process deviations in production.

Approach

There exist several state-of the art algorithms that can be used to analyse data and identify the influencing process parameter. This, however, requires an extensive literature review to analyse which methods better applies to industrial data. Thus, within the scope of this project, we investigate different algorithms to detect the factors that might influence the produced aluminum plate and to forecast the production.

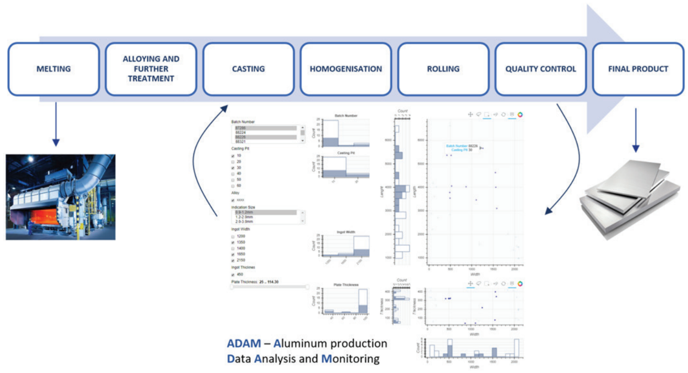
Note that the data we used within the scope of this project is collected by an ultrasonic device, used to scan the produced aluminum plates. For the visual analytics tool, however, there exist powerful visualization libraries that provide different interactive 2D visualizations. These visualizations provide a good base to support user to visually navigate through the data and explore them to gain insights and draw important conclusions.

Our next goal in this project concerns the identification of meaningful patterns in process data. The existing research covers a broad spectrum of pattern recognition methodologies that can be potentially applied to elicit patterns in data collected from industrial production. Hence, in this paper, we further analyse the applicability of different methods for recognition of specific ultrasonic patterns which may indicate critical process deviations in aluminum production.

Expected and Achieved Results

During a parallel aluminum cast, each batch results in several ingots via a casting pit. We developed a visual analytics tool (ADAM: Aluminum production Data Analysis and Monitoring) which includes scatter plots, showing the front and the top view of ingots, linked with three frequency histograms which provide information about the number of indications in length, width, and thickness of cast ingot. ADAM has been successfully presented at the poster session in EuroVis2019.

Further effort in this project has been put to define a classification model to classify the ingots into “good” and “bad” quality regarding the not-metallic indications they have. Moreover, we defined a prototype of a glyph-based visualization to scale multidimensional data and methods (currently, the classification model) to reveal the relationships among production parameters and the production quality. Yet, batches and ingots have a different distribution of indications in length, width, and thickness. It is important to group similar batches and ingots in order to investigate the influence of production parameters in a more precise manner. To do this, we integrated interactive pattern search in our tool and allowed the user to search for ingots with similar distribution compared to a selected ingot.



Status / Progress

This project officially started in April 2018. In it, Pro²Future is working with our Company Partners AMAG, TU Graz Institute of Computer Graphics and Knowledge Visualisation, and TU Graz Institute of Interactive Systems and Data Science towards the creation of visual- and data analytics tool for quality improvements in aluminum production. We have already deployed an advanced version of ADAM, including the interactive exploration of indications and the pattern search. In near future, we will focus on visualizing the extracted relevant production parameters and on defining methods that should help the users to understand the difference between them with regarding to the quality criteria.

The first results of this project including the interactive exploration of indications and the pattern search have been submitted to the 54th Hawaii International Conference on System Sciences, which took place in 2021.

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AREA 3

MFP 3.1-5 SINPRO

Predictive Maintenance for Production Environments SINPRO

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.1-5
Project Title:	Predictive Maintenance for Production Environments
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	27 Months, 01.04.2018 - 30.06.2020
Strategic Volume:	15 %

Work Packages

WP 1: Project Management & Coordination

WP 2: Prediction Model

WP 3: Advanced Visual Analytics for Quality Improvements

WP 4: Knowledge Modelling & Integration

WP 5: Strategic Project – Data Analytics Methods Base

Company Partners

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This multi firm project (MFP) will investigate a novel decision support technology for assistance in the manufacturing- and production setting for plants in the context of the sintering process. The motivation is, that the outcome in product quality and the manufacturing efficiency can be increased by understanding the circumstances of all components and optimizing their interacting.

Within SINPRO, a huge amount of sensor data is gathered from a sinter production machine and analyzed to understand, which components of the production process affect the quality of the final product. With these findings a prediction model should be defined that uses the detected influencing factors of the whole process and predicts the quality and amount of production. On the top of that, the existing rules of the rule based expert system are investigated to understand current system-changing events and the resulting rules. With these findings, existing rules will be adapted and optimized, and new rules defined to gain a higher production and quality increase on the sinter production machine. Finally, the influencing factors, the prediction model and possible rules, as well as the production data, will be visualized to make the research outcome better understandable for the user.

The pursued results and targeted impact contain findings about the process and relationships in the sinter plant and the sinter process; a better representation of parameters in the sinter plant and the implementation of further analysis in an interactive way, forecasts and predictions for process variables and quality characteristics and a customized expert system and advanced decision support.

The novelty value and scientific relevance embrace the application of data analytics and visual analytics approaches in the area of a sinter plant in the steel industry; new scientific findings and contributions in the field of visual interactive prediction in the industrial sector; requirements and solution models for introducing data analytics in an industrial context; findings about the possible uses or the connection between data analytics and visual analytics; insights into the interplay and connection of data and rule-based decision support in the industrial environment.

Goals

The overall goal in this project is to optimize the production process of sinter material. This should be achieved by increasing the amount of the produced material from the sinter strand as well as improving the quality of the produced material. One of the most important factors to reach this goal is the optimization of the burn through point (BTP) of the material, which should be as close as possible to the end of the sinter strand.

Use Case 1: Understanding the influencing parameters for optimizing the harmonic diameter (DH).
Use Case 2: Optimizing the BTP towards the end of the sinter strand.

By applying the research methods described below, the implementation of the Use Cases should lead to fulfil the project goals.

Approach

The approach is to understand which factors affect the quality of the final sinter product. With these findings, the project goal should be achieved. The research methods and topics of interest of the approach contain a time series analysis and classification of existing data on production and quality; an identification of influencing variables for the identified classes; the creation of a prediction model for defined parameters; visual preparation of the data from the sinter plant; an user-specific representation of the visualizations; implementing interaction concepts for visual analysis of the data; an extension of the rule-based expert system with findings from the data analysis.

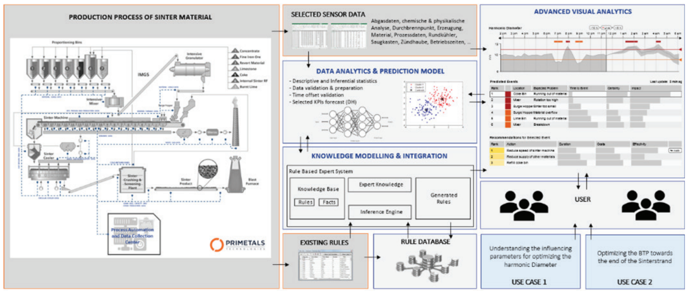
Expected and Achieved Results

The overall goal in this project is to optimize the production process of sinter material. This should be achieved by increasing the amount of the produced material from the sinter strand as well as improving the quality of the produced material. One of the most important factors to reach this goal is the optimization of the burn through point (BTP) of the material, which should be as close as possible to the end of the sinter strand.
We first defined a time model to have reference points for the analysis tools. We further used this model with the feature engineering and selection methods to identify the most relevant parameters for the production. These features are then applied to define a forecasting model to predict the harmonic diameter as a central quality parameter indicating the grain sizes distribution of the finished sinter. Due to the complexity of the model we developed and presented an approach for the increase of the explainability of the complex (black-box) forecasting model, enabling easier discovery of new insights and control strategies.

To visually assess temporal data and the relation between attributes inclusive the related correlation coefficient, we made use of two open-source visual analytics applications and extended their functionality. First, we took advantage of Ordino, an interactive rank-based web application, which is used for data-driven approaches to create, visualize, and explore rankings of items. Second, we added further functionality by using TourDino to calculate and visualize similarity measures. TourDino helped us in seeking relationships and patterns in data and provided an overview of the statistical significance of various attribute comparisons without losing the existing ranking.

Further effort has been put in defining a concept to extend the rule-based expert system. This concept dictates three steps:
(i) development of a prototype for a strand speed control; the purpose of this control is to keep the actual BTP around the BTP setpoint in an acceptable range and the speed as stable as possible
(ii) integration of the prediction models provided by WP 2 into the expert system
(iii) (optional) communication with WP3 for visualization: visually display intrinsic factors which have direct relationships to each other and are related to the strand speed control, and thus to the sinter productivity

The results we obtained so far have been submitted to AISTECH2020.



Status / Progress

The SINPRO project officially started in April 2019 and will last until June 2020. Due to several revisions of the sinter machine, the start was postponed to October 2018, a prolonging of the project end to December 2020 has been negotiated.

The SINPRO team at Pro2Future GmbH is working with our Company Partner Primetals Technologies and the Scientific Partners from the Institute for Application Oriented Knowledge Processing (JKU-FAW), the Institute for Computer Graphics (JKU-CG) and the Institute of Institute of Interactive Systems and Data Science (TUG-ISDS). The associated partners can be found on the first page of this document.

The Kick-Off Meeting was in October 2018 and several tele-conferences and two workshops regarding important parts of the project, e.g. for the currently installed expert system from Primetals Technologies and the data exchange for the dataset from the sinter machine at Voestalpine Stahl have been hold since then. There were additional meetings for getting in touch with the provided data, getting explanations and gaining an extensive understanding of what is happening at the sinter machine. The first investigations and research resulted in a schematic description of the whole project, showing the individual components and the two use cases of the projects (see Figure).

As next, we analyzed different methods to identify influencing factors and define a prediction model to predict DH. These methods should help us to address main Use Case. Hand in hand with this goal, an interactive visual analytics tool has been defined to increase the explainability of obtained results/models and of the current production data. Finally, we worked on adapting the rule-based knowledge processing expert system with new rules to allow higher production and quality increase on the sinter production machine.

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AREA 3

MFP 3.2-1 GuFeSc
Predictive Maintenance for Products

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.2-1
Project Title:	Predictive Maintenance for Products
Project Lead:	Dr. Heimo Gursch Know-Center GmbH
Duration:	39 Months, 01.01.2018 - 31.03.2021
Strategic Volume:	20 %

Work Packages

WP 1: Requirements Analysis and Concept

WP 2: Ex-Post Prototype

WP 3: Single Machine Predictive Prototype

WP 4: Scaling Predictive Maintenance

WP 5: Strategic: Supporting Cognitive Decision Making

Company Partners

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TU Graz, Institute of Computer Graphics and Knowledge Visualisation
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Know-Center GmbH
Research Center for Data-Driven Business & Big Data Analytics
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Nowadays, customers require more and more specialised products adapted to their specific needs and circumstances. This results in a large number of product variants and options, creating a considerable challenge in the maintenance and support of all these products. Since customers also expect a high quality of support for all products, personnel working in testing, maintenance, repair or customer support require considerable time to familiarise themselves with all variants and available options so that they can satisfy these expectations.

This is as cost intensive for the manufacturer as it is cumbersome for the worker. Hence, there is a large potential for assistance systems that provide help to the maintenance and testing personnel and reduce their required training effort. This project researches support systems for maintenance and testing personnel, which are based on data collected during the testing and operation of the devices.

One major aspect is to split up the devices into their components. This spilt-up is then the basis to identify relationships between the collected data and the affected components. Since there are many product variants and options, it cannot be expected to have a sufficiently large data basis for all products. Hence, the approaches researched here should be capable of transferring insights discovered in one particular setup to other setups if the circumstances deem this reasonable.

This is an important aspect to support maintenance and repair personnel in handling rare problems and setups just as profound as the most common once. The prediction of wearout in some parts is another important aspect of the project. By modelling and estimating the expected wearout of parts, their lifetime can be estimated allowing to schedule required maintenance actions well in advance.

Goals

A large number of product variants and options make maintenance and support tasks a complex undertaking where the unique characteristics of the product at hand need to considered. It also implies that there are only a small number of commonalities between different product variants and options. The objective of this project is to research new support systems for workers in fault identification and maintenance. The support system should draw its knowledge from different data sources capturing aspects like successful or failed product tests, product usage data or maintenance action reports. All available data sources currently collecting knowledge for other primary uses should be investigated about their potential applicability for the envisioned maintenance and repair support systems.

Due to the large number of product variants and options it is unlikely that for each and every product configuration enough data are available to create a dedicated model. Instead, it is an objective to research the possibility of applying a model and its insights also to other, similar products. In this process commonalities between the different products should be identified allowing conclusions by analogy between the products and use them to derive support for maintenance workers dealing with unseen product variants. This is a requirement to adapt to new products or variants with small lot sizes. Hence, maintenance workers can be assisted with the required information about expected causes for equipment failure, provided with information about what spare parts are most likely required and when maintenance actions should be scheduled in advance.

Approach

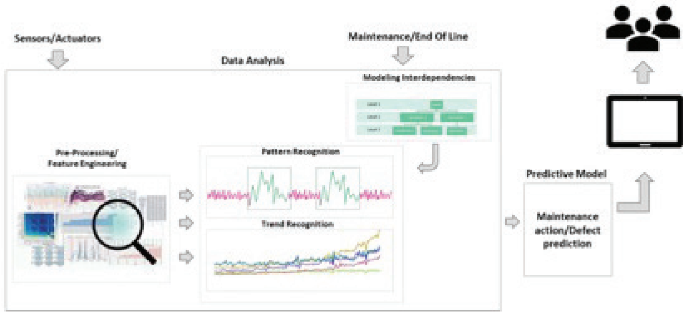
This project follows a fully data-driven approach where at the beginning of the project the available data sources of the industrial partner are evaluated according to their potential use in this project. In an explorative data analysis phase, the data sources are matched to the information needed to solve the posed questions. This matching shows the potentials and shortcomings in the available data sources highlighting where additional work or knowledge bases are required.

In the next step, the data are used to generate models by using machine learning approaches. These models are crucial for the approach, since they will be used to derive the support actions suggested to the workers from the data describing the case at hand. The models cannot be derived from a single data source but additionally require an interaction with workers to incorporate their knowledge.

Expected and Achieved Results

The project aims at the creation of predictive models to support maintenance workers by suggesting (1) components potentially responsible for failures, and (2) scheduling and type of maintenance actions. These models are derived in a data driven manner from currently available data sources and also knowledge captured by employees on a daily basis. To do this, the data and knowledge are analysed and transformed to train models by means of machine learning. In this process, potential missing information is identified leading to a plan on how to improve and adapt the data collection in the future.

Based on the collected data and the already existing product structure, the devices are split into components. Different error pattern observed in the past are then matched to the components, therefore creating the basis to suggest error causes and affected components for maintenance work. This is accompanied by a wearout prediction to estimate the life time of selected parts. Hence, the wearout prediction is essential to schedule necessary maintenance actions in advance.



Status / Progress

The project started with an intensive knowledge transfer between the partners involved in the project. Site visits and workshops provided an ideal platform to exchange knowledge about the conditions in manufacturing and maintenance. This knowledge is necessary to understand and interpret the data sources. The data in these sources were predominantly collected for other purposes, hence, they had to be transformed and re-evaluated for the current task at hand. This was done in two steps; firstly, by the means of exploratory data analyses, including correlation analysis, event and trend identification. Secondly, the interpretation and validation of the results regarding their applicability for the project's objectives.

An important preparation for the modelling is the component split of the investigated products and devices. The component split is the lowest level of granularity on which repair actions can be based on. This means, that in case of a necessary repair, the maintenance personnel might get the suggestion to check or replace one or multiple components. Moreover, we build models to predict a future failure of a device. For that purpose, we merged data from a final test system (end of line test) with service data and information about the countries where the devices have been shipped. The predictions results show that the interaction between country codes/average temperature of countries and final test system data leads to statistically significant predictions which can be used in an assistance tool.

When switching from repair to maintenance actions, the prediction of component wearout is currently investigated. However, since a large part of the data are not annotated, we work on methods to automatically annotate maintenance data, so that we can then build and train models to predict the wearout of components.

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AREA 3

MFP 3.2-2 ConMon

Scalable Condition Monitoring System for Test Environments

Area 3 - Cognitive Decision Support Systems

Project ID:	MFP 3.2-2
Project Title:	Predictive Maintenance for Products
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	36 Months, 01.01.2018 - 31.12.2020
Strategic Volume:	20 %

Work Packages

WP 1: Live Data Collector Prototype

WP 2: Model for Forecasting

WP 3: Visual Analytics Prototype

WP 4: Evaluation and Improvement

WP 5: "Strategic Project" - Data Analytics Methods Base

Company Partners

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The modern industry machines are endowed with multiple sensors producing huge amount of data. This also applies for automotive engine testbed where the durability of an engine is tested applying numerous sensors. The biggest challenge thereby is to collect and extract valuable knowledge from this data.
This task becomes even more complex since the data being generated by the sensors are multivariate time series. To be appropriate, to gain valuable insights from this data, one must possess expert knowledge in data analysis of time series data, as well as domain knowledge in automotive engineering. Yet, a testbed engineer is an expert in his domain but rarely in data analysis.
Thus, there is a need on a tool that can help the testbed engineers to readily analyse their data and gain valuable knowledge out of it. This knowledge can be for instance applied in for predictive maintenance, condition monitoring or for anomaly detection.

A durability test of an engine is divided in so-called cycles. The test cycle is defined by a given engine speed and is repeated multiple time until the target operating hours are reached. During a durability test, hundreds of measurement signals (in further text, channels) are measured and stored continuously.
Basically, the results of each cycle should be the same. However, in real live scenarios this is often not the case. When this happens, we are talking about anomalies. Given that such a durability test can take up to 1000 hours and involves multiple sensors, makes it very hard to detect such anomalies at an early stage of the test.

Goals

The goal of this project is to provide data- and visual analytics tools that can be used to detect anomalies cyclic data of automotive testbeds. The methods should be able to deal with large multivariate time series data and be used by domain experts (i.e., engineers) with limited or no knowledge in data analysis and visualisations. Using the provided tools, it should be possible to monitor and forecast the conditions in each cycle of a durability test. To achieve this, it is necessary to not only use data produced by the sensors but also provided by the engineers. The latter is done by providing the engineers the opportunity to deliver feedback that is then incorporated into the system.

Approach

There exist several state-of-the-art algorithms that can be used to define a forecast model. This, however, requires an extensive literature review to analyse, which methods better applies to industrial data. Thus, within the scope of this project, we investigate different algorithms to detect anomalies in multivariate time series and to forecast the durability test.

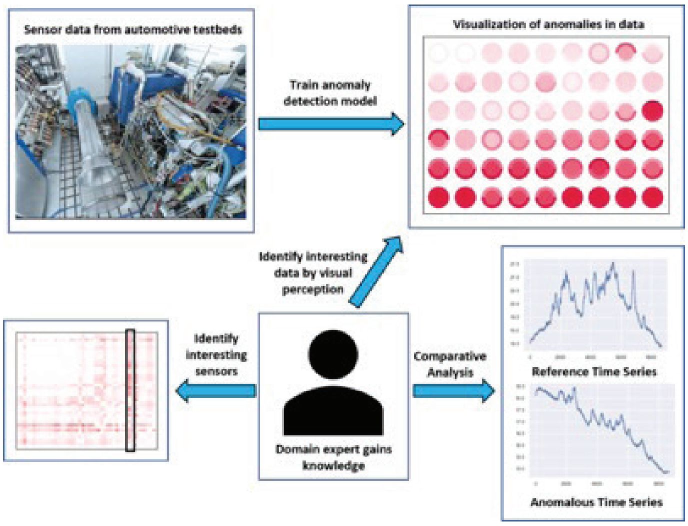
For the visual analytics tool, however, there exist powerful visualization libraries that provide different interactive 2D visualizations. These visualizations provide a good base to support user to visually navigate through the data and explore them to gain insights and draw important conclusion. However, the literature emphasizes the strength of a glyph-design when it comes to encode multivariate data and readily convey the spatial relationship.

Expected and Achieved Results

In this project, we propose an interactive visual analytics tool that displays the iterations of a durability test as a collection of color-encoded cycle glyphs. To do so, we aim to help the engineers to readily monitor the test and to detect potential anomalies. To achieve this, the engineer selects one glyph (or iteration) and the color of the remaining glyphs (or iterations) shows how much they deviate from the selected one: the darker the color of a glyph is the more it deviates from the selected one.

To calculate the anomaly score, we apply individual Machine Learning approaches (correlation-based anomaly detection, regression-based anomaly detection) which we have carefully selected considering their accuracy in detecting anomalies in multivariate time series data using 5-fold cross-validation.

Our visual analysis tool has been evaluated by the experts in the field with a pair analysis study. During this test, we investigated how the domain experts work with the proposed tool to detect anomalies on their daily analysis goals. The study has revealed that our tool aids the daily work in automotive testbed environments for two reasons. First, the visual analytics tool helps engineers to analyze the entire testbed dataset and not only a subset of well-known sensors. To do so, the engineers are able to investigate the correlation between the attributes (e.g., temperature and pressure sensor) and not only each attribute on its own. Second, using our tool the engineers are able to readily detect anomalies and explore their sources.



Summarized, our visual analytics tool provides promising methods to address the specific problems associated with automotive testbeds: analyzing multivariate time series and finding anomalies in reoccurring processes. The process and the results of the pair analytics study are published in BigVis2020, co-located with the 23rd International Conference on Extending Database Technology (EDBT 2020) & 23rd Intl. Conference on Database Theory (ICDT 2020. Furthermore, we evaluated the accuracy of the used algorithms for anomaly detection in multivariate time series data performing cross-validation.

Progress

This project officially started in April 2018. In it, Pro²Future is working with our Company Partners AVL, TU Graz Institute of Computer Graphics and Knowledge Visualisation, and TU Graz Institute of Interactive Systems and Data Science towards the creation of visual- and data analytics tool that can be used to detect anomalies cyclic data of automotive testbeds. We have already deployed our first prototype and evaluated it with the domain experts using data from an automotive engine testbed. Recently, we are testing different methods to analyse the root-cause of the anomalies. The most accurate method will be added in our visual analytics tool as an additional feature to identify the anomalies and established a timeline from the normal situation up to the time the anomaly occurred.

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AREA 3

StratP 3.4 SUPCODE

Supporting Cognitive Decision Making

Area 3 - Cognitive Decision Support Systems

Project ID:	StratP 3.4
Project Title:	Supporting Cognitive Decision Making
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	36 Months, 01.04.2019 - 31.03.2021
Strategic Volume:	100 %

Work Packages

WP 1: (Data) Analytics Methods Base & Comp. (Data) Analytics

WP 2: Decision Making Methods Base & Comp. Decision Making

WP 3: Secure Data Transmission

WP 4: Visual Analytics

WP 5: Dissemination

WP 6: Project Management

Academic Partners

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Industry 4.0 is considered as the "fourth industrial revolution" that either fully automatizes the production in the manufacturing industry or optimizes the collaboration of workers and machines. This is only possible when using different helping operators that facilitate the entire product life cycle, such as the decision support assistance systems. The power of the decision support systems lies on providing immediate assistance in situations where human judgment disregards the reactions times. This is considered as highly important particularly in risky and uncertain conditions where making a poor selection might cause catastrophic consequences for humans and the operating environment. What makes these systems cognitive is that they apply methods that simulate the estimation and the thinking process of the humans to choose one option from a set of possibilities (Definition of decision-making methods & computational decision making). In order to enable companies to utilize such assistance systems it is paramount that data collected at the production site and sent to an analytics entity is sufficiently secured. This can be achieved by providing a secure connection (Secure Data Transmission). Another concern when working with cognitive decision support systems is the transparency. The outputs of the decision-making processes are often too complex even for the experts, to understand. Yet, this lack of transparency can be a key problem in many applications. In order to tackle this issue, there is a need on tools that can be used for e.g., to explain/explore predictions/decisions made by the applied model(s) (Visual analytics).

Goals

To support human decision making, Area 3 defines two objectives:
(1) Combine data-driven approaches with configuration management methods and simulation environments in order to provide a reliable, trustworthy (data) basis for decision making.
(2) Provide this objective basis for decision making to humans in such a way that it takes into account their cognitive capabilities (e.g., information filtering in stress situations) as well as the situation/context in which the decision has to be made (e.g., within production process versus design process) in order to ensure timely and optimal decisions.

This strategic project fosters these Area objectives by strategic research activities considering the following context:

- A secure data transmission module will be applied and extended that allows to transmit data from production site to assistive system.
- To ensure that end-user understand why the system made a particular decision, this project further focuses on state-of-the-art visualization tools (2D, 3D) and visual analytics methods that are used, e.g., to explain/explore decisions made by system, the applied model(s) respectively.

- The visual analytics tool can further be applied to support scheduling, performance monitoring, and anomaly detection for the manufacturing systems that might help the end-user in her decision-making process.
- The simulation of scheduling and re-scheduling after expected (predictive maintenance) and unexpected changes (e.g. down-time of machines due to failures) allows for a better resiliency of manufacturing processes. The (further) development of algorithms can therefore help in optimizing the design of production systems and schedules for shop floors in cases of stochastic failures.

Approach

- **(Data) Analytics Methods Base & Computational (Data) Analytics** In order to build this reliable, trustworthy (data) basis for decision making we will create a collection of methods which allow us to collect data, facts, rules, engineering models, simulation models, etc. for a specific decision-making process within a specific application scenario. A specific challenge will be the integration of different methods into hybrid approaches which combine the advantages of the individual approaches, e.g. integration of model-based and data-based approaches. In order to prove the reliability and trustworthiness of the resulting data/facts basis it will be crucial to invest effort in the creation of training and test data sets which can be utilized as gold standards in order to benchmark the approaches and tools being developed.
- **Decision Making Methods Base & Computation Decision Making** Decision support has to be personalized (to the individual human cognitive capabilities), contextualized (to the specific decision situation), and domain-specific in order to lead to timely and optimal decisions. Proven computational decision-making support mechanisms are visual analytics, (data-driven) recommender- and adaptable systems as well as simulations. Our aim is to synergize these methodologies in computational prototypes, enhancing decision-making support. Furthermore, we intend to implement specialized "industrial decision support" tools tailored to specific application domains. As with all human-machine environments, careful evaluation of the resulting methods and tools in real-world environments will be crucial to the success.
- Applying data transmission security in decision support assistance systems used in the manufacturing industry methods to protect company data
- Using visual analytics and data analytics methods to support transparency in decisions/models made/applied by/in decision-support systems in manufacturing industry
- New insights gained about the application possibilities or interlocking of data analytics and visual analytics

Expected and Achieved Results

Decision support has to be personalized (to the individual human cognitive capabilities), contextualized (to the specific decision situation), and domain-specific in order to lead to timely and optimal decisions. Proven computational decision-making support mechanisms are visual analytics, (data-driven) recommender and adaptable systems. To contribute with regard to the later, we worked on a tool that should assist the users in analyzing their data by recommending the analytical methods to be used as next. For the recommendations, we observe the current analysis process and adapt the information space to what the user prefers and needs.

First, we worked on human-in-the-loop approaches for interactive data classification and comparison, by integrating active learning algorithms and similarity search methods with high-dimensional data analysis (see Figure 1). Second, we worked on novel concepts how eye tracking, as a novel user sensing modality, can be leveraged to detect user interest in visual data analysis, and support adaptive systems for data exploration. In a third line of research, we have developed concepts for user guidance in complex visual data exploration applications. A set of design guidelines was developed and analyzed.

In order to advance the field of Visual Analytics it is very important to collect and discuss the state-of-the-art in particular sub-fields. Together with collaborators from the University of Utah we surveyed existing work on multi-variate networks. In collaboration with US and UK colleagues we summarized the state-of-the-art on how to analyse interaction provenance data that is collected while users perform an interactive visual analysis. Besides these activities, we performed original research on the following topics: (1) guidance, (2) tabular data analysis techniques, and (3) onboarding. For the purpose of flexibly ranking tabular multi-variate data we continued the development of the Ordino visual analysis application, designed the novel Taggle visualization technique, and extended it with a support view that allows users to statistically confirm visual patterns. In cooperation with Prof. Aigner and his group at FH St. Pölten we designed and evaluated how to effectively onboard users to new visualization techniques.

Part of the project is related to the work in demonstrator project DP3. Classification and machine-learning are important methods for flexible production systems and adaptive scheduling. Here, data-driven approaches to optimize the configuration of production systems have been combined with simulation approaches used to determine the impact of changed configurations on the production system in the future. The new approach has been partially presented at the intermediate evaluation for the common research program of Pro2 Future and the Center for Digital Production.

The system consists of three components: (i) a classifier system capable of learning machine configurations given a particular product and the current state of the machine and tools, (ii) a scheduling and simulation system that is capable of re-organizing the production schedule if changes are required, and (iii) an integration component that links and controls the data-flows.

Web-based technologies are used to provide the technical connectivity. The scheduling component provides the means to rearrange the production schedule. However, this re-organization has again effects on the machine and tools usage.

Frequent Itemsets Mining is a fundamental mining model in Data Mining. It supports a vast range of application fields and can be employed as a key calculation phase in many other mining models such as Association Rules, Correlations, Classifications, etc. Many distributed parallel algorithms have been introduced to confront with very large-scale datasets of Big Data. However, the problems of running time and memory scalability still have not had adequate solutions for very large and “hard-to-mined” datasets. We proposed a distributed parallel algorithm named DP3 (Distributed PrePostPlus) which parallelizes the state-of-the-art algorithm PrePost+ and operates in Master-Slaves model. Slave machines mine and send local frequent itemsets and support counts to the Master for aggregations [1]. In the case of tremendous numbers of itemsets transferred between the Slaves and Master, the computational load at the Master, therefore, is extremely heavy if there is not the support from our complete FPO tree (Frequent Patterns Organization) which can provide optimal compactness for light data transfers and highly efficient aggregations with pruning ability. Processing phases of the Slaves and Master are designed for memory scalability and shared-memory parallel in Work-Pool model so as to utilize the computational power of multi-core CPUs. We conducted experiments on both synthetic and real datasets, and the empirical results have shown that our algorithm far outperforms the well-known PFP and other three recently high-performance ones Dist-Eclat, BigFIM, and MapFIM. Furthermore, a secure data connection framework has been developed, and it has been deployed at the pilot factory Vienna. To this end, a hardware component together with AVL and this component has been adapted to the context of data analytics in industrial settings.

Status / Progress

This project officially started in April 2018 and will last until April 2021. In it, Pro²Future is working with our Scientific Partners from Institute for Interactive Systems and Data Science (TU Graz ISDS), Institute of Computer Graphics and Knowledge Visualisation (TU Graz CGV), Institute of Computer Graphics (JKU ICG), Institute for Application-oriented Knowledge Processing (JKU FAW), PROFACTOR GmbH, and Evolaris next level GmbH to foster the research objectives of the area.

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AREA 3

MFP II 3.1.1 VAPS
Visual Analytics for Production Systems

Area 3 - Cognitive Decition Making

Project ID: MFP II 3.1.1
Project Title: VAPS - Visual Analytics for Production Systems
Project Lead: Dr. Belgin Mutlu
Pro2Future GmbH

Duration: 48 Months, 01.04.2021 - 31.03.2025
Strategic Volume: 18 %

Work Packages

WP 1: Project management

WP 2: Dissemination and exploitation

WP 3: Visual Analytics Tools for monitoring tasks in BU Band

WP 4: Visual Analytics Tools for monitoring tasks in BU Bramme

Company Partners

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Academic Partners

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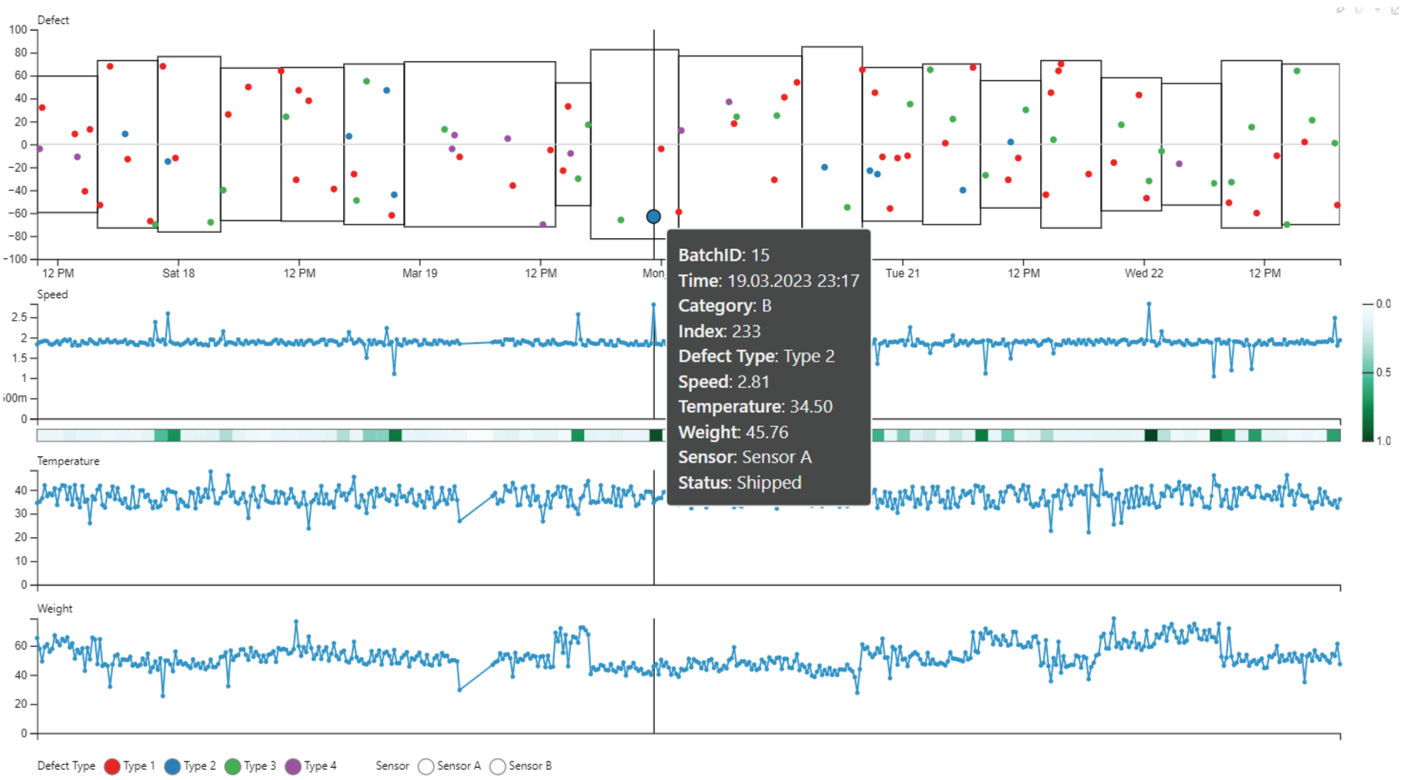
The objective of the project is to develop a prototype for an online visual analytics application. To achieve this goal, the project focuses on creating dashboards using Microsoft Power BI. These dashboards facilitate interactive and visual connections between various datasets, such as process data and segment data. To enhance user engagement, the project also devises innovative interaction concepts and generates user-specific visualizations. A pivotal aspect of this endeavor involves conducting statistical analyses based on an existing dataset. By leveraging the available data, the project aims to derive meaningful insights through data analysis. This approach not only aids in uncovering patterns and trends but also guides the development of effective visualization strategies within the Power BI dashboards.
The ultimate aim is to empower users to intuitively explore and comprehend complex data relationships and trends. The utilization of Microsoft Power BI as the platform for this prototype underscores its capability to provide a seamless and user-friendly environment for data visualization and exploration. The development of interactive dashboards aligns with the overarching objective of offering a dynamic and engaging experience to users. By customizing visualizations to cater to user preferences and needs, the project seeks to elevate the effectiveness and relevance of the analytics application.
In summary, the project's core mission is to construct a prototype for an online visual analytics application. This is achieved by crafting interactive dashboards using Microsoft Power BI, which facilitate visual exploration and interaction with diverse datasets. Through data analysis, statistical evaluations, and the creation of tailored visualizations, the project aims to empower users with valuable insights and a user-centric analytics experience.

Goals

Use Case 1 (BU Band)
The primary objective is to construct a prototype for an online visual analytics application. Dashboards within Microsoft Power BI facilitates interactive exploration, connecting process data with segment data. To achieve this, interaction models, user-specific visualizations, and statistical analyses based on existing data are developed. Key exploration areas include replacing current analysis tools, linking errors to process data, defect identification on coils, statistical defect cause analysis, and expediting analysis through visual data analysis and direct database connectivity.

Use Case 2 (BU Bramme)
This scenario focuses on interactive projection data visualization to identify variables influencing fault types. Microsoft Power BI is used to create both interactive and static dashboards. The goals encompass unifying reporting architecture, visualizing defects on slabs through projection, analyzing influencing factors of defect types like OZE, and representing work processes interactively using resource time scales.



Custom Visual "Multiple Stacked Charts"

Use Case 3 (Consulting): This case entails consulting services to aid in selecting appropriate visualization types. Expertise in perception-optimized design and data preparation is shared to enhance visualization effectiveness. Collectively, these use cases drive the creation of an innovative online visual analytics framework, improving data interpretation, analysis efficiency, and decision-making processes.

Approach

The project methodology is based on a systematic approach that seamlessly combines technical expertise and strategic understanding. It starts with the initial pre-project phase, where we gather all the necessary requirements. This initial phase sets the tone for subsequent phases, which include project kick-off meetings, extensive research analysis, joint co-design, iterative feedback and refinement loops, and finally preparation for launch. The development concludes in the final operational phase, where the dashboards created are used by the end users and embody the collective essence of the whole process.

Expected and Achieved Results

Use Case 1 (BU Band)

- Successfully delivered 4 use cases
- Created dashboards for an overview on warehouse capacities and material flow
- Created custom Power BI visual for quick analysis and comparison of hundreds of parameters

Use Case 2 (BU Bramme)

- Successfully delivered 4 use cases
- Publication of custom visual for efficiently comparing multiple parameters over a common axis on Microsoft AppSource (https://tinyurl.com/t6xmya92)
- Created three custom visuals tailored to the needs of end users

Use Case 3 (consulting)

- Successfully created design process guidelines for dashboard and provided consultation to several departments

Status / Progress

The project has made significant progress in establishing a solid foundation for the planned online visual analytics solution. At this stage, significant progress has been made in several key areas:

1. Use Case Development: The project has successfully developed comprehensive use cases that serve as blueprints for the creation of interactive dashboards (see figure). These use cases align with specific business objectives and user requirements, acting as guiding principles for the subsequent development stages.
2. Technical Framework Implementation: A substantial portion of the technical framework has been implemented. Microsoft Power BI has been harnessed to construct interactive dashboards, bringing the envisioned online visual analytics application to life. The design of comprehensive interaction models and user-specific visualizations is underway, ensuring an engaging and intuitive user experience.
3. Data Analysis and Visualization Prototyping: The data analysis phase is well underway, leveraging existing datasets to derive meaningful insights. Statistical evaluations have yielded valuable patterns and trends, serving as the foundation for data-driven visualizations. Prototypes of these visualizations are in the process of being developed, with initial feedback indicating promising results.
4. Consultation and Collaboration: Collaborative efforts have borne fruit, with cross-functional teams contributing insights from different business areas. The consultation process on appropriate visualization types has begun, facilitating a common understanding of perception-optimized design principles and data preparation techniques.
5. Iterative Refinement and Feedback Integration: The project has embraced an iterative approach, allowing for continuous refinement based on user feedback and evolving requirements. This iterative cycle ensures that the interactive dashboards evolve to align more closely with user needs and strategic goals.

In summary, the project stands at an advanced stage of development, with use cases defined, technical implementation underway, data analysis and visualization prototyping in progress, and collaboration efforts yielding valuable insights. The project's strength lies in the synergy of cross-functional teams, technical proficiency, and strategic vision, all of which highlight its capability to provide an effective online visual analytics solution.

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AREA 3

MFP II 3.1.2 PreMoBAF

Data-driven methods for predicting and monitoring the behaviour of Blast Furnace and Electric Arc Furnace

Area 3 - Cognitive Decition Making

Project ID:	MFP II 3.1.2
Project Title:	PreMoBAF - Data-driven methods for predicting and monitoring the behaviour of Blast Furnace and Electric Arc Furnace
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	48 Months, 01.04.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Project Management
WP 2: Dissemination and Exploitation
WP 3: Prediction of the thermal behavior
WP 4: Identification and prediction of anomalies
WP 5: Rule and Preference Learning
WP 6: Characterization of the raw material
WP 7: Modeling the deviation from process models

Company Partners

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Blast furnace (BF) and electric arc furnace (EAF) are key processes in iron and steel production. The complex dynamics within these furnaces pose a challenge for accurate modeling, primarily due to the inaccessibility of the internal processes for direct measurement. Consequently, process operators heavily rely on their experience to select appropriate measures for identifying and rectifying deviations from normal operational conditions.

While first-principle modeling has been considered to be a natural way for understanding the operations of production processes in ironmaking, constructing such models has been exceptionally demanding due to the process complexity. The underlying complexity of the mechanisms inherent in these dynamic systems has proven to be quite formidable. As a result, the resultant models are somewhat constrained in their practicality due to their heavy reliance on assumptions, which are necessary to simplify them. This, however, comes at the expense of accurately capturing the nuances of the real process. Conversely, more intricate first-principle models which closely resemble the actual process can pose challenges due to the excessive number of parameter needing approximation, as there is no established theoretical guidance on the parameter values. Attempts have been made to employ data-driven techniques to model the intricate behavior of both the blast furnace and the electric arc furnace, albeit with limited success. While existing models have managed to capture certain aspects of the process dynamics, they fall short in revealing the underlying mechanisms at play. Due to this "black box" characteristic of the models, the acceptance, applicability and thus the benefit in the industrial context is limited.

The objective of this project is to leverage data-driven approaches, coupled with causal methods and explainable AI (xAI), to gain a deeper understanding of the internal dynamics governing blast furnace and electric arc furnace operations.

Goals

With the overarching goal of understanding inner dynamics of the blast furnace and electric arc furnace, several perspectives of achieving this goal were established. These are focused around: (1) the detection of deviations from normal operating conditions, (2) modeling of the temporal behavior of the thermal and chemical properties during blast furnace operation (3) characterization of the raw material in electric arc furnace operation and (4) prediction of deviations from established EAF process models.

These goals are achieved through the application of data analytics techniques and the development of suitable machine learning and deep learning models based on the findings from the evaluation of

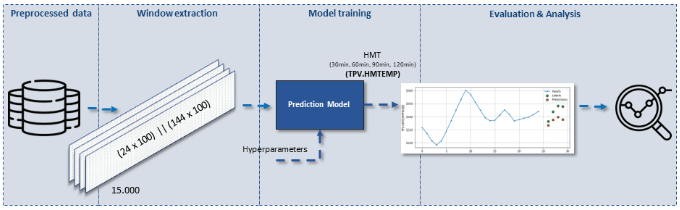

Figure 1: Simplified diagram of the modelling approach

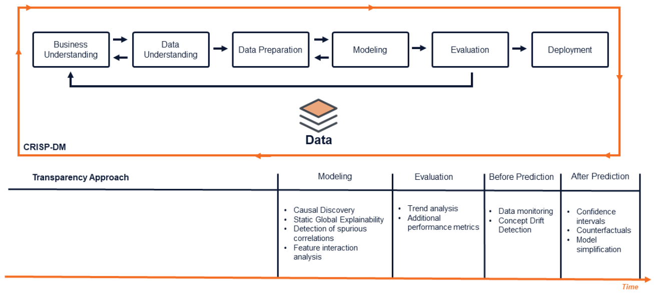

Figure 2: CRISP-DM methodology and concept of presented Transparency Approach

existing process and control data. The results provided by these machine learning models should be supported by explainable AI methods to provide a reasoning for the results of the algorithmic decision making. In addition, large emphasis is placed on utilization of causality-based methods which utilize observational process data for discovery of underlying causal generative mechanisms. Inputs from these methods not only improve the performance and transparency of machine learning models, but also drive a knowledge discovery process.

Approach

In order to model the behavior of these Ironmaking processes several approaches are utilized. In practice, when dealing with industrial data, there are distinct challenges like: discrepancies arising from sensor and equipment wear and tear, periods of shutdown, correlated data, data imbalance, missing values, and temporal inconsistencies due to manual input. Data pre-processing phase comprises three steps: data cleaning, filtering out downtime periods, and finally adjusting data through domain-specific rules (see Figure 1).
In the modeling phase, due to transparency requirements, methods such as RandomForest, Gaussian Regression, and Support Vector Machine were used to establish a baseline performance. This baseline performance was compared with more complex models based on LSTM mechanism, Autoencoders, and even more complex approaches such as Temporal Fusion Transformers to establish performance-transparency tradeoff. From the perspective of causal modeling, we utilized methods such as: FCI, LiNGAM and ANM. Additionally, methods such as PCMCI were used to model the temporal behavior of the previously mentioned ironmaking processes. Finally, state-of-art approaches for xAI (SHAP, Anchors, LIME, Ceteris Paribus, etc.) were utilized to discover explanations on the local and global level. Furthermore, from the perspective of reliability of the ML models, uncertainty metrics can be utilized to address issues with the model parameters (epistemic uncertainty). Confidence intervals and Trust Scores are some of the methods which were utilized in identification of ML model uncertainty.

Expected and Achieved Results

The overall objective of the project is to develop a transparent approach for modeling and understanding certain aspects of the process behavior in ironmaking processes, i.e., blast furnace and electric arc furnace operation. In the first stage of the project focus is put on modeling and predicting thermal behavior of the blast furnace. In order to achieve this goal, we developed a transparency approach, which is based on the well-known CRISP-DM methodology (see Figure 2) and takes into account intricate specifics of the blast furnace operation. This approach goes beyond development of a ML model for predicting thermal state indicators and provides an overall set of methods which should be utilized to ensure stable operation and utilization of ML model results.

During the model development, methods for causal discovery and global explainability have been deployed to ensure valid basis model training. Furthermore, we proposed additional model performance metrics developed from the case specific blast furnace operation requirements. Additional model performance metrics provided an insight into ML model stability and additional basis for model evaluation and finally, ML model selection. We identified use case appropriate methods for monitoring data provided to the ML model and reducing model uncertainty through concept drift detection. Finally, we proposed a collection of methods that, once deployed, provide an insight into the reasoning behind model prediction after inference time through model simplification and counterfactual instance explanation. By providing model simplification and counterfactual explanations, additional insights are provided, not only into the reasoning behind the ML model, but also into the complex blast furnace process. This additional layer of transparency allows the extraction of various process rules and overall inference logic.

Status / Progress

In the first stage of the project focus was put on modeling and predicting thermal behavior of the blast furnace. Conversely, in the second stage of the project, focus is put on detecting anomalous blast furnace process state i.e., leveraging causal insights for anomaly detection. Drawing inspiration from state-of-art research, we utilize causal knowledge to enhance the detection of anomalies. This approach involves constructing a causal structure that provides insights into relationships between the observed process variables. To build this causal structure, we employ algorithms designed for structure learning such as FCI, GES, etc. Following the domain expert validation of the main causal structures of the causal graph, we started with the analysis of graph structure properties. For in-degree property provides information on the number of incoming connections a node has and can potentially indicate the importance of this observed variable within the process.

These nodes act as "hotspots," indicating areas of heightened interest for anomaly detection. In the current state, through intensive collaboration with domain experts we were able to develop a causal graph (data-driven, domain verified) which reliably captures the complex dynamics of blast furnace. Additionally, through utilization of graph analysis methods we found hotspots node and currently utilizing data-driven modeling for establishing a baseline anomaly detection performance and evaluating against other state-of-the-art methods such as Autoencoder-based approaches for anomaly detection. The overall approach is depicted in Figure 3.

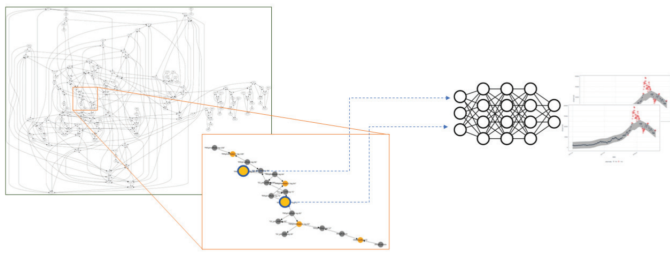

Figure 3: Overall approach for Anomaly detection based on causal information.

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AREA 3

MFP II 3.3.3 PREMAC
PRedicitive Maintenance für Krankomponenten

Area 3 - Cognitive Decition Making

Project ID:	MFP II 3.3.3
Project Title:	PREMAC - Predictive Maintenance für Krankomponenten
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	24 Months, 01.04.2021 - 30.09.2023
Strategic Volume:	18 %

Work Packages

WP 1: Project management
WP 2: Dissemination and exploitation
WP 3: Creation of the Health Index
WP 4: Creation of a predictive model
WP 5: Data quality assessment
WP 6: Feasibility study digital wire break detection
WP 7: Standardization

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The efficiency and safety of heavy industries depend significantly on crane systems, making the condition of critical components, such as wire ropes, vital for seamless production processes. However, continuous stress, wear, and tear on wire ropes can lead to fatigue and unforeseen failures, resulting in costly downtime and safety hazards. Our ambitious project focuses on developing advanced predictive maintenance approaches for wire ropes in crane systems. Central to our strategy is the timely detection of wire break development, a crucial indicator of wire rope health. We delve into various topics, including sensor data dependencies and pattern recognition techniques, to create a robust Health Indicator (HI) that accurately reflects the wire rope's condition. Additionally, we explore the impact of factors like bending cycles and operating time on wire break development.
The primary aim of this project is to create a predictive model that estimates the remaining service life of wire ropes, enabling proactive maintenance planning and timely replacements. By implementing this model, we anticipate substantial improvements in crane system reliability, significant reduction in downtime, and enhanced worker safety.
To achieve our objectives, we thoroughly investigate sensor data dependencies and leverage pattern recognition techniques to develop an accurate Health Indicator (HI). We also analyze the relationship between wire break development and critical factors such as bending cycles and operating time. By drawing insights from these investigations, we aim to create a robust predictive maintenance model for wire ropes.

Goals

The primary objective of our project is to advance predictive maintenance approaches focusing on crane systems. By developing cutting-edge methodologies and leveraging data-driven techniques, we aim to improve the efficiency and safety of crane operations within logistics environments. A significant aspect of our research involves investigating methods to analyze large and heterogeneous datasets commonly generated in logistics operations. These datasets encompass diverse information, such as sensor data, operational logs, and maintenance records. Our goal is to develop effective data analysis techniques that can extract valuable insights and patterns, crucial for informing predictive maintenance strategies.
Central to our project is the creation of a reliable prediction model capable of estimating the remaining useful life of wire ropes in crane systems accurately. This model will utilize data-driven approaches, including machine learning algorithms and statistical methods, to forecast wire rope health and degradation with high precision.
While focusing on the development of the prediction model for

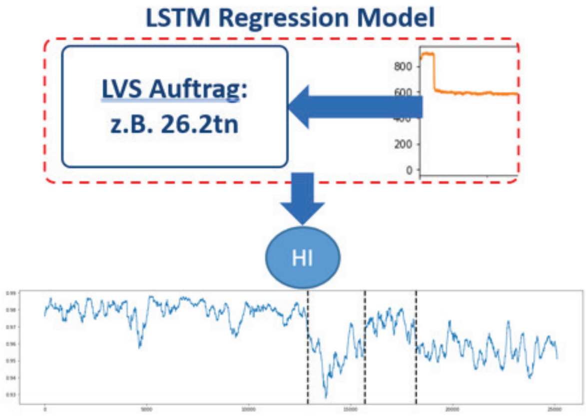

Figure 1: Health Index framework based on LSTM

Crane 220 at Kontiglühe 2 during the initial phase, we envision a transferable model that can be adapted for other cranes, contingent on the availability of relevant data. This transferability will enable wider adoption and scalability across various crane systems, contributing to industry-wide improvements in predictive maintenance practices.

Moreover, we strive to develop approaches that provide optimized recommendations for crane operation and maintenance intensity. These data-driven insights will empower crane operators and maintenance teams to make informed decisions, leading to reduced downtime, minimized maintenance costs, and enhanced overall operational efficiency.

Approach

Our approach to developing advanced predictive maintenance methodologies for wire ropes in crane systems combines the fusion of crane logistics and sensor data, change-point detection techniques, outlier removal based on domain knowledge, and the creation of a Health Index (HI) framework. Leveraging the power of deep learning and integrating domain knowledge, we aim to achieve improved accuracy and interpretability in our predictive model.

Applying change-point detection techniques, we extract cyclic data patterns from the integrated dataset. This help identifying periods of significant change in the wire rope's condition, aiding in detecting anomalies or potential degradation events. Leveraging domain expertise, we identify and remove outliers from the data. By filtering out irrelevant or noisy data points, we ensure the accuracy and reliability of subsequent analyses and predictions.

We aim to develop a novel technique for estimating the Health Index (HI) of the wire rope, leveraging Long Short-Term Memory (LSTM) deep learning architectures. LSTM models excel at capturing temporal patterns in time series data, enabling us to map these patterns to crane logistics data and wire rope degradation trends. To enhance the accuracy and interpretability of the HI, we integrate domain knowledge into the model development process. This incorporation of expertise from crane engineers and maintenance personnel provides valuable context and constraints for the predictive model.

As part of our HI framework, we implement a physics-based approach that considers wire rope efficiency. By combining data-driven techniques with fundamental physics principles, we can achieve more accurate predictions of the wire rope's condition.

To assess the effectiveness of the constructed Health Index, we evaluate it against real wire rope condition data over an extended period of more than six months, encompassing approximately 25,000 operational cycles. This rigorous evaluation demonstrates the HI's robustness and its ability to capture wire rope degradation trends effectively.

In addition to evaluating the HI's accuracy, we employ a novel causal inference-based approach to enhance its robustness and interpretability. This approach helps us identify causal relationships between various factors and the wire rope's health, providing valuable insights for maintenance planning.

Expected and Achieved Results

Health Index estimation: The approach involves the development of a novel technique for estimating the Health Index (HI) of wire ropes in an overhead crane using LSTM Deep Learning architectures. This technique leverages the strengths of LSTM in capturing temporal patterns from time series data. To create the HI estimation model, we map the temporal patterns extracted from the time series data of the wire rope's condition to relevant logistics data. This mapping allows us to correlate the operational history of the crane with the wire rope's degradation trends. By capturing degradation trends, the LSTM model learns to identify patterns and changes in the wire rope's condition over time.

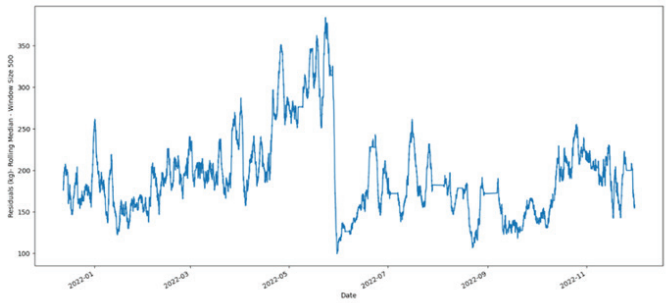

Figure 2: Moving median (window size: 500 strokes) of the absolute residuals of the linear regression over the entire rope life. Training data were selected in the period December.

Efficiency estimation (rope efficiency): The idea behind the efficiency estimation methods is, that the efficiency of the rope increases over a rope's life, and that this can be seen, among other things, by measuring the torque. To achieve this, a regression model is trained for a subset of the data at the beginning of the rope's life using the average torque measurements of cycles, with the avalanche weight as the target value. The model is subsequently applied to all other data and compared to the LVS weight. Residuals between estimated avalanche weight and actual value can indicate a deteriorating rope condition over a rope life.

Causal Effect: The causal effect refers to the impact that a particular intervention has on an outcome variable. This effect is often measured by comparing the outcomes of two groups: one group that receives the intervention and another group that does not. The difference in outcomes between the two groups is then attributed to the intervention. The outcome variable is the dependent variable that is measured. It is the variable that is affected by the intervention variable and is used to evaluate the effectiveness of the intervention. The method is used to calculate the causal effect (Average treatment effect, ATE) of raising and lowering on weight sensor measurement. Differences in causal effect over time should indicate decreased rope efficiency.

Status / Progress

This project aimed to assess rope condition using logistic and sensor data, covering various aspects such as data preprocessing, different methods for estimating rope efficiency and causality analysis. While we faced challenges in accurately identifying wire breaks with current sensor technology, our findings offer valuable insights.

Furthermore, we identified opportunities for future improvement, including the need for fully labeled data and data from multiple ropes to enhance dataset diversity and draw more comprehensive conclusions. In conclusion, this project has contributed significant knowledge to the field of rope condition detection, paving the way for future research. By refining our methods and expanding data sources, we can continue to advance rope condition assessment using sensor technologies.

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AREA 3

MFP II 3.1.4 KAL-GISS
Klassifizierung der Spritzgießverfahren

Area 3 - Cognitive Decition Making

Project ID: MFP II 3.1.4
Project Title: KAL-GISS - Klassifierzung der Spritzgießverfahren
Project Lead: Dr. Belgin Mutlu
Pro2Future GmbH

Duration: 30 Months, 01.10.2021 - 31.03.2025
Strategic Volume: 18 %

Work Packages

WP 1: Project management

WP 2: Dissemination and exploitation

WP 3: Classification and exploration of injection molding processes

WP 4: Evaluation

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To achieve technological advancements in production machines, gaining a comprehensive understanding of their inherent processes is crucial. Data analytics plays a pivotal role in attaining this understanding by processing data originating from these production machines. Specifically, for this project with ENGEL, the focus is on the plastic injection molding process. The data we analyze contains various signals generated by the production machines, encompassing parameters such as pressures, volumes, temperatures, specifics about the manufactured parts, and many more. At ENGEL, a diverse range of products is manufactured, ranging from small toy pieces to large plastic storage utensils, which presents unique challenges as this variety is reflected in the data.

In this project, our primary objective is to create models that can effectively classify and categorize specific features within these production processes. By harnessing the power of data analytics, we aim to gain insights that will enable us to derive insights that help improve the technological advancements in the injection molding process for ENGEL and its customers.

The data preparation process plays a vital role in this project, as it holds the key to discovering insights that hold value to the domain experts. We engage in close collaboration with those experts, working together to develop a robust strategy that takes into consideration all nuances and intricacies of the data. By understanding the challenges presented by the data originating from production machines, we define a set of features that will enable the model to generalize effectively to the underlying process. This important stage of preprocessing then empowers the model to discern patterns and relationships that contribute to improving the understanding of the plastic injection molding process from a data-driven point of view.

Goals

Prediction of injection molding machine specific parameters

The primary objectives of the KAL-GISS project revolve around establishing a robust data analytics pipeline capable of modeling the plastic injection molding process in a versatile manner. By crafting a well-defined set of features and employing customized state-of-the-art machine learning models, we aim to unlock a multitude of possibilities to

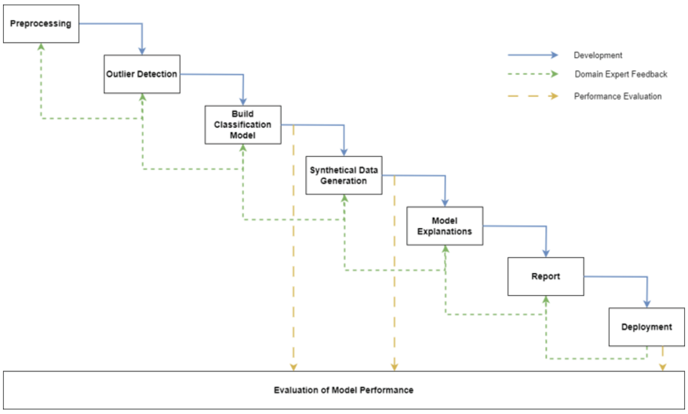

Figure 1: Preprocessing and modeling pipeline

create insights from historical data.
One example application is to infer the type of plastic material that was processed on a given machine for certain samples. This information is of interest to the partner company for various reasons. An example use case would be in service cases where decision support on the probability of certain parameters from the model leads to improvements in maintenance and repair processes that are done by service technicians.

Discovering causal structures in injection molding processes
To make informed decisions, a substantial amount of understanding of the relationships of the process-inherent variables is needed. Opposed to basic correlations, causal discovery can achieve insights that are closer to the true nature of the underlying process. Part of the project was to employ methods that uncover such causal relationships.

Approach

After analyzing the current state of the data, we dedicate a fair share of resources to improve a) the quality of the data and b) our understanding of the data by having the domain experts and their valuable knowledge in the loop. After the data is in a suitable state we start finding sets of features and models that fit this data. Again, this is an iterative process of presenting results and employing feedback from the plastic injection molding area of expertise. As a result, we obtain machine learning models that can predict certain parameters which can provide decision support for the aforementioned scenarios. For discovering causal structures, we intend to use the same, cleaned data that we obtained in the previous step. Different causal discovery algorithms are tested and the found structures are discussed and modified according to the domain knowledge.

Expected and Achieved Results

The expected results include a pipeline (see Figure 1) that takes as input the raw data that stems from the machines in production and outputs data that fits the needs for the downstream tasks such as classification, regression, and causal discovery. This takes care of missing or ill-defined data as well as the removal of samples that are considered anomalies in the given context. Selecting a feature set that is as little as possible but still contains the needed information is also part of this process.

The key contribution of our project lies in developing models that describe the manufacturing processes using preprocessed data. These models serve a dual purpose. Firstly, they have the capability to predict important parameters accurately, enabling stakeholders to make well-informed decisions with confidence. Secondly, these models offer valuable insights into the underlying cause-effect relationships present within the data, shedding light on the fundamental structures governing the manufacturing processes.

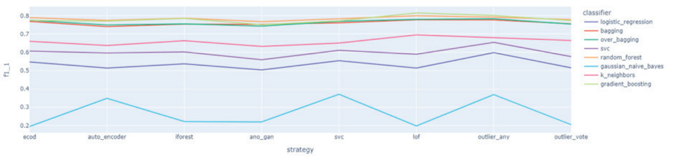

Figure 2: Analysis of the influence of outlier detection methods on the performance of classification algorithms

As of now, the data preprocessing is implemented, and a reduced feature set has been derived that is performing well on some benchmark prediction tasks. We are still in the process of designing causal discovery algorithms to extend the general understanding of the injection molding process.

Status / Progress

As mentioned previously, we have successfully completed the preprocessing stage, which involved a sophisticated outlier removal strategy to address data irregularities. Our focus then shifted to building classification models for predicting parameters of interest, resulting in the fine-tuning of a model to predict the plastic material used in specific production settings. This predictive capability is particularly valuable for cases where the information on the plastic material is unavailable to the partner company.

Notably, our machine learning models have achieved remarkable accuracy (see Figure 2). We developed models that can classify two different plastic materials with 100% accuracy, using only a limited number of features and data samples. For a more nuanced analysis, with the guidance of domain experts, we expanded our model to distinguish between nine classes of plastic material with an 80% accuracy rate (weighted F1 score).

To ensure transparency and comprehensibility, we incorporated explainable artificial intelligence (xAI) methods. These techniques allow us to extract insights from black-box models and present them in a human-understandable manner, making the decision-making process more transparent and accountable.

Currently, our focus is on identifying causal dependencies among various signals from the injection molding process. To achieve this, we are implementing various causal discovery algorithms to uncover the causal relationships between these signals. One promising approach is the creation of causal graphs for different plastic materials. These graphs illuminate the manufacturing process differences for each material, revealing their distinct properties on a causal level. Some materials show significant differentiation due to contrasting physical and chemical properties, while others exhibit more subtle variations, indicating closely related properties with nuanced differences.

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AREA 3

MFP II 3.3.1 ZEWAS

Zeitreihenanalyse zur Erkennung von Wartungsarbeiten an Schweißgeräten

Area 3 - Cognitive Decition Making

Project ID:	MFP II 3.3.1
Project Title:	ZEWAS - Zeitreihenanalyse zur Erkennung von Wartungsarbeiten an Schweißgeräten
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	9 Months, 01.04.2021 - 28.02.2022
Strategic Volume:	18 %

Work Packages

WP 1: Project management

WP 2: Dissemination and exploitation

WP 3: Detection and categorization of maintenance events

WP 4: Creation of a prediction model

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The Perfect Welding division of Fronius International offers welding devices and services to customers on five continents. Data analytics and data-driven solutions are one key aspect to excel in the welding market. In this project, maintenance welding and condition data is analyzed to detect the performed maintenance events and actions. The main objective of this project is the detection of maintenance actions based on the telemetry data collected by the welding machines. The automatic identification of maintenance events will increase the quality and amount of useful maintenance data, helping to overcome the challenge of incomplete maintenance logs posted in many data analytics applications so far. ZEWAS investigated two different approaches for maintenance event detection, one focused on template matching and one based on changepoint detection. The template matching is based on a window-based similarity search using a reference maintenance event. The distance approach used to estimate the similarity is a correlation-based approach. The second approach is based on Pruned Exact Linear Time (PELT) as a change point detection method combined with additional post filtering steps based on a mean ratio and distribution threshold analysis. As a result, we found that these approaches could help to identify maintenance events. The results of both approaches must be validated against maintenance logs. To increase the number of documented events, we analyzed data already logged by the machines, such as changes of component serial numbers, gaps in the otherwise automatically logged condition data, and compared them with the provided maintenance logs. While each of these data sources are potentially not complete, their unification helps us to identify the real maintenance events. The proposed framework based on PELT and extended by post-filtering identified different candidate events of which 75% of candidate events are validated by the maintenance logs. Moreover, the proposed framework showed a drop in the FP (False positive rate) rate of 20% when evaluating for a specific machine.

Goals

ZEWAS aims to detect maintenance events from sensor data, with a focus on changes in the wire core. The wire core is replaced when issues like wire jams occur due to wear. This complex maintenance activity takes minutes, and normal operations see rare occurrences, weeks, or months apart. Predicting wire core changes is crucial for proactive scheduling. However, finding partners with comprehensive logs for evaluation has been difficult. The objective is to detect wire core maintenance actions from welding and condition data, even with in-

Figure 1: An example of an identified maintenance events verified by an entry in the maintenance logs.

complete logs. Automating maintenance logs would relieve shop floor workers from manual recording burdens. In highly optimized manufacturing lines, automatic log generation is valuable, as workers lack time for manual record-keeping. Evaluating the framework requires more documented maintenance actions affecting the wire core. Domain experts suggest considering wire core and wire feed as a single component to increase documented events, though this may introduce higher variability. Nevertheless, this approach helps evaluate the system with available data.

Approach

This section presents the results of how various Machine Learning methods were applied to detect maintenance actions, e.g., the correlation-based annotation for template matching and PELT as change point detection approach. The goal of this project is to test the hypothesis that maintenance actions can be detected from condition monitoring data. Multiple sensors are integrated in each welding device to continuously monitor the components of the welding system. Various measurements such as components temperature and motor currents are collected. In addition to this automatically collected data there are also logs of maintenance actions manually documented by shop floor workers and engineers. Depending on the Fronius customer, these logs proved to be less than complete since the additional effort of meticulously keeping maintenance logs is not feasible in many shop floor environments. This led to the need for new solutions to automatically identify events in the condition data that indicate maintenance actions.

Expected and Achieved Results

Correlation-based annotation

Initially, we used the correlation-based annotation approach for maintenance event detection. This approach consisted of a simple two steps methodology. Firstly, select the relevant maintenance event that is already documented in maintenance logs as a template. Secondly, the pattern of the selected maintenance event is searched in the remaining data. To do this, the data is split up in overlapping windows of a predefined size. Any windows that have a sufficiently high similarity to the template are listed as potential candidate maintenance events. One crucial aspect concerning this approach is tuning the hyperparameters. In this case, we used GridSearch to select the relevant parameters. Moreover, this approach is univariate; therefore, the statistical features are explored and considered as input features for this model separately. One crucial advantage of this approach is the simplicity, that helps to understand and interpret results.

This approach is applied in a particular machine and only the documented maintenance logs are considered in this case. As a results 229 candidate events are identified using the mean of motor current as input feature. The main advantages of this approach are that it can identify a lot of potential candidate events and can identify already documented maintenance actions as shown in the example in Figure 1.

Change Point Detection (CPD) and post-filtering

The proposed framework based on the PELT (Pruned Exact Linear Time) as its central change point detection (CPD) approach is depicted in Figure 2. The framework's aim is to detect real maintenance events with a high sensitivity and low FP rate. In this setup, small subsets of maintenance data together with the completed condition monitoring and welding data are the input data to the framework and the outcome is the list of potential candidate maintenance evets. The framework consists of two core components, namely PELT used to detect initial potential maintenance events and a heuristic post-filtering approach aiming to reduce the FP rate in the potential maintenance events. The post-filtering methods are motivated by the fact that the most informative sensors concerning maintenance events show larger variability

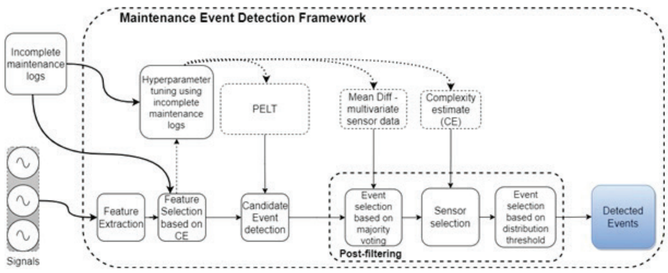

Figure 2: Event detection framework based on PELT and Post-filtering.

and higher absolute values before the performed maintenance event due to worn-out wire feed components. This can be seen in the more significant peaks and valleys of the wire feed motor current before the maintenance event.

The proposed framework had a noticeable impact on reducing the FP rate and showed promising results in detecting maintenance events, particularly with effective post-filtering, but further advancements are needed to handle complex signal changes and improve generalizability across different machines.

To examine the generative nature of our framework, we conducted evaluations using the Microsoft Azure Predictive Maintenance dataset, which is a comprehensive dataset containing sensor data, error logs, and maintenance records. This evaluation aimed to assess the framework's capability to accurately detect maintenance events by utilizing the complete and diverse information available in the dataset. The evaluation demonstrated that the framework outperformed cases with no or only one post-filtering, resulting in improved accuracy and reduced false positive rates without significant impact on sensitivity. These promising results are beneficial for applications requiring low false positive rates to gain trust and acceptance in manufacturing environments.

Status / Progress

In this project, two event detection approaches were deployed and evaluated using welding data and data from a public dataset. Event detection helps to identify already performed maintenance events, thus introducing high sensitivity score by a low FP rate.

The results of correlation-based annotation approach show that already documented maintenance events can be detected. However, the outcome strongly depends on the reference events. This could limit the search results only to a specific pattern provided by reference pattern. Similarly, the results of the CPD with post-filtering shows that the proposed framework can detect already documented events with a high sensitivity rate. Overall, the results are promising in the context of maintenance detection, but only a small number of the maintenance events of wire core and wire feed were available for the evaluation in the welding data. The discussion of the high number of FP in the results with domain experts generated the hypothesis that some maintenance events, such as minor cleaning and adjustments, are not documented yet and show up here as FP events. Finally, the results CPD with post-filtering framework evaluated in comprehensive public dataset are superior in terms of sensitivity and low FP rate. In this experiment, the outcomes showed that the FP rate can be reduced by around 10% on average keeping its original high sensitivity achieved by PELT approach.

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AREA 3

StratP II 3.4.1 SERAM

Supporting users in exploring and reasoning anomalies in multivariate timeseries

Area 3 - Cognitive Decition Making

Project ID:	StratP II 3.4.1
Project Title:	SERAM - Supporting users in exploring and reasoning anomalies in multivariate timeseries
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	21 Months, 01.07.2021 - 30.09.2023
Strategic Volume:	100 %

Work Packages

WP 1: Project management

WP 2: Dissemination and exploitation

WP 3: Literature review

WP 4: Conceptual design

WP 5: Implementation

WP 6: Evaluation

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The increase in large and complicated data sets across various industries has led to a growing need for data analytics tools that provide practical insights to facilitate decision-making. The overarching goal of our project is to create a seamless synergy between human intelligence and AI capabilities, resulting in an efficient collaborative framework. Within this framework, a particular focus lies on seamless identification, exploration, and comprehensive understanding of anomalies in complex multivariate time series data.

Central to this project is the development of an AI system that takes on the task of detecting potential anomalies, while giving human users the tools and techniques to optimize this symbiotic decision-making process. By using state-of-the-art methods such as annotation, machine learning and the meaningful incorporation of domain knowledge, our project aims to facilitate the collaboration between humans and AI.

To realize this objective, we introduce an innovative visual analysis approach, named MANDALA (Multivariate ANomaly Detection And exploration). This methodology employs kernel density estimation for semi-supervised anomaly detection. MANDALA places the power in the hands of users, enabling interactive configuration of normal data parameters, which in turn serves as essential training data for the algorithm. The platform subsequently facilitates the exploration and comparative assessment of anomaly candidates, their related dimensions, and temporal aspects. Our comprehensive visual analysis ecosystem includes customized components, including a scatter plot matrix with semantic zoom capabilities. Here, normal data is visually represented using hexagonal binning diagrams, while scatter plots are used to show candidate anomaly data. In addition, the system supports analyses with a broader scope that includes all dimensions and a narrower focus that is limited to specific pairs of dimensions.

Goals

Assisting users to identify and explore anomalies in multivariate time series data

Visual analytics techniques play a central role in representing complex multivariate time series data in an intuitive and comprehensible manner. Visualizations such as line charts, scatter plots, heatmaps, and time series plots should be used to depict the data's temporal evolution and relationships between different variables. Employing advanced anomaly detection algorithms aids in the automatic recognition of potential anomalies within the dataset which can be then highlighted using one of these visualizations. With the help of interactive interfaces users can delve into the data, zoom in on specific time periods,

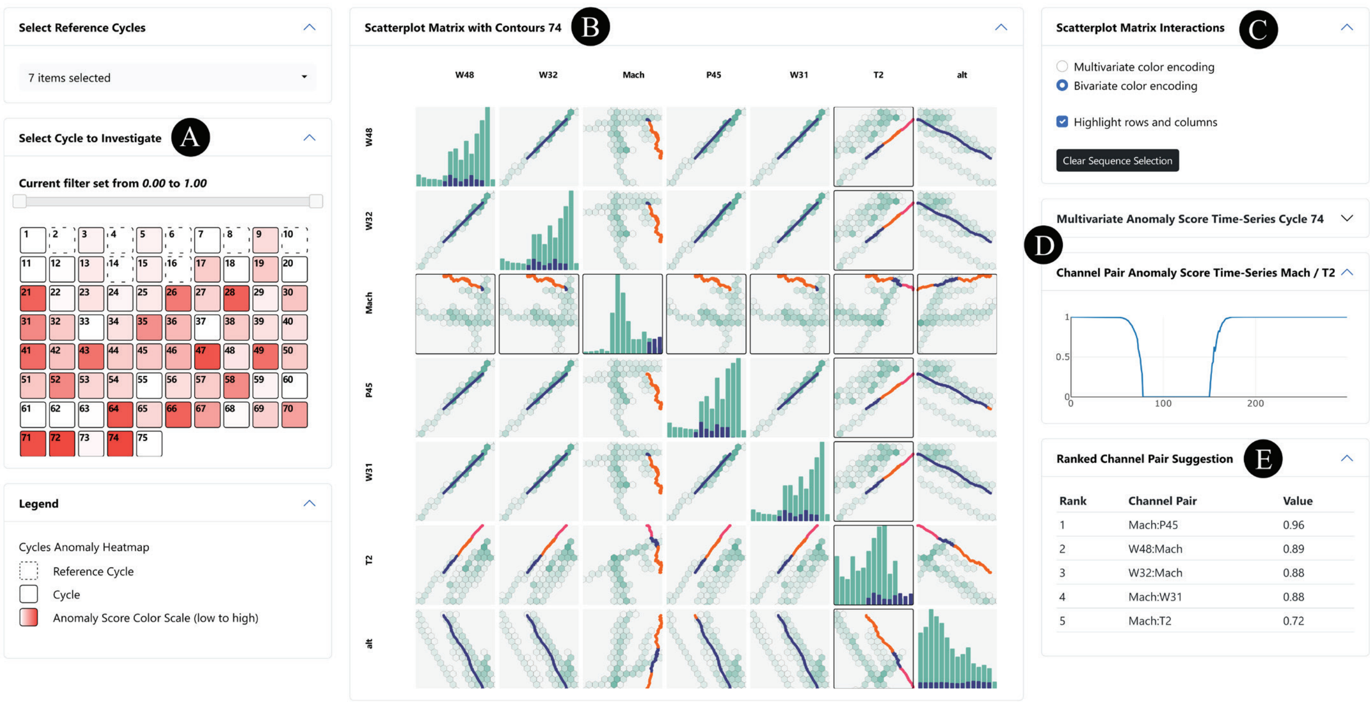

Figure 1: MANDALA – Visual Exploration of Anomalies in Multivariate Time Series Data

and focus on variables of interest. Interactive filters and brushing techniques help users isolate and analyze specific segments of the time series data. With a feedback loop, users can provide feedback on the system's suggestions and accuracy. The AI system can learn from user interactions and adapt its anomaly detection algorithms and guidance strategies accordingly.

Two-dimensional representation to improve the detection of anomalies within a temporal range in a multidimensional space

When dealing with multivariate time series data, it's often challenging to identify anomalies that occur within a specific timeframe. A two-dimensional representation provides a condensed view that highlights the temporal dimension, allowing users to concentrate their analysis on a particular time interval of interest. This technique involves projecting the complex multivariate time series data onto a two-dimensional space while retaining temporal context, enabling a more focused and accessible exploration of anomalies.

Enabling users to identify the dimensions that contribute to the anomaly score in multivariate time series data

In multivariate time series data, each variable or dimension represents a unique aspect of the observed phenomenon. An anomaly score is typically calculated based on the collective behavior of these dimensions over time. Enabling users to identify contributing dimensions allows them to grasp the specific aspects of the data that are deviating from the norm. Anomaly detection algorithms often assign weights or importance scores to each dimension based on their influence on the anomaly score. By visualizing these importance scores, users can discern which dimensions are contributing more significantly to the detected anomalies. This aids in understanding the underlying causes of anomalies.

Approach

The tool uses a semi-supervised learning method using kernel density estimation (KDE) to detect anomalies. It introduces scatter plot matrices (SPLOMs), hexagonal binning plots and line plots as visualization and exploration aids. These techniques allow versatile comparisons between individual dimensions, pairs of dimensions and the whole dataset, while also facilitating temporal analysis. Consequently, it provides adaptable perspectives on the data.

The exploration process facilitates the validation, explication and improvement of anomaly detections derived from the automated KDE-based approach. Users are able to confirm the accuracy of anomalies, provide explanations and refine the anomaly detection process.

Expected and Achieved Results

Figure 1 illustrates the user interface of MANDALA, our visual analytics tool to detect and explore multivariate time series anomalies, their influencing, and temporal scope. (A) The semi-supervised approach requires users to select reference data. The red color encoding highlights anomaly candidate cycles that differ from reference data. (B) The scatterplot matrix features semantic zooming and visualizes bivariate data of investigated anomaly candidate cycles as scatterplots and the distribution of bivariates of reference data as hexagonal binning plots. The diagonal shows the univariate distribution for each dimension of the reference data and the anomaly candidate cycle as two histograms in superposition. (C) The color of scatterplot points can be changed to multivariate or bivariate color-encoding, changing the scope of the analysis. (D) The temporal scope of anomalies can be explored through line plot views. Those views can filter the scatterplot matrix through brushing and linking. (E) Bivariate anomalies are ranked by their anomaly score in the ranked channel pair suggestion view.

Status / Progress

Our MANDALA tool has been officially released and is now accessible through the following link: https://demo1.pro2future.at/#!/.

This tool represents a significant milestone in the domain of anomaly detection and exploration within multivariate time series data.

With the introduction of MANDALA, users are invited to explore a comprehensive platform designed to facilitate anomaly detection and exploration. Through its user-friendly interface and a range of features, MANDALA offers a toolset to effortlessly tackle the complexity of multivariate time series data.

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AREA 3

StratP II 3.4 UNSUDET

Understanding and Supporting Users in Decision-Making Tasks

Area 3 - Cognitive Decition Making

Project ID:	StratP II 3.4
Project Title:	UNSUDET - Understanding and Supporting Users in Decision-Making Tasks
Project Lead:	Dr. Belgin Mutlu Pro2Future GmbH
Duration:	24 Months, 01.07.2021 - 30.06.2023
Strategic Volume:	100 %

Work Packages

WP 1: Project management

WP 2: Dissemination and exploitation

WP 3: Literature review

WP 4: Conceptual design

WP 5: Implementation

WP 6: Evaluation

Academic Partners

JKU Linz, Institute of Computer Graphics (ICG)
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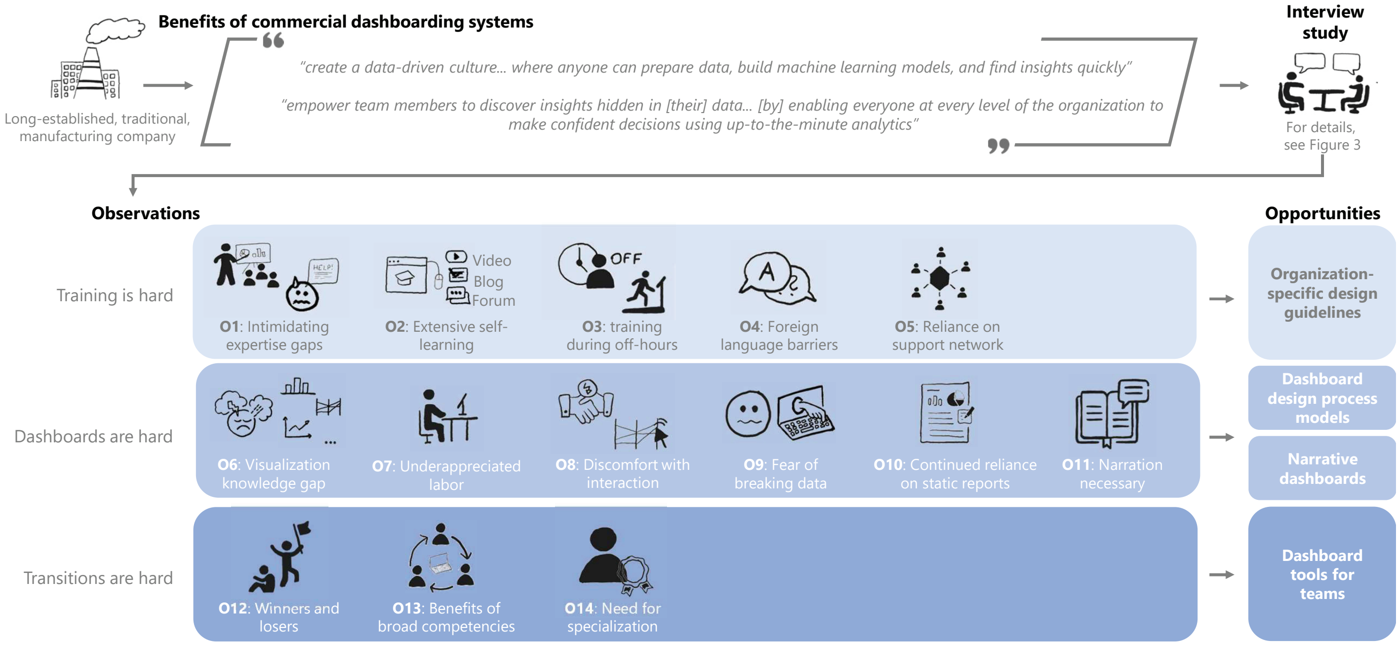
This project aims to facilitate a harmonious collaboration between human expertise and AI advancements, acknowledging the growing integration of AI in various aspects of our lives. The focus of this project is to develop a range of methodologies fostering effective cooperation between humans and AI systems. This collaboration seeks to enhance the interaction between humans and machines, particularly in decision-making processes across different application scenarios. The project's goals include exploring various thematic domains, each contributing to the overarching objective of improving the synergy between humans and AI.
One of the key areas of study is the utilization of visual analytics and dashboarding tools in practical settings. The project places a strong emphasis on identifying and addressing challenges that hinder the smooth adoption of these tools. To achieve this, the project employs intelligent strategies that take into account users' existing knowledge of dashboards. Additionally, the project delves into Interaction Provenance, thoroughly investigating how users engage with Visual Analytics tools and devising methods to guide users towards seamless utilization of these tools.

Goals

The goals of the project include research into various topics, all of which contribute to the overarching goal of improving the collaboration relationship between humans and AI:

Understanding the use of visual analytics and dashboarding tools by users and companies: The use of visual analytics and dashboarding tools has become a central aspect of modern information processing. This initiative takes an in-depth look at how users and businesses use these tools to gain insights from complex data sets. A key focus is on identifying and breaking down barriers that hinder the seamless adoption of visual analytics tools - from technological and organizational obstacles to broader environmental considerations. This effort spans a longer period of time to uncover shifts in adoption and meet the needs of various stakeholders, including data scientists and decision makers.

Dashboard onboarding strategies: Integrating new users into the world of static or interactive dashboards is a major challenge. This project addresses the development of strategies that build on the user's existing knowledge of how to use dashboards. These strategies are carefully tailored to guide newcomers through the nuances of dashboard interaction and ensure a seamless transition into using these powerful tools.



A summary of the observations and opportunities from our study into the socio-technical challenges of employees at a large, conventional company as they transitioned to using Power BI.

Embedded analysis of high-dimensional data: Navigating the complexity of high-dimensional data requires innovative approaches. This project presents a comprehensive exploration of interaction provenance - an in-depth analysis of user interactions with visual analytics tools. Using dimension reduction algorithms, the project aims to extract user strategies and enable a hybrid approach that uses both topology and attribute-driven layouts. This allows users to drive the decision-making process, promoting a harmonious collaboration between human intuition and AI-driven insights.

Uncovering visual patterns for decision-making: The inherent challenge of extracting insights from high-dimensional data is addressed by identifying visual patterns. These patterns are revealed in embedded latent spaces and provide deep insights that support decision-making processes. The project extends its reach by incorporating automated labelling strategies, improving the comprehensibility of visual patterns and reducing cognitive load.

Approach

Understanding the use of visual analytics and dashboarding tools by users and companies: We conducted a study to understand the effects of transitioning to Microsoft Power BI within one of our industry partner's settings. Our study included a diverse group of participants spanning various employee roles, backgrounds, skills, and experiences. A total of 19 volunteers from diverse IT and data analysis roles, with full approval from their supervisors, participated in this study. Upon analysis, two participants were excluded due to their notably different and less personalized responses during the individual interviews. Consequently, we focused our analysis on the insights gathered from 17 participant interviews. We divided the interview questions into three parts. In the first part, the interviewers introduced themselves, the research project, and the objective of the interview, clarified the compliance with data protection regulations, and asked for permission to audio record the conversation. The second stage gave the floor to the participants by first addressing general information such as their role at the company and their experiences using Power BI. More in-depth questions focused on the workers' intrinsic motivations and problems faced when making the transition to Power BI. In the final stage of the interview, the interviewers asked the participant for any other things they wished to share, and they wrapped up the interview.

Expected and Achieved Results

Understanding the use of visual analytics and dashboarding tools by users and companies: Together with Prof. Miriah Meyer from Linköping University, we submitted a paper to IEEE VIS'23, titled Transitioning to a Commercial Dashboarding System. It was accepted and will be presented at the conference this year. In this paper, we report on the results of an interview study with 17 participants working in a range of roles at a long-established, traditional manufacturing company as they adopted Microsoft Power BI. The results highlight several socio-technical challenges the employees faced, including difficulties in training, using, and creating dashboards, and transitioning to a modern digital company. Based on these results, we propose a number of opportunities for both companies and visualization researchers to improve these difficult transitions, as well as opportunities for rethinking how we design dashboarding systems for real-world use.

Dashboard onboarding strategies : This is an ongoing work in collaboration with Prof. Niklas Elmqvist, Aarhus University, Denmark. We are working on implementing strategies that leverage the work on storytelling to create impactful onboarding strategies. The project has also resulted in an MSc Thesis titled Dashboard Onboarding from a User's Perspective: Storytelling as a key to creating and improving the onboarding experience. The main goal of this work was to find a well-working programmatic solution for dashboard onboarding, which can help users to understand the dashboard, its visualizations, and its interactions.

Status / Progress

This project resulted in an accepted paper for IEEE Visualization 2023 on "Adapting to a Business Dashboard Platform" and a completed Master-Thesis on "Dashboard Onboarding from a User's Perspective: Storytelling as a Key to Creating and Enhancing the Onboarding Experience.

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AREA 4.1

MFP 4.1.1-1 CAVL-SD
Cognitive AVL: Smart Development

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.1-1
Project Title:	Cognitive AVL: Smart Development
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	36 Months, 01.04.2018 - 31.03.2022
Strategic Volume:	10 %

Work Packages

WP 1: Information Model of the Product Development Process

WP 2: Information Infrastructure

WP 3: Application and Administration Tools

WP 4: Use Cases and Integration into AVL Infrastructure

WP 5: Dissemination

WP 6: Project Management

Company Partners

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Academic Partners

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University of St. Gallen, Interaction and Communication-Based Sys.
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Whether manufacturing physical products or delivering virtual services, corporations engage in a variety of sub-processes which are interrelated both within and across different phases of the production development process. In addition to achieving the core functional purpose of each step, each of these sub-processes generates information. This can be information about the product itself as well as information on the process. There are countless examples of information generated during production development. Corporations have already started to collect and store such information, with the expectation that this data might prove useful in the future as a means of generating valuable insights about production, and thus as a means of improving the production process and the generated product. Although this information may already be stored, most of it is not yet integrated into the overall production development process. In addition, such data is usually designed and used in a very specific context (e.g., monitoring the quality of the product during a particular production step) which leads to this data being generated in a wide range of proprietary or open formats (for example, as plain comma-separated-value files) which lack proper or standard facilities for preserving possibly important accompanying metadata about the production development process.
The MFP aims to develop a framework which allows (i) semantic modelling of the overall production development process and its underlying sub-processes, (ii) an interface to the production environment, to facilitate (iii) the active integration of process data into the semantic model, which leads to the potential for (iii) a data-driven optimization of the overall process. This will result in an application framework for cognitive production processes (linking the research with Area 4.2), which enables a process to act based on historical and currently perceived process information. The framework must provide tools and applications which allow creation, management, and adaptation of the models of the underlying sub-processes. Additionally, methods need to be derived which prepare and link process data generated in the various stages of the production process with the semantic model by means of meta-data. Once integrated into the process and linked to process data, the framework will be used to monitor and optimize key performance indicators (KPIs) of the production process. Automated reasoning (cognition) will be implanted to allow optimization of an individual process or of the overall process composition. To validate the ease of integration as well as the benefits of the framework and its underlying cognitive process, it will be tested in the context of dedicated use-case scenarios.

Goals

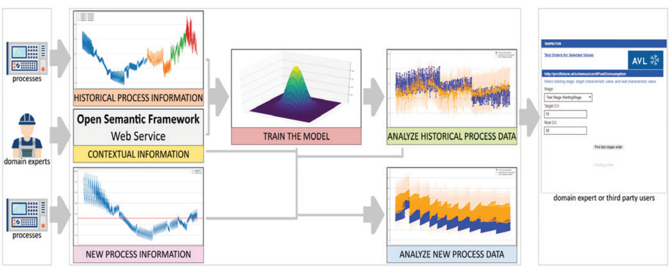
In order to remain competitive, companies constantly need to individualize and optimize their production development processes. One way of achieving this is by means of active integration and utilization of process data. For this, a foundation of models and tools is required that allow creation and management of data-related models, as well as a way to link such models with whatever process data is available. The goal of this project is to research how semantic technologies can be applied in the context of complex industrial processes. This requires the development of structures that enable easy mapping of the production development process into process-models. In addition, methods need to be established to allow the integration of unstructured data (such as time-series) into these process models. Such structures can be used as a basis for the optimization of individual processes and for the management of interdependent processes. Using such mechanisms allows a company to better understand the impact of individual steps of the product development process on the overall process, and to include this information as a driver of change in the development process. By providing predictions of the impact of potential changes on the production process, flexible and adaptive production processes are enabled.

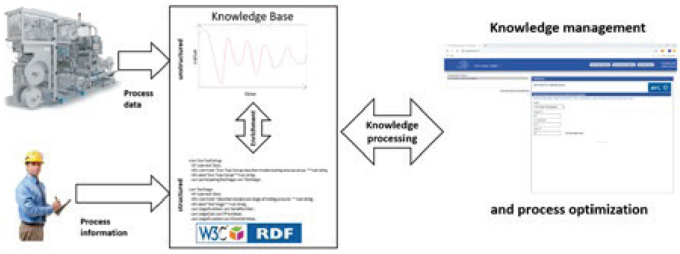
Approach

First appropriate information models and interfaces linking the production system to the semantic model framework are established. An information model is established as a group of interlinked resource description framework (RDF) ontologies. Each ontology maintains information relevant to a specific problem. Second, interfaces to the production system are designed and developed by extending the semantic model framework. This includes interfaces to process information which can be enriched with metadata; interfaces allowing the saving, access to, and management of process information; as well as interfaces which allow external applications to access the framework. In a third step prediction models are developed which allow to estimate the quality of processes and allow for their optimization.

Expected and Achieved Results

The product development process framework developed within this project will allow its users to model the overall production development process, while utilizing interfaces into the production environment allowing active integration of process data into the model to facilitate data-driven optimization of the modelled process. So far, the initial framework has been developed, and a simple product development process has been modelled. Based on this framework, we are currently investigating how structured data stored in the form of directed graphs of resources can be linked to unstructured data like time-series data produced during production, as well as how the system can be used to gain information about ongoing production to further assist smart management of the production process. After the concepts for this data integration are derived, the project will focus on the application of cognitive reasoning for process optimization. As the feasibility and benefits of such a semantic framework will be demonstrated and tested in the context of several specific use cases of the company AVL List GmbH, tools which allow the integration of the framework into their product development process will be developed.





Status / Progress

The project officially started in April 2018. Pro²Future is working with our Company Partner AVL List GmbH, the Institute of Technical Informatics at TU Graz, and the working group “Interaction and Communication-Based Systems” at the University of St. Gallen. The project was successfully kicked off and project joure fixes are held at regular intervals (approximately every 3 weeks). The first months of the project were used to establish an in-depth understanding of the production development process of AVL. In parallel, work on the semantic framework (Open Semantic Framework, OSF) started, which is used to semantically represent the product development process. OSF builds on top of the Resource Description Framework (RDF), a specification by the World Wide Web Consortium (W3C) that was designed for standardization of Semantic Web technologies. Within RDF, relationships between objects - henceforth “resources” - are described using subject-predicate-resource triples, with the predicate constituting the relationship between a subject and a resource (e.g., “Apple is-a Fruit”). Triples can be combined into directed RDF graphs which can be queried via query languages such as SPARQL to retrieve context information. OSF was used to implement a first version of a typical product development process. The project successfully developed ways to link structured and unstructured data by means of appropriate Web-based embedding of unstructured formats, which will enable this data to be used in the context of semantic technology platforms.
Analyzing the provided testing data using graph based querying languages highlighted the limits of classical reasoning, with the reason being that the quality of data available in the various data lakes is not known, which limits any form of reasoning based on this data. To overcome these limits the project developed statistical methods (Bayesian Kernel Methods), which allow to predict the quality of process data with uncertain quality based on process data from later process stages where the quality is clear. The methods allow to assess the quality trajectory within a production development process and enable the application of reasoning. The resulting system, i.e., semantic reasoning enriched with machine learning (also known as model driven analytics) allows to use the best of two worlds, i.e. the reasoning capabilities associated with semantic technologies in combination with the modelling and classification capabilities provided by machine learning techniques, for the continuous optimization of production lifecycles.

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AREA 4.1

MFP 4.1.1-2 SAFE-TRACK

Failsafe Autonomous drone-based warehouse check beyond visual line of sight

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.1
Project Title:	SAFE-TRACK - Failsafe Autonomous drone-based warehouse check beyond visual line of sight
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	7 Months, 01.09.2020 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 1: Use cases and requirement analysis

WP 2: Drone monitoring station software

WP 3: Implementation and integration of Drone Monitoring Station

WP 4: Testing and system evaluation

WP 5: Dissemination

WP 6: Project management

Company Partners

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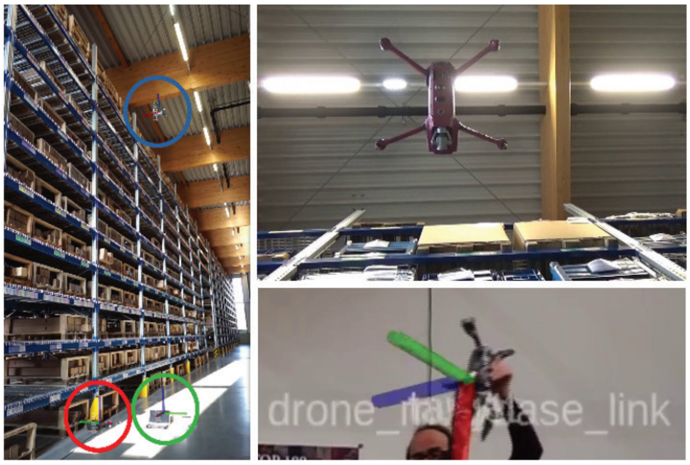
Drones are excellent machines to carry cameras, laser scanners and sensors to provide data for industrial and commercial applications. Thanks to GPS technology their operation in outdoor applications has been increasing steadily in recent times. However, the adoption of drone technologies in environments where GPS positioning is not reliable has been slower and always subject to the requirement of having a drone pilot deploy the drone for the application. This issue is even more present in indoor working areas, such as warehouses and other industrial facilities.

Recent technological innovations in drones, computer vision and machine learning are cutting down the gap to make indoor drone automatic industrial operations economically feasible. On-board odometry allows a drone to have a rough estimate of its local positioning, which estimation is based entirely on data from on-board sensors, and which is calculated entirely on computers on-board the drone. A drone may therefore gather data relevant to an industrial application relying only on its on-board odometry. However, the odometry calculation may malfunction or it may in some cases provide bad estimates, which impacts the value of the gathered data – an example of this are pictures whose location data is inaccurate.

A successful implementation of drones performing tasks inside industrial facilities and warehouses, especially when working in the potential presence of human workers, requires additional layers of security. In this context, it is necessary to minimize the risks of an accident involving the drone. A possible approach, to achieve safe indoor drone automatic industrial operations is to add a second sensing layer off-board the drone, for instance with a monitoring station. Therefore, there is an interest in studying external means to achieve drone localization. In the case of a malfunction of the on-board drone odometry, this event can be detected by comparison to the localization data. Moreover, the overall drone system (consisting of the drone and the monitoring station) can be studied under the point of view of fail-safety.

Drone performing an automated inventory task, acquiring the current status of the inventory in a warehouse.



Drone flying and performing an inventory taking task in a warehouse. The left image shows the relevant reference frames: drone (blue), tracking camera (green) and frame (red) fixed to a relevant point on the ground. Bottom-right: Image of the frame of the drone.

Goals

In this context, the project SAFE-TRACK has had a focus on achieving automated drone-based inventory management (left Figure), without maintaining line of sight to the drone. This is required to enable flights within operating hours – which means that the drone is collaborating with humans and logistics equipment. Over a period of seven months, Area 4.1 (Cognitive Products, P2F), TU-Graz (Institute of Computer Graphics and Vision), D-ARIA and Roto Frank Austria have developed and tested methods to secure and monitor drone operations in warehouse environments.

Approach

We have investigated the capability of tracking a drone during operation by means of external tracking cameras – to support the operation of the drone and towards achieving a higher degree of autonomy in its operation. Part of our focus has been on fail-safety, that is in short, on achieving a drone system (consisting of the drone and the monitoring station) with no single point of failure, which could cause an accident involving the drone. Our second focus has been on working towards achieving automated operation well aligned with safety regulations, but which does not require a safety pilot (or an operator) maintaining line of sight to the drone during operation.

Expected and Achieved Results

Our experiments have shown the capabilities of our system to track the drone with high reliability and positioning accuracy. In our system, the drone is tagged to ease the vision-based re-detection and tracking task and the tracking camera is placed statically inside the working environment. In the right figure, we show our results on the task of tracking a drone by means of external cameras. The cameras have been registered, that is localized between each other and to the environment, in order to be able to embed our 3D data in the images (and videos) of the experiment. In the images, the following reference frames are depicted (see right Figure): (blue) frame of the drone, (red) reference frame fixed to a relevant point on the ground and (green) reference from of the tracking camera.

Our work represents a first step towards achieving the safe operation of drones in warehouse industrial environments. The experiments demonstrate the feasibility of utilizing automated external monitoring in indoor drone operations. Among other advantages, our system provides more information to the operator, such as flight statistics over time and the repetitive acquisition of metrics that reflect the performance of the drone in each particular area of the warehouse where the system is deployed.

For drone operations as a whole, our external monitoring solution signifies an additional layer of security, which can be used as part of the navigation architecture towards achieving fail-safety in drone industrial operations.

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AREA 4.1

MFP 4.1.2-1 Simatic Failsafe 4.0

Development Processes and Tools for Cognitive Products

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.2-1
Project Title:	Simatic Failsafe 4.0
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	24 Months, 01.12.2017 - 31.11.2019
Strategic Volume:	10 %

Work Packages

WP 1: Analysis of "State of the Art" and Familiarisation with the Siemens Environment

WP 2: Architecture and Design: System and Involved Elements

WP 3: Realisation of Demonstrators

WP 4: Dissemination and Exploitation

WP 5: Project Management

Company Partners

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Academic Partners

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The proliferation of industrial monitoring and control systems has led to the generation of a huge amount of data. It is predicted that 50 billion devices will be connected to the Internet by 2020, with the majority generating data in industrial settings that can be used to optimize industrial processes and to increase flexibility and integration along the product life-cycle. As the Internet of Things paradigm spreads into the industrial realm, we need to take into consideration additional aspects of industrial processes, such as their safety. The desire for better and faster production has created an industrial environment where people and cognitive machines collaborate in the same physical space. Consequently, the safety of people and of equipment has emerged as one of the greatest concerns for engineers in human-robot collaborative work settings. Manufacturers of Programmable Logic Controllers (PLCs) have invested a lot of resources in upgrading their PLCs, so that they are capable of detecting anomalies and of ensuring safety for the system and workers in the case of failures. Complex systems with multiple control units still represent a significant challenge, since the optimal safe state of the entire system needs to be determined and reached in time and space.

This MFP investigates how functional safety, availability, and maintainability can be improved in industrial environments. Analysis tools and methods stemming from the domain of predictive analytics will be applied to data sources already available in industrial fail-safe modules. Integrating data analytics (the main focus of Area 3's research) into industrial fail-safe processes denotes a prerequisite for future cognitive products and production processes, as it should fulfill the level of dependability which is required in industrial cognitive applications. In addition, the project investigates the required transition of traditional, static approaches to fail-safe operation into more challenging dynamic environments. This is necessary as smart factories which employ cognitive production processes are expected to exhibit non-static behavior, including rapid changes of tooling, physical movement of robots, and even the reconfiguration of entire manufacturing processes when required. Consequently, future fail-safe mechanisms must also be cognitive in order to adapt to or, ideally, anticipate these dynamics to guarantee fail-safe properties at all times. To do this, the project will investigate how to achieve an integration of predictive maintenance and fail-safe operation. This will result in novel cognitive Predictive Failsafe (PdF) mechanisms, which enable a system to adapt its fail-safe measures to new configurations and situations, as well as to forecast and mitigate errors.

Goals

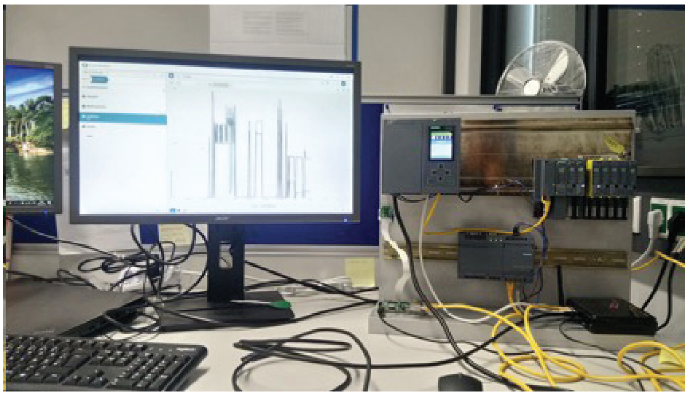
The overall goal of this project is to enhance fail-safe strategies for their application in cognitive production environments. This will be done by extending fail-safe strategies to include prediction of the mostly likely future states, thus leading to the new paradigm of Predictive Failsafe (PdF). PdF will give a system the ability to adapt its fail-safe measures to new configurations and situations that dynamically arise in smart factory environments, with the goal of protecting itself and its working environment, including human workers. In order to achieve the PdF paradigm two key elements are required: data sources for obtaining data that is relevant to fail-safe predictions, and prediction algorithms for analyzing this data. Identifying safety-relevant data sources and obtaining access to their data is not straightforward, since fail-safe components are usually deliberately shielded from the rest of an automation system. Obtaining this data is however crucial to PdF, especially since insufficient data quality can lead to incorrect conclusions and decisions, which is especially critical when dealing with safety-relevant data. Accordingly, one research goal of the project is to establish new mechanisms which provide a simple way of tapping into existing data sources in order to achieve the overall research goal of investigating how this data can be used in combination with machine learning and statistical methods to establish new, cognitive predictive failsafe mechanisms.

Approach

Being able to connect to and therefore utilize data sources is a key requirement for PdF. The project thus initially focused on the development of methods which allow access to and communication of fail-safe data produced by PLCs of the Simatic family. In a next step, existing fail-safe approaches and their underlying methods as well as application scenarios were studied in detail, providing a starting point towards the creation of new predictive fail-safe approaches for cognitive products and processes and establishment of their requirements. In order to demonstrate the applicability of these new approaches they will be implemented as demonstrators in a virtual environment that simulates real-life hardware and the services established in the earlier steps of the project.

Expected and Achieved Results

The first results of the project were the research, evaluation, and generation of the practice-relevant, future fail-safe scenarios for the Simatic automation device family. Based on our research, a first use case was established which concerns the application of the Simatic system in prospective collaborative industrial environments. As a result, a demonstrator for a dynamic fail-safe system was developed. The demonstrator is fully integrated into the Siemens production environment and demonstrates how selective, dynamic safety mechanisms can potentially be achieved based on Simatic automation in future collaborative workspaces. During the implementation of the use case, interfaces to access a Simatic's safety data as well as interfaces which allow connections with higher level services and systems (i.e., Siemens' TIA-portal and Mindsphere cloud environment) were established. These interfaces constitute a starting point for all further implementations in the project. The fail-safe mechanisms which are already implemented in the Simatic system are currently being investigated in detail. Our current research focuses on the application of machine-learning and statistical methods to improve fail-safe mechanisms as well as to establish a first iteration of predictive fail-safe mechanisms. Based on PdF mechanisms, the project aims to develop mechanisms for adaptive availability, which inform a user in advance about the likelihood of a given system entering a fail-safe state and offer concrete guidance on how to optimize the system to increase its reliability and availability. Predictive fail-safe will be used to establish services which allow Siemens to achieve improved context for any occurring fail-safe events within the Simatic product line, thus helping to further improve and optimize the performance of automation systems.



Status / Progress

This project officially started in December 2017. Pro²Future is working with company partner Siemens AG and the Institute of Technical Informatics at TU Graz towards the creation of novel predictive fail-safe approaches. The project was successfully kicked off and project joure fixes are held at regular intervals (every 3 weeks). In the initial phase of the project methods which allow the initial integration of data produced by Simatic fail-safe modules into the Simatic development environment as well as the Siemens edge and cloud environments (Mindsphere) were developed. Additionally, the concept of "Predictive Failsafe" was ideated, shaping the research direction of the project. Early work in the project concerned functional safety for collaborative workspaces.
This led to the development of a first demonstrator, which shows how dynamic fail-safe mechanisms can foster the collaboration of humans and machines in a cognitive production environment. To improve availability of existing safety solutions the project developed two new soft-error mitigation strategies. The first method concerns the application of parity bits in the context of existing 1oo2D failsafe architectures to enable such systems with error correction capabilities.

The second approach concerns the just in time (JiT) identification of read and write memory operations, prolonging the transfer of a system into its safe state until the system tries to read from a corrupted memory address. Besides the investigations into memory mitigation strategies the project also investigated how system parameters can be forecasted and monitored. A concept for temperature forecast and change point detection was developed, which allows to forecast environmental temperature based on temperature observed at the CPU of a failsafe module. In addition, change point detections were implemented to identify both slow (seasonal) and rapid (external influence: e.g., fire) changes in temperature, which would allow a system to contextualize its environment and trigger respective alarms. As a system's safety often depends on external components (such as sensor), the project how data analytics and statistics can be used to predict sensor aging. In this context a first demonstrator with artificial data has been developed and currently real sensor data is collected to enhance and extend the demonstrator.

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AREA 4.1

MFP 4.1.3-1 DRIWE

Dependable RF Communication Systems for In-Car Wireless Sensors

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.3-1
Project Title:	Dependable RF Communication Systems for In-Car Wireless Sensors
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	36 Months, 01.03.2018 - 28.02.2021
Strategic Volume:	10 %

Work Packages

WP 1: Analysis of Constraints and Current State of In-Car RF Communication

WP 2: Investigation of new RF-communication systems

WP 3: Validation of New Concepts for Dependable RF-Communication Systems (Demonstrators, Design, and Implementation)

WP 4: Dissemination

WP 5: Project Management

Company Partners

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Academic Partners

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In order to establish new services and applications in the context of cognitive products and production processes, it is necessary to have information on the current and historical behavior of the target system. To monitor and gather such information, a dependable communication infrastructure and sensors with adequate sampling rate are needed. A good example for products which are currently undergoing rapid cognification are cars. Real-time monitoring of temperature, pressure, acceleration, voltage, chemical composition, or force, measured at a high sampling rate (100 Hz) within defined areas of the vehicle, constitute vital information which can be used for autonomous driving, online optimization of vehicle performance, or to guide future development of car components.

Vehicles are a challenging environment for sensor integration, partly because vehicles and their components (such as motors) are becoming increasingly compact, leaving little room for a sensor system. Given these spatial constraints, hardwiring the sensors within a motor block is not an option, although this would provide sensors with a continuous power supply and means of wired communication. For this reason, autonomous sensor solutions are required in the context of in-car communication, as they can provide flexibility in terms of sensor placement and energy supply. Current in-car communication is based on the Bluetooth Low Energy (BLE) standard, a radio frequency (RF) technology. BLE provides considerable flexibility regarding sensor placement and exhibits good power consumption characteristics. Unfortunately, the in-car environment contains many metallic surfaces which can result in unwanted reflections of RF wireless signals and a corresponding reduction in signal quality, thereby negatively impacting communication dependability.

This MFP investigates how the intelligent design of antennas and wireless RF communication systems can be optimized for in-car communication. Antennas, among other system components, play a crucial role in RF communication and can therefore be adapted to improve communication within a specific environment. Given the vast amount of different car designs and sensors, it is simply not possible to establish a one-design-fits-all antenna design and communication infrastructure for optimal in-car communication. To provide dependable communication, the underlying solutions must be individually adapted for their application environment to achieve optimal performance. The goal of the MFP is therefore to develop a framework which allows optimization of the antennas used by the sensors and the underlying communication network topology in an RF communication system, given a target in-car environment.

Goals

Dependable communication plays a key role in the implementation of cognitive services and applications. Given the increasing diversity of products and their designs, bespoke communication frameworks are necessary to achieve dependable performance. The automotive industry is a very good example for the continuing individualization of products. Given the vast differences of in-car environments, the development of in-car communication requires novel solutions in order to optimally adapt the communication system to its operational environment. In this project, RF wireless communication systems will be investigated in terms of their application in this domain.

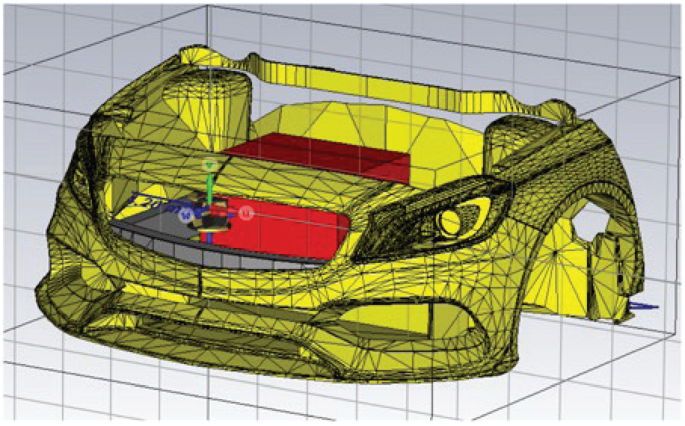
The project will establish key performance indicators (KPIs) which allow the assessment of wireless communication systems in in-car environments. Based on these KPIs, the project will research means of improving communication quality. As real-world experiments for in-car communication are very costly, the overall goal of the project is to establish a simulation framework for the automated design of in-car wireless communication systems. The envisioned framework will allow a specific in-car environment to be modelled, which can then be used to design the optimal RF wireless communication system for that environment. Optimization will be achieved by adapting antenna designs, antenna types, sensor positions, and communication network topologies for the target environment, resulting in bespoke, dependable communication solutions.

Approach

In order to establish a framework for the design of wireless communication systems for in-car environments, the following approach is taken. First, existing RF communication solutions for in-car environments are analyzed and KPIs are established to assess the quality and dependability of communication solutions. Second, a simulation framework is established, based on existing simulation software and parameterized using real-world sensor measurements. This simulation framework will be used to calculate the KPIs of a communication system in a specific in-car environment. It will then be used to iteratively generate, evaluate and optimize an antenna and communication system design until an optimum has been reached for a specific in-car environment.

Expected and Achieved Results

This project involves the systematic exploration and development of dependable RF communication systems for in-car environments. The project will result in an in-depth analysis of RF constraints in cars. So far, an initial electromagnetic simulation model of a motor block and a typical RF antenna has been established in order to investigate the behavior of reactive near-field and radiative near-field of antennas and the corresponding propagation effects within the in-car environment. Using standard RF sensor hardware, various tests and measurements were designed and are currently being performed in order to specify the characteristics of the sensor hardware. These experiments involve establishing the directional characteristics of the wireless sensor node and its antenna in environments with differing amounts of metallic elements. The results of the experiments will be used to tune the simulation. Once the simulation is aligned with this ground truth, the project will focus on the optimization of wireless sensor nodes in in-car environments. The optimization approach will investigate to what extent multiple-input and multiple-output (MIMO) antenna systems, different antenna types such as directed antennas and broadband antennas, as well as environment-specific antenna designs can improve the dependability of wireless in-car communication. The most promising concepts and technologies will be evaluated in the context of a demonstrator. The methodology resulting from this MFP is a first step towards establishing individualized, dependable wireless communication which is specifically adapted to the communication environment of a product and its production processes. The approach taken and results gained can be abstracted and used to facilitate future cognitive services in other branches.



Status / Progress

This project officially started in March 2018. Pro²Future is working with company partner AVL List GmbH and the Institute for Microwave and Photonic Engineering at TU Graz. The project was successfully kicked off and project jour fixes are held at regular intervals (approximately every 3 weeks). The first months of the project were used to establish an in-depth understanding of in-car environments. Based on this investigation a first electromagnetic simulation model of an in-car environment was established. In order to tune the simulation, various experiments with standard in-car sensors were performed. The resulting data will be used to specify realistic parameter values for future simulations and will be outlined in the first project publication. The next step that will be taken is the extension of the simulation environment. This will allow us to model a specific in-car environment and to design a RF wireless communication system which is optimized for this environment. An initial Matlab-Model for Wireless Communication Simulation was implemented which is based on the previously performed experiments as well as simulation data which was gained via CST experiments. To assess the quality of a given solution the calculation of a link budget is crucial, therefore a first draft for link budget calculation was established, which allows to evaluate the performance/requirements of various antenna types from simulation. In addition. the project investigated raytracing as a possibility to enhance the accuracy of the channel model.

First results of the project as well as an outline on the planned simulation framework (titled “Achieving Robust and reliable Wireless Communication in Hostile In-Car Environments”) were presented at last year’s international conference on Internet of Things. Additional project findings have been accepted at the IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (IEEE-APWC 2020) as well as the International conference on broadband communications for next generation networks and multimedia applications (CoBCom 2020).

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AREA 4.1

MFP 4.1.3-2 CSG
Cognitive Smart Grids

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.3-1
Project Title:	Cognitive Smart Grids: Dependable, Interoperable, and Adaptive Communication for Smart Grids
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	24 Months, 01.04.2018 - 31.03.2020
Strategic Volume:	10 %

Work Packages

WP 1: Use Cases and Requirements Analysis

WP 2: Analysis and Evaluation of Smart Grid Communication Architectures

WP 3: Communication Architecture Recommender System

WP 4: On-line Adaption of Smart Grid Communication Systems

WP 5: Dissemination

WP 6: Project Management

Company Partners

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Academic Partners

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Due to the ongoing integration of distributed energy resources such as domestic photovoltaics into the existing distribution grid, conventional – mostly passive – monitoring and control schemes of power systems are no longer applicable. This has led to increased research into smart grid technologies, in particular how novel control schemes can be applied on a distribution-system level with the aim of implementing new services to mitigate the problems associated with distributed energy resources. Dependable communication plays a central role in smart grid operation.

The advent of the Internet of Things (IoT) paradigm has precipitated an ever-growing number of wireless communication technologies and protocols which could be utilized in the context of smart grid operation, among many other industrial IoT applications. The available protocols differ in their operation characteristics, including communication range, bandwidth, supported nodes, and network topologies. When designing a new smart grid control or monitoring scheme, the question arises which communication protocol is best-suited for the task. In addition, protocols must exhibit different levels of dependability in order to satisfy the given use-case requirements.

This MFP investigates potential wireless communication protocols for smart grid operation, and the results can be abstracted to their application in the context of industrial IoT applications in general. Dependable communication is a cornerstone for future cognitive products, as it allows them to gain information from the outside world beyond their own sensors, and to act in a distributed fashion. As cognitive services are often highly information dependent, using the right means of communication is crucial for their success The MFP thus aims to systematically investigate potential wireless protocols and their properties (such as bandwidth or dependability attributes) in order to derive a detailed analysis of available protocols. The analysis will be mapped into a knowledge base (ontology), which will be used to establish a recommender system to allow the specification of dedicated smart grid communication use-cases and support decisions about underlying communication protocols. This will be done by outlining the potential technical and economical performance of the available protocols in the context of the particular use case. In addition to building a recommender system, the project will research strategies which allow the online adaptation of protocols in case of any changes in their operation environment or requirements, as well as fail-over functionality to further improve dependability of smart grid operation.

Goals

Within this project, detailed characteristics of candidate wireless communication protocols for smart grid operation will be established based on typical smart grid monitoring and control application requirements. Once established, these characteristics will be used to (i) develop an ontology-based recommender system which allows a user to specify a dedicated smart-grid communication use-case, and to receive recommendations for suitable protocols for the implementation of that use-case. These recommendations are based on technical and economical feasibility. Additionally, the ontology will be used to (ii) enable a use-case dependent parameterization of the target protocol (i.e., recommending not only the protocol but also a suitable parameterization). The protocol characteristics will also be used for (iii) adaptation and reparametrization of protocol parameters during runtime as well as fail-over mechanisms (such as switching between communication protocols in case of a communication fault) in order to further strengthen and leverage the dependability of the protocols to the level required within a specific smart-grid operation use-case.

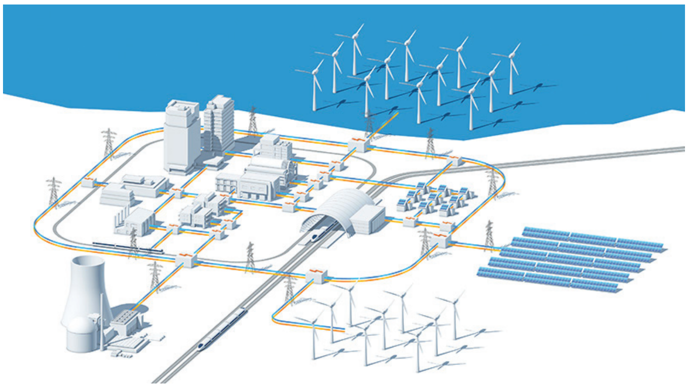
Approach

First, a detailed screening of smart-grid communication use-cases is performed. Based on this screening, required key performance indicators (KPIs) are established which allow the assessment of wireless protocols regarding their application in a smart-grid communication scenario. Second, an in-depth analysis of existing wireless protocols is performed. The protocols are investigated regarding their technical specification, their potential parameterization, parameter influence on protocol performance, protocol requirements and limitations, as well as available mechanisms to increase dependability. This information is used to establish an ontology of wireless protocols, which is used to implement a recommender system. Finally, the information is used to perform online adaptation of protocols.

Expected and Achieved Results

In the first phase of the project, smart grid monitoring and control use-cases were investigated to establish communication requirements. Use cases where wireless communication is used to control system-critical infrastructures impose very strict requirements on communication in terms of underlying availability, maintainability, reliability, and security. In the context of this analysis the need for retrofitting brown-field electric substations was identified, leading to the development of a Bluetooth low energy (BLE) based mechanism, which allows time-synchronized collection of data within secondary substations and an on-site configuration of sensors by authorized maintenance personnel.

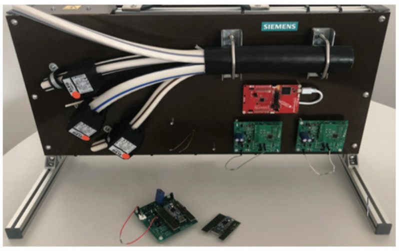
In a second step, an in-depth analysis of available wireless communication protocols was performed. The technical parameters of various relevant protocols, both short and long range, were established. The focus of this analysis was the protocols' dependability as well as external factors which impact their performance. The analysis was used to establish an ontology which represents the detailed protocol information. Ongoing research investigates how the ontology can be integrated into a semantic framework to implement a recommender system. The aim of this system is to allow a user to establish suitable protocols or protocol combinations for a defined communication use-case. Finally, the project focuses on establishing mechanisms which allow automatic parameterization of protocols for their application in the target use-case. In addition, the project aims to develop online methods to adapt a communication protocol in response to environmental changes to enable fail-over mechanisms for maintenance of connectivity and communication requirements.
As they will be generalizable beyond smart grid applications, the project results are a first step towards establishing dependable wireless communication for cognitive products and their production processes.



Status / Progress

The project officially started in April 2018. Pro²Future is working with company partner Siemens AG and the Institute of Technical Informatics at TU Graz. The project was successfully kicked off and project jour fixes are held at regular intervals (approximately every 2 weeks). The first months of the project were used to establish an in-depth understanding of smart grid communication use-cases. This investigation lead to the development of a Bluetooth-low-energy (BLE) based protocol which can be used for the time-synchronized collection of measurement data in secondary substations. This work resulted in a BLE based no low engineering demonstrator (see left picture in figure) for the monitoring of substations, which allows the easy application of sensor nodes within a substation environment and utilizes BLE to achieve a drift < 1 µs across all nodes, which constitutes a requirement for the calculation of complex system parameters such as phase angles across different sensor nodes.

In parallel, the semantic framework was prepared to implement the recommender system, which allows a user to specify a communication use-case and required KPIs. Based on this information the system computes the best communication technology (or best combination of communication technologies) to implement the use-case. After that the project focused on the development of tools for the cognitive management of communication in dynamic environments, by assessing current available link qualities (across multiple radios) and adjusting the used communication channels and payloads accordingly to achieve robust and dependable communication. This led to development of a demonstrator (see right picture in figure) which allows to assess and rate currently available link qualities (across multiple radios) and adjust the used communication channels and payloads accordingly to achieve robust and dependable communication. Currently the project focuses on refining and expanding the methods for dynamic communication channel adjustment utilizing metaheuristics and deep learning approaches.



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AREA 4.1

MFP 4.1.3-3 CONVENIENCE
Cognitive building automation infrastructure and services

Area 4.1 - Cognitive Products

Project ID:	MFP 4.1.3-3
Project Title:	Cognitive building automation infrastructure and services
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	11,5 Months, 16.04.2020 - 31.03.2021
Strategic Volume:	10 %

Work Packages

WP 1: Requirements Analysis

WP 2: Secure, scalable and dependable communication

WP 3: Functional interaction software components

WP 4: Dissemination

WP 5: Project management

Company Partners

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Academic Partners

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Increased automation can be observed in many application domains. One good example for concepts stemming from digitalization and the domain of IoT precipitating automation is the home automation sector. Home automation also known as domotics allows a user to control lighting, climate, entertainment systems, and appliances in its home. The trend of home automation is fostered by appliances and products become smarter and connected, which allows their control and concertation. While new buildings often feature home automation systems an even bigger market in the context of home automation is retrofitting existing buildings and appliances with home automation solutions. Given the rapid development of new products, protocols and interfaces home automation system providers face a number of challenges. Their systems must allow an easy integration of an ever-growing market of solutions often differing in the used underlying technologies, for which they must provide dependable control solutions. In addition, given the private nature of home the systems must be secure and compliant to privacy regulations, while offering solutions which are easy and intuitive to use, scalable and optimize a living / office space in a non-intrusive way. This requires modular and flexible solutions which can be continuously adapted to allow for the integration of new products and appliances. Similar to other application domains of digitalization a dependable and secure connectivity between system and appliances is a key aspect. Wireless communication technology provides a good alternative to its wired counterpart as it ideally reduces installation and service efforts and does not intervene in the target environment. However, this freedom comes with a cost as wireless communication does not necessarily provide the required dependability e.g., due to interferences among devices communication solutions.

This MFP aims for developing an IoT strategy for an existing home automation solution. This concerns the evaluation and refinement of the underlying IT-infrastructure and services to allow for scalability, while providing dependable and secure communication and interaction between the systems entity. In addition, the project will develop wireless communication technology, which minimizes interference (in terms of communication) among the systems entities and adjusts to application scenarios to optimize the dependability of the overall system.

Goals

CONVENIENCE aims for the conception of an IoT strategy and roadmap for an existing home automation solution and provide is on new methods and concepts to (i) improve the scalability of the system in terms of the number of connections between the managed entities (ii) provide the seamless integration of IoT / mobile devices in the system, (iii) ensure a secure communication within the system and provide means to protect and shield sensitive data from attacks or data leaks and at the same time (iv) allow for a decentralized and concerted update to maintain the system (server, apps, studio, ...). In addition, the project will investigate the application of (v) a wireless over-the-air update functionality for the customer as well as the (vi) adaptivity and configuration of wireless communication among different radio technology.

Approach

First, a detailed screening of the existing system and its architecture is performed. Based on this screening the systems performance and accordingly the optimization potential will be established. In parallel to the system's screening the requirements of the application scenarios are identified. This information is used to establish a strategy for the system's improvement and highlights technological gaps in the context of wireless communication which can be tackled. The system's roadmap is developed in the context of existing and established open source software. Identified tech gaps in the context of dependable wireless communication (e.g., dependable over the air updates, cross technology communication) will be researched and the resulting technology will be tested in the form of demonstrators and real world use cases of the system.

Expected and Achieved Results

The outcome of the project is two-fold. On the one hand the project will result in a roadmap outlining the necessary steps and concepts to refine an existing home automation system to

- improve the scalability of the overall system
- allows for the seamless integration of new entities in the system
- ensure a secure communication and data storage within the system
- allow for decentralized updates.

As wireless communication plays an important role to realize such a system the project will also investigate f wireless communication in the context of home automation to provide and establish concepts/ methods for

- dependable wireless over-the-air update functionality
- the concertation of different wireless communication technology within a home automation system

The investigated topics will result in tech demos and prototypes and accompanying methodology which allow the transfer of the project results in other application domains.

Status / Progress

The project officially started in April 2020. Pro²Future is working with company partner HMI-Master GmbH and the Institute of Technical Informatics at TU Graz. The project was successfully kicked off and project jour fixes are held at regular intervals. The first months of the project were used to establish an in-depth understanding of the home automation use-case as well as the existing automation system. In addition, a screening of frameworks to enhance the scalability and dependability of the system was performed to establish the IoT-roadmap. Within autumn 2020 work on the communication aspects will start.

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AREA 4.1

StratP 4.1.4 PREDISCOVER

Unified Dependable Wireless Services for Cognitive Products

Area 4.1 - Cognitive Products	
Project ID:	StratP 4.1.4
Project Title:	PREDISCOVER - Unified Dependable Wireless Services for Cognitive Products
Project Lead:	Dr. Konrad Diwold Pro2Future GmbH
Duration:	36 Months, 01.03.2018 - 28.02.2021
Strategic Volume:	100 %

Work Packages

WP 1: Use cases and communication requirements for smart products

WP 2: Roadmap and open research questions

WP 3: Project management

Academic Partners

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TU Graz, Institute of Microwave and Photonic Engineering (IHF)
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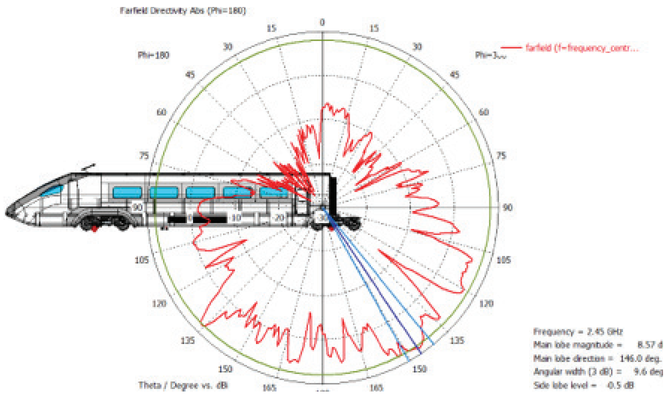
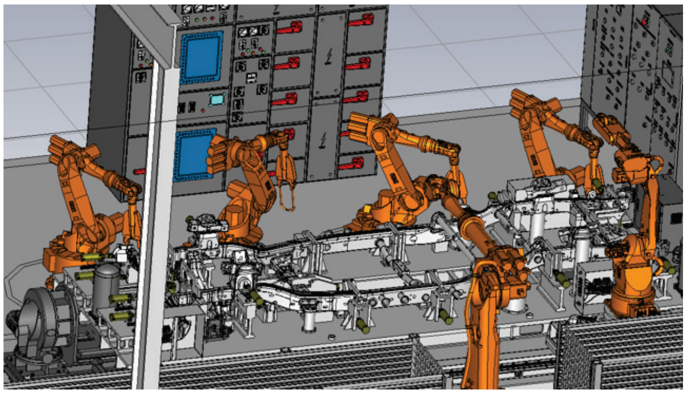
In this strategic project, use cases and communication requirements for smart products in various environments are investigated. The goal is to provide unified dependable wireless services for cognitive products. These wireless ICT platforms enable cognitive products to anticipate, react, and adapt to their environment. The research in this strategic project focuses on various sensors, with a particular emphasis on location sensing. This allows the cognitive products to be aware of their environment and develop a model of themselves.
Another important aspect is the ability of cognitive products to network and communicate effectively. This enables them to interact and cooperate with other cognitive products, their environment, and humans. The wireless services encompass batteryless RF-based sensing of the cognitive product's environment, localization both within and outside the production environment, and networking of products and production systems.
A key aspect of the project is the co-designing of these wireless services to maximize their dependability while minimizing their total cost of ownership. The results of the strategic project are of great significance for several Manufacturing Flagship Projects (MFPs). In particular, they have implications for MFP 1 (sensing and localization), MFP 2 (all wireless services), and MFP 3 (networking).
By addressing these challenges, the project aims to create a strong foundation for the development and implementation of cognitive products with robust and efficient wireless capabilities. This will pave the way for a new era of smart and interconnected devices in various industries.

Goals

The goal of this project is to pre-investigate and identify application scenarios of a communication infrastructure for cognitive products. This preliminary investigation enables the requirements for the targeted communication infrastructure to be determined in a targeted manner. The results of these investigations will be consolidated in a unified roadmap, which will serve as the starting point for targeted research and development in strategic follow-up projects. In summary, the goals are as follows:

- Identification of application scenarios and requirements for a communication infrastructure for cognitive products.
- Identification of open research questions regarding existing technologies.
- Identification of cross-technology research questions.
- Consolidation of application scenarios, technologies and research questions in a roadmap as a starting point for strategic follow-up projects.





Approach

PREDISCOVER is structured in two phases. Phase 1 is used to establish a wide range of use cases across potential application domains. These will be discussed and developed together with potential industrial partners as well as the academic partners in the project. In the second phase the functional and nonfunctional requirements of the use cases will be established. These requirements will then subsequently be used to identify suitable technology for implementing unified dependable wireless services and to identify current shortcomings (research gaps) which must be addressed in future projects in order to allow for a truly unified service architecture. As a whole, the project will therefore result in a roadmap outlining the direction of future strategic research that will lead to the envisioned communication infrastructure and services.

- Development of representative communication use cases for cognitive products and their requirements.
- Initial screening of existing communication technologies regarding their suitability in the context of communication of intelligent products.
- Development and identification of potential cross-technology research questions.

Expected and Achieved Results

In the course of the project, several communication scenarios have been developed. These scenarios span many domains (building automation, autonomous driving, factory automation, infrastructure monitoring) and are the result of discussions with ongoing project partners as well potential future project partners. A number of research articles are the direct result of the developed use cases. We are currently working on a mapping between technologies and use cases that will allow us to identify potential research gaps in these specific domains and to develop a general, strategic roadmap that will allow us to work towards developing a unified communication infrastructure for dependable wireless services.

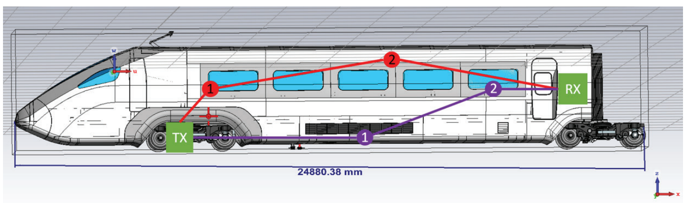
- Application scenarios that can be used to evaluate a communication infrastructure for cognitive products.
- Requirements for a communication infrastructure for cognitive products.
- Identification of open technological and cross-technological research questions.

Status / Progress

This project officially started in March 2018 and will last until April 2021. In it, Pro²Future is working with our Scientific Partners from Institute for Technical Informatics (TU Graz ITI) and the Institute of Microwave and Photonic Engineering (TU Graz IHF) to foster the research objectives of the project. The first phase of the project was successfully completed and a number of communication scenarios for cognitive products and production processes have been developed in a wide range of application domains (building automation, autonomous driving, factory automation, infrastructure monitoring). As a first result of PREDISCOVER, the article "The Quest for Infrastructures and Engineering Methods Enabling Highly Dynamic Autonomous Systems", was presented at the 2019's European Conference on Software Process Improvement. Another publication which was established in the context of the project concerns communication-based localization mechanisms (e.g. by utilizing ultra-wide-band technology) an emerging trend and viable use case for communication infrastructures. The article co-authored with colleagues from the Institute of technical Informatics was accepted and presented at the IEEE 16th Workshop on Positioning, Navigation and Communications.

The project focused on investigating diverse wireless communication scenarios in industrial applications and environments, including those with dynamic and changing conditions. Each scenario had specific requirements (such as situation, system type, data type, and feasibility), which guided the design of sensor system architectures. One aspect of the project involved establishing a system with visual capabilities and thoroughly evaluating its communication to a backend through simulations. Additionally, the wireless communication channel was characterized to ensure reliable representation.

In another use case, the project tackled the challenging environment of a firetruck, where RFID tags were used to track equipment. The goal was to establish a reliable tagging system in the physically demanding metal environment. Various approaches were developed to create a functional solution.
Furthermore, the project investigated wireless communication in industrial manufacturing sites, where requirements constantly vary due to moving elements. A dynamic system architecture was devised to cope with the changing setup. Challenges included considering the impact of movable components and material properties on wireless components like antennas.
The project's outcomes provided robust wireless communication solutions, tailored to the specific demands of various industrial scenarios.



Parameter	Antennentyp + Position			
	MIFA red	MIFA violet	MIFA direct	U-Slot direct
Path loss	-66 dB	-61 dB	-92 dB	-81 dB
Distance	4m + 8m + 7m (19 m)	9m + 6m + 4m (19 m)	16 m	16 m
TX Power	0 dBm	0 dBm	0 dBm	12 dBm

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AREA 4.1

MFP II 4.1.1.1 CORVETTE

Cognitive Sensing for Vehicle Fleet Driven Data Services

Area 4.1 - Cognitive Products

Project ID:	MFP II 4.1.1
Project Title:	CORVETTE: Cognitive Sensing for Vehicle Fleet Driven Data Services
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	36 Months, 01.05.2021 - 31.04.2024
Strategic Volume:	18 %

Work Packages

WP 1: Requirements and System Design

WP 2: System Development and Integration

WP 3: Edge Processing and Intelligent Sensing

WP 4: Backend Postprocessing/Training Methods

WP 5: Testing, Demonstration and Evaluation

WP 6: Dissemination and Exploitation

WP 7: Project-Management

Company Partners

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Academic Partners

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The CORVETTE project aims to establish a robust software infrastructure for cognitive vehicle fleet monitoring, enabling comprehensive data-driven services. The project encompasses diverse CORVETTE services, from data-driven development support to predictive maintenance and identifying emerging mobility trends through fleet data analysis. AVL is the esteemed company partner.
In the initial phase, rapid prototyping of onboard measurement hardware will ensure seamless data acquisition in real vehicles for method development. Concurrently, existing AVL solutions, such as AVL SMS, will facilitate swift data-driven method development.
CORVETTE's core focus is on developing methods for onboard measurement hardware and the CORVETTE backend, addressing multiple use cases involving monitoring vehicle movement, displayed information, and various driving parameters. One key challenge is achieving high-resolution monitoring of driving parameters, with a sampling rate of at least 10 Hz frequency, crucial for realizing the project's objectives.

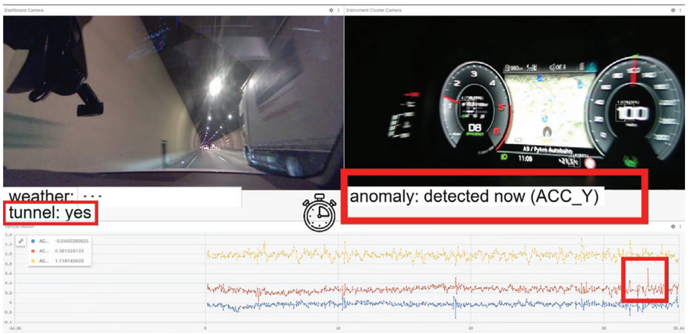
The main objectives of the project are:

- Efficient data collection through rapid prototyping of onboard measurements
- Designing modular devices for tailored data capture and future expansions which can be deployed in different vehicle types
- Backend infrastructure for data storage, data analysis, and live re-training of machine learning models
- Performing onboard data capture, interpretation, and preprocessing for intelligent analysis with a high resolution (>10 Hz)

Goals

Onboard Data Acquisition: Data is collected and pre-processed onboard the vehicle, prioritizing data collection and transmission to minimize communication overhead. This approach focuses on capturing valuable information for higher-level CORVETTE services and novelty. Contextualized data for advanced CORVETTE services is generated using Statistical Machine Learning (ML) techniques, such as Autoencoders and Gaussian Mixture Models, along with preprocessing methods. The primary goal is to ensure robust and stable ML methods, enabling reliable detection even with variations in input data. Privacy preservation is achieved through ML-based data preprocessing.

Backend Data Processing: The central CORVETTE backend efficiently manages the Onboard Devices, handling device management and aggregating all collected data for higher-level services. The project aims to achieve a flexible and scalable backend, implementing routing



mechanisms for automatic provision of specific services for incoming Onboard events and context-sensitive data processing. Multimodal ML methods will be designed to automatically assign incoming Onboard data to situation classes. The backend will support individual Onboard ML model training, where existing Automated Machine Learning Frameworks will be extended for automated model generation, with a focus on adapting models for embedded ML on Onboard Devices (e.g., Pruning). We will provide suitable visualizations and Northbound interfaces for easy data access and seamless integration with higher-level systems.

Demonstration and Testing: The developed methods in CORVETTE will undergo thorough testing and demonstration through various implemented use cases, showcasing their adaptability across different scenarios. Agile and iterative method development, based on real vehicle data, will ensure continuous evaluation. The project will culminate in a long-term test, where the methods and the CORVETTE Framework will be showcased.

Approach

The project adopts a scientific approach, with a primary focus on developing systematic methods for integrating and utilizing real-time vehicle data in higher-level services, both at the vehicle level and fleet level.

The following topics are investigated:

- ML-based anomaly detection and novelty detection in multimodal measurement time series
- Automatic ML-based contextualization and preprocessing of measurement time series
- Privacy-aware ML
- Methods for improved ML Robustness & Reliability
- SOA / Microservice Service Architectures
- Automated generation of ML models
- Methods for automated model transformation (Embedded ML)

Expected and Achieved Results

The research contributes to the field of industrial applications of machine learning, specifically addressing domain-specific challenges posed by multimodal sensor data. This includes tackling issues related to robustness, privacy, and changepoint/novelty detection, tailored to the unique requirements of the industry.

The achievement of the goals becomes visible by:

- Robust and adaptive ML models for anomaly or novelty detection in vehicle sensor data.
- Situation-specific generation of ML classification models
- Prototype CORVETTE onboard measurement hardware
- Prototype CORVETTE Backend
- Demonstration of the CORVETTE concept in the context of two defined use cases (Automated model generation, OnDevice data acquisition / recognition, Automated classification of incoming OnDevice measurement time series on fleet level, Higher-level service integration)

In the project's initial phase, the software infrastructure was successfully established, enabling effortless integration of new applications within Docker containers. This modular approach ensures easy addition of functionalities. Applications can be conveniently downloaded and updated directly on onboard devices in the Docker environment.
A unified software system remains consistently available, accessible at system startup regardless of the number of vehicles or onboard devices. Several implemented use case applications are currently operational on the devices. These applications include:

- Digit Dashboard Detection – QR code approach to identify regions of interest (ROIs)
- Weather and Tunnel Detection
- Anomaly Detection – Monitoring acceleration data
- Up/Download of recorded data to a backend where data analysis algorithms are applied
- Retraining of ML models in the backend which can be updated on the edge device in runtime

Status / Progress

The setup includes a powerful NVIDIA Jetson XAVIER AGX edge device onboard the vehicle, enabling efficient GPU-based video frame preprocessing. The data processing and communication pipeline is fully operational with all components in place. Applications can be easily installed and launched within the onboard docker container environment, storing pre-processed data for backend analysis. The backend, hosted on MS Azure, securely stores recorded data using blob storage, with data transmission facilitated by an LTE router setup.

The software infrastructure for cognitive vehicle fleet monitoring has been successfully established, with several high-performing applications already implemented and running on the edge device. The system architecture allows for easy adaptation, updates, and extensions within a git environment.

Implemented applications boast high detection accuracy, exceeding 85% overall and even surpassing 95% in specific cases like weather and tunnel detection during test drives.

The uploaded data is invaluable for model retraining, especially when the edge device lacks prior dashboard recordings. After a single test drive, sufficient data allows us to retrain models using our pipeline, ensuring high detection accuracy tailored to the specific vehicle.
This agile and extensible software infrastructure enables efficient deployment and management of various applications, ensuring a cutting-edge and adaptable onboard ecosystem. As the project progresses, we will expand the number of applications to further enhance vehicle intelligence and optimize fleet operations.

- Real-time Monitoring: Provides live data on vehicle performance and status
- Predictive Maintenance: Utilizes data analytics to forecast potential maintenance needs
- Fleet Analytics: Offers comprehensive insights into fleet-wide performance and trends
- Driver Behavior Analysis: Assesses driving patterns to enhance safety and efficiency
- Traffic and Weather Information: Delivers real-time traffic and weather updates to optimize routes

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AREA 4.1

MFP II 4.1.2.1 CompEAS-BSW

Compositional Embedded Automotive System Basic Software

Area 4.1 - Cognitive Products

Project ID:	MFP II 4.1.2.1
Project Title:	CompEAS-BSW - Compositional Embedded Automotive System Basic Software
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	48 Months, 01.04.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Use-cases and requirements analysis
WP 2: Long-term maintenance of Basic Software (LongtermBSW)
WP 3: Generic support for non-functional requirements (GenericNFR)
WP 4: BSW concepts for compositional application software (CompASW)
WP 5: Dissemination
WP 6: Project Management

Company Partners

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Academic Partners

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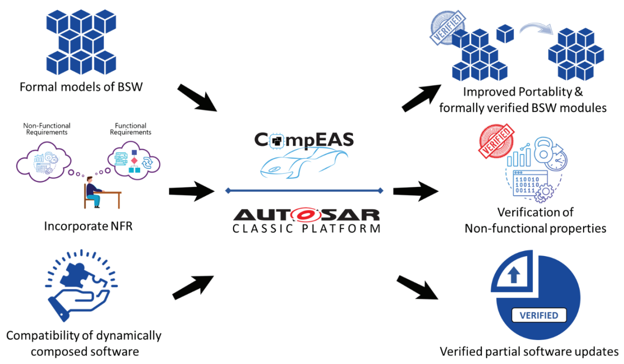
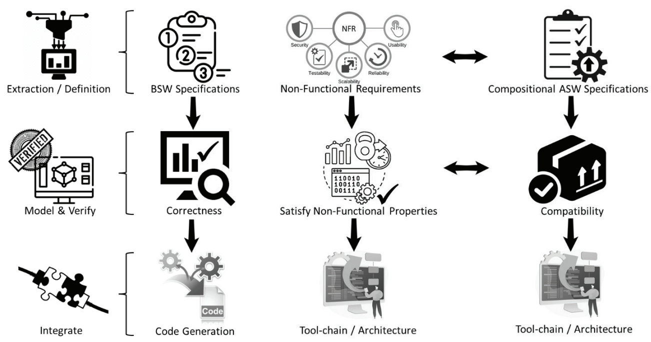
Embedded systems for vehicles are still implemented in a strictly static way: The individual functions are first implemented and tested separately for each Electronic Control Unit (ECU); their integration in an ECU is then largely manual. However, there is little support for dynamic modifications or partial updates in the field and there are currently no established and standardized mechanisms for ensuring the preservation of correctness during or after a modification. This applies to both the basic and application software and needs to change significantly due to the increasing number and complexity of in-vehicle and cross-vehicle functions.

First, the computing power required for future vehicles (e.g., for AI and machine learning for ADAS and autonomous driving) cannot be increased simply by installing more ECUs. Instead, a wide range of functions must be integrated on as few devices as possible per vehicle to reduce costs, weight, energy consumption, etc. In addition, new hardware functions (e.g., processors with domain-specific functions) to dynamically variable logic (e.g., in FPGAs) are constantly added. In addition, wireless networking of vehicles brings new challenges. While customers want convenient access to new features and flexible customization, security vulnerabilities or software failures need to be addressed in a timely manner to prevent malfunctions and attacks. This relevance is not only about the careful development of a reliable Embedded Automotive System (EAS), but also about its long-term maintenance. The software must be re-integrated during updates and the basic software must be adapted to new hardware. CompEAS-BSW is dedicated to automating the necessary processes by exploring new concepts for model-based software design and the composition of modular software with changing non-functional requirements.

CompEAS-BSW addresses with the dynamic composition and reliability of the entire software stack of embedded systems: The holistic approach ranges from the conception of future basic software (model-based OS design and portability) to module-based software development and partial updates (automatic integration and non-functional requirements). The results of CompEAS-BSW results should help to improve/expand the service and product portfolio of the partners while optimizing internal development processes. The technology transfer through the intensive interaction of all partners is expected to open up new business models, as more flexible and reliable products and services can be offered to customers.



Overview of CompEAS-BSW



Approach

Goals

The goal of this project is to investigate reliability aspects and the dynamic composition of software and hardware of complex computer platforms or EAS over the entire system stack. Scientific methods are to be used to (1) derive concrete questions from the current industry practice, (2) develop viable solutions for the systematic realization and long-term maintenance of future EAS, and (3) transfer the knowledge gained to partner companies and established standards.

The project is about the evaluation/development of new technical concepts that are close to general research focusing on the Classic AUTOSAR environment. It focuses on Classic AUTOSAR and thereby on (1) improvements to the low-level Basic Software (BSW) layer (OS, drivers) with respect to portability and verification, (2) support for modeling of non-functional requirements (NFRs) in middleware through automatic AUTOSAR configuration/verification/code generation according to these NFRs, and (3) improvement of integration and verification of compositional application software.

Approach

The approach is to apply formal methods to model and verify embedded operating systems (OS). By analyzing common programming paradigms in embedded OS, we create consistent formalizations for hardware and software models (HW/SW), that ensure compliance with functional and non-functional requirements. Non-functional requirements (NFRs) are integrated into BSW through a "Budget Manager", which enables systematic derivation of target values that satisfy the NFRs. Implement generic NFR managers in operating systems to enable offline analysis and online management of NFRs. Improve system maintainability through runtime software updates and compatibility checks via SWC fingerprinting and algorithms, enhancing both modeling and compositional aspects of EAS.

Expected and Achieved Results

The expected outcomes of CompEAS-BSW project are:
LongtermBSW: Concepts for model-based development of BSW with the aim of verifying models with respect to the target architectures and porting basic software largely automatically.
GenericNFR: Concepts for the formal specification of non-functional requirements (NFR) in the sources of Application Software (ASW) with the aim of formalizing these NFRs of the BSW and enabling the BSW to comply with them at runtime.
CompASW: Concepts for extracting NFRs and generating metadata for individual software components (SWC) of the ASW with the aim of automatically checking them for compatibility ("automatic integration" for partial changes (updates, etc.).
The publication of the project results at scientific conferences and in journals, the technology transfer to the company partner and, if necessary, the publication of concrete implementations of the results in open-source software.

Status / Progress

The project officially started in December 2020. Pro2Future is working with company partner Elektrobit GmbH and the Institute of Technical Informatics at TU Graz. By April 2021, three PhD students have started their work in the respective work packages WP2, WP3, and WP4. The project jour fixes take place weekly and serve to exchange knowledge, synchronize on the research progress, and discuss research results. After the initial literature review and understanding of Elektrobit AUTOSAR Operating Systems (OS), all the work packages have defined their research path, which deals with long-term maintenance, integration, and formalization of NFRs, and dynamic composition respectively.

Long-Term BSW: Based on existing work and an initial literature review, we proposed an extensible framework that integrates formal methods, LLVM, and Worst-Case Execution Time (WCET) tool to improve the portability and correctness of OS. First, we developed a static analysis framework based on a WCET tool to verify the correctness of the hardware-dependent code of OS. The idea is to model the hardware-dependent code using formal method Event-B and verify it for correctness against the functional requirements. After verification, we will integrate the hardware-dependent models with the hardware-independent OS models in the formal method: UPPAAL. The models will be verified for correctness against functional and non-functional requirements. In the next step, the models will be translated into code using LLVM.

GenericNFR: The industry partner has provided Non-Functional Requirements (NFRs) on aspects such as application response time, homegenous core utilization, etc. To address these Generic NFRs systematically, we conducted a literature review. In collaboration with the industry partner, we propose the following approach: (1) Modeling generic NFRs: Creating a mathematical model that describes the crucial variables that affect the NFRs. The goal is to quantify NFRs. (2) Formal generic NFR specification: we will look at established methods, such as AUTOSAR Timex, to formally specify NFRs within the research community. (3) Modeling NFRs for optimization: In this phase, we will address NFRs and the application as an optimization problem. We will use metaheuristic or evolutionary algorithms to find feasible solutions. (4) Validation: This will be achieved by testing potential solutions on an embedded platform, using a customized monitoring and analysis module.

CompASW: The CompASW work package is concerned with improving the maintainability of the system through partial software updates. In order to develop a robust partial update mechanism for automotive systems, algorithms must be developed to analyze the various dependencies and requirements (functional and non-functional) of SWCs and perform compatibility checks. These compatibility checks must be performed on the target hardware by the BSW and based on the results, the system must be prepared for an update. To achieve this, this work package is divided into 2 parts. Part 1 deals with the identification and extraction of meta-information for compatibility checks during software integration. Using this information, Part 2 deals with developing algorithms that perform "online" compatibility checks during automatic software integration by the BSW on the target system.

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AREA 4.1

MFP II 4.1.2.2 TWIN-SOLUTION

Digital Twin enabled commissioning and testing of failsafe automation

Area 4.1 - Cognitive Products

Project ID:	MFP II 4.1.2.2
Project Title:	TWIN-SOLUTION: Digital Twin enabled commissioning and testing of failsafe automation
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	48 Months, 01.04.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Project management

WP 2: Dissemination and Exploitation

WP 3: Automatic generation of safety and failsafe tests for automated testing of future automation components

WP 4: Methods to support digital twins, virtual configuration, and commissioning of automation systems

WP 5: Demonstrators

Company Partners

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Academic Partners

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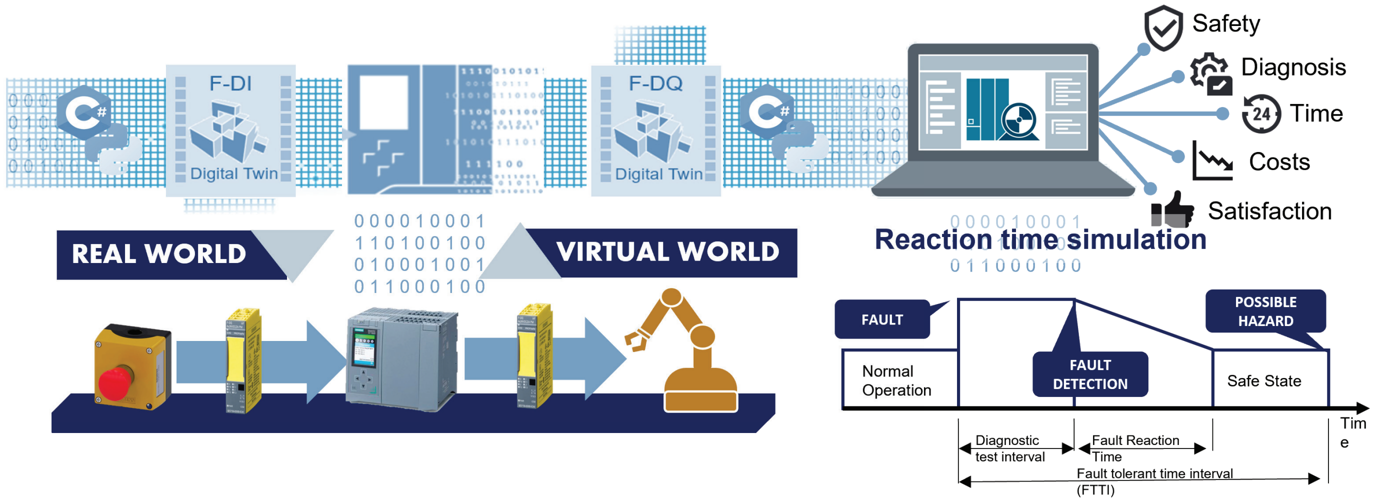
Due to the complexity of automation systems, extensive on-site engineering is required during installation, commissioning, and maintenance. Skilled engineers and technicians need to be close to the automation system to assemble and configure components, perform rigorous testing, and fine-tune control parameters, making this approach resource costly. Furthermore, working on a real physical system does not provide full flexibility, meaning that during the testing and configuration phase, the automation components can be damaged if a system is configured wrongly. This is especially a problem with safety-critical systems since testing in such systems often requires dangerous fault injection to test implemented safety functions and see if they can protect operators, machines, and the environment in the case of failure.

To reduce on-site engineering and allow more flexibility to the engineers and technicians, virtual commissioning and digital twins are emerging as promising concepts in automation systems, especially in safety-critical ones. Virtual commissioning is a process that involves simulating a physical manufacturing environment using software systems. The primary purpose of this simulation is to provide engineers with an opportunity to validate their configurations and test behavior before system debugging in the manufacturing production environment, enabling remote design, installation, and maintenance of automation systems that comply with defined standards and regulations without hardware equipment.
The core of the successful virtual commissioning process is a digital twin, which can represent a virtualized copy of various physical assets ranging from a production line to a single component. The digital twin integrates all data, models, and information of a physical asset, including its behavior and technical performance. The role of the digital twin is to predict and optimize performance. Digital Twins enable the virtual test of a system's behavior and have a high potential for the rapid execution of risk analyses and system tuning to verify the consistency, correctness, and completeness of an automation/autonomous system.

In the safety system, the configuration of safety functions and their testing is of very importance since, besides machines and the environment, human lives are also at stake, and the wrong configuration could lead to hazardous events. In this project, we wanted to develop a digital twin of the safety components and leverage the use of a virtual environment to do risk-free testing and parametrization (i.e., virtual commissioning) of the safety systems and their safety functions complying with the safety standards.



Goals

As virtualization and digital twin technologies hold great promise, the goal is to use these approaches to reduce commissioning and maintenance time in the automation industry while ensuring system consistency and features, such as safety. The research involves analyzing the behavior and performance of current safety-related physical components (e.g., safety controllers or safety input/output modules) to create their digital copies (i.e., digital twins) in the virtual environment. Since safety in these components is ensured with multiple safety functions, the goal is to successfully implement all safety functions and produce highly accurate digital replicas (i.e., digital twin) of the safety component that can aid in thorough testing and validation, ultimately contributing to enhanced safety and reliability in automation systems. The implementation of such digital twins will also lead to decreased resource requirements and offer a faster, safer, and easier way to meet the strict requirements set by safety standards. The long-term goal is to contribute to the identification and development of technologies that will play a crucial role in industrial and process automation, especially in safety-critical systems, in the years to come.

Approach

In the beginning phase, the behavior and performance of current physical safety-related components are analyzed. To ensure an organized approach, we categorized and prioritized the safety functions of these devices based on the valuable insights of on-field control engineers. In the next phase, Siemens' virtual portfolio and their virtual embracing tools, such as PLCSIM Advanced v3.0 and SIMIT tool are carefully analyzed. These tools together with a result of components analysis played a main role in our research and development process. The focus lies in comprehensively researching each safety function, creating a digital footprint of these functions, and understanding how they behave (i.e., their capabilities and limits) in the virtual industrial environment. Moreover, based on the relevant norms and regulations we design rigorous tests and conduct simulations, with a special emphasis on critical aspects like reaction time.

Expected and Achieved Results

The first outcome of the project was the detailed study and analysis of the safety functions implemented in real physical devices, which enabled the translation of their functionalities and performance to the virtual world. The safety components analyzed were the fail-safe input and output modules, indicating that in the first phase of the project, the goal was to have 2 digital twins so that the entire input-control-output automation loop could be simulated. Based on these results, the first version of the digital twins was developed using a simulation platform called SIMIT tool. Due to the complexity of the device itself and the complexity of the underlying software, the initial versions of the digital twins simulated some key safety functions that could be used for further evaluation of the overall system. One such simulated function is a logical behavior of the safety component that simulates the usage of safety architectures such as 1oo1 or 1oo2. This enables engineers to simulate and test the logical behavior of the entire system that uses safety-related components. In addition to the logical aspect, digital twins simulate additional functionalities. For both digital twins (i.e., input and output), a safety function is implemented that calculates the worst response time of the modules and informs the user about it. For the digital input, the behavior of the discrepancy analysis is simulated, which enables error detection in sensors connected to the fail-safe input module. In addition to the simulation itself, the developed digital twins impact industrial automation by enabling new and more efficient approaches such as safety-related relevant data collection, which becomes possible without additional hardware, simplifying processes and reducing costs. In addition, the new way of generating data supports research and development of novel approaches for preventive and predictive maintenance and revolutionizes the way systems are managed and maintained.

Status / Progress

The project officially started in April 2021. Pro2Future is working on this project with the industrial partner Siemens AG and the scientific partner Institute of Technical Informatics at TU Graz to develop a digital twin for safety-related industrial devices. In the previous period, an analysis was conducted on a range of useful tools, mostly provided internally by Siemens. Using selected tools, new digital twins were developed for the fail-safe digital input modules and fail-safe digital output modules. These digital twins have the capability to simulate various safety functions recommended by safety standards, which are present in the current physically available fail-safe modules.

To fully utilize the digital twins, additional data was needed: module-specific data and custom (i.e., user) configurations for specific devices/projects. To enable the use of the different types of data in the digital twin a special script was developed. The script allows the user to select a module and collect the relevant data from various sources, which are then used to generate a file readable by the digital twins. In addition, the script allows fine-tuning of important parameters such as watchdog time, which is a critical factor in calculating the maximum reaction time, and thus observes the impact on the overall system parameters in the context of safety-critical systems. Additionally, an automated test process, where the developed components as well as the overall system can be tested, is developed. The test cases used are derived from the official integration tests used by the integration team at Siemens to test a real (i.e., physical) fail-safe module.
Finally, the implemented digital twins are used and tested in the demonstrator, which shows how a simple safety loop can be simulated using the developed digital twins. The safety loop consists of an autonomous robotic arm as an actuator and a safety curtain as a sensor. The safety curtain detects the presence of the worker in the robot's workspace and activates all necessary actions (i.e., stopping or slowing down the robot arm) to protect the worker. In addition, the demonstrator has an emergency button that can be pressed in the event of a dangerous event.

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AREA 4.1

MFP II 4.1.2.3 CompEAS-HW
Compositional Embedded Automotive System Hardware

Area 4.1 - Cognitive Products

Project ID:	MFP II 4.1.2.1
Project Title:	CompEAS-HW - Compositional Embedded Automotive System Hardware
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	45 Months, 01.07.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Project Management

WP 2: Dissemination and Exploitation

WP 3: Use Cases und Requirements Analysis

WP 4: Optimization of processor power characteristics in software (PCOpt)

Company Partners

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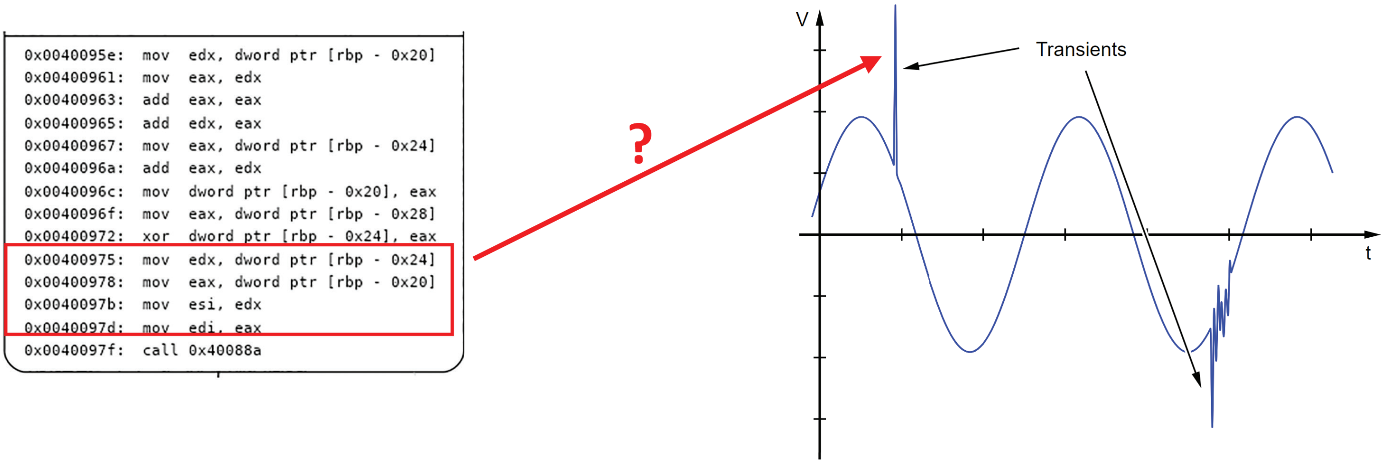
The execution of software has a significant impact on various runtime characteristics of the hardware. Software critically influences the energy consumption, thermal, or the electromagnetic behavior of a microcontroller unit. While Electromagnetic Compatibility Check analyses can be used for side-channel attacks, critical temperature patterns and LoadJumps (LJ) or PowerPeaks (PP) can lead to malfunctions. The new topic "Optimization of processor power characteristics in software" under CompEAS-HW shall be dedicated to the avoidance of LoadJumps and PowerPeaks.

Together with its industrial partner Elektrobit Automotive GmbH (Erlangen), CompEAS-BSW project has been dedicated to reliability aspects and the dynamic composition of software for embedded automotive systems (EAS). These aspects are now to be extended to the hardware together with Infineon AG (Munich) across the entire system stack.

The CompEAS-BSW project is already dedicated to the specification and implementation of Non-Functional Requirements (NFR) for software components. Hardware often imposes limits on their fulfillment/implementation through Non-Functional Properties (NFP). Intermediate Basic Software (BSW) or Hardware Adaptation Layer (HAL) layers mediate between ASW and HW and require a complete and formal specification of NFR and NFP. Unfortunately, this specification is usually inadequate, which is why novel concepts must be developed to mitigate the resulting problems. The collaboration with Infineon in CompEAS-HW will lead to new insights for the optimization of processor performance characteristics in software.

Goals

The CompEAS-HW (Compositional Embedded Automative Systems) project investigates the interactions and synergies between embedded automotive software and hardware. Scientific methods are to be used to (1) derive concrete questions from practice, (2) develop viable solutions for the systematic implementation of future hardware and (3) transfer the knowledge gained to the partner companies and established standards.



Analysis of Load Jumps and Power Peaks

Overarching optimizations at the compiler, BSW, and HW levels are intended to facilitate the development of software that fundamentally triggers fewer (or no) Load Jumps and PowerPeaks. This, in turn, has implications for the design of future hardware and software, as well as the mechanisms they contain for handling critical LJ/PP situations at runtime. The insights/results obtained can serve as information for software developers (Dos & Don'ts) as well as for the creation of specifications/guidelines for compiler and BSW vendors. They should support the development and optimization of future hardware (e.g., processor cores, on/off-chip components).

Approach

The approach under CompEAS-HW is to analyze processors by executing code sequences with respect to LJ/PP. The effects of concrete code sequences can be determined by HW simulation, self-monitoring (if supported by the hardware), or external measurement. For this purpose, appropriate models must be implemented, or test setups must be realized. The next step is to create a methodology to detect critical code sequences in real code or even generate them specifically for the test case generation. Then develop a method to statically and dynamically resolve the critical code and optimize its execution at runtime.

Expected and Achieved Results

CompEAS addresses with the dynamic composition and reliability of the entire software stack of embedded systems: The holistic approach ranges from the conception of future basic software (model-based OS design and portability) to module-based software development and novel processor architectures (optimization of energy behavior).
The results of CompEAS are expected to help improve/expand the partners’ service and product portfolio while optimizing internal development processes. It is expected that the technology transfer will open up new business models through the intensive interaction of all partners, as more flexible and reliable products and services can be offered to customers. All partners are expected to benefit from the CompEAS employees as highly qualified experts for further projects and as co-designers of future automotive standards, thus also strengthening the industrial location Graz and Austria. From an academic perspective, a significant contribution to the scientific community is expected: This should include the scientific publication of the results.

Status / Progress

The project officially started in July 2022. Pro2Future is working with company partners Elektrobit GmbH, Infineon Technologies AG and the Institute of Technical Informatics at TU Graz. The project jour-fixes take place weekly within CompEAS and serve to exchange knowledge, synchronize research progress, and discuss research results. The project has made significant progress in several key areas. The initial focus was on establishing the necessary development environments and ensuring seamless access to systems and hardware resources. This was followed by the establishment of efficient device communication and logging mechanisms to enable comprehensive data collection. An Expert Exchange Workshop held at Infineon Germany in August further enriched our understanding and insights.

A notable achievement was the successful development of an experimental setup that can detect voltage spikes, bursts, and outages - a crucial step in our investigation. To establish a solid foundation, we meticulously evaluated and reproduced previously known faulty code sequences, gaining valuable insights in the process. Subsequent analysis and inference allowed us to identify possible causes for the observed problems. The establishment of a robust debug framework was instrumental in accurately identifying and examining erroneous code sequences. In addition, through a comprehensive analysis of both known and randomly generated code sequences, we examined the performance of various compilers and test sequences and generated insightful statistics on code coverage. On the hardware side, the project has made significant progress as we have successfully developed an experimental setup engineered to detect voltage anomalies, such as spikes, bursts, and outages. This progress culminated in the inclusion of initial measurements with embedded device benchmarks, a promising step forward. As the project progresses, we will build on these achievements, further refining our methods and contributing to the progress in our field.

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AREA 4.1

MFP II 4.1.3.1 Enhance UWB

Benchmarking and advancing localization and communication performance UWB

Area 4.1 - Cognitive Products

Project ID:	MFP II 4.1.3
Project Title:	Enhance UWB - Benchmarking and advancing localization and comm. performance UWB
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	36 Months, 01.07.2021 - 30.03.2024
Strategic Volume:	18 %

Work Packages

WP 1:	Project-Management
WP 2:	Dissemination and Exploitation
WP 3:	Testbed Design and Implementation
WP 4:	Methods for non-line-of-sight (NLOS) detection and mitigation
WP 5:	Study of UWB and BLE performance and co-existence issues

Company Partners

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The rapid digitalization across all industrial sectors has fostered an increased need for connectivity in heterogenous application environments. As a consequence, research and development of radio-based technologies for long- and short-range communication has intensified over the last decade, with a multitude of technologies and protocols currently available. Ultra-WideBand ("UWB") is a radio-based communication technology that offers reliable data transmission for indoor and outdoor application scenarios. Latest UWB transceivers are relatively energy-efficient and thus support battery-powered mobile applications. UWB has applications in automotive, data transfer, radar, mobile phones, real-time localization, and related industrial applications, and has the potential to catalyze the seamless digitalization of shop floors, warehouses, and process chains.

Several challenges remain for UWB, including the mitigation of non-line-of-sight (NLOS) conditions in the context of localization applications. Another challenge concerns the use of UWB systems in the presence of co-located wireless devices sharing the same frequencies (e.g., Wi-Fi 6E devices), which can result in detrimental collisions that may degrade the communication and localization performance.

To further advance NXP's existing UWB solutions, the project ENHANCE-UWB aims to develop a testbed allowing for the reproducible study of UWB in complex application environments. Bluetooth Low Energy communication (BLE) often functions as a communication link for localization systems and as UWB is often used in combination with BLE (e.g., for discovery purposes), the ENHANCE-UWB testbed should also allow benchmarking of a BLE link's communication performance in the presence of co-located wireless devices sharing the same spectrum. Overall, the envisioned testbed will allow the project to pursue the following research directions:

- UWB real-time non-line-of-sight (NLOS) detection and mitigation
- Performance study of UWB and BLE co-existence issues with co-located wireless devices (e.g., Wi-Fi 6E devices)

Goals

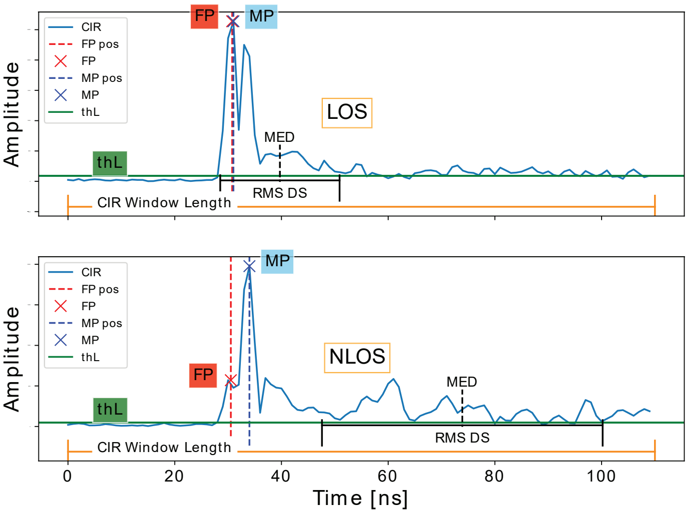
G1: Design and realization of a UWB testbed for the reproducible study of NLOS and coexistence scenarios.
G2: Development of NLOS detection and mitigation strategies and their demonstration and evaluation in the ENHANCE-UWB testbed.
G3: Incorporation of Master/Bachelor projects and thesis into ENHANCE-UWB.

Approach

We focus on the investigation of NLOS conditions in the context of UWB localization scenarios, as well as on the development of NLOS detection and mitigation strategies. A particular focus of this work lies on the study of 'strong NLOS' conditions, i.e., situations where the LOS component is blocked entirely and no longer detectable by the receiver. As outlined in the project goals, this aims to answer the following research questions:

- Is it possible to detect and mitigate NLOS conditions without requiring environment specific training data (new environment)?
- Is it feasible to define a quality metric to indicate, with high probability, that LOS conditions are present?

In a first task, suitable and challenging testing scenarios will be designed for implementation and execution within the ENHANCE-UWB testbed. The different CIR signals in NLoS/LoS will be analyzed. In a second task, existing approaches for NLOS detection and mitigation will be adapted for application on NXP UWB hardware. These approaches will serve as a baseline for further investigation. In a third step, the testing scenarios defined in the previous step will be implemented in the testbed and the baseline methods will be tested and benchmarked. The results serve as a starting point for the development of novel and refined NLOS detection and mitigation concepts. The last task of the work concerns a final benchmarking of the developed methods and the creation of a demonstrator regarding the best derived methods.



Expected and Achieved Results

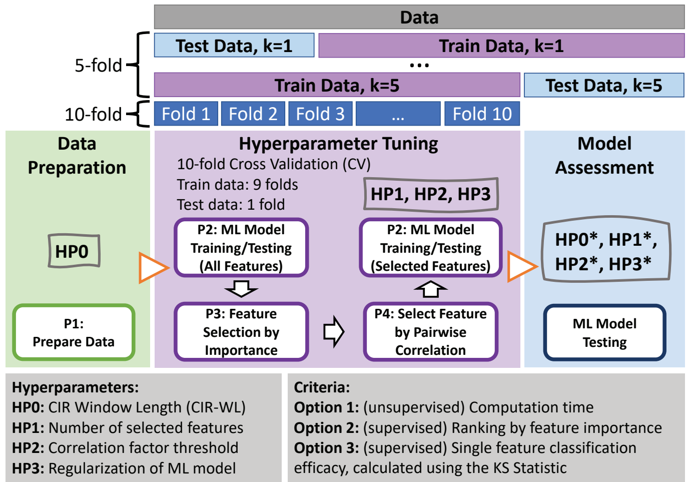
We have developed an automated machine learning workflow for developing ML models for categorizing UWB NLoS/LoS situations. In order to decrease the computational complexity, our solution employs two key strategies:

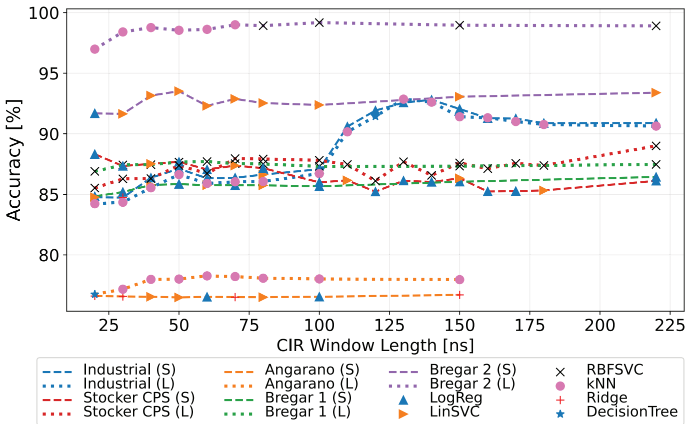
(1) feature selection, we choose the most essential features for classification and only use them.

(2) by reducing the CIR Window Length (CIR-WL) for feature extraction, the feature extraction time is reduced.

We employ a large number of features (29), various ML classifiers to create our models, and five datasets to test them in order to compare them fairly to the State of the Art (SoA). Nested Cross-Validation (Nested CV) is used in our suggested ML pipeline in order to perform hyperparameter (HP) tuning and provide unbiased performance estimates for our ML models.

To get results that are generalizable, we specifically took into account 29 features and investigated the impact of feature selection across five different datasets. We demonstrated that we can extract two sets of just 3 and 8 features, resulting in tiny machine learning models (less than 1 kB) and quick computation speeds (3.6 ms and 27.7 ms, respectively, using an 80 MHz ESP8266 microcontroller). Compared to the state of the art, this enables a runtime reduction of more than 90% while retaining an average classification accuracy of more than 85% across all five datasets.





Status / Progress

We have investigated and suggested techniques to apply ML-based feature selection and shorten the window length of the channel impulse response for feature extraction to lower the computational complexity of NLoS classification models. In our future work, we will expand on this analysis in future work by using NLoS error mitigation in addition to classification. Regarding our ML pipeline, we are planning to include the feature extraction time as part of the HP tuning inside the ML Pipeline, we further want to enhance our feature selection methodology.

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AREA 4.1

StratP II 4.1.4.1 E-Minds-1
Embedded Intelligence for wireless communication services

Area 4.1 - Cognitive Products

Project ID:	StratP II 4.1.4
Project Title:	E-Minds-1 - Embedded Intelligence for wireless communication services
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	31 Months, 01.09.2022 - 31.03.2025
Strategic Volume:	100 %

Work Packages

WP 1: Project management

WP 2: Dissemination und Exploitation

WP 3: Training Embedded Intelligence

WP 4: Verification of Embedded Intelligence

WP 5: Deployment of Embedded Intelligence

WP 6: Case Studies

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The objective of this project is to provide techniques and toolchains that make it possible to train and deploy AI/ML models for embedded systems with little resources. This should allow the use of trustworthy embedded intelligence in the future in cognitive products and production systems. The project will showcase the created methodologies and toolchains by applying them to industrial case-studies.

Goals

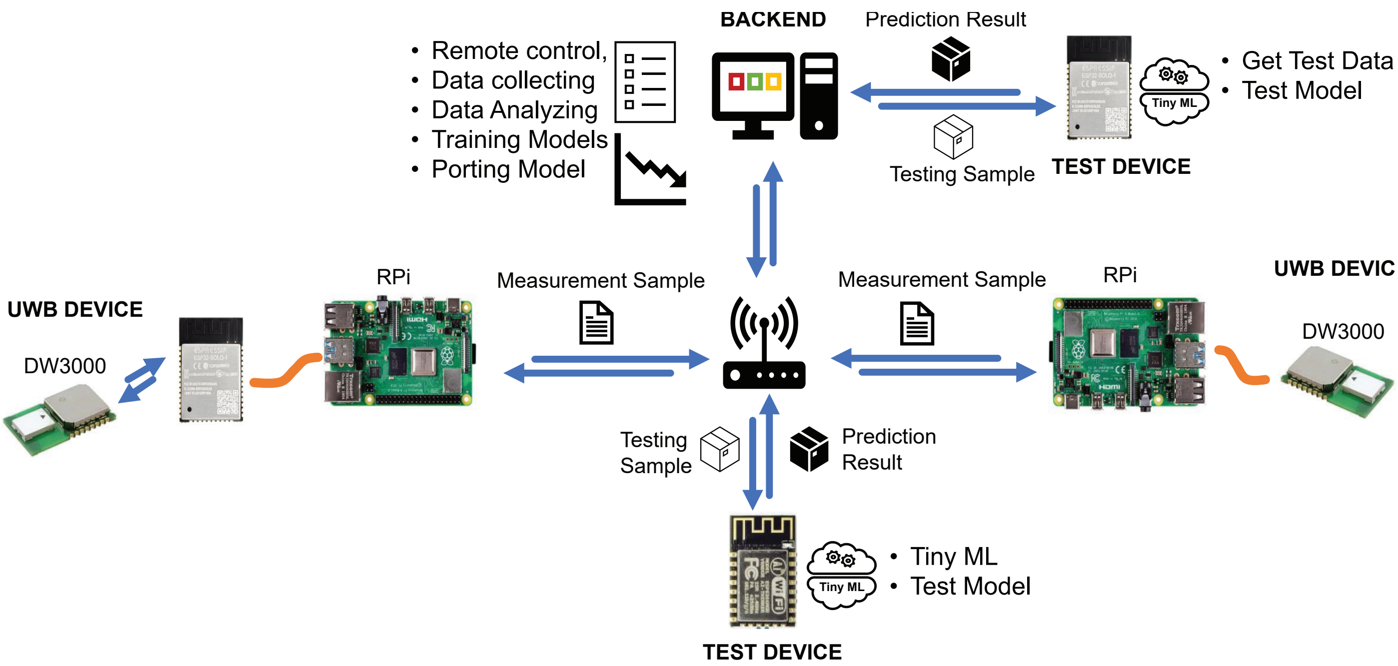
In today's swiftly changing tech landscape, two vital domains emerge: creating AI/MI models for resource-constrained embedded systems and integrating Cognitive Wireless Sensing into evolving wireless communication, especially in the context of 6G research priorities. Our exploration delves into these contexts, examining efficient AI/MI model creation and seamless Cognitive Wireless Sensing integration.
We're crafting a comprehensive training framework. This encompasses data collection, evaluation, training technique selection, and model provisioning. To achieve optimal results, we aim to:

- Integrate varied training frameworks and concepts from different MFPs and literature.
- Investigate compression principles for simplifying models for embedded device use.

Efficient model deployment onto designated devices is central to our project. We're actively developing semi-automated toolchains for streamlined implementation. The designed toolchain's demonstration aligns with the specifications from the "Enhancing UWB with Embedded Intelligence" case study. We're meticulous in selecting and developing the case study to ensure accessible training data, methodologies, and efficient measurement models for embedded ML models.

Approach

Firstly, to ensure the successful outcome of our work, our approach begins with an in-depth exploration of existing training frameworks, concepts, and methodologies in the literature about embedded intelligence .
Moving forward, our trajectory involves the selection of diverse models and techniques that align seamlessly with the ground truth of our task. These chosen models must inherently adhere to the constraints imposed by our task's model, including factors like timing considerations.
With our chosen models in hand, our next step entails deployment through a meticulous process involving compression and pruning techniques drawn from existing literature. This strategic approach aims to optimize the models while maintaining their integrity and performance.
Subsequently, the culmination of our efforts leads to the presentation of our meticulously developed toolchain in the form of a demonstrative showcase, prominently featuring the advancements made in the realm of "Enhanced UWB." This showcase serves as a testament to the effectiveness and practicality of our approach.



Basing our insights on thorough scientific research, we have identified a set of foundational points that can serve as a starting base for addressing and aligning with the previously mentioned key approaches:

- To achieve the compression and portability of various types of models, it is essential to consider multiple frameworks. For instance, the MicroML Library demonstrates the capability to port several types of models, such as Decision Trees (DT) and Support Vector Machine (SVM) models, while not accommodating Perceptron's. On the other hand, the Micro Learn Library specializes in porting Perceptron's and for DTs.
- Conducting an evaluation of these frameworks becomes imperative to showcase their respective strengths and compatibility with different models. This assessment will show which framework is most suitable for specific types of models, optimizing their performance .
- The process of generating versatile files from the porting frameworks extends beyond the typical showcasing solely on platforms like Arduino. To ensure broader usability across various MCU implementations, two critical points must be addressed: (i) Framework Adaptation and Tailoring: The first imperative involves adapting and tailoring the framework outputs to harmonize seamlessly with diverse MCU environments; and (ii) C-Library Generation for Runtime Adaptability: The second focal point centers around the generation of libraries featuring specific models. These libraries should possess the capability to adapt dynamically during runtime on the MCU by remote commands. This approach can facilitate a broader and more adaptable implementation, allowing for increased flexibility and versatility.

Hardware requirements: To obtain an accurate performance estimation for various applications under different constraints, it is imperative to apply the techniques across distinct categories of hardware. This entails evaluating the techniques on the following HW-categories:

- Slower Hardware without FPU and DSP Instructions: This category involves hardware configurations that lack Floating-Point Unit (FPU) and Digital Signal Processor (DSP) instructions, which often pose limitations on computational capabilities (e.g., ESP8266).
- Hardware with FPU and DSP Instructions: The second category encompasses hardware equipped with FPU and DSP instructions, allowing for enhanced computational capabilities (e.g., ESP32).
- For a thorough evaluation, it's crucial to include hardware customized for the intended purpose. This specialized hardware should closely match the applications, shedding light on techniques' real-world performance and suitability. A prime example of this is the nRF52833, coupled with the DW1001, which aptly suits Ultra-Wideband (UWB) applications and is prominently featured in the literature.
- A larger memory space provides testing advantages. Despite optimizing models for constrained memory, having more memory allows realistic testing of significantly reduced models. Larger memory accommodates larger ML models, facilitating accurate reduction estimation without immediate implementation constraints. This comprehensive approach enhances reduction potential assessment.
- Communication capability: For smooth and flexible communication while in motion, it's crucial to support device interaction during operation. This means being able to adaptively transfer data and model parameters on the fly, especially for live demos. To achieve this, equipping the hardware with an additional wireless communication port becomes important, enhancing its versatility and practicality.

Expected and Achieved Results

Our project encompasses several key objectives. Firstly, we aim to develop efficient techniques for model selection and training within the domain of embedded intelligence. Furthermore, we are confident in our ability to devise methods that assess and validate the correctness and behavioral aspects of models, including their timing characteristics. Additionally, we are dedicated to refining methods to optimize model sizes for deployment on embedded platforms. Our focus also involves creating seamless and automated deployment processes for specific embedded devices, seamlessly integrated into our training platform. Moreover, we are enthusiastic about data collection and plan to implement machine learning-based approaches to enhance applications of Ultra-Wideband (UWB) technology. These combined efforts will culminate in a demonstrator that effectively showcases our accomplishments. Guiding our endeavors is a structured framework that serves as a roadmap to attain these objectives.

Example: Toolchain/Demonstration Framework Architecture

Figure 1: Demonstrates a key research outcome - the creation of a measurement and testing framework. The UWB devices are connected to a Raspberry Pi, which acts as a forwarding and flash device, channeling data to our Backend for collection. The measurements collected can be sent to an MCU without an existing UWB driver. The MCU receives continuous test data for model evaluation. During testing, performance metrics such as prediction duration, outcome, and memory usage are sent back to the backend for further analysis. This structure results the advantage to offer dual capabilities: real-time data execution and testing using stored test data. This allows for comparing the original model to its scaled-down version. Furthermore, verification primarily focuses on the MCU, negating the need for extensive implementation with other hardware.
The approach facilitates testing the same model across diverse hardware setups, enabling the creation of a hardware/model benchmark.

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AREA 4.2

MFP 4.2.1-1 CoExCo

Cognitive Polymer Extrusion and Compounding

Area 4.2 - Cognitive Productions Systems

Project ID:	MFP 4.2.1-1
Project Title:	Cognitive Polymer Extrusion and Compounding
Project Lead:	Univ.-Prof. Dr. Georg Steinbichler, JKU Linz, Institute of Polymer Extrusion and Compounding DI Dr. Wolfgang Roland, JKU Linz, Institute of Polymer Extrusion and Compounding Mag. Bernhard Löw-Baselli, JKU Linz, Institute of Polymer Extrusion and Compounding Univ.- Prof. Dr. Kurt Schlacher JKU Linz, Inst. of Automatic Control and Control Systems Techn.
Duration:	48 Months, 01.04.2017 - 31.03.2021
Strategic Volume:	7 %

Work Packages

WP 1: Project Management

WP 2: Data Management System

WP 3: Inline-Compounding Film Line

WP 4: Pipe Coextrusion

WP 5: Corrugated Pipe Extrusion

WP 6: Gravimetric Dosing

WP 7: Coextrusion Blow Molding

WP 8: Dissemination

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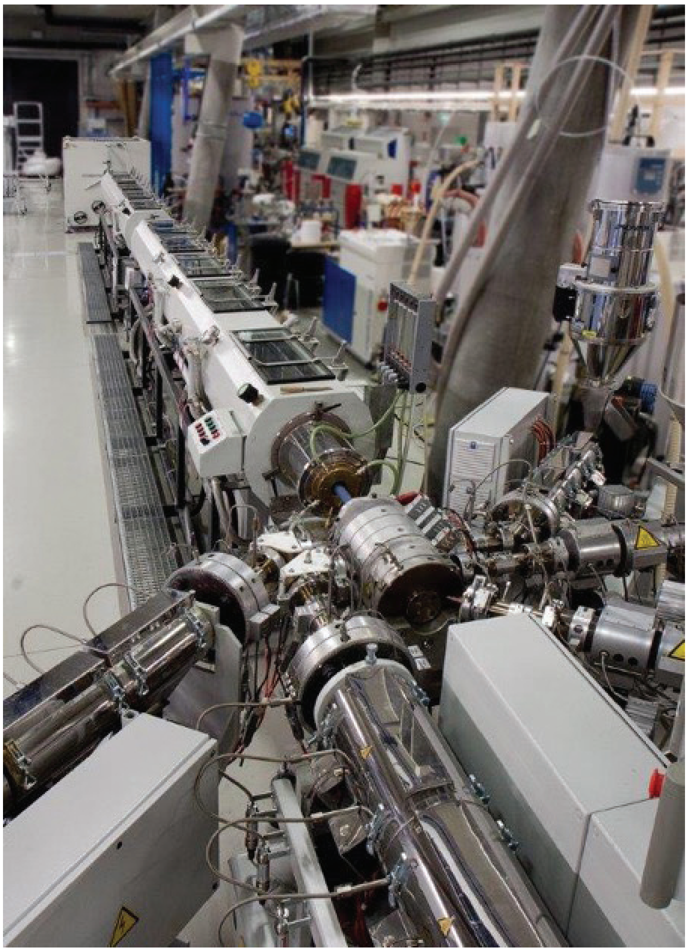
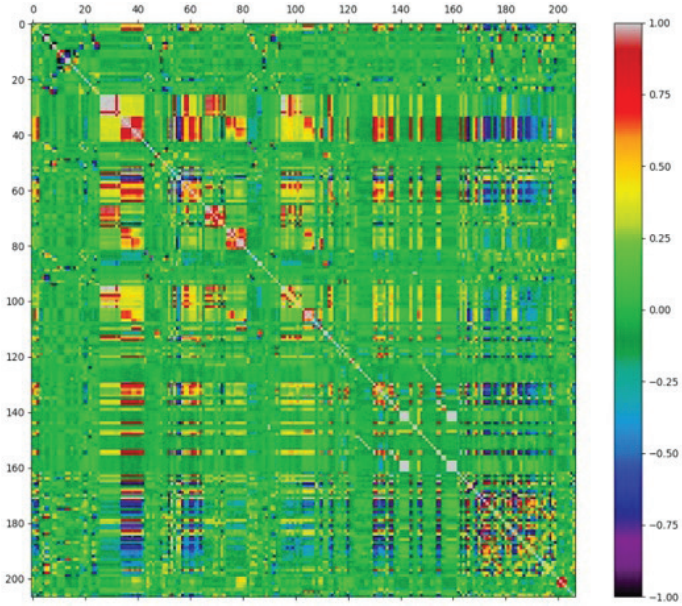
Polymer processing plants show a nonlinear relation between extruders and downstream equipment, so this MFP will investigate and develop novel strategies for self-optimization in the field of film and sheet processing, pipe coextrusion, corrugated pipe processing, gravimetric dosing, as well as coextrusion blow molding. Up to now concepts of self-optimization for polymer processing lines are unknown in applicable complexity but the production systems would need almost real-time reactions based on process data. Therefore productivity and quality remains highly dependent on the operator in production runs as well as in ramp up after material change.





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Goals

As processes for polymer production show a high variety the goals of this MFP do either. The thermal management of extruders will be investigated, as extruder mostly have several but uncoupled heating zones. New control algorithms will be developed showing improved temperature management in heating as well as in operating change. Gravimetric dosing will also be investigated, as dosing units change to volumetric mode when shaked. Volumetric mode will become independent from screw characteristic lines by applying data based modeling and improvements to gravimetric mode sensitivity will be investigated. Online layer thickness measurement techniques will be developed to be applicable to corrugated pipe processing and the separation point inside the corrugator will be investigated for improvements of the cooling process. Furthermore, many simulations are intended to create a mathematical model that describes the process in a new way. As many polymeric products are processed by coextrusion, this process will be investigated by developing a novel coextrusion demonstrator to study the occurrence for layer rearrangements and flow instabilities in more detail under clear conditions. By means of data modeling and big data analysis new models for process design will be developed.

Approach

By combining approaches and data of physical/mathematical modeling (first principle), numerical calculation (e.g. network theory), CFD-simulations, experimental and production data, model-based control engineering, smart data mining etc. control concepts will be developed especially designed for polymer processing. Additionally, new sensor concepts will be applied or developed when needed for online process or quality control.

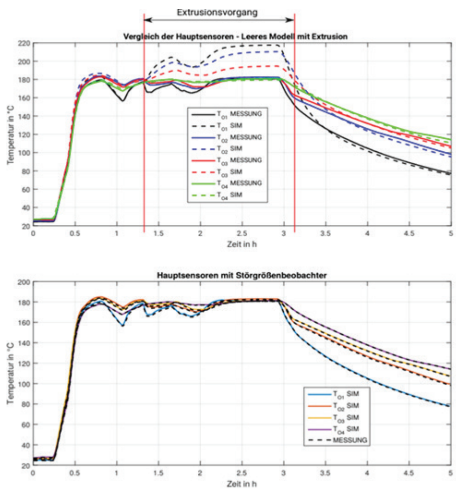
Expected and Achieved Results

In modeling of corotating twin-screw extrusion a parametric study based on a dimensional analysis was performed, leading to novel parameters for the dimensionless conveying parameters of kneading blocks (like A1;see below). Consecuting research work will perfom a) an regression analysis leading to analytic expressions to enable fast and accurate screw design calculations and b) an experimental validation.

Additionally, to estimate the temperature distributions within the extruder and the heat flow between melt and barrel a model predictive control for start up, as well as set point and material change was developed. Experimental validation was performed showing good accordance when applying disturbance observer based on precise process model (see below).

Status / Progress

Due to personnel changes the project was slightly in delay and under serious reconfiguration, but in the meanwhile progress is as expected and good results have been achieved.



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AREA 4.2

MFP 4.2.2-1 ASP
Adaptive Smart Production - Part DP 1

Area 4.2 - Cognitive Productions Systems

Project ID: DP 1 WP1.5, MFP 4.2.2-1
Project Title: ASP - Adaptive Smart Production
Project Lead: Univ.-Prof. Dr. Franz Haas
TU Graz, Institute for Production Engineering

Duration: 24 Months, 01.01.2018 - 31.12.2019
Strategic Volume: 10 %

Work Packages

WP 1: „Design-Benchmark“ of SOTA E-Powertrains

WP 2: „Production-Benchmark“ of One E-Powertrain

WP 3: Derivation of Assembly Process of One E-Powertrain

WP 4: Optimization Strategies in the Assembly Process („Design for Production“)

WP 5: Empirical Verification and Validation of the „Design for Production“

WP 6: Project Management

Company Partners

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The rising share of e-mobility in the transport sector motivates this project. Electric vehicles, whether battery or hydrogen driven, are increasingly replacing combustion-based vehicles. Nevertheless, the absolute number of electric vehicles on the road is still relatively small. This is partly due to the fact that the infrastructure for re-charging is only slowly increasing, and partly due to the relatively high start-up costs of such vehicles. Making electric vehicles affordable requires the production costs to be lowered, which needs among other things to reduce the production cost of one of the main cost drivers: the electric powertrain. The electric powertrain consists of e-motor, gearbox and power electronics. Producing this electric powertrain at as low costs as possible is therefore a key requirement for future automotive development.

Reducing production costs requires changes in the production paradigms, in particular when compared to production of conventional powertrains. It is not sufficient to tailor existing manufacturing processes for increased efficiency. This is due to the fact that the current production lot size of electric powertrains is still at low volume meaning that the full capacity of the production machines cannot be used. Producing different electric powertrains in the same production plant solves the capacity problem, but new challenges emerge: How can different electric powertrains be produced in the same production plant without any delays, ramp-up time and defect parts? The answer is a new paradigm: adaptive and cognitive production.

Goals

The goal of this project is to establish a new paradigm of production systems for electric powertrain assembly. Future assembly lines for electric powertrains must be (i) **more flexible**, to achieve assembly of high variety and low volume parts. Combining the high variety with high efficiency addresses the issue of ramp-up time (converting the assembly process). (ii) **Reducing ramp-up time** is essential when assembling many different types of powertrains. In this project, reducing the ramp-up time will be investigated by combining simulation of the assembly process (virtual) with data from the real assembly process (physical). This combination will lead to a very significant and powerful prediction and better plannable ramp-up time. Decreasing production costs can also be achieved by (iii) **reducing assembly time**. This can be realised by (iv) **well-balanced human-machine interactions** in each assembly cell and assembly operation. Regarding this, the human factor (cognitive load in complex assembly process) needs to be considered. Hence, the cell itself needs cognitive and self-learning elements for engaging flexibly with the human worker. Flexibility is also a factor when connecting different assembly cells. Flexibility in terms of connected assembly cells will be investigated for (v) **adaptive and flexible plant and cell layout structure**.

Approach

Starting with the analysis of the architecture of different electric powertrains and their assembly processes, we will pinpoint similarities and differences. Based on this analysis, the requirements of the whole assembly line and each constituent assembly cell will be established. Existing technologies for each requirement (e.g. collaborative robots for heavy parts, cognitive guidance systems for complex assembly operations) will be investigated in more detail. After evaluation, a candidate solution will be implemented in an existing physical assembly process and in a simulation-based model. This proof of concept will present new adaptive and cognitive paradigms in production, as well as an overview of the weaknesses and challenges of this new paradigm.

Expected and Achieved Results

The achieved results in the project are a (i) **detailed description of the assembly workflow** of different electric powertrain architectures. This is necessary to demonstrate the diversity of assembly processes and to capture the limits of current assembly lines. Current trends in e-motor technology emphasize that new motor technologies will be used in future powertrains. Therefore, a further focus lies on (ii) **e-motor assembling**. The ongoing project should demonstrate an (iii) **assembly line concept for e-motor production** focusing on the attributes of adaptivity and flexibility. To investigate the impact of promising technologies on these attributes, an (iv) **innovative test bed for e-powertrains** must be developed. This test bed is built on the outcomes of (i)-(iii). In (iv) **a real-world assembly process** will be examined in more detail. In tandem, the test-bed evaluation provides information of high importance to improve both the assembly process and the design process of future electric powertrains. This information concerns efficient (v) **ramp-up and scale-up** scenarios for the assembly process. Based on these findings, future electric powertrains can be designed with a stronger focus on efficient assembling ("design for manufacturing", "design for assembly"). To avoid information loss the findings should be reported in a (vi) **design checklist**.

Status / Progress

This project officially started in January 2018. In it, Pro²Future is working with our Company Partner AVL List GmbH and our scientific partners the Institute of Production Engineering and the Institute of Machine Components at TU Graz. We have held the project Kick-Off and started with investigation of different electric powertrain systems provided by AVL.

During the investigation, new ideas were created and combined with the results of a brainstorming process: 12 high-potential product ideas for future electric powertrains (regarding the whole powertrain and the e-motor) were developed to increase the efficiency of the cooling process. Furthermore, four high-potential manufacturing ideas were created concerning a new method of stacking the electric sheet in e-motors. After that, the assembly workflow for different electronic powertrains was described in detail. This workflow highlighted two facts: the assembly process of an e-motor depends heavily on the type of motor, and the assembly process of different electric powertrains (excluding the e-motor) is usually very similar.

In addition, the e-motor is typically purchased as a finished part, which is then assembled into the electric powertrain. Therefore, we have not investigated the e-motor in detail and instead focused on other electric powertrain components. In the next step of this project, the assembly line concept was developed. Starting with the big picture of the adaptive and flexible layout structures for the whole plant (bionic layout structures), we could deduce the assembly cell structure. We are currently investigating assembly cells, which need to be highly flexible in their design to contribute to the flexibility of the entire production process. We are also developing our simulation model and implementing new assembly strategies (with collaborative robots, learning machines etc.) for the cognitive production system.

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AREA 4.2

MFP 4.2.2-2 ASP 2

Adaptive Smart Production 2

Area 4.2 - Cognitive Productions Systems

Project ID:	MFP 4.2.2-2
Project Title:	ASP 2 - Adaptive Smart Production 2
Project Lead:	Dr. Markus Brillinger Pro2Future GmbH
Duration:	36 Months, 01.04.2020 - 31.03.2023
Strategic Volume:	14 %

Work Packages

WP 1: Literature
WP 2: Requirement Definition
WP 3: Workflow, Instrumentation and Testing Design
WP 4: Simulation and Optimization
WP 5: Implementation
WP 6: Verification and Validation
WP 7: Dissemination
WP 8: Project Management

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The project MFP II 4.2.3-2 Adaptive Smart Production 2 (ASP 2), deals with two use-cases: fuel-cell component assembly and high-speed bearing system improvement.

The use-case fuel-cell component assembly in the field of mobility answers following questions:

- How to optimize fuel cell design for efficient production (DfM and DfA)?
- How to adapt existing production lines to follow market uptake?
- How far production processes from other domains can be used for fuel cells systems.
- Also, focusing on how to adapt existing production lines to follow the market uptake in the next 5 – 10 years.

Another use-case deals with high-speed bearing system for electric powertrains systems. Higher speed e-powertrains must be designed to achieve the required power as this must compensate for the downsizing of these e-powertrains. Another reason is that the demand and sales of these compact down-sized e-powertrains, which is increasing over time. However, the knowledge of production-based bearing behavior of high-speed bearing systems in the automotive industry is still at low level. Thus, this use-case focuses on the instrumentation and testing of a testbed to investigate the influence of manufacturing and assembly tolerances on the bearing system behavior, e.g. noise, vibration, harshness, load-based bearing temperature and the testbed behavior in general and operation conditions. To support this investigation, we will apply state of the art classification algorithms which uses image data in combination with other measurands taken on the testbed and gain system knowledge.

Following research questions will be answered:

- What is the impact in terms of design & validation to develop and validate designs & products able to provide the required performances?
- What is the impact in terms of production tolerance to reduce production costs?

All use-cases addresses the megatrends for customized products (which requires flexible production systems), silver society (requires an age-based workspace adaption) and personalized mobility (specific to the trend of e-mobility).

Goals

ASP2 has as its goal:

- To develop of innovative high-speed testbed and test procedures for e-drive components
- To develop innovative products and test methodologies for e-drive (bearing system in the loop)
- To create success stories supported by data analytics
- To develop innovative fuel cell designs enabling production cost decrease /performance increase
- To identify cost-efficient bipolar plate materials and corresponding manufacturing processes
- To adapt production lines from conventional ICE assembly line to FC stack and BOP assembly line (Production Engineering for AVL customers)
- To adapt production line for high-voltage battery assembly and fuel cell stack assembly (AVL BIC)
- To gain experience of production-based bearing systems behavior of high-speed bearing system
- To investigate the influence of manufacturing and assembly tolerances on the bearing system behavior, e.g. noise, vibration, harshness, load-based bearing system temperature and the testbed behavior in general
- To investigate the general conditions and new opportunities to use the classification algorithms based on image data in the field of testbed monitoring combined with mechanical measurands.

Approach

The project starts with a literature in the topic of fuel-cell component assembly line and for high-speed bearing systems for electric powertrains systems. The literature results will be summarized in a state-of-the-art report. The requirements definition for a new assembly line and the high-speed bearing systems will be set based on literature outcome and further developed with workshops along the company partners and Pro²Future on-site visits of the existing production system in mobility. Defining the requirements will embrace machine, process, human and quality aspects.

Based on the requirements definition, the workflow, instrumentation and testing design will be initiated. After an ideation phase, possible concepts for assembly workflows for fuel-cell component and testing of high-speed bearing systems will be derived. These concepts will be evaluated based on the defined requirements. A simulation model proves the derived best-performing concept and is used for further optimization. This optimization is done via specific simulation tools, e.g. Siemens PlantSimulation for assembly and e.g. MKS for testbed. It helps to identify and focus on critical issues in highly flexible assembly lines and high-speed systems. The identification of the critical issues will be supported by the classification algorithms based on image data which are recorded on the testbed and illustrate the testbed behavior.

The implementation phase transfers the optimized best-performing concept for both use-cases onto shopfloor and laboratory. Connecting and testing hard- and software systems (e.g. cobot with manufacturing execution system, high-speed bearing testbed) will be the focus in this workpackage. First, a prototype of the assembly line/workstation/ high-speed bearing systems is built-up at Institute of Production Engineering and Institute of Machine Component and Development Methods at TU Graz. Further from the prototype, two adaptions will be derived for the fuel cell component assembly and high-speed bearing systems, which are transferred to the company partner AVL. Verification and validation are followed post the implementation and installation of the two adaptions at company partners. The focus lies on acceptability of new technologies by the workers/testbed engineers, safety for workers, personalized workspace adaption as well as performance of high-speed bearing systems. The outcomes are two best-practice use-cases for design, implementation and evaluation of a high-performance fuel-cell assembly lines and Design-for-Production recommendations resulted by the high-speed bearing systems.

Expected and Achieved Results

The results of the project can be stated in general as a new approach for future assembly and production line adaptation, considering the human as a critical success factor. Implementation, verification and validation of a new production concept generates a unique selling proposition:

Considering the use-case fuel-cell component assembly, innovative fuel-cell designs (based on design for efficient assembly), which enables a decrease in production costs will be developed. Furthermore, a strategy for production line adaptation for high-voltage battery assembly, fuel cell assembly, e-motor and fuel-cell can be derived.

Considering the use-case testbed and test procedures for high-speed bearing systems for electric powertrains systems, a beyond state-of-the-art testbed will be developed to investigate the influence of manufacturing and assembly tolerances on the bearing system behavior. The generated data assists to optimize the assembly line towards increasing quality and flexibility. On the top of that, we will acquire knowledge about the conditions under which classification algorithms based on image data can be used combined with mechanical measurands.

Status / Progress

The project started at 01.04.2020 with a literature in the topic of fuel-cell component assembly line and for high-speed bearing systems for electric powertrains systems. The literature results will be summarized in a state-of-the-art report which will be published in Q3/2020.

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AREA 4.2

StratP 4.2.3-1 ENERMAN-1
Cognitive Energy Management Systems for Industrial Production

Area 4.2 - Cognitive Productions Systems

Project ID:	StratP 4.2.3-1
Project Title:	Cognitive Energy Management Systems for Industrial Production
Project Lead:	Dr. Markus Brillinger Pro2Future GmbH
Duration:	15 Months, 01.01.2019 - 31.03.2021
Strategic Volume:	100 %

Work Packages

WP 1: Definition Test Environment

WP 2: Definition Instrumentation Measurement and Analysis Tools

WP 3: Demonstrator

WP 4: Dissemination

WP 5: Project Management

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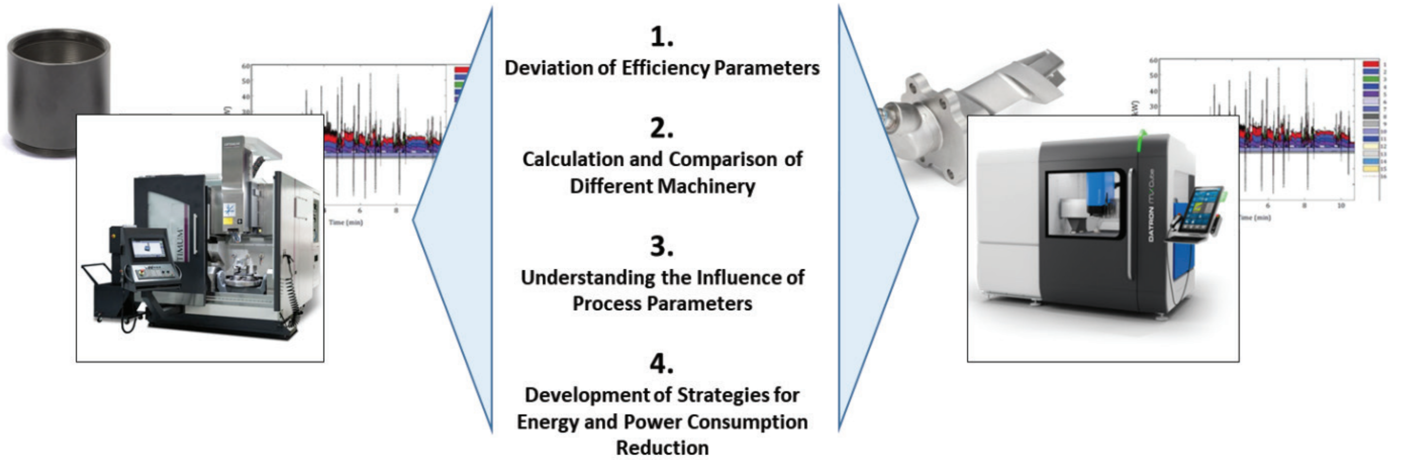
The research vision of the strategic project ENERMAN-1 deals with decreasing the energy consumption in continuous as well as batch production as a subject of extremely importance for all partner organizations. In it, the energy demand of machinery during manufacturing were investigated with respect to smoothing power peaks and lowering the total energy demand. The focus lies on reducing high energy consumption due to long process times and decreasing the high-power peaks due to acceleration of machinery components. The benefit of smoothing power peaks and lowering the total energy demand in production lies in a significant cost reduction of the process. The vision of this project is to provide a scientific output leading to a significant reduction of energy and power consumption of the production systems.

Goals

ENERMAN-1 has as its goal the detection and reduction of energy demand of produced parts in batch and continuous production systems. The research goal is to develop a standardized new energy management system within a continuous extrusion and batch production system by (i) derivation of efficiency parameters (e.g. efficiency labels, retrofit factor, …) for different manufacturing processes (subtractive, polymer extrusion) and (ii) calculate and compare different machinery at JKU Linz as well as TU Graz. To increase the (iii) understanding of influence of processing parameters on energy consumption (e.g. an optimum barrel temperature setting to polymer melt quality) will help to (iv) develop strategies for energy and power consumption reduction for typical batch and continuous production (e.g. power factor correction, peak load optimization, drive technology with excellent efficiency class, thermal insulation, split and adapted circuits for process cooling). Creation of (v) academic fundamentals are the basis for industry cooperation in future.

Approach

The research approach and method of this strategic project is focused on the ICT-supported strategies, methods and model-based control technologies by application of experimental and computational modelling within a continuous and batch production system. Key technologies will be the wireless infrastructure and data mining. Special strategies to reduce the energy consumption represent the framework of a new system that is also influenced by the results of the other Pro²Future working groups (e.g. cognitive decision making).



Expected and Achieved Results

The results of ENERMAN-1 can be summarized as follow:
A unique test system with intelligent evaluation software for continuous and batch production are installed at Living Lab for polymer extrusion and compounding at JKU Linz, for batch production within the new pilot factory at TUG with the brand name "smartfactory@tugraz". In continuous production a new metrology method for identifying the length-based energy input in an extrusion process were developed. The new metrology method helps to identify the energy input in an extrusion process which is crucial for verification of the process simulation.

Indicators for energy efficiency for a representative set of production technologies were developed and evaluated in case studies. Based on this case studies guidelines for energy efficient product design are under progress. These guidelines developed in ENERMAN-1 will evolve the competence of the center and covers long-term industrial interests. The project results can be exploited in four business cases: (i) distributing the knowledge via training and education, (ii) providing the developed hard- and software, (iii) consultative providing the gained knowledge and (iv) performing truly-joint research cooperation projects.

Status / Progress

Definition of Test System

In it, the state-of-the-art of science and technology for energy management systems for continuous and batch production were identified. Furthermore, the research gap for energy management systems were determined. Two specific use-cases were defined, one in continuous polymer extrusion process and one in batch production.

Testing Equipment and Analysis Tools

This workpackage embraced an approach for negotiating or mitigating the research gap by combining the domain knowledge of mathematics and control algorithms (REGPRO, JKU Linz), extrusion (IPEC, JKU Linz) and batch production (IFT, TU Graz) as well as measurement instrumentation and testing (University of Maribor). The outcome of this workpackage was the selected hardware (sensors, control hardware…), the programmed software (control algorithms,…) and developed key performance indicators (energy saving potential, retrofitting factor,…) based on the requirements specified in this workpackage.

Demonstrators

In this workpackage methodologies for energy management were developed which are still in implementation phase for continuous polymer extrusion processes at LivingLab (at JKU Linz) and for batch production in smartfactory (at TU Graz). The implementation process covers the installation of selected hardware (sensors, control hardware…) and software (control algorithms,…) for the detailed use-cases of continuous polymer extrusion and batch production. In nearer future the workpackage will be finished. The deliverables will be the installed energy management system in both production systems.

After this, the implemented system and their limits will be explored. Based on the developed key performance indicators (energy saving potential, retrofitting factor…), practical energy saving recommendation will be derived. Furthermore, a strategy for improving the energy management systems in continuous and batch production must be given. The outcome will be an energy improvement-report and a strategy for enhancing the developed energy management system.

Dissemination

The project results are still under dissemination at high-ranked scientific conferences and journals with high impact factor.

Project Management

This workpackage is ongoing along the complete project runtime. In it, the project manager deals with organizational and scientific issues (e.g. meeting and appointment organization, controlling costs target, responsibility for publication strategy…).

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AREA 4.2

MFP II 4.2.1.1 AI-Gran 2

AI based smart optimization of underwater granulation

Area 4.1 - Cognitive Production Systems

Project ID:	MFP II 4.2.1.1
Project Title:	AI-Gran 2 - AI basierte smarte Optimierung einer Unterwasser Granulierung
Project Lead:	Mag. Bernhard Löw-Baselli JKU Linz, Institute of Polymer Processing and Digital Transformation (IPPD)
Duration:	36 Months, 01.04.2021 - 31.03.2023
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Regelung der Unterwassergranulierung

WP 4: Restfeuchtemessung

WP 5: Modellierung des Zentrifugaltrockners

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The manufacture of plastic products is closely related to the use of plastic pellets. There are numerous influencing factors in the production of these pellets that have a significant impact on their quality. The process begins with the melting of the filling material in an extruder, although this part of the process cannot be directly influenced.
The molten material is then directed from the extruder through a diverter valve towards a die plate and cutter. The cutting tool is a rotating knife head. The material is pressed through the perforated plate and the resulting strands of plastic are cut off under water by the cutting tool. The cutting tool is a rotating knife head. The cut off pellets go through a hose into a collection container. There is also a camera in the hose that takes pictures of the pellets.
The pellet quality is of great importance, which is why the machine parameters must be set precisely. In this project, the quality of the pellets is defined by the regularity of their shape. Any deviations in the pellets must be detected and corrected to ensure consistent quality. It should be noted here that the process temperatures, depending on the plastic material, must be kept within a specific range in order to avoid undesirable effects on the plastic properties.
The production of plastic pellets is a complex process that is influenced by the interaction of many factors. Choosing the right machine settings, monitoring temperatures and regularly checking pellet quality are crucial to producing high quality plastic pellets.
Overall, plastic pellets play an important role in the plastics industry. Optimizing pellet production and maintaining consistently high quality pose significant challenges. This requires a holistic approach to ensure the plastic pellets meet the high standards.

Goals

In order for the later products to achieve the desired quality, it is crucial that the plastic granules meet certain quality standards. The main goal is to ensure that these granules have an even and smooth shape. In order to meet this goal, existing camera software is used, which supplies the images of the granules. A suitable controller is to be developed that can effectively correct deviations in the granules.
By analyzing the readings provided by the camera software, one will be able to identify deviations in the size and shape of the granules, allowing the controller to make the necessary adjustments to the machine parameters to ensure quality.

In order to achieve the desired quality, the machine parameter settings depend heavily on the materials used. In order for the granulate to have a high quality, it is crucial that the setting values of the parameters are adjusted according to the material used. However, we are striving to design a controller concept that is ideally independent of the material. This would not only increase flexibility, but also minimize the effort for individual adjustments.

Approach

The measuring principle still has to be adapted so that the measured values are of sufficient quality. The current approach ensures that the range of fluctuation in the measured values is too high. The strategy for solving this problem is that the sections in which the images are taken are clocked in such a way that the variation in the measured values is small enough to make a statement. The proposed control concept consists of a model-free optimization process. This uses the parameters of the camera software and sets the contact pressure of the knives, the temperatures and the number of revolutions of the cutting tool.

Expected and Achieved Results

It is possible to measure the required machine parameters and also adjust them individually, provided the values to be set are within their setting range.

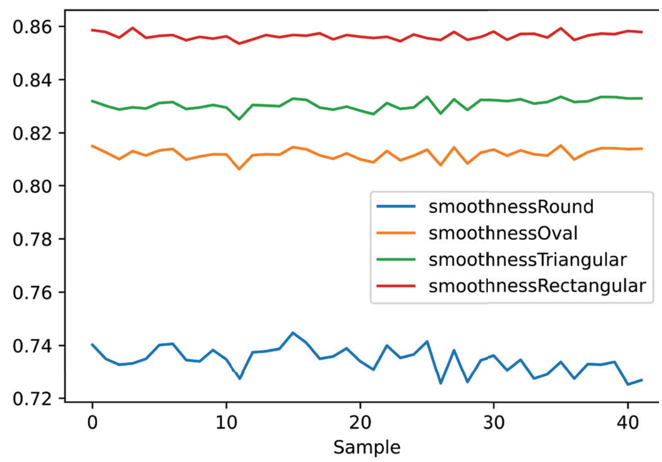
The quality of these measured values could also be checked. With the camera system, a new approach enables a remarkably smaller range of fluctuation of the required camera parameters compared to the old system. A more precise evaluation of the data is achieved through the rapid and continuous recording of images at short intervals. The camera system captures images in rapid succession until a predefined number is reached. Meanwhile, these images are evaluated in parallel to obtain the relevant information about the pellet quality. Then the procedure is repeated for the next scanning step.

In contrast, the previous approach was to capture a single image at each sampling step. Although this enabled a shorter sampling time compared to the current method. However, this method also had disadvantages, in particular a higher fluctuation range of the recorded data.

The consistent series of image recordings in connection with the simultaneous data analysis leads to a more targeted, more precise data acquisition. By reducing the range of fluctuation, the results become more reliable and reproducible. This has a significant impact on the efficiency of the overall operations and helps to significantly increase the quality of pellet production.

Status / Progress

Thanks to the functioning access to the machine, the machine parameters can now be read and set, and the quality of these values can be described as satisfactory. An important step in improving the process was to adapt the evaluation of the camera software. The fluctuation range of the parameters could be noticeably reduced by taking pictures quickly. In particular, the smoothness values, which are of great importance for the subsequent controller, show improved consistency.



A sample consists of about 15 recorded images, which provide a more meaningful basis for analyzing the pellet quality.
It remains to be determined how the parameters change when the pellets no longer have the desired quality and the controller has to intervene. It is important to verify whether possible changes in machine parameters can be detected or whether they cannot be reliably identified due to the unavoidable fluctuations. Effective control of the process requires the ability to recognize and respond to changes in pellet quality.

As part of process optimization, a filter based on a machine learning model was developed. This filter has the important task of recognizing and filtering out faulty image fragments. Such fragments can arise from a variety of circumstances, such as the overlapping of multiple pellets, the presence of foreign objects, or artificially created image artifacts due to incorrect exposure.

The filter can learn to recognize characteristic features of erroneous image fragments and distinguish them from the actual pellet images. This significantly improves the accuracy and reliability of the image analysis. Defective images are sorted out before they can flow into further processing, which increases the quality and efficiency of the entire manufacturing process.

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AREA 4.2

MFP II 4.2.1.2 SmartCom
Smart Compounding

Area 4.1 - Cognitive Production Systems	
Project ID:	MFP II 4.2.1.2
Project Title:	SmartCom - Smart Compounding
Project Lead:	Mag. Bernhard Löw-Baselli JKU Linz, Institute of Polymer Processing and Digital Transformation (IPPD)
Duration:	48 Months, 01.04.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Hybride Modellierung Schneckenelemente

WP 4: Gesamtmodell für gleichlaufende Doppelschneckenextruder

WP 5: Applikation für Regelung bei prozessbedingten Viskositätsänderungen

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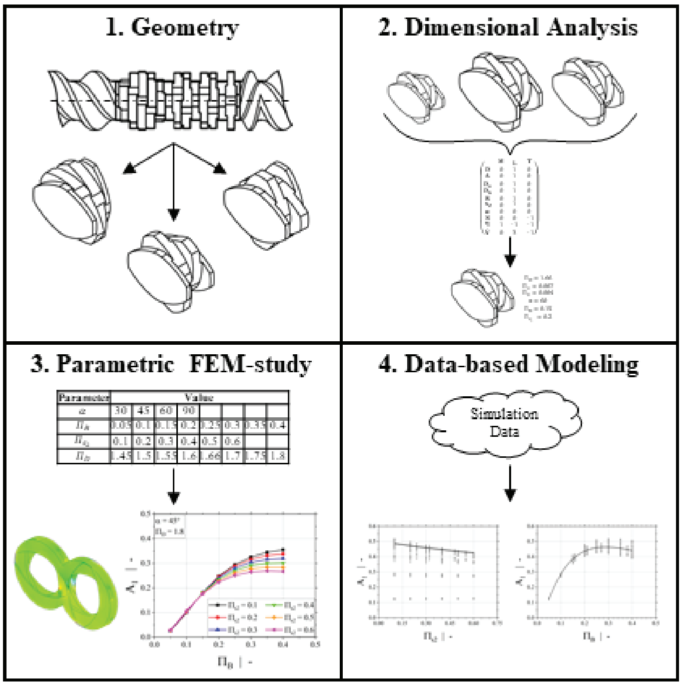
To tailor the property profiles for their respective applications, almost all plastic materials undergo a compounding step as a part of their processing history. Due to its excellent mixing capability, economic efficiency, and flexibility, the fully-intermeshing co-rotating twin-screw extruder is the most important processing machine for compounding. The extruder has to fulfil various functional tasks, including solids conveying, melting the polymer(s), distributive and dispersive mixing of the individual components, devolatilization of the melt, and melt conveying. For this purpose, the extruder design is commonly modular and uses both segmented barrels and different screw elements that are used according to the function of the corresponding processing zone. The most important screw elements used in industry are conveying elements and kneading blocks. The screw configuration and the processing parameters mainly define the flow conditions within the extruder, which finally have a significant influence on the quality of the extruded product.

The sub-project Smart Compounding paves the way for digitising this essential processing step by developing (i) a novel modelling framework for the flow conditions in fully-intermeshing co-rotating twin-screw extruders, (ii) model-based soft sensors, and (iii) optimised control concepts. This allows the process behaviour (as pressure-throughput behaviour, melt temperature development, residence time, and others) to be accurately predicted by means of computer-aided screw and process design tools. Furthermore, the compounding process can be monitored inline to detect batch fluctuations, machine wear, and other external influences. By the implementation of smart control concepts, the machine can react to these disturbance variables completely autonomously. This increases the overall equipment efficiency (OEE) by reducing machine downtimes, optimizing the energy management, and minimizing the amount of reject being produced.

Goals

The main objective of this project is to significantly outperform existing modelling frameworks predicting the conveying and power consumption behaviour in the processing zones of a fully-intermeshing co-rotating twin-screw extruder. By avoiding geometry simplifications (e.g., negligence of clearances or application of the flat-plate model) and consideration of the fundamental physics of the flow process, an increase in accuracy should be achieved. Another major novelty value of



the models that is being sought is their real-time capability (e.g., avoidance of numerical simulations) and generalisability (applicability to arbitrary extruder sizes and plastic materials), which is the prerequisite for the implementation of the models into industry 4.0 applications (digital twins, smart sensors, predictive maintenance tools, and others). In compounding applications, the extruder is commonly operated in combination with a melt pump. Thereby, the extruder screw speed is controlled to maintain a certain melt pressure level at the screw tip. Using aforementioned flow models, a smart control concept for the extruder screw speed should be developed to account for process-related viscosity fluctuations.

Approach

A hybrid modelling approach that combines analytical, numerical, and data-based methods is employed. The screw configuration of a co-rotating twin-screw extruder commonly includes elements of different geometry. At first, sub-models for the conveying elements and the kneading blocks are developed. In a second step, the sub-models are coupled to create a holistic model that is capable to predict behaviour of the entire extruder screw configuration. Finally, a lab-scale twin screw extruder is used to experimentally validate the results. A wide range of processing conditions (throughput and screw speed), material properties (materials with different viscosities), and geometry variations (different conveying and kneading elements) commonly used in industry is considered.

Expected and Achieved Results

A dimensional analysis based on the Buckingham Π-theorem was carried out to reveal the independent dimensionless influencing parameters both for the conveying element and the kneading block. These parameters were then varied within ranges of practical interest within a huge parametric design study. For each design point, a numerical simulation using the commercial CFD software ANSYS Polyflow was carried out to obtain four characteristic target quantities, namely the dimensionless drag-flow capacity A1, the dimensionless element conductance A3, the dimensionless turning point B2, and the dimensionless turbine parameter B3 to characterize the pressure-throughput behaviour and the power consumption, respectively. Note that for a Newtonian fluid, the relationships for the conveying behaviour and the power consumption are linear, and thus, only two characteristic points are required. The numerical dataset was then used for the data-based modelling step. Using the open-source software package HeuristicLab, a set of eight symbolic regression models was derived to predict the target quantities A1, A3, B2, and B3 for both the conveying elements and the kneading blocks. With mean relative errors below 2%, excellent accuracy between numerical data and model predictions could be achieved. Furthermore, the conveying models for kneading blocks have been validated successfully. Taking into account three different commercial plastic grades and kneading blocks with three different staggering angles, the results clearly outperformed state-of-the-art models using the flat plate assumption.

Status / Progress

So far, in the project Smart Compounding prediction models for the conveying performance and the power consumption for two characteristic processing zones of fully-intermeshing twin-screw extruders – conveying elements and kneading blocks – were successfully developed. Whereas the accuracy of the prediction models for the kneading blocks has been shown experimentally for a wide range of processing conditions and different materials, validation of the conveying elements is currently under planning.

The models were also integrated into a screw calculation software tool that enables to evaluate and assess the performance of entire screw configurations. This tool enables accurate prediction of pressure build-up capacity (i.e., determination of back-pressure length), melt temperature development along the extruder length, and power consumption, and thus, computer-aided design procedures for twin-screw extruders in industrial compounding processes addressing an increase of process reliability and minimisation of production scrap.

Since the prediction models only use simple algebraic relationships, they can be evaluated in simple spreadsheets or processed by machine controls (e.g., programmable logic controllers). Consequently, a smart control concept for the extruder screw speed, which aims to suppress pressure fluctuations that occur at the end of the extruder, is currently under development. A first mathematical model for the pressure conditions at the end of the extruder and the downstream melt pumps was created. The undesired pressure fluctuations, previously only observed in production machines, could be reproduced on the test machine on site in initial trials. The software for communication with the OPC UA server is being expanded to include interfaces for the newly added pressure sensors. This configuration allows significantly faster and thus higher-resolution measurements, and also avoids the occurrence of aliasing. Further tests will be carried out, in particular for the parameterisation of the mathematical model.

The modelling strategy developed in this project can also be extended to include other target variables. For example, the residence time distribution of the melt or the mixing effect in the extruder screw could be modelled. Since plastic melts usually exhibit non-Newtonian behaviour, more complex material models could be taken into account.

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AREA 4.2

MFP II 4.2.1.3 SmartCoEx
Smart extrusion blow molding

Area 4.1 - Cognitive Production Systems

Project ID:	MFP II 4.2.1.3
Project Title:	SmartCoEx - Smartes Coextrusionsblasformen
Project Lead:	Mag. Bernhard Löw-Baselli JKU Linz, Institute of Polymer Processing and Digital Transformation (IPPD)
Duration:	48 Months, 01.04.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Projektmanagement

WP 2: Dissemination und Exploitation

WP 3: Modellierung der Coextrusion

WP 4: Thermisches Management

WP 5: Modellierung des Extrusionsprozesses

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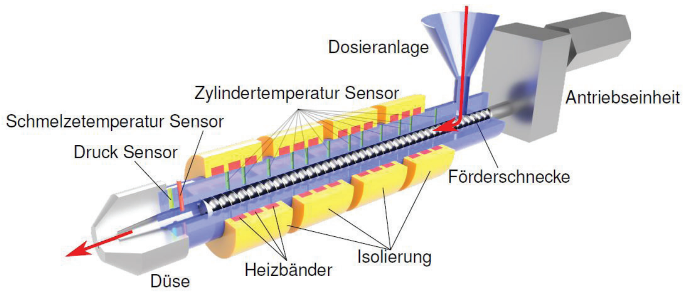
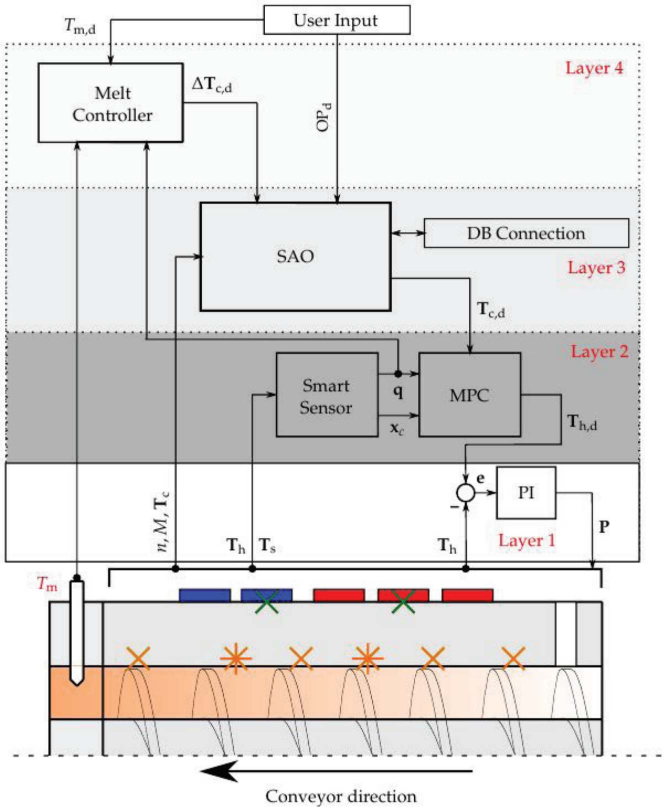
An important process for the production of plastic products such as packaging, pipes, etc. is the extrusion process. In this process, plastic granules are fed into a machine, the extruder, conveyed through the extruder cylinder with a complex screw and melted with the help of pressure and heat. The heat required for melting is generated by friction and heating elements, and the pressure is generated by the screw. The pressure, mass flow and temperature of the melt should assume values that can be specified at the outlet. With the newly developed control, the extrusion process can run faster, more efficiently and in a more environmentally friendly manner, while at the same time ensuring optimal product quality. This process should be as energy-efficient and environmentally friendly as possible, but it should also be able to extrude a large number of polymers in such a way that the end products are of high quality. Today's challenges are the lack of active cooling and the processing of granules with varying properties, e.g., in recycling. The standard is that experienced employees set the extruder with the help of recipes in such a way that the best possible behavior is achieved under the same conditions. Changes over time due to defects or changes in the composition of the granules cannot be specifically taken into account. The recipes also have to be elaborately created. Modern extrusion is an extremely complex process that changes a lot over time and the best possible settings have to be found.



Goals

In order to ensure adequate quality of the extruded products, the material melt temperature must be close to an appropriate desired melt temperature. The temperature controllers commonly used in extruders do not regulate the melt temperature, but rather the temperatures in the barrel. The control concept developed should be able to regulate the temperature of the melt. The advantage of a control concept that controls the temperature is that it can react to small changes in the melt temperature. A concept that only controls the barrel temperatures cannot react to small changes in the melt temperature. Another goal is to achieve a quick start of extrusion and a quick heat-up phase of the extruder. The commonly used PID controllers are slow and do not take into account the coupling effect between the heating zones. Therefore, the concept must be model-based. Waste should be minimized, and energy-efficient operation should be guaranteed. The concept must be applicable to different extruder types that differ in size and number of sensors and actuators. Production-related restrictions must be observed to ensure high product quality. The concept must make it possible to extrude different materials without knowing their physical properties.



Approach

The control concept developed consists of several superimposed layers. The first layer includes the heater band temperature control implemented as a PI controller. The next layer consists of an observer (smart sensor) and a model predictive controller. A model predictive controller calculates appropriate temperature targets for the heater band temperatures to achieve the desired temperature profiles in the extruder while meeting any defined process or vendor-specific constraints. Another superimposed concept enables fast operating point changes by determining optimal cylinder temperature profiles. A material-independent melt temperature controller forms the top layer of the developed concept.

Expected and Achieved Results

To underpin the applicability and effectiveness of the newly developed control concept for different types of extruders, extensive test series were carried out on two different extruders. These test series enabled a thorough analysis of the performance of the control concept in various operating phases, including heating processes, extrusion starts, operating point changes and fault scenarios. The capabilities of the concept were comprehensively evaluated both through detailed simulations and through practical tests on industrial extruders. An outstanding advantage of the control concept became apparent when the operating point changed. The quick and accurate adjustment of the process parameters enabled a seamless transition between different production requirements. This flexibility plays a crucial role in modern production environments where rapid changeovers are required to meet dynamic market demands. The control system also proved to be extremely robust and reliable in disruption scenarios. It responded quickly and effectively to various disruptive factors such as material variations or temperature variations to maintain process stability. This counteracted possible negative effects on product quality and ensured continuous production.

Overall, the results of the test series clearly demonstrate the high performance and applicability of the control concept developed on various types of extruders. The precise control and the ability to flexibly adapt to changing production conditions make the concept a promising solution for optimizing the extrusion process. It makes a significant contribution to improving efficiency, product quality and sustainability in plastics processing and opens up new opportunities for innovative plastic products in various branches of industry.

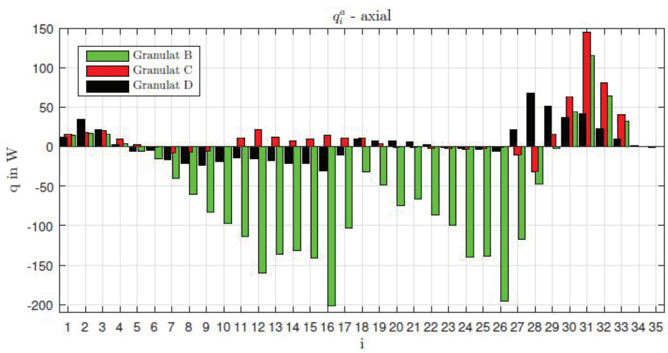
Status / Progress

A multi-layer concept to control the melt temperature of the extruded material within an extruder was developed and successfully implemented. The concept is based on a thermal finite volume model of the extruder. A Model Predictive Control (MPC) in conjunction with a Smart Sensor was introduced to regulate the extruder according to the desired temperatures inside the extruder. The estimation of the heat flows from the intelligent sensor not only enabled an analysis of the extrusion process, but also an optimization of the mechanical extruder design (screw geometry, dimensions).

An optimal duty cycle routine selects appropriate MPC setpoints to reduce duty cycle time and thus minimize the amount of scrap material during the extrusion process. A melt temperature controller for a material during the extrusion process adjusts the desired values in the barrel until the melt temperature is within a desired range. The form of the intervention is based on the current estimate of the heat flow.

The concept developed is material-independent and has been successfully implemented on various types of extruders. The whole concept was validated through benchmark experiments, which confirmed the performance of the controller in production-specific situations. In addition, the results of the experiments were compared with the results of a standard controller. Only one point measurement of the melt was used. However, the shape of the radial temperature profile of the melt temperature affects the product quality. In order to adjust the temperature profile of the melt to a desired shape, measurements could be taken with an advanced sensor to adjust the shape of the intervention of the melt temperature controller accordingly.

A patent application has been filed for the results, with the prospect of publication of the patent as of August 15, 2023.



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AREA 4.2

MFP II 4.2.1.4 SmartWell

Smart corrugated pipe production

Area 4.1 - Cognitive Production Systems

Project ID:	MFP II 4.2.1.4
Project Title:	SmartWell - Smarte Wellrohrproduktion
Project Lead:	Mag. Bernhard Löw-Baselli JKU Linz, Institute of Polymer Processing and Digital Transformation (IPPD)
Duration:	48 Months, 01.04.2021 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: Project Management

WP 2: Dissemination and Exploitation

WP 3: Energetische Analyse des Blasformprozesses

WP 4: Festigkeitsanalyse

WP 5: Feldversuch und Optimierung instrumentierte Formbacke

WP 6: Experimentelle Validierung- und Optimierung

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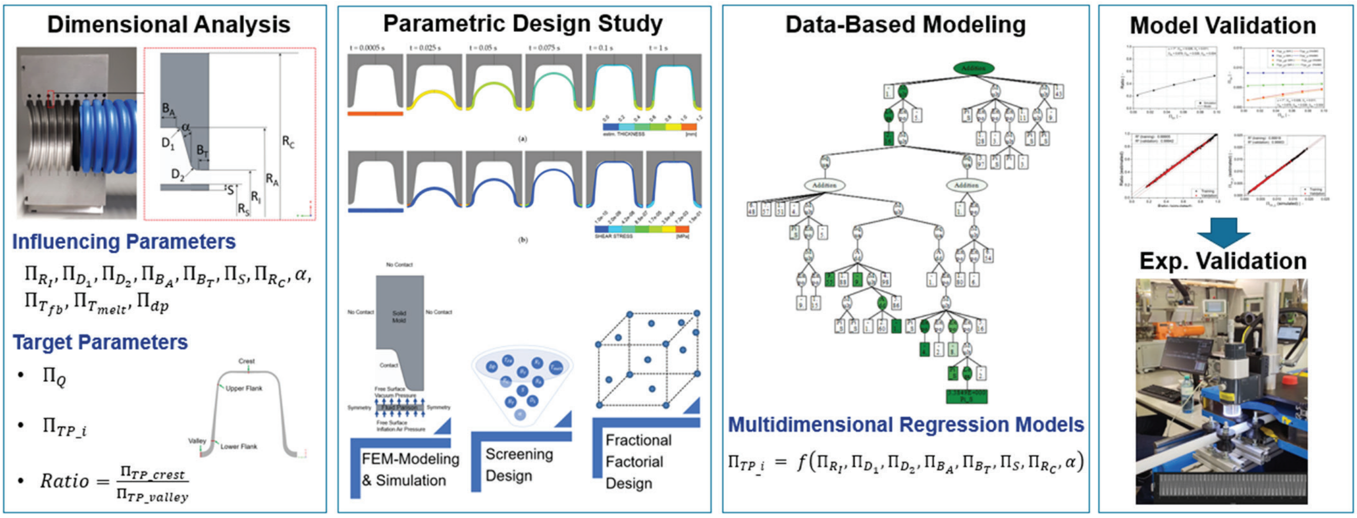
Corrugated pipes provide both higher stiffness and higher flexibility while simultaneously requiring less material than rigid pipes. Due to rising commodity prices, pipe manufacturers have been driven to produce corrugated pipes of high quality with reduced material input. To the best of our knowledge, corrugated pipe geometry and wall thickness distribution significantly influence the mechanical properties of the final product. Essential factors in optimizing wall thickness distribution include adaptation of the mold block geometry and structure optimization. In addition, the energy flow in the corrugator, in particular the cooling process of the corrugated pipe, is also important for corrugator design. Modeling and simulation of the thermal energy flow during the corrugated pipe extrusion from the die exit to the finished pipe from the corrugator is the basis for solution strategies aiming at process optimization in terms of efficient cooling. Therefore, in this research work, a workflow, guidelines, and mathematical models are developed to predict the wall thickness distribution, the cycle time for the entire inflation process and the dissipated energy of the entire pipe manufacturing process. Subsequently, the models can be used for structural analysis, enabling digital mold block design, optimization of wall thickness distribution, optimization strategies with respect to fast and efficient cooling of corrugated pipes, and optimization of corrugator performance considering thermal energy aspects. The results of this research work can provide an important contribution to sustainability and resource conservation.

Goals

The main objective of this research work is the smart optimization of the production process of corrugated pipes. A variety of modeling methods are used to achieve the project goals. We implemented a hybrid modeling approach combining analytical, numerical and data-based modeling for corrugated pipes. Multi-dimensional mathematical models were developed and implemented using symbolic regression analysis based on genetic programming for predicting the wall thickness distribution as function of the mold geometry and initial parison thickness. These models are later optimized by taking the thermal energy flow parameters into account. Thus, the production process can also be optimized for efficient cooling. Furthermore, to ensure the reliability and performance of the created pipe geometry, a mechanical performance analysis was also performed based on the models to determine the strength of a geometry. These results will help to develop guidelines for energy-efficient manufacturing a lightweight corrugated pipe that has the required mechanical performance with minimum material requirements. In addition, the findings can be used for the effective design and operation of corrugator and for the optimization of corrugated pipes.

Approach

In the progress of this project, a hybrid modeling approach that combines numerical and data-based modeling is implemented. The workflow is structured as follows: first, the mold block geometry with different



mold shapes is analyzed. Then, the similarity theory is applied to determine the dimensionless influencing geometry and processing parameters, and then a comprehensive parameter design study is conducted to identify the most critical influencing parameters. The results of numerical simulation are later used as input for data-based modeling so that mathematical models can be developed. Furthermore, a mechanical performance analysis is performed based on the wall thickness models to determine the achievable strength of geometry. In order to gain insight into the physical conditions during the mold process, a selected mold block, equipped with a specifically devised sensor inset, will autonomously collect data for the analysis process.

Expected and Achieved Results

In general, the expected results of this research work relate to the knowledge gained to optimize the manufacturing process and the final product itself, as well as to optimize the corrugator design. Using engineering simulation and data-based modeling to develop mathematical models for the prediction of the wall thickness distribution and the heat flux in the corrugator. Furthermore, guidelines and strategies for manufacturing a lightweight corrugated pipe that has the required mechanical performance with minimum material requirements will be provided.

So far, the initial stage of modeling the entire process of corrugated pipe extrusion has been achieved. The influences of major geometry parameters on the parison inflation process were identified and investigated by applying the theory of similarity, dimensional analysis, and a parametric design study. Correlations between independent and target parameters were established and utilized to estimate the wall thickness and its distribution in corrugated pipes. Multi-dimensional regression models of the wall thickness distribution as a function of mold geometries in extrusion blow molding of corrugated pipes were developed using heuristic approaches and implemented for mold design in the early design phase. The comparison of numerical simulation results and model predictions also confirmed the validity and feasibility of the regression models developed in this work. First comparisons with experimental trials delivered promising results. These results showed that the wall thickness predictions capture the reality as long as the velocity of the extruded parison approximately equals the line speed of the corrugator. For new processes, the proposed method may prove to be a valuable tool for minimizing the number of expensive and time-consuming experiments when evaluating (new) pipe designs and may add value well before the final product is produced. The developed models allow a target variable (of the corrugated pipe geometry) to be predicted without manufacturing and prototyping of a product. In addition, the regression models can cover a wide range of geometry variations as they are dimensionless, and as long as the new geometry is within the chosen dimensionless geometry parameter range. For very small and very large corrugated pipes, there is some risk that the dimensionless parameters fall within the extrapolation range for various reasons.

Status / Progress

Based on the results of the initial stage, the further stage of process modeling is carried out by taking the heat flux in the corrugator into account. Therefore, some new parameters (processing parameters, e.g., mold and melt temperature, vacuum and air pressure, no-flow temperature, etc.) were additionally extended to the previous dimensional analysis. Up to now, the individual thermal energy flow in the corrugator has been investigated, which includes all processing stages (parison inflation process, cooling in the mid channel and air cooling). Numerical simulations (thermal simulations with phase change material) have been carried out to analyze the cooling process. On the basis of the simulation results, the influencing parameters (e.g., heat transfer coefficient, melt and mold temperature, corrugator speed, wall thickness, etc.) during the cooling process can be identified. In addition, the cycle time for the entire inflation process could be determined for each initial melt temperature and the heat transfer between polymer and mold block. In order to allow full automation and interconnection between flow and finite element (FE) simulation software, the consecutive simulation study was scripted in Python so that both the inflation and shrinkage process can be investigated. As the process now involves many parameters, a statistical screening design study (two-level fractional factorial design with one center point) was conducted to determine which influencing parameters contribute the most to the variability in the target parameters (wall thickness ratio, total pipe cooling energy, and inflation time) and which parameters have statistically significant effects on the target parameters. Subsequently, a comprehensive parametric-driven design study of the corrugated pipe extrusion process will be conducted for a wide parameter range. The developed approximation equations will be derived by means of symbolic regression using genetic programming based on the numerical simulation results. The accuracy of the models is later evaluated using error analysis and validated against an independent dataset that is not previously considered in the modeling.

For inline sensing of physical parameters during the mold process, a sensor inset for the mold blocks has been designed, and the technology for fabrication of additively printed sensors on the surface of this inset, that can withstand the harsh environmental conditions during the production process of the corrugated pipes, has been developed. Various physical sensor principles have been evaluated with regard to their suitability to provide data about the actual casting and debonding process of the pipe in the mold block, and a demonstration device together with the autonomously operating measurement electronics has been realized for first tests in a real manufacturing environment.

Moreover, a new method for measuring pipe wall thickness was also developed. An optical coherence tomography (OCT) sensor was implemented inline directly after the corrugator, so that the process can be automated and allows us to get a better indication of the relationship between process variation and wall thickness distribution. The inline OCT sensor supports the machine operator by facilitating process start-up, process monitoring, and process troubleshooting. This inline measurement concept offers great potential for process digitalization (e.g., autonomous operation by means of a model-based machine control). Up to now, the wall thickness of pipes in production has been measured commonly atline with a caliper gauge, which has a high measurement uncertainty. Alternatively, the wall thickness distribution can be measured more accurately offline using optical microscopy.

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AREA 4.2

MFP II 4.2.2-1 SUPRA-1

Sustainable Production and Assembly 1

Area 4.2 - Cognitive Productions Systems

Project ID: MFP II 4.2.2-1
Project Title: Sustainable Production and Assembly 1
Project Lead: Dr. Markus Brillinger
Pro2Future GmbH

Duration: 3 Months, 01.04.2020 - 31.03.2023
Strategic Volume: 14 %

Work Packages

WP 1: Literature

WP 2: Power Peak Reduction

WP 3: Dissemination

WP 4: Project Management

Company Partners

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SUPRA refers to efficient and sustainable production strategies in batch production, namely peak power reduction. In it,

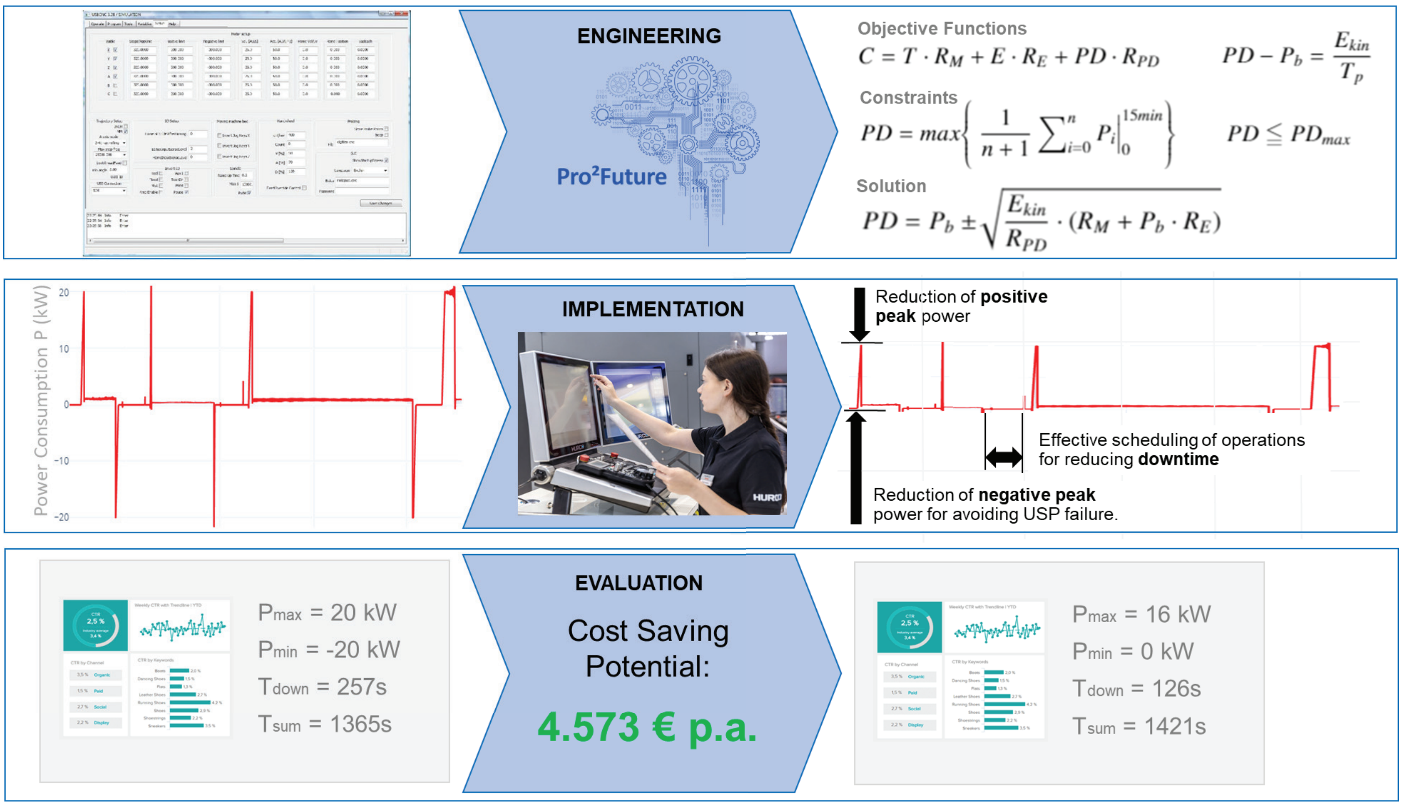
- existing KPIs for sustainable production, e.g. Franz Haas' EEC (energy efficiency coefficient) will be applied.
- new KPIs for sustainable production will be developed.

Goals

By using the methods developed in the strategic project "MFP 4.2.3 – Cognitive Energy Management Systems in Industrial Production Systems" (ENERMAN-1) executed in funding period 1, new methods for power demand peak detection (e.g. edge device) and prediction methods (e.g. machine learning), with high relevance to machining processes were investigated. Based on the this, the SUPRA project refers to develop and apply new sustainability-KPIs focusing on peak power reduction.

Approach

The project starts with a literature review in the topic. After that, mathematic models for peak power reduction will be derived, implemented and evaluated at shop floor level.



Expected and Achieved Results

SUPRA will reduce the peak power level of different machining processes, e.g. milling, ultrasonic machining, and therefore decreasing the power demand in batch production processes in metal industries. This will reduce the production costs and therefore achieve a competitive advantage for the participating company. The result will be a cornerstone in future sustainable production systems dealing with power demand and energy efficiency.

Status / Progress

The project started at 07.07.2020 with a literature in the topic of peak power reduction. First achieved results were already implemented at company partner's shopfloor.

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AREA 4.2

MFP II 4.2.2.12 QA_HEdge-2

Quality Assurance using High-Frequent Edge Technology

Area 4.1 - Cognitive Production Systems	
Project ID:	MFP II 4.2.2.12
Project Title:	QA_HEdge-2 - Quality Assurance using High-Frequent Edge Technology
Project Lead:	DI Muaaz Abdul Hadi Pro2Future GmbH
Duration:	8 Months, 01.02.2023 - 30.09.2023
Strategic Volume:	18 %

Work Packages

WP 1: Project management

WP 2: State of the art in defect detection

WP 3: Method 1: Analytical methods for defect detection

WP4: Method 2: P2D2 evaluation for defect detection

WP5: Method 3: Method from Siemens AG AMW/Monitor tool

WP6: Comparison of all methods from 1 to 3

WP7: Dissemination

Company Partners

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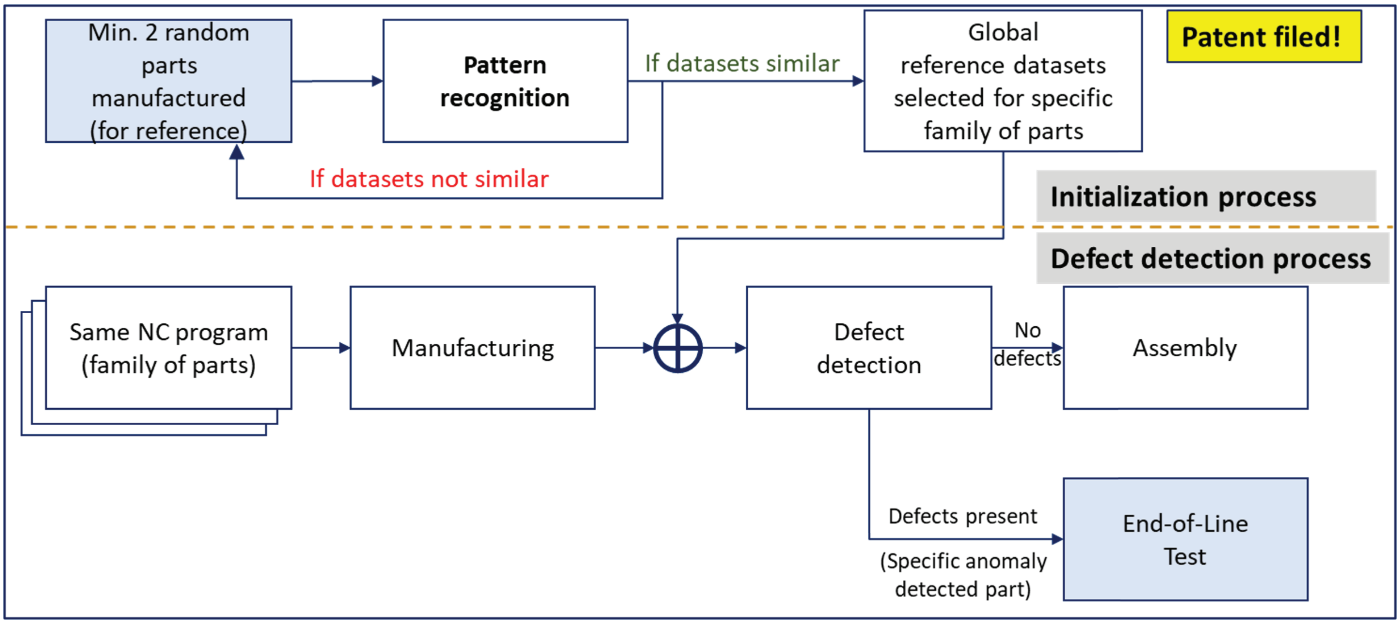
The adoption of automation, connectivity, and data analysis in data-driven industries and shop floors has resulted in improved efficiency, productivity, and profitability of manufacturing processes. However, the complexity of the manufacturing process, coupled with high production speeds and product variety, poses a higher risk of defects and quality issues. To achieve zero-defect manufacturing, it is essential for shop floors to prioritize quality and defect detection. This ensures that products are manufactured according to the required quality standards and specifications. By identifying defects during the production process, manufacturers can pinpoint the root causes and take steps to minimize the production of defective products in the future. This reduction in defects leads to cost savings by avoiding scrap and rework, while also enhancing the overall efficiency of the production process. Moreover, quality and defect detection efforts can provide valuable insights into the root causes of defects. This knowledge can be leveraged to drive process improvements and elevate the overall quality of the production process.
Based on the current techniques used in the industry, quality detections are performed during the end-of-line tests or on products that have been assembled. For example, the fuel cell stacks are tested for performance, leakage, or internal operations post the stacking or electrical integration into the stack. Generalising in three simple steps, first, manufacturing of individual parts is done, - second, assembly of the manufactured parts into a developed product, - and finally, end-of-line testing is performed to test and validate the complete product. The approach presented in this project is from a patent - P2D2 (Power Processing for Defect Detection) and offers a paradigm shift of quality tests from end-of-line testing to the first step, i.e., manufacturing. In this project, however, the defect detection approach from P2D2 is benchmarked with AnalyzeMyWorkpiece tool from Siemens AG. Various sized defects are induced in the material and the defect detection is validated using both approaches.

Goals

The goal of the "QA_HEdge-2" project is to answer the research questions with respect to detection of defects in a material. Specifically, the following questions were investigated in detail:

- What is the minimum size of material imperfections (pores, segregations, etc.) in machining operations to still be detectable by high-frequency machine data?
- How can the minimum size of material imperfections be described analytically by known parameters (e.g. cutter diameter, feed rate, cutting speed, etc.)?
- How accurately do different methods detect the material



imperfections (method of Pro2Future, method of Siemens AG) compared to the analytically described limit values?

Apart from the aforementioned goals, an important aspect of extending the results of P2D2 for defect detection was developed and achieved.

- Extension of the achieved results to identify minute pores, i.e., material imperfections.
- Solidifying the workflow methodology of P2D2
- Testing the approach on different subtractive manufacturing processes and with different materials.

Approach

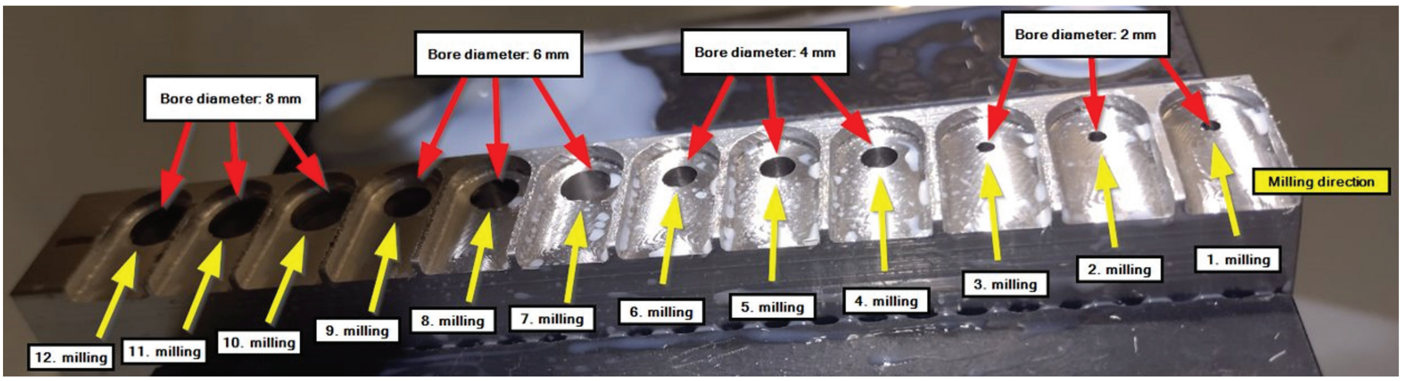
The approach is threefold:

1. From the perspective using analytical methods: Description of analytical relationships between machining parameters with mathematical correlations in analytical form along with visualization of correlations.
2. The aspect of benchmarking of P2D2 versus the method from Siemens AG: This includes the preparation, execution and evaluation of the experiments using the method from Siemens AG (toolkit called AnalyzeMyWorkpiece - AMW/Monitor). A CNC machine at TUG IFT is used for this purpose.
3. To further depict the robustness of P2D2 workflow, see diagram above.

tool from Siemens and the P2D2 approach. This was tested on several parts and one of the parts is as depicted in the figure below.

Status / Progress

Addressing the goals of the project, the benchmarking evaluation is yet under progress for different material, i.e., steel. With respect to the P2D2 approach, specific models were researched and developed to generate value in the manufacturing process. Detailed description and the models implemented are not highlighted due to IPR. With the help of these models, defects with less than 1mm and up to 0.5mm (steel material) were detected with high accuracy. Further extension of these models is already in progress to enhance the correction rate of detection and to further detect micro defects. Thus, the data evaluation methods used in both, grinding and milling, proved reliable and focused in detecting defects and improving the quality of manufacturing process.



Expected and Achieved Results

To goal from one of the sub-topics was to develop a mathematical model that determines cutting forces, cutting torques and cutting performance as a function of various parameters (speed, cutter diameter, pore diameter, etc). The realization was that a number of factors influence the measured values: cutter diameter D (linearly influencing), non-linearly influencing are – pore diameter d, cutting speed vc, feed per tooth fz, number of cutting edges cutter z, sampling interval T.

The second and third goal was a benchmark evaluation between AMW

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AREA 4.2

MFP II 4.2.2.13 SUPRA-2

Sustainable Production and Assembly 2

Area 4.1 - Cognitive Production Systems

Project ID:	MFP II 4.2.2.13
Project Title:	SUPRA-2 - Sustainable Production & Assembly 2
Project Lead:	DI Muaaz Abdul Hadi Pro2Future GmbH
Duration:	24 Months, 01.04.2023 - 31.03.2025
Strategic Volume:	18 %

Work Packages

WP 1: State of the Art in related four use-cases
WP 2: Methodology development
WP 3: Workflow, instrumentation and testing
WP 4: Simulation and optimization
WP 5: Implementation and further optimization
WP 6: Verification and validation
WP 7: Dissemination
WP 8: Project management

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Academic Partners

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The project "SUPRA-2" is motivated by company partner AVL. Sustainable production and assembly (SUPRA) are critical aspects in the development and implementation of fuel cell technology. Fuel cells are promising technologies for clean and efficient energy conversion, and they have the potential to play a significant role in reducing greenhouse gas emissions, addressing energy security concerns, and most importantly addressing SDGs and EU Green deal. Among the various types of fuel cells, the polymer electrolyte membrane fuel cell (PEMFC) and the solid oxide fuel cell (SOFC) are two of the most widely researched and developed technologies. PEMFCs are known for their high energy efficiency, quick start-up time, and compact design, making them well suited for transportation and portable power applications. SOFCs, on the other hand, are capable of operating at high temperatures, providing high fuel utilization and thermal efficiency, making them suitable for large-scale stationary power generation and cogeneration applications. In order to achieve sustainable production and assembly of fuel cells, it is essential to consider various aspects of the fuel cell life cycle, such as the materials used in their production, the manufacturing processes employed, and the end-of-life scenarios for the fuel cells. With a focus on PEMFCs and SOFCs, this research aims to identify sustainable production and assembly practices, as well as to explore the potential for further improvements in terms of reducing the environmental impact and increasing the economic viability of these technologies.

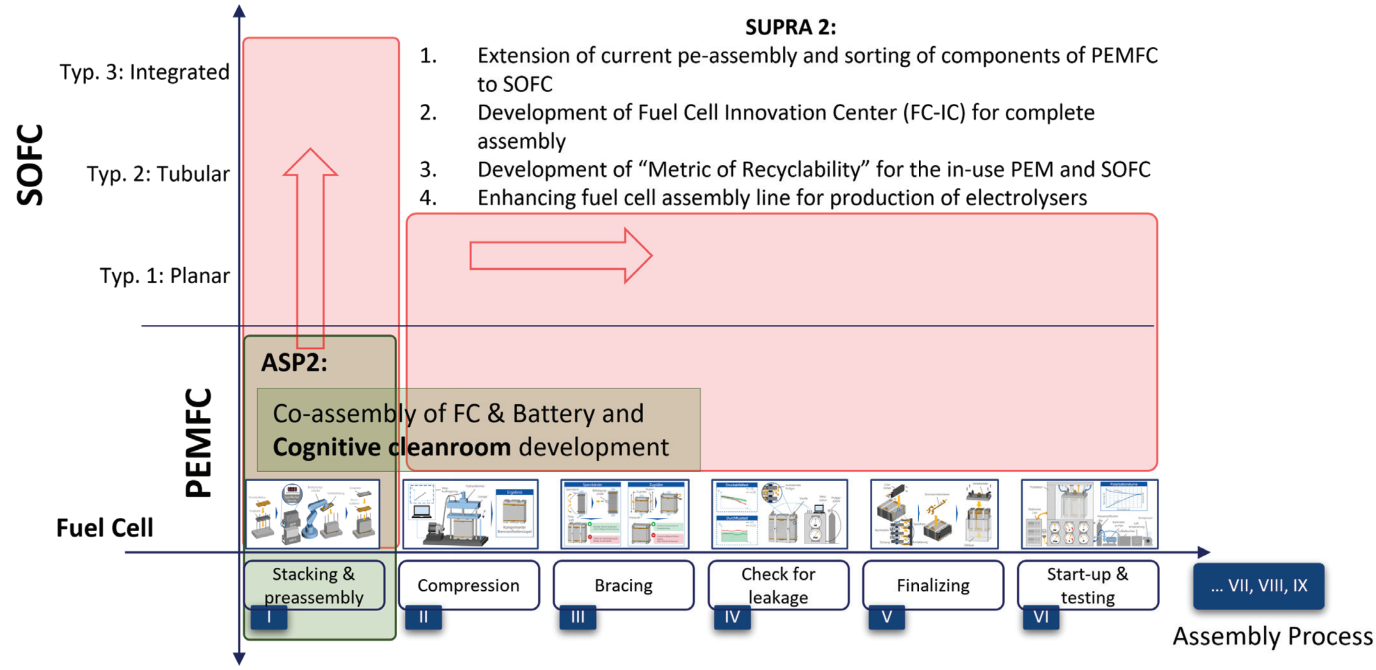
Goals

The focus towards the Sustainable Development Goals and Circular Production is addressed by the SUPRA-2 Project. Four topics or goals will be addressed in this SUPRA-2 project. They are:

- UC1: Extension of current pe-assembly and cleanroom cabin of PEMFC to SOFC
- UC2: Development of Fuel Cell Innovation Center (FC-IC)
- UC3: Development of "Metric of Recyclability" for the in-use PEM and SOFC
- UC4: Enhancing fuel cell assembly line for production of electrolysers

The goals among the four use-cases are summarized below:

- Extension of ASP2 results, i.e., pre-assembly and sorting of individual components along with the cleanroom demonstrator, to a new type of fuel cell.

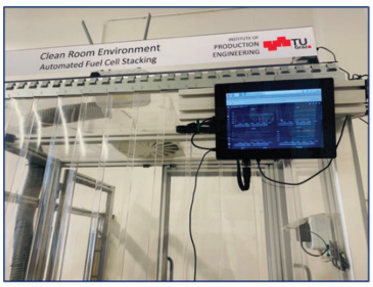


- In ASP2, the focus was on Gen0 and Gen1 PEMFC. However, this will be extended to include SOFC in SUPRA 2.
- Design and development of complete assembly process line at IFT for: PEMFC – Extension to include all assembly steps until start-up and testing; and SOFC – Development from pre-assembly to start-up and testing.
- Acquisition, construction, and testing of the assembly line to simultaneously perform assembly operations of both, PEM and Solid-oxide fuel cells.
- A beyond state-of-the-art demonstrator for combined assembly of both fuel cells -> Fuel cell innovation center (FC-IC).
- Real-time sensory data acquisition of the in-use products.
- Data processing and visualization along with anomalies detection to ensure predictive maintenance.
- Finally, an evaluation metric, i.e., metric of recyclability, will be developed to indicate the level of recyclability of the fuel cell.
- This metric will indicate a score and based on this score; the right feasible direction will be chosen.
- The production of electrolysers that are used for electrolysis.
- Methods and design of these electrolyser units
- Development of initial demonstrators via additive manufacturing technologies
- Three different electrolyser units will be developed -> alkaline electrolyser, PEM electrolyser, and solid-oxide electrolyser.

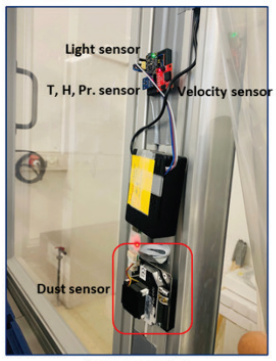
Approach
The use-cases are intertwined with one another as depicted in the image. Use-case 1 extends the developments from ASP2 project to include other assembly steps in the PEMFC and SOFC. Additionally, the project will also address the production of electrolysers, with which hydrogen production can be achieved much cheaper than supplied by high-pressure cylinders.

Expected and Achieved Results
The four sensory capsules are well integrated into the cleanroom cabin and are continuously monitoring the parameters. They are further displayed on the control monitor which also has an integrated control of the filter-fan-unit. This extension has been followed by the results of ASP2 project. The control mechanism developed in this project extends the reliability of the system. Thus, the system now operates in a closed loop without no or minimum interference. As depicted in the images, one of the sensory capsules are shown among the four capsules.

Status / Progress
Addressing the goals of the project, the first use-case is in progress, i.e., extension of current pre-assembly and sorting of components from PEMFC to SOFC. Also, the cleanroom cabin developed is further enhanced to parametrize the conditions of both fuel cells. Once this is achieved, the research will continue with the second use-case for the integration of further steps in fuel cell assembly of PEMFC. Here, the complete integration of assembly will form the basis for the development of fuel cell innovation center (FC-IC). As aforementioned in the goals, the metric of recyclability will be developed based on the data retrieved from the existing in-use products. And finally, in the last use-case, the design and development of electrolyser units will be focussed on using additive manufacturing technologies existing at Institute of Production Engineering.



Real-time visualization of the environment



Sensor capsule 1

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AREA 4.2

MFP II 4.2.3 ACTION II

Adaptive Cobot Integration

Area 4.1 - Cognitive Production Systems	
Project ID:	MFP II 4.2.3
Project Title:	ACTION II - Adaptive Cobot Integration
Project Lead:	Dr. Markus Brillinger Pro2Future GmbH
Duration:	29 Months, 01.04.2021 - 30.09.2023
Strategic Volume:	18 %

Work Packages

WP 1: Problem Definition, Requirements Analysis and Technology Screening

WP 2: Development of Concepts for Collaborative Robotic Automation Environments

WP 3: Implementation

WP 4: Verification, Validation and Integration

WP 5: Dissemination & Exploitation

WP 6: Project Management

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The complexity and demands of assembly tasks in production have been found to increase cognitive load in assembly workers. This leads to physical stress effects induced by work overload. To determine how assembly tasks can be assessed for stress effects, the project conducted a study using wearable sensors to measure heart rate and heart rate variability. The project showed that heart rate and heart rate variability, along with questioning of the assembly workers, is a valid process for stress detection and classification. The project used the machine learning algorithms, Random Forest and K-Nearest-Neighbours, to analyze heart rate and heart rate variability. These algorithms were able to distinguish between assembly task and rest phase, as well as between an easy and hard type of assembly tasks, which is a significant novelty of the project.

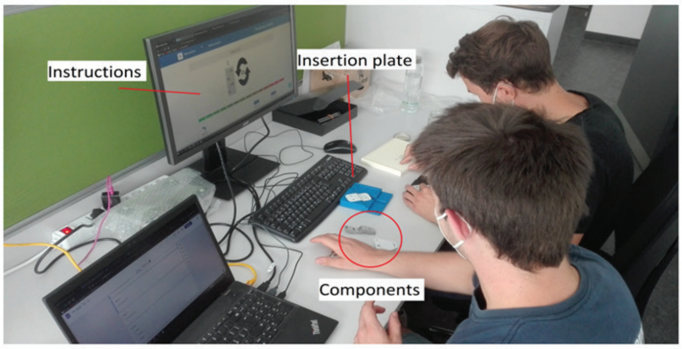
Goals

In the state of the art, a wide variety of stress detection studies were conducted. However, these were carried out exclusively under laboratory conditions with highly accurate and expensive measuring equipment which require specialized personnel to use. Furthermore, there are no studies in the literature so far, that assess the stress of workers during assembly operations with commercially available wearable sensors. As a consequence, the research questions of this project emerge as follow:

- Are there commercially available sensors which are able to measure physiological stress responses?
- Can machine learning algorithms distinguish between workload (overload) phases and rest phases by evaluating vital parameters of subjects during assembly tasks?
- If this is the case, is it possible for the algorithms to distinguish between the workload of a task based only on the measured stress responses?
- If machine learning algorithms can satisfy the previous research questions: how well do machine learning algorithms perform in recognising and classifying stress?

Approach

This project investigates how the condition of a subjects measured by means of a commercially available wearable sensor is related to the subjectively perceived stress. Based on two machine learning algorithms, Random Forest algorithm (RF) , K-Nearest-Neighbours algo-



rithm (KNN), it is investigated if and how precisely these algorithms can distinguish between a person put under work overload and a resting phase. For this purpose, a study is conducted in the field of assembly tasks. The assembly tasks during the study must be performed by each subject faster than calculated by the Method Time Measurement (MTM) method, which should induce work overload related stress to the subject. The physiological stress response is measured by the relative changes in of HRV and HR. In addition, a subjective assessment of workload was conducted using the NASA-TLX method. The results are compared afterwards.

Expected and Achieved Results

In this project, a commercially available wearable sensor was used to measure time series of HR and HRV of subjects. Two machine learning algorithms, KNN and RF, were trained to automatically distinguish between the difficulty levels of an assembly task. The KNN was found to have lower overall accuracy compared to the RF. The RF algorithm was found to be more suitable for both stress detection and stress differentiation. The highest achieved labeling accuracy between 75% and 90% was produced by an unbiased RF classifier. The detected stress levels are compliant with the subjective stress perception: Robustness comparison for algorithms trained on all subjects but one and tested on the missing subject with absolute maximum normalisation. The NASA-TLX score is interpreted with an given workload scale: low (0-9), medium (10-29), somewhat high (30-49), high (50-79), and very high (80-100). The global minimum approach reduced the accuracy of both algorithms significantly. One reason for this decrease in accuracy is the resulting form a skew change and decrease of deviation of the distributions resulting form the normalisation and scaling. When the absolute maximum value normalisation is applied the resulting distribution of data has more similarity (standard deviation, skew, quantiles, ect.) to the distribution of the raw data when compared to the minimum value scaling. The minimum value scaling tightens the distribution and therefore reduced the standard deviation of the resulting distribution compared to the raw data distribution. This effect leads to worse performance especially with respect to the KNN algorithm which is highly affected from the distribution of the data.

Status / Progress

At first a research about how stress affects vital parameters of humans was done. This research led to the conclusion that for stress detection the behaviour of the HR as well as the HRV of workers are major indicators of stress in the wide range of human vital parameters. In order to validate the capability of the commercially available wearable sensor in use a project where the subjects were equipped with such sensor was performed. The study put the participants under different amounts of stress determined by the amount of tasks to be concluded within a set target time (lower than the MTM target time). The first evaluation of the collected data proves that the sensor was capable of collecting data with enough precision and accuracy with consequence that a differentiation between a assembly task phase and rest phase was possible. Furthermore, the feasibility of two machine learning algorithms for stress detection and differentiation was investigated. The first step was to validate machine learning algorithms (KNN and RF) on their capability of differentiating rest phases from assembly task phases. Since this approach yielded good result further validation tests were performed. At the beginning the algorithms were tested and trained on one participant's dataset. Then with all participants datasets and then finally the algorithms were trained on all participants datasets but one and tested with the missing participant to remove the training data bias. As a result, the RF achieved an accuracy within the range of 75% to 90% with a data normalisation on the absolute maximum of the datasets. This result could be improved by a hyperparameter tuning of the classifier. The simple KNN uses much less resources than the RF but the accuracy of the RF outperforms the KNN as mentioned in the previous section. Based on the evidence presented, it can be concluded that subjective stress can only be approximately operationalized for the time being. Nevertheless, it is possible to recognize and differentiate different workload levels of workers via a commercially available sensor system and a machine learning classifier.

In future, it is planned to expand the target group of the studies to also include female participants as well as participants over 35 years of age and with different levels of education. Furthermore, it must be investigated how valid the machine learning algorithms are regarding more complex assembly processes. In addition, the examination of the performance of ML algorithms with much more training datasets available can give more insights on the feasibility of a universally applicable stress detection algorithm. Finally, long-term studies with the same target groups over months should investigate how the objective and subjective stress perception changes. Other research topics, aside investigating further algorithms, might include the challenge of interpreting HRV with the help of EEG data in order to get a deeper understanding of positive- and negative-stress just form the HRV data. It reveals a significant change with increased activity. However, it is not always clear whether this is due to positive activation or corresponds to negative stress. Further on, the use of personal data not only has to be in conformity with all existing privacy laws, but should also be done with the aim of maximising the positive impact of this technology on the individual instead of exploiting the data to maximise the financial profit.

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AREA 4.2

MFP II 4.2.3.2 ASP2 II

Adaptive Smart Production 2

Area 4.2 - Cognitive Productions Systems

Project ID:	MFP II 4.2.3.2
Project Title:	ASP2 II - Adaptive Smart Production 2
Project Lead:	Dr. Markus Brillinger Pro2Future GmbH
Duration:	36 Months, 01.04.2020 - 31.03.2023
Strategic Volume:	14 %

Work Packages

WP 1: Literature
WP 2: Requirement Definition
WP 3: Workflow, Instrumentation and Testing Design
WP 4: Simulation and Optimization
WP 5: Implementation
WP 6: Verification and Validation
WP 7: Dissemination
WP 8: Project Management

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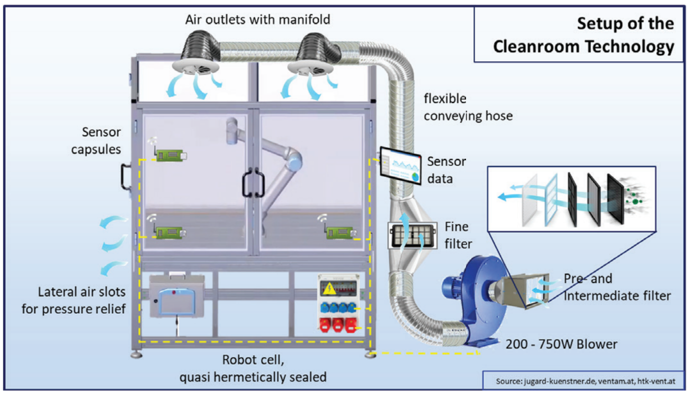
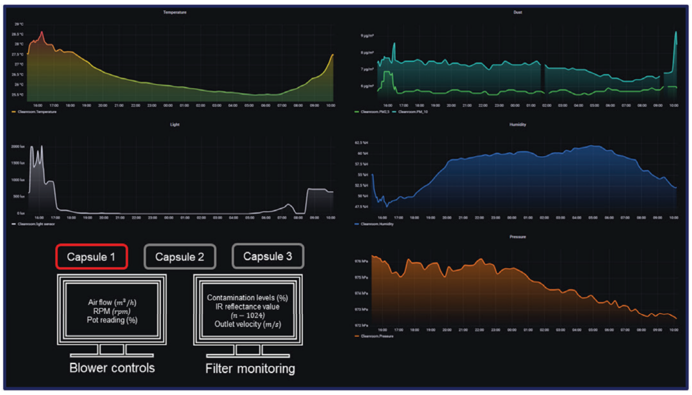
In recent years, research in the field of fuel cells is gaining momentum. Leading automotive industries are investing in e-mobility. In fuel cell research, topics such as fuel cell durability, degradation phenomenon, catalyst performance enhancement, etc., are mainly researched upon. However, one fails to recognize the need for innovations in the area of assembly systems for the stacking process. In this project, a modular approach referencing two topics is addressed. Firstly, the gripping of bipolar plates and the membrane electrode assembly layers for the stacking process. Second, the development of modular cleanroom for the stacking process of the polymer electrolyte membrane fuel cell (PEMFC). A vacuum end-effector (VEE) gripper is innovated, designed, and manufactured using 3D printing methods. It is then tested in real-time at the maximum acceleration of the Cobot. The cycle time of assembly per unit cell achieved was 1.25s; for comparison, manual stacking per unit cell is averaged to approx. 8s. Therefore, huge potential savings in assembly time were denoted. Additionally, the benefit of using a vacuum end-effector gripper mitigates the particulate matter induced via manual handling. This prevents the early degradation of the fuel cell. The assembly technology postulated in this project integrates a complete loop of design, manufacturing, and assembly of the VEE gripping mechanism. With respect to the second topic, the cleanroom is designed and developed to address the fuel cell contamination occurring during the handling and manual assembly of the PEMFC. Four sensory capsules situated in the cabin, where the stacking process takes place, capture the relevant data with respect to the environment. These sensors measure parameters such as temperature, pressure, humidity, dust levels, i.e., particulate matter, etc., and monitor the environment. Additionally, the filter-fan-unit responds to the measured parameters accordingly to deliver clean air to the cabin. Thus, addressing the closed-loop system for the fuel cell stacking process.

Goals

The **focus** towards the Sustainable Development Goals and Circular Production is addressed by the ASP2 Project. At ASP2, the goal is to develop a resilient adaptive system of the **fuel cell stacking process** that must be integrated with the existing battery stacking process. Vacuum end-effector (VEE) **gripping mechanism** is developed for handling of unit cells along with the stacking process. The concept of **ISO standard cleanroom** for stacking process is also **prototyped** at the institute. In ASP2, we focus on:

- Development of **flexible handling technology** for gripping of BPP and MEA layers.





- Analysing the **necessity** of a clean environment, i.e., cleanroom for the stacking operation.
- Development of a **modular cleanroom** with ISO standards.
- A GUI (Graphical User Interface) of **real-time monitoring** of cleanroom which also indicates the **control environment** of the filtering and high-efficiency blower system.
- **Stacking process** of the unit cell components, which form the core of each polymer electrolyte membrane fuel cell (PEMFC).

Approach

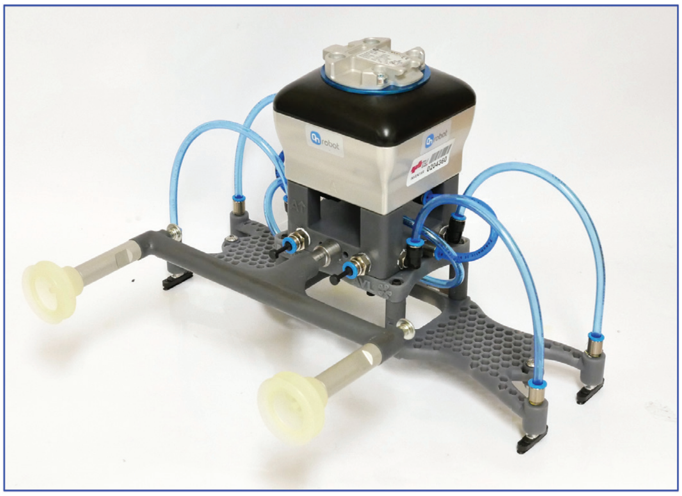
The challenge was to handle the individual unit cell components robotically since some of them are very sensitive and limp. Until now, the cell plates have been stacked almost exclusively by hand, due to careful handling and maximum precision in positioning is required to guarantee the full power potential of the fuel cell with the longest possible service life. For the automation of stacking, a collaborative robot was used on which a specially developed vacuum end-effector (VEE) made by SLA printing was mounted.
In the aspect of development of cleanroom, the basic approach is to utilize the data generated from the sensory system to enhance the stacking process via the developed user model. Four sensory capsules with 6 sensors in each capsule record the data and displays it on a GUI with real-time monitoring and control. They are: Temp – °C, humidity – %, pressure – Pa, velocity of airflow – m/s, light intensity – lux, and particulate matter – µm are monitored. Through the developed graphical user interface (GUI), airflow – m³/hr is controlled.

Expected and Achieved Results

The runs with the fastest settings had an angular velocity of 180deg·s-1 with an angular acceleration of 500deg·s-2. Since the suction cups were dimensioned accordingly, the holding force was suitable for the test sequences. During the verification of the VEE gripper, the time of a sub-cycle lasted 5s. This sub-cycle included the parallel gripping of the two-unit cell components - BPP and MEA, and two intermediate layers - between the unit cell components (see Figure 6). The cycle time of the stacking process per handling object is therefore 1.25s. For comparison, manual stacking at this assembly station resulted in an average cycle time of approx. 8s, with comparable accuracy. The unit cell components were assembled with high accuracy. In this case, the BPP and the MEA layers could be positioned congruently to each other, with an accuracy of less than 0.2mm. The unit cell stack, i.e., the entire stack, for the Gen0-PEMFC includes 142 BPPs and 142 MEA plates, therefore 284 unit cell components. Assuming that another 284 intermediate layers are placed in each of the shaft magazines of the unit cell components, the total number of handling objects would be 568. Therefore, the stacking of the entire unit cell stack would take 710s or 11.83min without interruptions of material feeding. By further calculation, the cycle time of 1.25s per handling object would mean a theoretical unit cell stack production of 15200 pieces per year. This is achieved by assuming 568 handling objects, an overall equipment efficiency of the system of 80% and a two-shift system of 8 hours each.

Status / Progress

This cleanroom concept is developed with the idea of using HEPA filters for supplying clean air. HEPA filter system are cheaper compared to the HVAC systems. When coupled with sensors and a decision-making model, an automated cleanroom can be developed. Until now, industries or OEMs have not defined an ISO standard for the stacking of fuel cells, therefore they define these standards internally. To be certified as a 'cleanroom,' certain standards must be met. ISO 14644 defines these classifications that range from ISO 1 to ISO 9. In the ASP2 project, a cleanroom cabin with varying ISO standards from 6-9 is developed. The standard needed could be achieved with the help of a control system. The maximum particles per m³ are monitored via the high-efficiency blower and the filter system. The three filtering stages, pre-filter, intermediate filter, and fine filter, helps in maintaining the required ISO standard. Four sensory capsules, which are located at optimized locations in the cleanroom cabin measure the necessary parameters and display them in a visualization environment via a graphical user interface (GUI). Through the GUI, airflow (m³/hr) into the cabin can be controlled along with the operation of the high-efficiency blower. Moreover, the three sensor capsules with twenty-four sensors also present a visualization environment for monitoring. For example, if the particulate matter increases, the airflow into the cabin increases and vice versa. This system control is an automated process, and the data generated via the sensors is stored in a repository for further quality checks.



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AREA 4.2

StratP II 4.2.4 E-MANAGER

Energy Management for Industrial Production

Area 4.1 - Cognitive Production Systems	
Project ID:	StratP II 4.2.4
Project Title:	E-MANAGER: Energy Management for Industrial Production
Project Lead:	Dr. Markus Brillinger Pro2Future GmbH
Duration:	29 Months, 01.04.2021 - 30.09.2023
Strategic Volume:	100 %

Work Packages

WP 1: Literaturrecherche & Forschungsfrage

WP 2: Use-Case Definition & Differenzierung

WP 3: Entwicklung der Methodik

WP 4: Implementierung

WP 5: Verifikation & Validation

WP 6: Disseminierung & Verwertung

WP 7: Projektleitung

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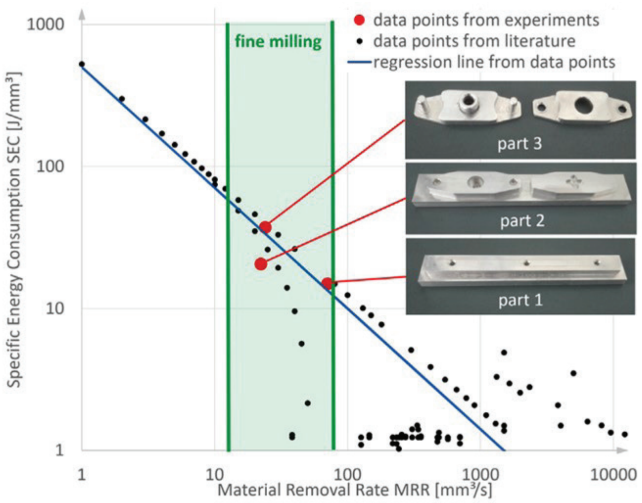
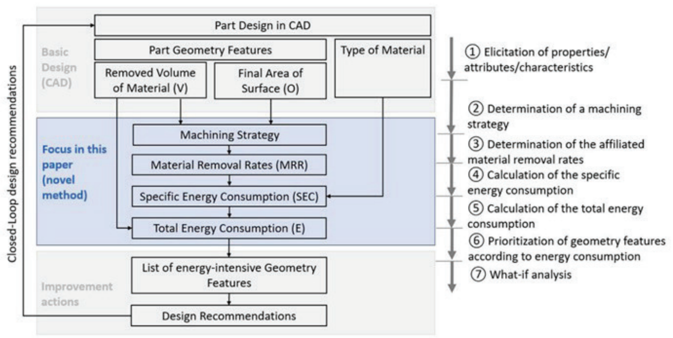
To reduce CO2 emissions, besides the automotive industry, manufacturing industries are increasingly under pressure to optimize processes and procedures for energy efficiency. These optimizations mainly involve the production processes, where most energy demand occurs. Alternatively, when most of this energy demand can be determined during the product design phase, the product designer can make energy-efficient decisions in the design phase. Most product designers are unaware of their decisions' significant impact on a product's energy demand. Therefore, this project develops a workflow and novel method for predicting the energy demand of parts of their machining operation during the design phase. For this purpose, 29 energy consumption models for machining processes are examined, and the data published in the literature are summarized. Four resulting comprehensive process maps are derived, which enable the prediction of a part's energy consumption due to machining, specifically, the milling operation, based on the geometric features of the part. This was further verified on three machined parts. The workflow and methods developed in this project are some of the first steps to facilitate conscious decisions already in the product design phase. The benefits of the method were demonstrated in a final survey: Both product designers and machine operators showed in this survey that their estimation of the energy consumption of the parts investigated differed by orders of magnitude.

Goals

All state of the art energy consumption models in machining examined are based on machining parameters, which cannot be determined solely based on geometry. The second point to note is that all models are based either on general physical relations or on experimentally determined data, but there is no formal mathematical inductive derivation. Thirdly, some specific models are difficult to generalize or the accuracy of these models is greatly reduced. The question, therefore, arises as to how the extensive data and models in the literature can be used to predict energy consumption during the machining phase. Moreover, the prediction must be done at the product design phase by the use of geometrical features of the designed part and the volume of raw material of the part. The challenge lies, on the one hand, in the fact that in the product design phase, there is not yet any precise information about the subsequent machining and the associated related parameters. On the other hand, a key basis of many models for predicting energy consumption is the process-related material removal rate (MRR), which is also not known precisely in the product design phase but can be estimated between upper and lower borders based on literature and industry experience.





Approach

In the progress of this project, we first investigated how such a prediction of the energy consumption of parts can already be made in the design phase with the help of a workflow and which parameters are necessary for this. It is shown that the workflow is more comprehensive than can be researched in this project. Therefore, the core of this workflow, the method that assigns different geometrical features to energy consumption. In the next step, this method is derived theoretically. In contrast to existing methods from the literature, which are derived inductively from experiments, this project proceeds deductively and derives an analytical connex between energy consumption and part geometry. This correlation is verified in the following step utilizing experiments for machining and validated in the next step through a user study with product designers and machine operators.

Expected and Achieved Results

To determine the energy consumption of the parts already in the design phase, data from the corresponding machining process and the part geometry from the CAD software are necessary. The entanglement of these data is the first novelty of this project. From the CAD software, the material, surface and volume properties assigned to the part are read out, as well as the individual geometry features. Based on these properties, a machining strategy is assumed for each geometric feature. With the assumed machining strategy, the metal removal rate, the specific energy consumption and finally the total energy consumption are calculated for each geometric feature. Finally, the geometry features are sorted and prioritized according to the ranking of energy consumption. These can be fed back to the designer as a design recommendation in the form of a closed loop to create awareness and enable the designer to design parts in a more energy efficient way. Furthermore, as part of this workflow, this project investigates how total energy consumption can be derived from an assumed machining strategy, thus developing an analytical method, which is the second and the major novelty of this project. To verify this method we focussed on the machining strategy of fine milling.

In this project, a workflow for predicting the total machining-related energy consumption of a part during the design phase was developed. Within this workflow, a novel method was derived that links parameters from product design, like the removed volume of material, with data from the literature for machining. Therefore, 628 data points from the literature were elicited and reverse-calculated to create process maps for steel, aluminium, cast iron and nickel. In most of the studies in literature, the parts were machined without lubrication. However, the data points for nickel come from a study that uses a special form of minimum quantity lubrication and therefore they are significantly lower than the others. This method was verified based on 3 experiments. Experiments were performed for 3 aluminium parts and the novel model was applied. All experimentally assessed values of energy consumption were within the upper and lower limits of the developed theoretical model. Hence, it was shown that it is possible to predict the total energy consumption in machining processes based on the part geometry and material type within reasonable margins of error. The benefits of the workflow were confirmed by two surveys: The novel method limits the variance of the estimates of the energy consumption of the parts of part designers and machine operators by more than a power of ten. From the results until now, we can draw the following conclusions:

- First, the specific energy consumption for machining of all investigated material types decreases with higher material removal rates.
- Second, the energy consumption of machining a part can already be estimated in the design phase. In the cases researched in this project, a maximum deviation from the experimentally measured energy consumption of 208% for machining could be determined.
- Third, the maximum deviation of the presented model is, however, smaller than the deviation of the opinion-based estimated energy consumptions of designers and machine operators, which was shown by a study carried out. The deviation in this study was several orders of magnitude higher than that of the model.

Status / Progress

On this basis, further research must be carried out, which includes material types, machine types, machining strategies, but also geometry features. The novel method developed in this project was verified on machining, which is a subtractive manufacturing process. Further approaches are to include other manufacturing processes, e.g. additive manufacturing. Furthermore, detailed investigations are necessary to derive the machining strategy from individual geometry features (surface, volume) of the part and, subsequently, how the material removal rate can be assumed. Hence, the machining strategy plays a major role in the proposed model. A new study of the relation between material removal rates for different machining strategies is necessary unless the values reported are still used in the industry as rough estimates. To transfer the results into an application, an implementation of both the workflow and novel method in a software tool is necessary. This can be used by product designers to analyse and subsequently optimize their product design in the context of energy consumption in machining processes. This step is currently being taken by Pro2Future GmbH, whose strategy includes sustainable production processes. The software tool, which incorporates the findings from this project, is currently under development based on the fact that the benefit of the novel method has been shown in Fig. 9. This project represents a first step towards a geometry-based energy optimization of a part in the design phase, which contributes significantly to clean, energy-efficient, and thus sustainable production.

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nonCOMET Proposal Development

	Project Name	Funding Call	Funding Inst.	Leader	Consortium
2018/2019	INHABIT	H2020, ICT-32-2018	EU	The Provost	Pro²Future, Stichting GmbH, TU Graz
	HOTMET	H2020, DT-SPIRE-06	EU	NORCE	Pro²Future, ATOS Spain, Saint Gobain Cer., FerroAtlantice
	Digital Inspector	IKTdZ	FFG	Pro²Future	Siemens, TUG, Joanneum Research, SES-imagotag
	CyPhy	H2020, ICT-01-2019	EU	TU Delft	Pro²Future, TH Aachen, EURECAT Centre Tecnologic
	ICP-FWF	Int. Coop. Proj	FWF	Pro²Future	JKU, Universidad Nacional de Education a Distancia
2020	AI MAN	H2020, ICT-38-2020	EU	NORCE	Pro²Future, ATOS Spain, Senior Europa SL
	Delight	Chist-Era	FWF	University Bochum	Pro²Future, TU Vienna, HSG, LNU, IMTA
	X-AMINOR	Energieforschung	FFG	Joanneum Research	Pro²Future, Siemens AG Österreich, Austrian Power Grid
2021	Prev. Maint. in Manuf.	FF4EuroHPC	EU	3ACES	Pro²Future, Armengaud Innovate GmbH
	TWIN	Stadt der Zukunft	FFG	TUG/IBGH	Pro²Future, AIT, Siemens AG Österreich, Digitalfindetstatt
	AI-Flight	Take Off	FFG	TU Graz	Pro²Future, D-Aria, Roto Frank
	Hasslacher-Challenge	TechHouse Pitch	TechHouse Pitch	AIG	Pro²Future
	DiPro	Fast Track Digital	FFG	AIG	Pro²Future, Armengaud Innovate, Antemo, Fuchshofer
	P²aaS	COMET Module	FFG	Pro²Future	JKU, TUG, WU Wien, Cambridge, TU Darmstadt, IWI, Alpla, ACDP, EVVA, Fronius, KEBA, Siemens, TCM
	Tiny AI	COMET Module	FFG	Pro²Future	JKU, TUG, TUM, DFKI, AVL, Fronius, STMicro, STTech, Trumpf
	DIADEM	ZDMP	EU	AIG, ITML	Pro²Future
	Sustainable Production System	WTZ Österre-ich-Slowakei	BMK/BMVIT	TUKE FMT	Pro²Future
	UC18 ADEDIM	TRINITY Demonstration	EU	AIG	Pro²Future, ITML
	UC6 DASH-PROD	TRINITY Demonstration	EU	ITML	Pro²Future, Armengaud Innovate GmbH
	circular_b2b	FTI DL	FFG	Pro²Future	Syrion, WU Wien
	GreenFashion4Future	Talente Praktika	FFG	Pro²Future	-
	SmartSync4EnergyAu-tonomy	NEXT GREEN TECH	Land Steiermark	Pro²Future	TUG
	Multi-ID-Smart	Horizon-CL4-2021	EU	Universität Bremen	Pro²Future, Cranfield, Caltec, Fabrician, AVL, Kairos Digital, Dare2Innovate, ...
	VibroHone	CORNET	FFG	Pro²Future & DFMRS	IWU Deutschland, TU Graz, BIMAQ
	4.0_inklusive	Projektfonds Arbeit 4.0	AK Steiermark	Team Styria	Pro²Future
	recAIcle	AI for Green	FFG	Pro²Future	MU Leoben, Siemens AG
	REWAI	AI for Green	FFG	Pro²Future	JKU, TUG, Lenzing AG

Year	Project Name	Funding Call	Funding Inst.	Leader	Consortium
2022	AI Enabled Green Technologies	Stadt der Zukunft	FFG	AIcosystems	Pro²Future, KF Universität Graz
	PLUFF	ACRP	BMK	Pro²Future	UBIMET, BOKU
	ecoDesigner	Digitale Transformation OÖ - Upper Vision	FFG / Land OÖ	Pro²Future	LCM, Pamminger Maschinenbau, Pamminger Verpackungstechnik, Haratech, Miba, Profactor, RO-RA, SCCH, INFABITY,
	ADVENTURE	IKTdZ	FFG	Green4Cities	Pro²Future, Aicosystems, BOKU Wien
	AIfSP	FEMtech	BMK	Pro²Future	-
	WorkpAIce	Horizon-CL4-2021	EU	JKU Linz	Pro²Future, Trumpf DE, Fraunhofer, Fronius, Prenode, Polytechnico Milano, Sony, Beam-IT, IMA SPA
	WorkpieceAI	Horizon-CL4-2021	EU	ACDP	Pro²Future, TUM, EVVA, Univ.Bolzano, IeAT, Grabher, Reifenhäuser, v-trion, MayrMelnhof, Open, Celornis, SmartRobotics, …
	IoT-Circulate	Horizon-CL4-2021	EU	Universität Bremen	Pro²Future, ATB, Cranfield, TUKE, SPINEA, AVL, KAIROS, Dare2Innovates SL
	Stress-Based Workflow Management	Coin KMU	FFG	Pro²Future	Antemo, FH Campus 02, AIG, ITML, SVI
	ENEBLA	UFO	Land Steiermark	Pro²Future	TUG
	EManager 1.2+	OECD-WTZ	BMK/BMVIT	Pro²Future	Uni Maribor
	TOMM	Talente Praktika	FFG	Pro²Future	-
	AI-2-Meet-PEP	PdZ	FFG	VIF	Pro²Future, AVL, CDP, TUWien, STIWA, TTTech, LMC, Messfeld, KFU, WUWien, Syrion
	E³SUSTAIN	PdZ	FFG	Pro²Future	AVL, CDP, KnowCenter, MIBA, Palfinger, Profactor, Syrion, Tripan, Haratech, EVVA
	enCODE your Gains	SpinOff Fellowship	FFG	Pro²Future	-
	VibroHone NR	CORNET II	FFG	Pro²Future	DFMRS, IWU, TUG, BIMAW
	Sustainable Production System 2	WTZ Österreich-Slowakei	BMK/BMVIT	Tuke FMT	Pro²Future, TUG
	DPA_inklusive 2	Projektfonds Arbeit 4.0	AK Steiermark	Team Styria Werkstätten GmbH	Pro²Future
2023	CSSPeC	Talente Pratika	FFG	Pro²Future	-
	EmCoSy	Talente Pratika	FFG	Pro²Future	-
	E-HAZARD	ASAP	FFG	Pro²Future	UBIMET, ÖBB
	ReCoDiML + TampAssSy	FEMtech	FFG	Pro²Future	-
	Transformative Technologies	COMET Module	FFG	Pro²Future	Fronius, Trumpf, Infineon, KEBA, ÖGK, Siemens, Engel, AVL, EVVA, voestalpine, Primetals, GAW
	Live AI	COMET Module	FFG	Pro²Future	Fronius, Trumpf, AVL, EWW, Siemens, STMicro, TU Graz, JKU Linz, TU Munich, DFKI Kaiserslautern
	Mentor5	ERASMUS-EDU-2023	EU	Pro²Future	TU Graz, Found.ation Maker's Place Private Company, SVEUCILISTE U ZAGREBU EKONOMSKI FAKULTET, INFINITIVITY DESIGN LABS, EUROTRAINING EDUCATIONAL ORGANIZATION, Centar za inovacije, CCIV, CECIMO
	Smart_Waste	INTERREG	EU	VSB Ostrava	Pro²Future, University of Economy in Bydgoszcz, GABEN, CTU Prag, TUKE FML, Poznan Uni of Technology
	Digitalisation as Key Enabler	OEAD-WTZ	OEAD-WTZ	Pro²Future	Universität Zagreb
	P2D2	SpinOff Fellowship	FFG	Pro²Future	TUG
	E3SUSTAIN	Produktion und Material 2023	FFG	Pro²Future	TRIPAN, AVL, MIBA, HARATECH, TUG, JKU, KnowCenter, SCCH, ACDP
	HiCycle3D	Leitprojekt PuM 2023	FFG	FH Kärnten	Pro²Future, Haratech, ÖBB, Tiger Coatings, Magna Steyr
2024	Alpine Water Prediction	ACRP	FFG	Pro²Future	UBIMET, APG, Verbund, EVN, TIWAG, KELAG
	Drone-Carriers	Klimaneutrale Stadt	FFG	Pro²Future	Siemens, STRABAG
	WasteCycle	AI for Green	FFG	Pro²Future	MU Leoben, Saubermacher, Mayer Recycling

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REWAI
Reduce Energy and Waste using AI

nonCOMET

Funding Call:	FFG, AI for Green (2021), Grant #892233
Project Title:	REWAI - Reduce Energy and Waste using AI
Project Lead:	Dr. Michael Haslgrübler Pro2Future GmbH
Duration:	36 Months, 01.04.2022 - 31.03.2025

Work Packages

WP 1: Project Management

WP 2: Causality Analysis

WP 3: Virtual Sensor Implementation

WP 4: Trustworthy Edge Bades Explainable AI

WP 5: Counterfactual-based Explainable Predictions

WP 6: Dissemination

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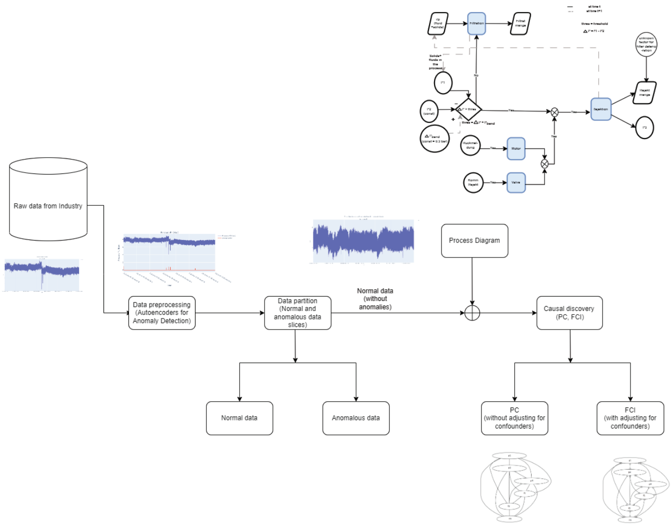
The REWAI project aims to enhance sustainability through cognitive decision-making, utilizing explainable AI techniques to augment human intelligence with machine intelligence. For this purpose, it contributes (i) virtual sensor implementation for quality prediction in time series, (i) development of trustworthy Explainable AI techniques which establish trust with users, (iii) establishing the cause-effect relationships within the production parameters. Along with company partner Lenzing, these interfaces will enable human workers to be in control and provide human oversight by creating trust in Human-AI collaboration. The main factors of the environmental impact in global fashion industry are the use of resources (lands, water, chemicals, etc.) and energy, and greenhouse gas emissions. AI-based methods are leveraged to optimize resource efficiency and increase competitiveness of sustainable fibers, reducing the industry's footprint and boosting market pressure on unsustainable synthetics.

The process incorporates parallel sieves, arranged in dual groups, where each sieve executes filtration and rejection/backwash procedures. Filtration removes impurities from the input fluid (viscose), while rejection/backwash removes the filtered impurities. The outcome is the sought-after high-quality, clean material. The process entails a causal mechanism influencing the material quality. Adjusting parameters impacting output has the potential to elevate the final product's quality. Moreover, this mechanism is valuable for root cause analysis, identifying origins of faulty items, and it enables predictive analysis, anticipating faulty products and suggesting changes to prevent defects in advance. However, there are challenges behind the optimization and adoption of AI in this process, e.g., complex relationships among factors, finding global optima, ensuring stability, high dimensionality. Also, creating accurate and interpretable models is related to the right balance between intricate models and transparent decision pathways since those models often tend to function as “black boxes”.

To overcome these challenges, we use various AI-based techniques with the aspects of data analysis in production process and the real-life application. We implement a trustworthy AI in the production pipeline, fostering human-machine collaboration to enhance human performance by combining human perception with the process power of computers. To prevent low-quality outcomes, we focus on high-frequency data for initial optimization and low-frequency data to establish causal relationships between subsequent stages. This strategy aims to avoid inferior quality products that would require recycling, thereby reducing energy loss, plastic waste, and storage needs. Additionally, we develop techniques where the users can understand the implications of AI with confidence and control over the system by clearly communicating key data and methods.



Goals

REWAI focuses on diminishing the environmental impact of the textile industry with the aim of reducing operating costs and enhancing the competitive edge of unsustainable synthetic fibers. This initiative encompasses two primary objectives: (i) constructing a prediction system upon the already implemented sensor instrumentations to ensure timely intervention and (ii) trustworthy decision-support to the decision-makers throughout the production pipeline to guide human using AI tools. The pursuit of optimized production, minimizing energy loss, and waste necessitates (a) uncovering causality gaps and measurement gaps, (b) embedding energy-efficient explainable AI tools and (c) providing counterfactual-based explanations for what-if analysis to the overall process. We establish root cause analysis that identifies reasons malfunctions or suspicious activities by defining the underlying causal mechanisms. This knowledge allows us to enhance final product quality by addressing direct and indirect factors impacting output parameters. Meanwhile, the explainability in our system will ensure that the operators and end-users can understand the output of ML and predictions so that they can be able to perform human oversight, monitor the outputs continuously and be enabled to re-evaluate the model with ensuring the validated input and output.

Approach

We use diverse AI-based models, including CNN, RNN, LSTM, and the hybrid ML models, Autoencoders. Initially, we train these models individually on each sieve's data, later, perform combined training on all data for a unified prediction model. This approach aids in model comparison and evaluation of its generalization ability. The pivotal aspect of this is comprehending the operational intricacies of each machine and their interactions in parallel operations, along with discerning the impact of individual and collective machine behavior on sensor values.

We use anomaly detection to tackle component failures and build a causal graph for the process. Causal discovery algorithms identify relationships in normal and anomalous data, comparing cause-effect using metrics to locate anomaly origins. In the field of xAI, counterfactuals provide interpretations to point out which changes would be necessary to accomplish the desired goal.

Expected and Achieved Results

REWAI has two main objectives: (i) implementation of AI-driven quality outcome prediction within the production pipeline, (ii) building a trustworthy for decision-making system with the aspect of “human-in-the-loop”. Our primary focus is on comprehending the factors that lead to low quality production and provide this insight to the users with the context of fairness, explainability, auditability and safety.

We have used Autoencoders to drive an input representation from multi-dimensional time series data, thereby extracting relevant features. Later, we have created univariate and multivariate input-output structures and performed AI models to achieve real-time performance. Our findings show that these models can capture the meaningful features and the patterns by r educing input dimensionality, and they can be used for high-frequency data labelling where the changes and outliers occur at a lower frequency. Parallel to this, we have employed individual models for each sieve and a unified model trained on the entirety of the data to observe prediction models' sequence prediction performance. The goal of observing the behaviour of the prediction models with several approaches is to draw a framework for the XAI application according to the reasons behind the input-output relation. However, in practical scenarios, it is not always feasible to measure every quality attribute and establish a direct relationship with the final product quality. Hence, conducting causal discovery becomes essential to identify the key factors affecting product quality and optimize them effectively. Causality analysis serves two main objectives in this context. Firstly, it enables root cause analysis for identification of the reasons behind malfunctions or suspicious activities occurring in the process. Secondly, causality analysis holds the potential to improve final product quality. The knowledge derived from the causal graph can be utilized for predictive analysis for a feasible prediction of when a hole is likely to be created in the sieve, enabling proactive measures to prevent or mitigate potential issues.

Status / Progress

The project began in April in 2022. Data were collected in two phases: January 18 to June 2 2022, and June 13 to October 11, 2022. Our approach began with statistical analyses, offering insights into time series data behaviours for AI methods. The initial stage involved linear predictive models, serving as a foundational assessment of the data. Later, we transitioned to advanced machine learning models due to the intricate multidimensional nature of the data. These sophisticated models affectively captured in-depth features for more effective predictions. We observed that Autoencoders emerged as useful model to extract the representation of certain features and capture input data distribution in high-frequency time series containing diverse behaviours (e.g., binary and continuous signals). Additionally, the prediction performance of RNN-based LSTM and hybrid models with CNN has been demonstrating on single step and sequence prediction in univariate and multivariate input-output structures and different input sizes. Furthermore, RNN-based LSTM and hybrid models featuring CNN have been employing for univariate and multivariate input-output structures, across various input sizes for both single-step and sequence predictions.

Before conducting causality analysis, we applied Bayesian Change Point Detection to identify potential shifts or anomalies in the data that may affect the causal relationship between variables. By detecting and addressing these changes in the data, we can ensure that our causal analysis is accurate and reflects the underlying relationships between variables, as failures to account for change points can result in biased or incorrect causal inference. Using the results of the change point detection we were able to split the data into two groups: "good data" when the sieve operated perfectly, and "bad data" when some anomalous behavior occurred. Causal discovery was performed separately on both sets, considering the filtration and rejection/backwash processes. The main idea behind segregating data into two categories is to facilitate the root cause analysis. This process involves determining the factors that led to anomalies during unfavorable periods and pinpointing their origins. This comparative analysis involves assessing causal graphs from both sets of data and utilizing metrics like Structural Hamming Distance and Frobenius Norm to detect the (dis-) similarity between the graphs. Once the underlying reasons for these undesirable occurrences are identified, predictive analysis can be employed to proactively avert similar system failures. Ultimately, this approach aims to prevent any degradation in the product or system's performance. Considering the dynamic nature of the complete process, causal discovery with time lags was necessary to examine the delayed influences between variables on product quality. The resulting graph, produced using the LPCMCI causal discovery algorithm, sampled data every 10 seconds and considered 2-time lags (20 seconds) for the rejection phase on 10th Aug 2022 (good data). The entire procedure of causal discovery is depicted in the figure.

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X-AMINOR
Cross sensor PlAtforM for lifecycle-moNitORing of Transformers

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Funding Call:	FFG, e!MISSION (2019), Grant #3863340
Project Title:	X-AMINOR: Cross sensor Platform for Lifecycle-Monitoring of Transformers
Project Lead:	Dr. Ferdinand Fuhrmann Joanneum Research
Duration:	36 Months, 01.02.2021 - 01.01.2024

Work Packages

WP 1: Project management

WP 2: Phases, requirements and system concept

WP 3: Theoretical and empirical modelling

WP 4: Automated visual and acoustic diagnostics

WP 5: Platform and integration

WP 6: Evaluation in an industrial environment

WP 7: Publication and exploitation

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The current developments in the energy system pose new challenges to grid operators, as the increased integration of renewables and the introduction of dynamic loads into the power systems lead to a decoupling of consumption and production. Digitalization is one of the major tools for grid operators to tackle these challenges, as it allows them to implement flexible and advanced operation and planning strategies, which reduce costs while increasing service security.

Transformers constitute a core component in energy grids. Their availability and longevity can thus be seen as command variables in the context of service security. The outage of a transformer can lead to service loss in combination with high costs. Predictive maintenance is an important factor to increase the longevity of these essential infrastructure elements. At the start of its life, a transformer may fail due to mistakes made in the manufacturing process or its transportation and installation at the operational site. Towards the end of its life, the risk of failure increases due to its age and wear. Transformer fires, short circuits, mechanical faults, and overvoltage events are all destructive events that can occur during operation and cause significant damage to the transformer and its surrounding infrastructure. Unfortunately, destructive events can lead to a lack of data available for investigators during post-event forensics and failure analysis, which may impede the identification of the event's cause and the further development of preventative measures, for instance fire protection.
Due to the long-life expectancy of transformers and the large number of legacy components in the energy grid, comprehensive retro-fitting of these components is not economically feasible and additionally poses a logistical challenge due to the amount of components and associated required engineering. To achieve this, data from existing monitoring systems will be combined with additional, new data modalities and advanced models to enable improved and dynamic monitoring of transformers. In X-AMINOR, our solution aims at providing functionality for dynamic transformer monitoring and optimization of operation to reduce operation costs, preventing failures, and supporting intelligent grid planning strategies.

Goals

X-AMINOR aims at developing novel approaches for the exploitation of audio, video, thermal and other data towards achieving better lifecycle-monitoring of transformers, without requiring a comprehensive retro-fitting of these essential components of the power grid. The technical result of X-AMINOR is a mobile lifecycle-monitoring robotic and cloud backend solution to perform minimally invasive transformer monitoring to be deployed alongside standard existing transformer monitoring strategies. The robotic platform is equipped with a cross-/multi-sensor platform (audio, video, thermal), which can gather data similar to a traditional on-site inspection of the transformer. The system is initialized in the vicinity of a transformer and performs autonomous monitoring and assessment. Advanced data analytics are used to

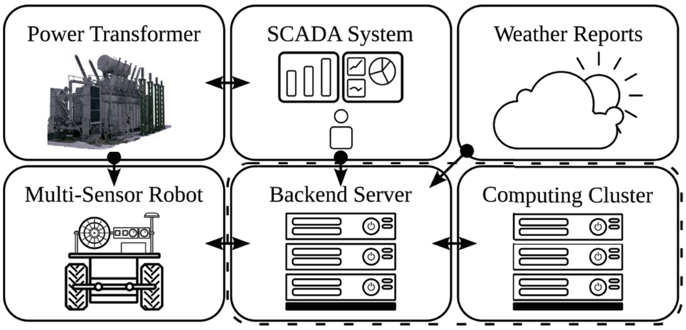
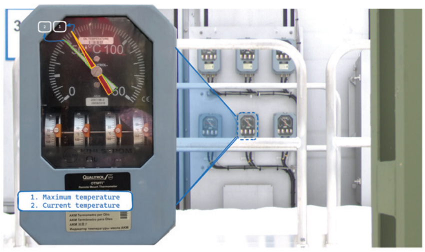


Figure 1 Proposed robotic multi-sensor platform and cloud backend solution for the lifecycle monitoring, inspection, and diagnostics of transformers. Shown: Data acquisition information flow diagram.



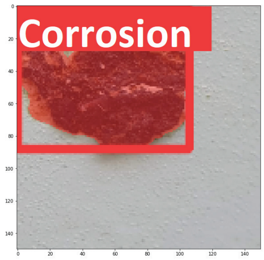


Figure 2 (left): Automatic vision-based localization and readout of legacy and non-legacy equipment, such as temperature and oil level meters. Figure 3 (right): Automatic detection of defects such as corrosion, dirt, or oil on the transformer surface.

build data models which provide the basis for predictive maintenance and continuous product improvements. The project will demonstrate this functionality on a system level in the form of a demonstrator.

X-AMINOR has been developed in the context of two application scenarios (final acceptance test after production and normal operation). Long term evaluation scenarios are used for an in-depth quantitative and qualitative evaluation of the system and allow the assessment of the quality of the developed methods and the benefit of such a system in the context of automated condition monitoring.

Approach

The use of continuous monitoring and predictive maintenance is essential to prolong the life of transmission systems and reduce any unexpected outages. Standard monitoring solutions are integrated into a SCADA system to monitor the key performance indicators (KPIs) of power transformers. The type of data which can be gathered from a transformer depends on the model. Generally, modern transformers have access to a greater range of information compared to older models (like winding hotspot sensors and dissolved gas analyzers).

In contrast, in the X-AMINOR project, we are developing a robotic multi-sensor platform and cloud backend solution to perform minimally invasive transformer monitoring to be deployed alongside standard existing transformer monitoring strategies (Figure 1). The robotic platform provides transformer on-site data periodically, which is processed and made available to stakeholders by means of the cloud backend. Our system will, among other capabilities, support the lifecycle-monitoring of the transformer and provide data for post-event forensics in the case of destructive events.

Expected and Achieved Results

X-AMINOR is designed to collect and analyze visual and acoustic information in addition to already available operating parameters in order to enable a more precise assessment of the transformer's condition. For an autonomous operation it requires suitable transportation means (mobile platform) and IT technologies (middleware and edge computing).

X-AMINOR utilizes recent developments from the area of the Internet of Things (IoT), where a range of protocols and architectures for instantiating intelligent monitoring systems have been proposed. To guarantee scalability, edge computing will be implemented via GPU-enabled computing nodes. This will allow nodes to preprocess data streams and perform first analyses, while the backend performs computation-heavy analytics as well as model training and development.

Visual diagnostics in X-AMINOR rely on three pillars: a reasonable accurate mapping of the transformer, resulting in an as-built 3D transformer model, and its utilization for the localization or registration of newly acquired images. These capabilities allow to localize detected conditions and findings, the visual detection of specific defect types known in advance and of generic changes on the transformer surface, such as those caused by rust and oil leakages. The precise localization of the positions of our multi-sensor platform, allows us to achieve acoustic, thermal and visual modelling of the transformer; as well as the automatic vision-based localization and readout of legacy and non-legacy equipment, such as temperature and oil level meters.

Our focus is on achieving results towards the leveraging of these multi-modal and sensor transformer data for the lifecycle-modelling of transformers. The data established with the X-AMINOR monitoring system will allow us to validate and tune existing aging models based on operational data. Moreover, such data can be used as additional model input to individually model a specific target transformer. Additionally, this information allows the development of new models which relate acoustic, visual, and thermal information established during end-of-line testing with operational data, allowing for a continuous evaluation of the transformer.

Status / Progress

The project consortium has implemented, integrated together, and tested the robotic multi-sensor platform and cloud backend solution, with a focus toward automatic dataset acquisition and processing. The data processing has been divided among the robot and the cloud backend. The main differences of the X-AMINOR system in comparison to similar ongoing projects are: our use of (1) a 3D microphone array to analyze noise patterns and their sources at the transformer's surface, (2) a more cost-effective robot (a Husky UGV, by Clearpath Robotics, for instance instead of a Spot by Boston Dynamics); and (3) our implementation of LiDAR only once – i.e., initially, to create an accurate 3D model of the transformer, which is used later as template for the precise 3D registration of the acquisition viewpoints by means of RGB-D images.

In the literature, a majority of approaches have focused on the detection of defects in individual 2D images. In the X-AMINOR project individual 2D detection results, such as oil leakage or rust marks, are integrated and consolidated in the as-built 3D model of the transformer. This way, the reliability of detections can be improved by correcting individual false positives via the results from other images. Based on the given 3D transformer model and the localization information of the sensor system relative to the device, a holistic detection model can be established, linking the different sensing modalities. Additionally, the system can read legacy equipment, such as analog displays and meters, from images acquired via the sensor system, which we have implemented for the readout of oil and winding temperature indicators.
In contrast to specific visual inspection tasks, change detection focuses on observing a scene over a longer period of time and on registering all types of expected or unexpected changes. X-AMINOR has aimed at building on the robustness of current methods from the literature, which fundamentally seem promising but had to be evaluated in detail for the present scenario. The effects of small amounts of training data as well as transfer learning methods are being examined.

During the project we have acquired measurements using our multi-sensor setup at a substation managed by our project partner, the Austrian Power Grid AG. Our first fully automated measurement campaign using the robotic platform, with automatic upload and data processing in the cloud backend, is taking place in the summer of 2023. Overall, these data acquisition and processing will allow us to monitor a relatively modern transformer installed at a substation for less than 20 years. Until the end of the project, we will test our algorithms, analyze their processed results, and create a roadmap for the further digitalization of the lifecycle-monitoring of transformers through robotic systems.

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recAIcle
Recycling-oriented collaborative waste sorting by continual learning

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Funding Call:	FFG, AI for Green (2021), Grant #4352943
Project Title:	recAIcle: Recycling-oriented collaborative waste sorting by continual learning
Project Lead:	Dr. Michael Krisper Pro2Future GmbH
Duration:	36 Months, 01.09.2022 - 31.08.2025

Work Packages

WP 1: Project Management

WP 2: Requirements and Framework Design

WP 3: Sense, Detect and Observe

WP 4: Learn and Adapt

WP 5: Augment and Support

WP 6: recAIcle System Development & Integration

WP 7: Evaluation

WP 8: Dissemination

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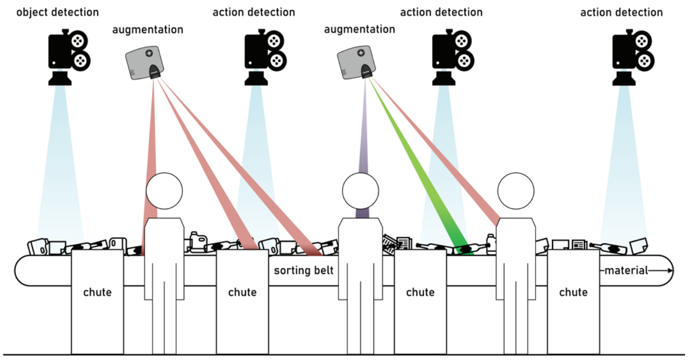
Waste contributes significantly to greenhouse gas emissions. As economic growth is the main driver for increased waste generation, a decrease in waste production while maintaining economic growth is a primary objective of the new European Circular Economy Action Plan. Recycling constitutes a key solution to this issue as it reduces the demand for primary, raw resources and mitigates the loss of value in waste management. Accordingly, the EU aims for high recycling rates and has a current target of 70% of packaging waste to be recycled by 2030 and 65% of municipal waste to be recycled by 2035.
Recycling requires materials to be pre-sorted. Despite the already utilized sophisticated sensors and machinery, manual sorting by human employees is still an integral part of waste sorting for recycling (1) to allow the quality assurance of material concentrates and (2) to achieve the high levels of purity required by recycling plants to produce high-quality recyclates. In this project, we aim to capitalize on human expertise by integrating human and machine intelligence into recAIcle: a human-guided approach to fine-tuning the sorting process, which additionally provides support to the human worker in the form of augmented guidance.

There is a clear benefit in interfacing and integrating sensor-based classification models with the worker's task in terms of improved machine learning classification and highlights the importance of the human worker in such applications. In combination with guidance and augmentation technology, increased robustness of the classification models will allow recAIcle to support workers by: (i) guiding them towards potential areas of interest, (ii) providing initial skill adaptation training and support for novice personnel, and (iii) reducing the monotony and strain involved in sorting tasks; leading to increased sorting efficiency and worker satisfaction. The developments planned within recAIcle are guided by at least two complementary use cases, both highly relevant in the context of current recycling efforts: plastic package sorting and battery sorting. With the methods developed within recAIcle we aim to increase the output of recyclable plastic waste by 25% without increasing the number of sorting workers. This will significantly help to increase the sustainability of waste management and further strengthen Austria as a leader in recycling and as a competitive and innovative technology provider in Europe regarding the sustainable development goals.

Goals
For all use case and application scenarios envisioned in the project, our focus is not on replacing the sorting worker's labor. While AI will radically alter how work gets done and who does it, the technology's



larger impact will be in complementing and augmenting human capabilities, not replacing them. To support these efforts the recAIcle project aims for the development of a novel continual learning approach, which enables the continuous improvement of automatic classification systems solely by observing a human worker completing the task. In return the system will be used to support an operator carrying out their task. The technologies will be applied to achieve efficient recycling (by significantly improving mixed municipal waste sorting rates) in a circular economy. By reciprocal improvement of human and AI, a robust automatic classification of mixed municipal waste can be achieved, while supporting workers during manual sorting efforts.

Our objective is to achieve a system with wide applicability. For this reason, we will focus on two or three different waste sorting use cases, for instance plastic, metal and batteries, to ensure that our methods are applicable to a broad scope of recycling material sorting problems.

Approach

From a purely technical perspective, a human sorting worker constitutes an expert sorting instance, comprised of sensors (i.e., vision), a classifier (i.e., expertise), and actuators (i.e., hands). By choosing an element to be removed from the material flow, the human worker indirectly annotates the element as one requiring classification by an automatic sensor-based sorting approach. The recAIcle project aims to use these and other indirect annotations as the core element for devising a novel, passively human-guided continual learning approach, which enables the continuous improvement of automatic classification systems by observing a human operator working in an application domain.

Expected and Achieved Results

There are several main challenges which will have to be addressed in the project. First, the recycling material flow varies across the year, depending on the presence of seasonal products as well as new products on the conveyor belt. And second, due to the monotony and strain involved in sorting tasks, the sorting workers will execute their task with a certain level of error rate, for instance picking from or leaving the wrong objects on the conveyor belt. To address these challenges, we will develop a continual or long-life learning framework, which is able to leverage data from the past, while focusing on the composition of the material flow in recent time, as well as from multiple plants.

Similarly, we will have to address challenges arising from the interactions between our system and the sorting workers. We are considering the usage of different sensing technologies for performing action recognition. Furthermore, our system is intended to support the workers without overwhelming them with information. For instance, an interesting use case is the detection and highlighting of dangerous waste particles such as batteries, for their removal from the material flow. Finally, we plan to test and compare the efficiency of the worker with and without the support of our system.

As the methods will be developed in the context of a specific automation scenario, they must be self-contained and resource efficient in order to be successfully deployed on standardized industrial hardware. Resource efficiency will be addressed from the design phase onwards, particularly in the system implementation.

In order to attain the development of methods applicable to multiple use cases, during the project we will implement and test our system in collaboration with at least 2 end users working with different material flows, for instance plastic and batteries.

Status / Progress

Our interactions with the recycling industry and several internal workshops have allowed us to perform a requirements analysis, achieve a design for our first prototype system and define use case and verification scenarios for our prototype system. We have designed a sensors and systems architecture allowing to learn from the sorting workers, see letft figure, without directly recording them. To this end it features cameras before and after each sorting worker, as well as other sensors installed either in a sorting cabin or at the conveyor belt. Assistance is provided by projectors that can interact with the workers by pointing at certain objects on the conveyor belt. The combination of sensors and cameras will allow the system to learn waste sorting by understanding which objects are to be picked up and where they are to be dropped off.

The first implementation of an object detection framework and a continual learning framework for the classification of trash have been developed, which will allow our system to adapt to changes in the material flow, e.g., seasonal changes or special holidays. One approach to allow the system to learn from workers is to track their hands and the actions they perform (right fgure). Currently this is also realized using object detection. Their integration into a single system and further testing are pending. Our ongoing algorithm development has been based on publicly available datasets. Meanwhile the deployment of our prototype system and a data acquisition campaign using recycling plastic material are ongoing at the Digital Waste Research Laboratory (DWRL) of our partner Montanuniversität Leoben.

Our consortium has presented our design concept at the Austrian Waste Management Conference 2023 (ÖWAV-Tagung 2023) and at the 19th International Symposium on Waste Management and Sustainable Landfilling (SARDINIA 2023). In order to attain the development of methods applicable to multiple use cases, we have contacted multiple potential end users. We have started a collaboration with Mayer Recycling, who is focused on metal sorting. We are in ongoing contact with companies focused on plastic recycling and sorting, but who could not start a collaboration this year. For plastic sorting we will start working at the DWRL. We plan to renew our contacts with plastic sorters, once our developed methods are more mature.

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TWIN
Digitale Zwillinge für zukunftsfähige Gebäude

nonCOMET

Funding Call:	FFG, Energie der Zukunft (2020), Grant #4122000
Project Title:	TWIN - Digitale Zwillinge für zukunftsfähige Gebäude
Project Lead:	Univ.-Prof. Dr. Michael Monsberger Graz University of Technology
Duration:	15 Months, 01.03.2022 - 31.05.2023

Work Packages

WP 1: Projektmanagement

WP 2: Systematisierung von Anwendungsszenarien digitaler Gebäudezwillinge

WP 3: Anforderungen zukünftiger Anwendungsszenarien digitaler Gebäudezwillinge

WP 4: Roadmap und Maßnahmen für die Realisierung digitaler Gebäudezwillinge

WP 5: Stakeholderprozess und Dissemination

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Digital twins are virtual replicas of physical objects or processes that are synchronized with the real thing and kept up-to-date to reflect reality. In the TWIN project we investigated the state and integration of digital twins for the construction and building industry. It is commonly assumed that digital twins have huge potential within the building lifecycle, notably contributing towards the "European Green Deal" objectives, since the building sector has a huge impact there.
Similar to the automotive industry or other huge production industries, the building sector has an enormous inherent complexity by incorporating many stakeholders, like suppliers, builders, maintainers, facility management, technicians, operators, and users over very long timeframes spanning several decades and even hundreds of years for some historical buildings. There are already many standards and models for specific phases, tasks and use-cases during construction, operation, maintenance, and usage. However, they are often disconnected, not updated, or not used holistically amongst different parties throughout a buildings' lifecycle. Hence, the application of digital twins in construction and real estate remains limited in practice. However, within research and demo projects, they showed promising results in the areas of energy management, site logistics optimization, model-based services, reduction of errors and simplification of collaboration amongst stakeholders. Still, practical challenges to their application include technology hurdles, stringent regulatory requirements and liability, trust and data protection issues within the construction and real estate sector. Also, the resource-intensive nature of initially creating and maintaining digital twins over time is a hindrance to their application.
The TWIN project serves as a precursor to a comprehensive lighthouse project, aiming to showcase the value of digital building twins. This intends to catalyze the application of digital twins in future building endeavors. This subsequent lighthouse project will address the holistic applications of digital twins throughout the building's lifespan, considering ecological impacts, stakeholder economic interests, and industry-specific regulatory challenges in Austria.

Goals

The main goal of the TWIN project is to prepare a roadmap for a comprehensive lighthouse project and research programme, aiming to demonstrate and apply digital building twins in real-world settings. It should stimulate the application of digital twins in future building ventures to help fulfill long-term sustainability goals. We strived for a holistic approach, spanning a building's entire life cycle, while accounting for ecological impacts, stakeholder economic interests, and

Erforderliche Kompetenzen je Projektphase je Usecasekette Projektabschnitte	Vorbereitung	Vorentwurf	Entwurf	Einreichplanung	Ausführungsplanung	Ausschreibung	Vergabe	W/Montage planung	Ausführung (BAU)	Übernahme (Betreiber)	Betrieb (FM)	Umbau	Rückbau	Wiederverwendung	Entsorgung/Recycling
asBuiltToWork															
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Planende	+	+	++	+	++	++	+		++		+	++	o		
Aufsicht								+	++	++					
Ausführende							+	++	++						
bbim															
AG/Nutzer									+	++	++				
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Ausführende								++	++	++	o	++	+	++	+
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Planende	++	+	+	+	+	+	+	+	+	+		+		+	
Aufsicht									+	+		+		+	
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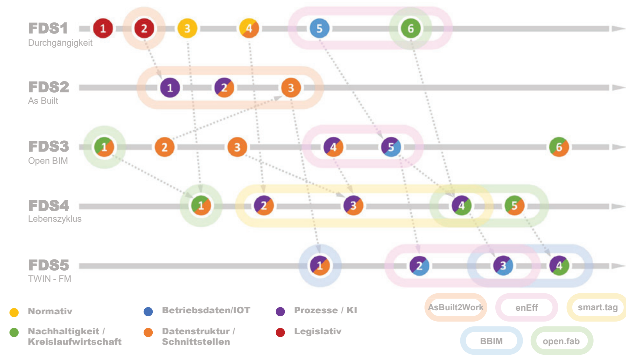

industry-specific regulatory challenges in Austria. Another integral part of TWIN's agenda was to pinpoint current technological gaps, and consequently extract the R&D needs for the following project. This includes proprietary software and standards as well as open standards and technologies. For the general recommendations, however, the focus in the project was on using open standards like IFC wherever possible, to avoid vendor-specific dependencies on single companies. The standards, methods and technologies should be future-proof and freely available to maximize the availability, impact and usability thereof.

Approach

To achieve the goal of retrieving a realistic landscape of the state-of-the-art in building industry and to give recommendations how to tackle them, we did several rounds of reconciliation and interviews with industry stakeholders. Initially, we performed a thorough assessment of potential digital twin applications, emphasizing their strengths and opportunities. This analysis already involved close collaboration with industry from different areas in the building domain, e.g., construction, manufacturing, operation, asset management, and digital facility management. Afterwards we combined, clustered, and selected five use-case-chains for deeper exploration in the subsequent interviews. Based on these interviews we did a gap and SWOT analysis which gave us insight on the problems, needs, fears as well as the potential benefits, gains and wishes from building industry regarding the wholistic application of digital twins and to give recommendations for a roadmap in the subsequent lighthouse project.

Expected and Achieved Results

The most important outcomes of the project are twofold:

1. A general roadmap as guidance for further development in future research projects and governmental direction.
2. Recommendations about specific aspects, technologies and required legal enhancements.

Furthermore, intermediate deliverables were created during the project, e.g., a collection of use-cases, stakeholder analysis, requirements analysis, dependencies, and a skill-and-responsibility-matrix amongst stakeholders in different phases of buildings, a gap- and SWOT-analysis, interview documentations and reports on state-of-the-art and technologies. The broad stakeholder interest in TWIN was evident by collecting 14 Letters of Interests from industry companies.

TWIN's outcomes, such as identified use cases, their ecological and economic evaluations, and spotted R&D gaps, were consolidated into a roadmap, laying the foundation for the lighthouse project. Here is the list of identified use-case-chains together with a short description of their purpose:

- **enEff**: Using digital twin to optimize energy-efficiency in heating, ventilation and air-conditioning for buildings.
- **asBuilt2Work**: Keeping digital twins, models and plans up-to-date to the current state of the building (“as it was built”).
- **smart.tag**: Identifying and tracing parts of buildings (maybe also including their usage history) and reuse them deconstruction or replacement.
- **Open.Fab**: Streamline the fabrication of building parts (batch construction, templates, modularization) and foster fabrication on-site.
- **BBIM**: Enable data continuity, reuse, and synchronization of digital twin models amongst all building phases and stakeholders.

The left figure shows a simplified responsibility matrix that was created throughout the project. The table depicts which stakeholder-group (consisting of users, planers, supervisors, and builders) are involved in which building phase, and how high their required skills and competencies should be.

Status / Progress

The project started in March 2022 and finished in May 2023. Pro²Future was working together with Graz University of Technology, Siemens AG, building Smart Austria and AIT. While we were participating in all actions, our focus was on the technological aspects rather than on the process or legal aspects. With monthly meetings we established a healthy communication and project synchronization style. Furthermore, we participated in several on-site workshops to collaborate and discuss with the other partners.

The right figure shows an excerpt from the recommended roadmap for future projects and research program. It shows the found use-case-chains and interrelations as well as the core issues and themes that must be addressed in these future projects.

Within this project, a transition of employees between partner companies took place: Konrad Diwold changed from Pro²Future to Siemens AG, and still continued to participate in the project (only from the other side from that time on). This transition fostered the collaboration between companies within the project even more and showed the positive impact of expert exchange and trust amongst the partner companies within the consortium.

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nonCOMET

AI-Flight
AI-Enabled autonomous flight of indoor drones

nonCOMET

Funding Call:	FFG, TAKE OFF (2020), Grant #4119098
Project Title:	AI-Flight: AI-Enabled autonomous flight of indoor drones
Project Lead:	Dr. Konrad Diwold, Dr. Michael Krisper Pro2Future GmbH
Duration:	14 Months, 01.09.2021 - 31.10.2022

Work Packages

WP 1: Project Management

WP 2: Requirements and evaluation AI-enabled situation aware drone operation

WP 3: AI-based situational awareness

WP 4: Autonomous drone flight monitoring and safety

WP 5: Dissemination

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In the last decade, drones are showing a great potential as data acquisition platforms, which can support industrial systems in achieving further automatization, for instance in tasks such as mapping/surveying and inventory taking. However, especially in indoor operations, the implementation of drone-based solutions must be supervised by safety pilots within visual line of sight, and often the pilot must manually fly the drone during the task. This necessity stems from the fact that such an operation requires the detection of safety hazards and bringing the drone to a safe halt during such situations.

Goals
AI-Flight aims towards achieving the autonomous operation of drone systems for indoor industrial applications, as well as towards the intermediate step of beyond-visual-line-of-sight operation. Many commercially available off-the-shelf (COTS) drones readily provide interfaces for the deployment of machine learning models to analyze the drone's video stream and acquired imagery and for the customization of the drone's operation. AI-Flight will assess the applicability of image processing artificial intelligence (AI) in the context of autonomous drone operation to achieve a dependable operation of COTS drones beyond visual line of sight in industrial indoor environments. This approach enables service providers to choose the COTS drone best suited for the application and to reduce their dependency on specific drone manufacturers.

Therefore AI-Flight will explore and test the provisioning of AI models to achieve situational awareness for COTS drones, which allows a drone during operation to detect, track and react to third parties (vehicles and people) and to obstacles inside and around the working area, and guide the compilation of further methodological steps and research directions required to achieve such a system..

Approach
In AI Flight, rather than building a fail-safe drone, we have investigated, tested and implemented safety extensions by means of external monitoring that enable a safer operation of COTS drones towards the achievement of a fail-safe operation inside industrial warehouse environments. AI-Flight will concretize the goals (situation awareness and external monitoring) into metrics and perform first necessary quantitative evaluations within a real logistics environment, focusing on warehouses arranged in corridors.

In addition, the project AI-Flight has had a focus on achieving automated drone-based inventory management, therefore, AI methods

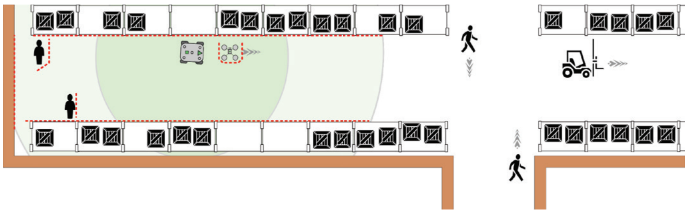

Figure 1: Situational awareness through external monitoring of the COTS drone by means of the MMS (or AGV).

to add new capabilities to COTS drones related to this industrial application have been explored. Keeping stock of warehouse inventory requires the employed drone to be able to count. Due to its camera, it has the necessary perceptive capabilities but still lacks the intelligence to count. We intend to equip the drone with counting capabilities via a trained convolutional neural network which generates density maps of desired objects. These can then be used to estimate the number of objects present during inventory taking.

approaches for fisheye multi-camera sensors (Figure 2, right), the automatic image/point-cloud segmentation of ground versus storage racks (Figure 3, center) and the omni-directional detection of certain objects – that is, either air-borne obstacles (e.g., drones), ground-based vehicles (e.g., fork-lifts) and human co-workers. Regarding the automatic in-place configuration of the system and in view of our external monitoring concept, we have investigated AI methods ensuring a good accuracy of the anchoring transformation of the MMS with respect to the surrounding hallway.

Our initial prototype for the automatic object counting AI method already achieved competitive results. Transfer learning was done with a small dataset of >100 samples. On the unseen validation samples the counting error was 25%. Our counting method has potential for improvement and further research. This will be explored over the course of follow-up projects.

The project partners organized a workshop at Roto Frank GmbH (Karlsdorf) in February 2022 for stakeholders interested in the topic of "safe indoor drone operations". The workshop attracted, among others, several safety certifications experts, potential end users, as well as 2 ma-

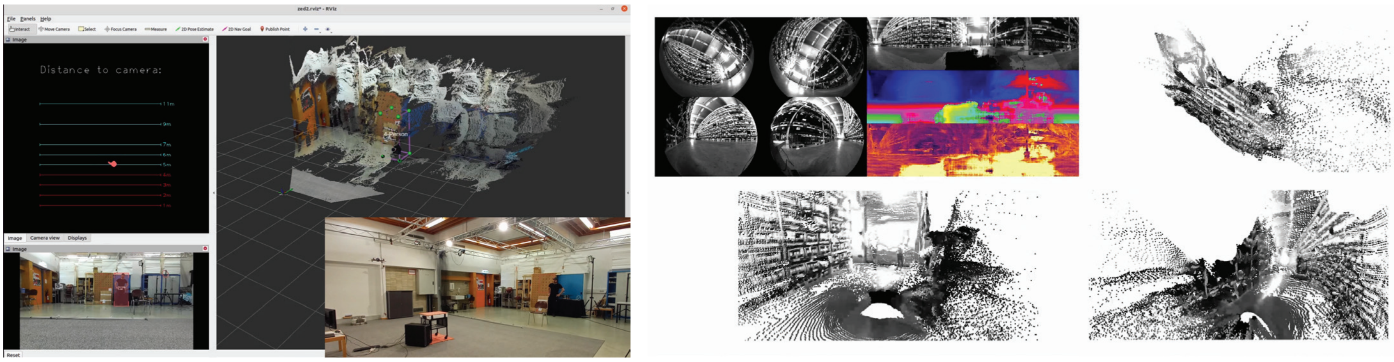

Figure 2 (Left): Initial prototype of our envisioned system, the MMS tracks the position of a person while the drone performs its task. The drone enters the safe state if the person approaches the system too much. Figure 2 (Right): Omni-directional depth estimation by means of fisheye multi-camera sensors and an appropriate AI method on an image dataset acquired at the warehouse using our own prototype hardware.

Achieved Results

As shown in Figure 1, our investigations have led us to the design of a Mobile Monitoring Station (MMS) to achieve the external monitoring of the drone. The MMS is an Autonomous Ground Vehicle (AGV), which monitors the COTS drone repetitively from the same point of view. Additional equipment – computing resources, AI methods and sensor systems – are installed on the MMS to monitor the immediate surroundings of the drone and its operational area. In our system: (1) the COTS drone can achieve stable flight inside the warehouse, but has only limited capacity to avoid collisions with obstacles; therefore (2) the MMS monitors at all times the flight of the COTS drone and its surroundings and provides commands to the drone to perform the task safely and in an optimal manner. The usage of a repetitive point of view of the drone from the MMS, allows a very reliable and repetitive drone tracking behavior by the MMS, allowing the deployment of such a system in different buildings, applications, and scenarios.

Figure 1 shows the MMS equipped with omni-directional situational awareness, which covers the area shown by the green circles surrounding the MMS. With this awareness it can detect people (co-workers), objects (fork-lifts and other drones) and obstacles (e. g., storage racks, walls, boxes, trolleys, …) precisely for safe operation. Fisheye cameras are an example cost-effective hardware to achieve omni-directional perception. Over the course of this project an initial prototype of this fail-safety system was achieved, details can be seen in Figure 2 (left).

The main topics that have been addressed regarding our envisioned drone system are omni-directional situational awareness – the automatic monitoring of the drone system and its surroundings –, the automatic in-place configuration of the drone system in the warehouse and the cost-effective adaptability of such a system to different application scenarios. Regarding the omni-directional situational awareness, we have tested and evaluated AI-based omni-directional depth estimation

nufacturers of automated AGVs for warehouse solutions. The content of the workshop influenced our planning and realization of other tasks and work packages, as well as the writing of our roadmap "towards an AI-enabled drone operation".

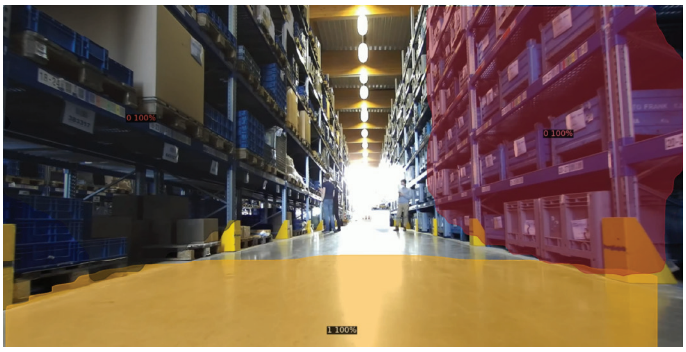

Figure 3: Developed Deep Learning method to classify ground points versus storage racks

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6

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7

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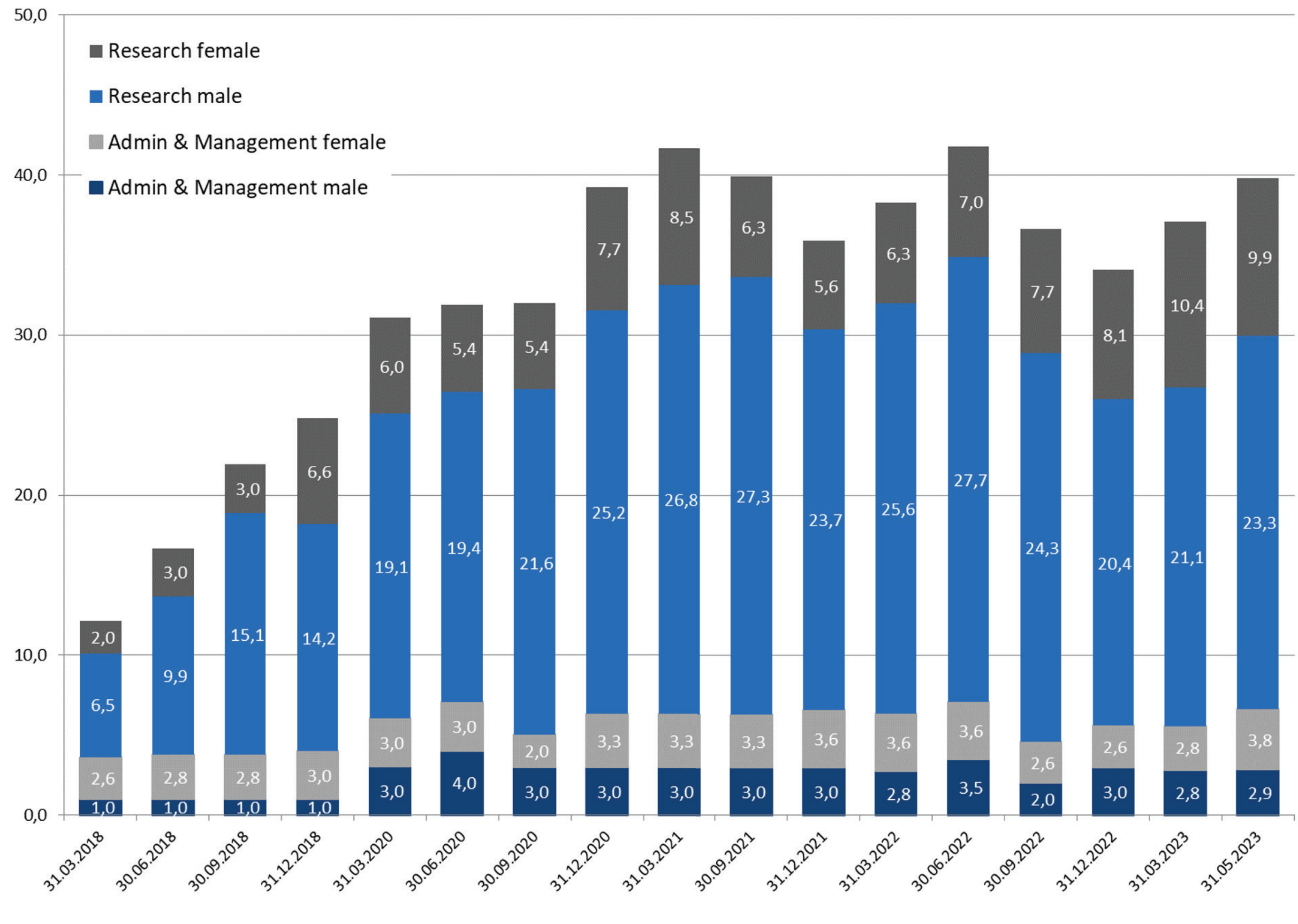
Human Resources Development 2018-2023



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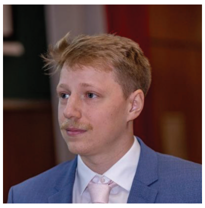

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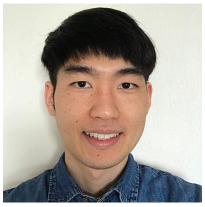

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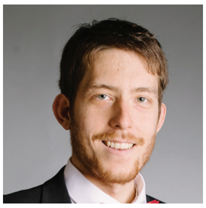

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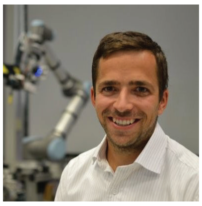

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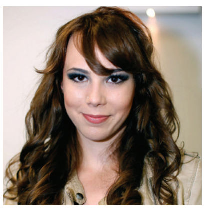

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HUMAN RESOURCES

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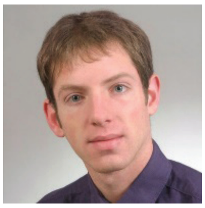

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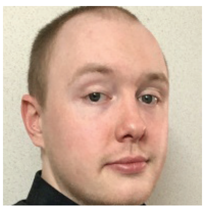

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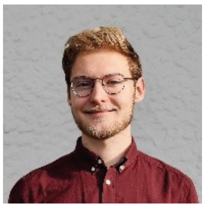

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8

PUBLICATIONS & TARGET VALUES

	2017	2018	2019	2020	2021	2022
Scientific Journals	3	9	8	7	25	38
Peer Reviewed Conference Paper	10	24	40	24	27	22
Books & Bookchapters		3	1	2	1	5
Other Publications & Special Talks	7	13	9	4	7	10
Technical Reports, Patents & Posters		2	6	2	7	2
Awards & Honors			5	3	4	4
Finished PhD	1	1	4		2	5
Finished Master/Diploma	2	4	7	3	5	
Finished Bachelor		2	3	1	7	5
Finished Habilitations		1		3		

Quantitative Indicators/Target values	Actual values				PLAN
	year 1	year 1-2	year 1-3	year 1-4	FP1
Indicators related to science					
Total number of publications in relevant journals	30	59	108	141	**110**
• thereof number of contributions in scientific papers with peer review	5	10	16	24	**30**
• thereof number of contributions at conferences with peer-review	28	69	84	106	**80**
• thereof number of co-publications between science and industry	3	13	24	36	**60**
Share of strategic research projects in entire research programme	22,68%	20,50%	28,32%	25,59%	**28,46%**
Share of 100% strategic projects	17,37%	10,26%	17,54%	16,01%	**17,71%**
Number of planned additional scientific partners (at organisation level)	1	3	4	7	**2**
Indicators related to industry					
Number of patents	0	0	1	2	**3**
Number of licences	0	0	1	1	**4**
Number of other IPR i.e. trademark rights, registered company name, ...	0	0	1	1	**0**
Number of prototypes	4	8	10	37	**25**
Number of spin-offs initiated by the research programme	0	0	0	0	**0**
Number of planned additional company partners	3	4	7	16	**4**
Human resources					
Total number of FTE at the centre in its full configuration	12,14	28,83	30,70	41,60	**45**
• thereof share of administrative staff (FTE)	29,85%	13,87%	19,54%	17,57%	**9,00%**
Total number of scientists at the centre (FTE)	8,52	24,31	24,18	33,77	**40**
• thereof share of female scientists (FTE)	23,48%	23,12%	23,24%	25,17%	**25,00%**
Number of PhD thesis in total	8	18	30	33	**27**
• thereof by centre staff	3	12	23	24	**15**
• thereof by staff of company partners	0	0	0	0	**2**
• thereof by staff of scientific partners	5	6	7	9	**10**
Number of master thesis (Diplom-/Masterarbeiten) in total	4	12	17	23	**28**
• thereof by centre staff	1	5	5	9	**4**
• thereof by staff of company partners	0	0	1	1	**8**
• thereof by staff of scientific partners	3	7	11	13	**16**
Number of bachelor thesis	0	4	8	11	**28**
Number of habilitations	1	1	1	4	**1**
Number of research stays at the centre (incoming)	0	2	2	2	**12**
Number of outgoing research stays	0	0	0	0	**12**
Number of internships	0	3	3	4	**10**
Number of lectures hold by Centre staff	6	6	8	34	**10**
Number of endowed professorships related to the centre	1	2	2	2	**3**
International Integration					
Number of partications of the centre in international projects	0	0	0	0	**4**
• as a coordinator	0	0	0	0	**1**
• as a partner	0	0	0	0	**3**
Number of international partners	10	12	13	13	**12**
• thereof international scientific partners (at organisation level)	6	7	7	7	**8**
• thereof international company partners	4	5	6	6	**4**
Number of international associated partners	7	7	7	7	**25**
Number of nominations in relevant international boards and commitees	36	45	45	45	**10**
Non Comet Area (Non-K)					
additional funded projects beside COMET	0 €	0 €	154 k€	258 k€	**4 700 k€**
• from assignment by companies	0 €	0 €	154 k€	243 k€	**1 200 k€**
• from national sources (e.g. FWF, FFG, regional funds…)	0 €	0 €	0 €	15 k€	**1 500 k€**
• from international sources (e.g. EU-programme/Horizon2020, ...)	0 €	0 €	0 €	0 €	**2 000 k€**
Centre specific indicators					
Number of Pro²Future-labeled innovations implemented @ industry	0	0	0	2	**5**
Number of externships @ industry	2	5	5	5	**15**
Number of pre-study programs for cognitive girls & boys	0	0	0	0	**8**
Number of international visiting delegations	0	1	1	1	**3**

Quantitative Indicators/Target values	Actual values				PLAN
	year 1	year 1-2	year 1-3	year 1-4	FP2
Indicators related to science					
Total number of publications in relevant journals	53	111			**140**
• thereof number of contributions in scientific papers with peer review	28	55			**40**
• thereof number of contributions at conferences with peer-review	22	44			**100**
• thereof number of co-publications between science and industry	8	23			**30**
Share of strategic research projects in entire research programme	29,42%	29,42%			**31,15%**
Share of 100% strategic projects	17,97%	17,97%			**19,97%**
Number of planned additional scientific partners (at organisation level)	0	1			**2**
Indicators related to industry					
Number of patents	2	6			**5**
Number of licences	0	2			**5**
Number of other IPR i.e. trademark rights, registered company name, ...	1	1			**0**
Number of prototypes	29	34			**25**
Number of initiated products, processes and services	0	4			**8**
Number of spin-offs initiated by the research programme	0	0			**0**
Number of planned additional company partners	1	0			**5**
Human resources					
Total number of FTE at the centre in its full configuration	37,79	38,68			**35**
• thereof share of administrative staff (FTE)	16,26%	14,50%			**21,50%**
Total number of scientists at the centre (FTE)	30,86	31,07			**27**
• thereof share of female scientists (FTE)	17,17%	33,44%			**30,00%**
Number of PhD thesis in total	31	32			**30**
• thereof by centre staff	19	20			**18**
• thereof by staff of company partners	0	0			**2**
• thereof by staff of scientific partners	12	12			**10**
Number of master thesis (Diplom-/Masterarbeiten) in total	12	17			**35**
• thereof by centre staff	4	5			**15**
• thereof by staff of company partners	1	1			**5**
• thereof by staff of scientific partners	7	11			**15**
Number of bachelor thesis	19	21			**10**
Number of habilitations	0	1			**1**
Number of research stays at the centre (incoming)	3	6			**15**
Number of outgoing research stays	2	4			**15**
Number of internships	10	23			**15**
Number of lectures hold by Centre staff	38	73			**20**
Number of endowed professorships related to the centre	0	0			**0**
International Integration					
Number of partications of the centre in international projects	1	2			**2**
• as a coordinator	1	2			**0**
• as a partner	0	0			**2**
Number of international partners	14	13			**15**
• thereof international scientific partners (at organisation level)	7	5			**6**
• thereof international company partners	7	8			**9**
Number of international associated partners	7	7			**4**
Number of nominations in relevant international boards and commitees	25	25			**50**
Non Comet Area (Non-K)					
additional funded projects beside COMET	292 k€	1 128 k€			**4 200 k€**
• from assignment by companies	100 k€	272 k€			**1 200 k€**
• from national sources (e.g. FWF, FFG, regional funds…)	192 k€	855 k€			**1 000 k€**
• from international sources (e.g. EU-programme/Horizon2020, ...)	0 €	0 k€			**2 000 k€**
Centre specific indicators					
Number of Pro²Future-labeled innovations implemented @ industry	6	10			**10**
Number of externships @ industry	3	9			**20**
Number of pre-study programs for cognitive girls & boys	1	3			**10**
Number of international visiting delegations	2	3			**8**
Number of A-ranked publications (in peer reviewed journals or conf.)	30	58			**70**
Number of scientific conferences organized by the Centre	0	1			**1**

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Finished PhD Theses

Shao, Lin: Interactive Visual Analysis and Guidance Methods for Discovering Patterns in High-Dimensional Data

Rathner, Raffael: The Influence of Shear and Elongation Forces in Extrusion Processes

Finished Master Theses

Laube, Markus: Skill Level Detection of Welder on IMU Data

Fleischhacker, Philipp: Validation of Feature Models using Semantic Web Technologies

Salomon, Elisabeth: WiFi-based Distance Estimation using the Channel State Information

Bichler, Stefan: Passive Engineering Process Management Framework

Leder, Dominik: Concept Development and Evaluation of Semi-Automated Riveting Processes

Finished Bachelor Theses

Paar, Mathias: Drehmomentmessung schnelldrehender Systems

Krizic, Mario: C2Akka: Leveraging Actors in Component Based Architectures

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Greben, Matthias: Signalmonitoring Concept for IO Module Development

Pereszteghy, Benno: Integration von Funktionstracing in OPC-UA

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Haslgrübler-Huemer, Michael: Skill Recognition in Industrial Production

Prechtl, Maximilian: Axial Torque Measurement in Single-Screw Extrusion

Hammer, Alexander: A Hybrid Framework to Investigate Selected Interfacial Phenomena in Plastics Co-Extrusion

Stritzinger, Ursula: Modeling Conveying and Power-Consumption Behavior of Fully Intermeshing Co-Roating Twin-Screw Extruders

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Manfredi, Samuel: Development of an adaptive machine-assisted assembly station

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9

SUCCESS STORIES & SCIENTIFIC POSTERS

COMET Success Stories

2018, Area 4.2: Industry 4.0 at Production Plants

2019, Area 1: Development of cognitive products

2020, Area 2: Privacy-respecting monitoring of manual assembly lines

2020, Area 4.2: Cognitive Elements as enablers for flexible and adaptive production systems

2020, Area 4.1: Creating Awareness in automation system

2020, Area 3: Scalable condition monitoring systems for test environments

2020, CRP DP1 (with ACDP): AI <> HI

2020, CRP DP2 (with ACDP): Adaptive Loading Station

2021, Area 4.2: Improved Energy Efficiency in Extrusion

2021, Area 3: Sinter Production Improvement

2022, Area 2: Process-Support

2022, Area 4.2: Modelling and Control in Extrusion

Success Story
COMET

Pro²Future

Pro²Future
Products and Production Systems of the Future
Programme: COMET – Competence Centers for Excellent Technologies
Programme line: K1-Centres
COMET subproject, duration and type of project: CoExCo, 04/2017-03/2021, multi-firm

Industry 4.0 at production plants – first results of CoExCo

On the way to self-optimizing polymer processing plants networking is a prerequisite. In further steps, a refined series of experiments can be developed from process data recorded in a database. Via analysis of correlation coefficients in the form of a correlation matrix one arrives at more sensitive data. Furthermore by means of big data analyzes and machine learning algorithms an improved model for control concepts can be deduced. Results from the first year of the project are presented here in more detail.

From Networking...

Based on the guiding principle of the K1-Center Pro²Future - The Future of Products and Production is Cognitive! - area 4.2 is committed to the development of cognitive production systems. The multifirm project 4.2.1 Cognitive Polymer Extrusion and Compounding (CoExCo) is being researched together with our company partners to implement Industry 4.0 in continuous polymer processing systems and processes.

Fig 1: Pipe production plant at company Poloplast (Copyright Poloplast)

On the way to the big goal of the self-optimizing system like a pipe production plant of company Poloplast (**Fig 1)** also new plant models will be developed.
Accordingly, plants were networked and, if necessary, additional sensors were installed in order to be able to monitor and archive the entire value creation process with regard to product quality, process conditions and machine settings.

... to database ...

Data is taken directly from existing OPC interfaces (usually OPC UA, OPC DA) from the plant PLC (plant control). The communication from the system to the SQL database is organized via an OPC UA server-client system of the Softing Data FEED OPC Suite (schematic representation in Fig 2). By means of a VPN tunnel, a stable and secure data transmission can be realized. A potential loss of data due to a network failure to company partners is countered by means of a local cache (store and forward). Currently, a sampling rate of about 200ms is achieved, which seems sufficient for a continuous process modeling and production monitoring.

Particular attention must be paid to the configuration of the data transfer, the data bank and the

Bundesministerium für Digitalisierung und Wirtschaftsstandort

bmvit Bundesministerium für Verkehr, Innovation und Technologie synchronization of the system times, as later data cleansing can only take place with extremely great effort, if at all.

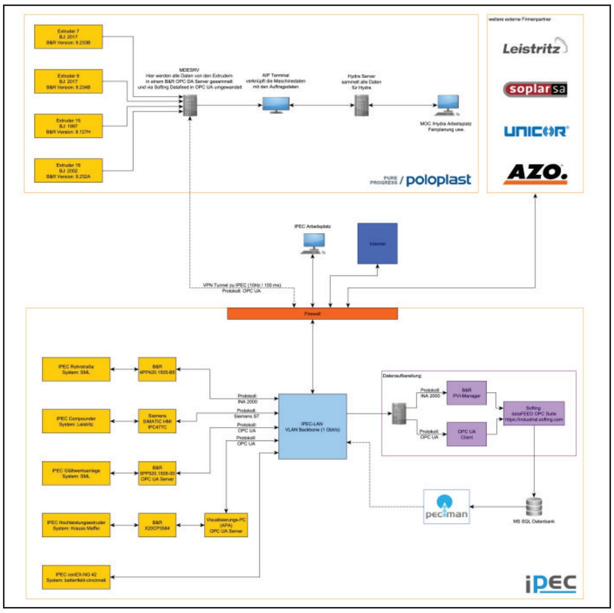

Fig 2: Schematic system networking of internal and external systems up to the database (Copyright JKU-IPEC)

... and first evaluation

Data from the database can be selected, transformed and thus prepared for initial preliminary analyzes. For pre-analyzes, correlation and determination coefficients of the system parameters are used. These should provide information about errors in the data set and options for parameter reduction.

As an example, a correlation matrix is shown here (**Fig 3**) with more than 200 system parameters. This was generated from more than 135 million data points.

Subsequently, machine learning algorithms can be trained on the reduced data sets and used to find the most important input parameters with regard to defined target parameters, but above all to quantify their impact values. Based on that, heuristic methods can be used to develop data-based models.

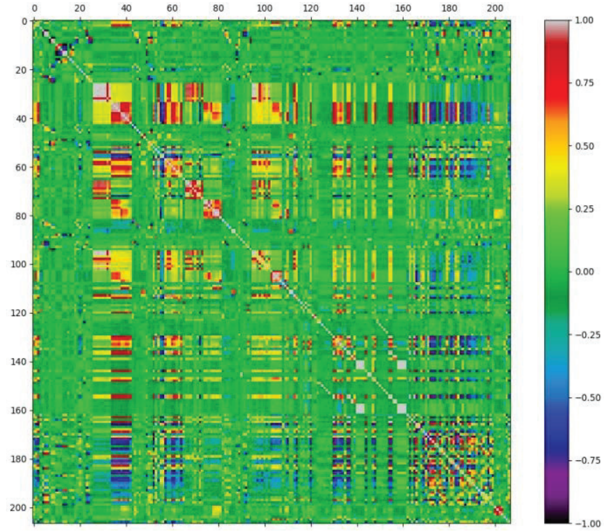

Fig 3: Correlation matrix of over 200 signals of a production plant (Copyright JKU-IPEC)

Impacts and effects

Among other things, competitive advantages and increased added value through optimized processing systems and processes are expected. This enables, for example, faster ramp-up of plants after a product change by means of improved control concepts, as well as positive effects on the environment through lower energy use.

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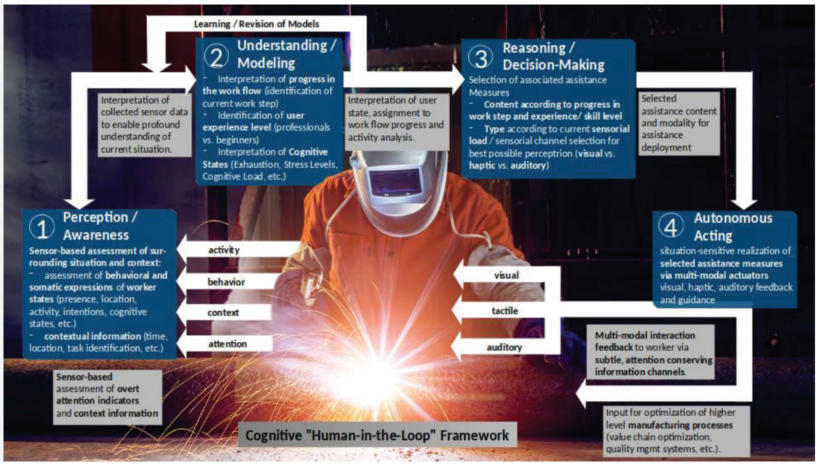
Poloplast GmbH & Co KG	Austria
Leistritz Extrusionstechnik GmbH	Germany
Unicor	Germany
Soplar	Swizerland
AZO	Germany

Pro²Future
Products and Production Systems of the Future

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: DP1, 4 Y, multi-firm



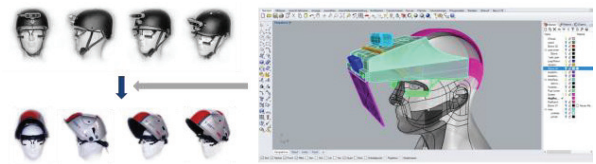
DEVELOPMENT OF COGNITIVE PRODUCTS

COGNITIVE PRODUCTS ENABLE THEIR USER TO BE WELL SUPPORTED IN EVER-CHANGING DIGITALIZED PRODUCTION ENVIRONMENTS

While digitalization enables production systems to be more flexible, the added complexity may be stressful to workers. With the establishment of assisting artificial intelligence-powered cognitive products, help is on its way. They can perceive the real world through sensors (perception and awareness), reason about what they have seen so far and what is seen now (reasoning, learning) and decide on their own according to pre-trained models if they need to act (prediction, decision making) through means of actuators (autonomous acting).

Built upon features we already see in today's products, such as online, real-time, self-* capabilities, cognitive products facilitate true collaboration between the analogous and digital domain.

Scientific and industrial partners established this vision, in welding through means of communication between welding torch, unit and shield. In this case different functionality is embedded in these devices and the head gear functions as a conductor and integrates the cognitive abilities of this cognitive product. In a first step, cognitive product design is essential for distributing and embedding sensors and actuators in respective industrial product. It provides the ability to quickly develop different generations of prototypes and analyse those for their applicability in the field with actual workers.



Computer aided cognitive product design enables fast progression through multiple prototype generations.

After the design process, the embedding of sensors, computing platform, actuators into an actual physical

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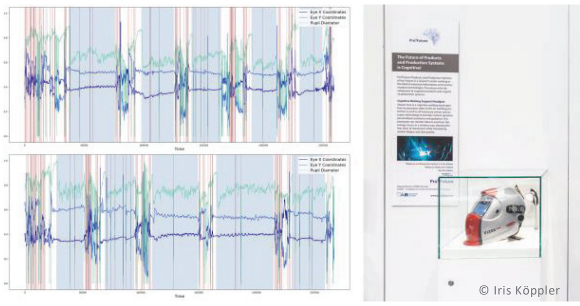
product, and deployment not in the laboratory but in the field, a rigours analysis of sensor data is required.

Features of sensors are investigated and analysed for solving a particular problem addressed by a cognitive product.

Afterwards, but based on the analysis, machine learning and artificial intelligence mechanism can be set up to solve various specific industrial problems, in this case we realised the following: (i) Online digitalization of industrial environments based on body-worn off-the-shelf RGB and RGB-D cameras, which can be then be used to support navigation in complex shop floors; (ii) Through gaze-based skill level detection, using eye tracking cameras, the proper amount of feedback can be given to a user. This helps novices to immediately be productive without excessive learning processes and avoids that experts are annoyed by overhelpful technology; With (iii) workflow recognition algorithms users do not get confused with lot-size-1 production. If mistakes occur, workers are able to correct it immediately with the help of the cognitive product on their own.

Impact and effects

Based on principles developed in this project, company partners, addressed not only welding support but also other areas of work affected by future problems of digitalization, such as: (i) assembly assistance, (ii) expertise transfer between workers, (iii) complexity management, (iv) early detection and avoidance of fatigue, (v) in-process quality control, (vi) detection and avoidance of safety and ergonomic hazards (vii) stress reduction through production changes or (viii) production optimization through identification of bottlenecks.



With the prototype developed (right) a company partner was able to analyse (left) how humans behave during welding tasks (blue phases) and establish a cognitive product in the form of a head gear to better support workers in this high voltage task.

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- TRUMPF Maschinen Austria GmbH + Co. KG, Austria
- KEBA AG, Austria
- Wacker Neuson Linz GmbH, Austria

This success story was provided by the consortium leader/centre management and by the mentioned project partners for the purpose of being published on the FFG website. Further information on COMET: www.ffg.at/comet

SUCCESS STORY

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Pro2Future
Products and Production Systems of the Future

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: COMET-Centre K1

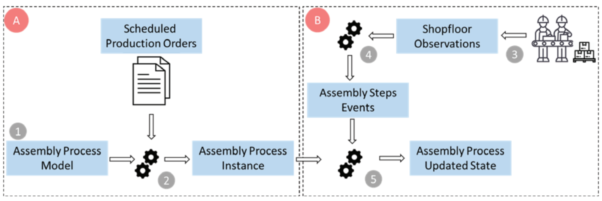
Type of project: A2PS,
2 Years, multi-firm

PRIVACY-RESPECTING MONITORING OF MANUAL ASSEMBLY LINES

SUPPORTING THE DETECTION OF DEVIATIONS, OPTIMIZATION POTENTIAL, AND JUST IN TIME REPLANNING WITHOUT EXPOSING WORKERS

As manufacturing companies move towards producing highly customizable products in small lot sizes, assembly workers remain an integral part of production systems. However, with workers in the loop, it is necessary to monitor the production process for timely detection of deviations and timely provisioning of worker assistance.

Direct monitoring of human activities raises legal and ethical issues. Legal regulations and union policies often limit the use of sensors such as cameras for direct observations of human activities. Therefore, assembly progress tracking needs a different approach relying only on indirect observations such as part picking or tool usage. Monitoring human assembly work, however, is highly challenging. To overcome minor disturbances in production, workers tend to rely on their tacit knowledge to apply various optimization techniques (team collaboration on complex tasks, tasks reordering, preparing steps for upcoming orders ahead of time etc.). These subtle optimizations make monitoring more difficult, as even with perfect observations available, these would not match the expected process.



Monitoring of Assembly processes require detailed model of each assembly process instance combined with partial observations from the shop floor.

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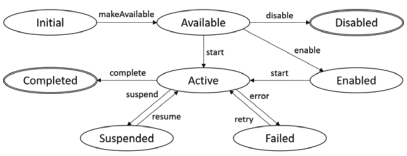
The research approach conducted jointly by the research and industry partners builds on a combination of multiple models: an assembly process model describing the optimal order of assembly steps; a constraint model describing which step dependencies cannot be physically violated; and a runtime model describing which steps could be worked on, should be worked on, are worked on, and are completed.



Assembly step progress model

Relying only on partial observations (note, that not all assembly steps involve parts picked or trackable tools) requires heuristics (rules of thumb) that need to be validated on real data.

Impact and effects

Evaluated with real observations from the assembly floor of our industry partner Wacker Neuson, we could demonstrate that accurate assembly step durations and assembly process progress is possible based only on indirect worker observations and maintaining a workers privacy. Specifically, using only part picking events, our approach is able to predict step completion times for key steps accurately within 1,12% of the assembly tact time.

The approach requires merely standard sensory infrastructure on the assembly floor such as weight-sensitive part boxes or pick-by-light systems. Process progress information is provided back in near real-time via a cloud-based solution hosted by Fabasoft.

Fabasoft Cloud-based Process Deviation Feedback Interface

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- Fabasoft Austria, GmbH, Austria

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SUCCESS STORY

Pro2Future
Products and Production Systems of the Future

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: Adaptive Smart Production, MFP 4.2.2, 2 years, single-firm

COGNITIVE ELEMENTS AS ENABLERS FOR FLEXIBLE AND ADAPTIVE PRODUCTION SYSTEMS

COGNITIVE ELEMENTS SUPPORT THE FLEXIBILITY OF ASSEMBLY WORKERS AND ASSURE HIGH FLEXIBILITY WITH BEST PRODUCT QUALITY

In many cases, products manufactured in low-wage countries cannot compete with those from Europe in terms of price. However, --to counterbalance with the increased production costs in Europe to the customer, additional benefits must be generated for the customer, such as: high quality, shorter delivery times, etc. Flexible production systems can be one such approach to reduce the production costs. They make it possible to manufacture different types of products with the same production equipment at relatively low costs.

In this project, a novel, highly flexible assembly system was developed for various electric drive systems to manufacture them inexpensively and with high precision. The strengths of man and machine have been optimally combined. While the assembly worker can act instantly with smartness and flexibility as the changes in product occur, machines such as robots on the other hand, are very well suited for repetitive tasks. In this project, the best of these two sides were combined so that the varying activities can be implemented quickly by the worker on the operating robot.

Equipping the assembly line with cognitive features allows the inexperienced workers to be quickly trained. This is achieved by analysing the assembly activities that are and will be performed by workers in the vicinity (assembly stations) and, if required, support them with informative and assistive systems.

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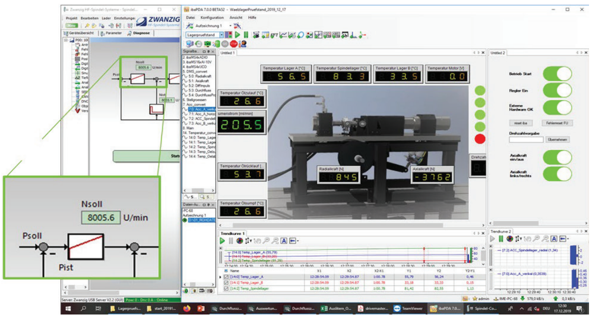
These informative and assistive systems are for example pick-to-light, pick-to-voice, screens, etc.

To quickly and reliably identify the quality-reducing factors in an assembly process for small batch size, an end-of-line (EOL) test bench is installed in the assembly line to test the fully assembled products. The product characteristics of the electric drive system (e.g. temperature development, life cycle, etc., at high speeds) extracted from the EOL test bench are linked to the assembly parameters (e.g. bearing pre-load due to manufacturing inaccuracies) by means of statistical methods ("machine learning"). Based on these correlations, product characteristics can be predicted with a high degree of accuracy at an early stage through the detailed recording of assembly parameters.

In addition, possible quality changes in the assembly of electric drive systems can be observed more quickly. Hence, flexible in-line correlations can be created, and the necessary reaction is initiated.

Impact and effects

Firstly, the novel, test bench-coupled assembly system approach has a positive influence on the product quality and costs of electric drive systems. This is also due to the man/machine collaboration and the increased flexibility associated with it, which contributes to economically sustainable production in Europe. Secondly, the error rate in the activities carried out by the worker is significantly reduced by the informative and assistive systems. This has also been validated with the help of an FMEA which was carried out by the experts.



Pro2Future: Innovative testbed extracting critical assembly parameters for increasing product quality.

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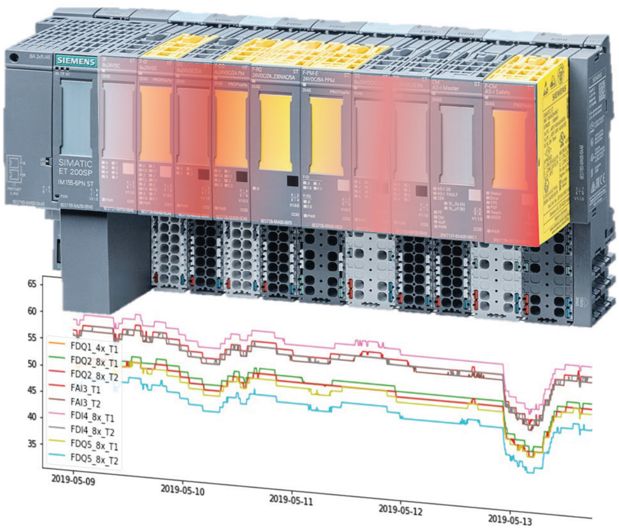
SUCCESS STORY

Pro2Future
Products and Production Systems of the Future

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: Simatic Failsafe 4.0, MFP, 2 years, single-firm



CREATING AWARENESS IN AUTOMATION SYSTEMS

ENHANCING AUTOMATION DEVICES WITH LOW-COST IOT EQUIPMENT ENABLES DEVICE-AWARENESS AND FOSTERS NOVEL COGNITIVE SERVICES

In the context of Cyber Physical Production Systems several research challenges have been identified. One constitutes the need for machines to contextualize themselves in the environment and thus gain awareness.

Recent advances in Data Analytics, Machine Learning, and Internet of Things (IoT) provide the necessary tools to enable awareness, however the adaption towards such technologies in automation is slow, due to the longevity of legacy systems. The project Simatic Failsafe 4.0 investigated how IoT can be used to retrofit legacy equipment in order to enhance it for contextual awareness. The investigated use case concerns enhancing programmable logical controllers with awareness regarding the temperature in environment to allow for the implementation of novel services such as condition monitoring enhancing the service portfolio of PLC systems.

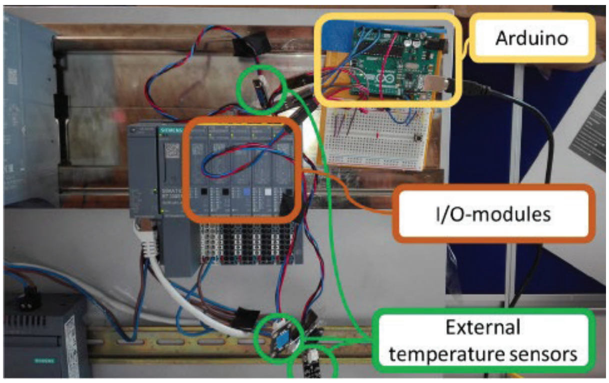


Figure 1: Experimental setup for enhancing PLCs with awareness: the five I/O-modules and three environmental temperature sensors that are connected to an Arduino. A temperature change can be achieved by shielding the PLC with a cover (Copyright Richard Bjetak)

The experimental setup used to implement temperature awareness within the project is shown in Figure 1. It consists of a Programmable Logic

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Controller SIMATIC S7/1500 (PLC) with Input/Output (F-IO) modules, a single board computer Raspberry PI 3 Model B+ (RPi), and an ATmega328 microcontroller (Arduino UNO). Each IO module has a microcontroller that is capable, among other features, to measure its own temperature.

Self-awareness is created by implementing an CUSum based change point detection algorithm, which monitors the processor temperature of the I/O-modules. Whenever an abrupt change happens the change point can be detected as fast as possible, keeping in mind the trade-off between the false alarm rate and the delay for detection. Besides self-awareness contextual awareness was realized, which allows the estimation of the environmental temperature based solely on IO module internal temperature measurements. In additional, thermal peer to peer comparison for the comparison of thermal behavior between different I/O modules was implemented.

The results of the changepoint detection algorithm are shown in Figure 2. Using the system, it is possible to detect thermal changepoints in the devices, furthermore this detection can be consecutively used to implement novel safety features and services on a device, edge or cloud level.

Impact and effects

The results demonstrate how environmental awareness can be established in legacy automation systems using affordable IoT equipment. By utilizing a minimal set of additional hardware such features can be implement allowing for a wide range of additional services such as condition monitoring thus leading to a further cognification of automation systems.

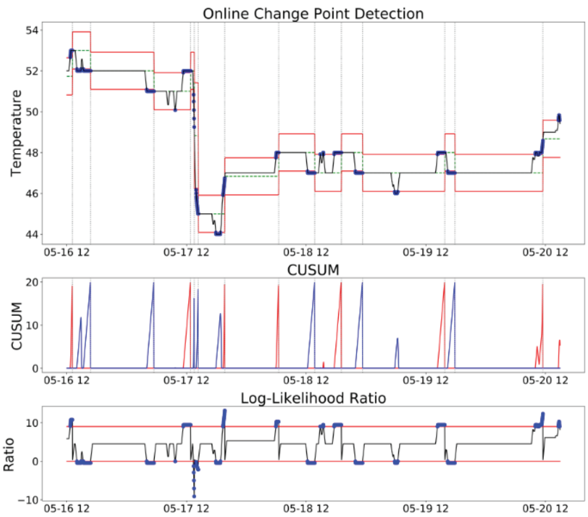

Figure 2: Results Changepoint Detection – The developed CUSum algorithm is able to detect changes in the environment, enhancing a PLC with contextual awareness (Copyright Richard Bjetak)

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SUCCESS STORY

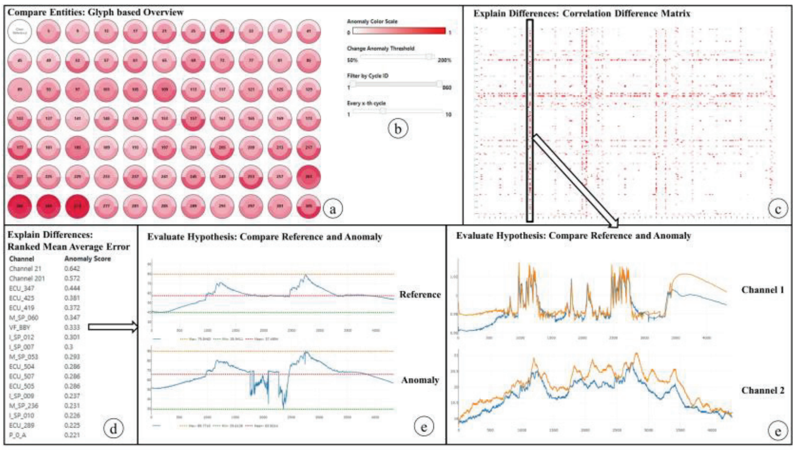
FFG Promoting Innovation.

Pro²Future
Products and Production Systems of the Future

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: ConMon, 3 Years, MFP



SCALABLE CONDITION MONITORING SYSTEM FOR TEST ENVIRONMENTS

Industry 4.0 is considered as the "fourth industrial revolution" that fully automatizes the production in the manufacturing industry. It is a large-scale digitalization of manufacturing, where the machines are connected producing large amounts of products with low costs. To achieve this, they are endowed with sensors which, in real time, collect, produce and exchange data (machine-to-machine, machine-to-human) with the purpose (i) to identify e.g., trace parts and subassemblies, (ii) to adapt the production to changing requirements and individual needs, and (iii) to optimize the production processes. However, the amount of data generated within production can be overwhelming for the human beings. First, the data has to be monitored and recorded using methods that can handle huge datasets. Next, the collected data has to be analyzed (often in real time) (i) to identify e.g., undetected process correlations, (ii) to gain an overview about the production, and (ii) to extract essential information. Finally, using this information the human being should be able to define prediction (e.g., about production issues) that aid the decision-making process. This becomes more significant, when the production process is divided into specific tasks and each task is repeated many times (=cycles) producing vast amount of data. For instance, in so called "durability test" in automotive industry, the engineers investigate the condition of an engine by using multiple sensors and defining and performing repeating tasks. What significant here is, that such a test can take thousands of hours, with up to twelve hours per cycle, which makes it quite difficult for the engineers to collect and monitor the data (time series data) of each iteration and to explore if there are any deviations between them. Yet, to tackle this issue, one can use an interactive visual analytics tool.

Visualizations have shown to be effective in dealing with huge datasets: since they are grounded on visual cognition, people understand them and can naturally perform visual operations. Concretely, by assigning data to visual characteristics people can intuitively extract valuable information and perceive properties of their data (outliers, patterns, etc.) which might remain undiscovered by other means of analyzing

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them. Returning to our example with the durability test, a visualization tool would imply that data being collected by the sensors in each cycle is transferred to the engineer in a way so that the engineer can readily obtain insights and draw general conclusions out of it.

In this project, we propose an interactive visual analytics tool that displays the iterations of a durability test as a collection of color-encoded cycle glyphs. To do so, we aim to help the engineers to readily monitor the test and to detect potential anomalies. To achieve this, the engineer selects one glyph (or iteration) and the color of the remaining glyphs (or iterations) shows how much they deviate from the selected one: the darker the color of a glyph is the more it deviates from the selected one. For the calculation of the anomaly score, we use data simultaneously collected by ~500 sensors, times series data respectively. Another important factor what has to be taken in account is, the time series data we deal within the scope of our work, is multivariate due to dependencies between the individual attributes.

Impact and effects

We performed a pair analytics evaluation with three testbed engineers, to investigate how the engineers work with the proposed visual analytics tool on their daily condition monitoring analysis goals. The study has revealed that our tool aids the daily work in automotive testbed environments for two reasons. First, the visual analytics tool helps engineers to analysis the entire testbed dataset and not only a subset of well-known sensors. To do so, the engineers are able to investigate the correlation between the attributes (e.g., temperature and pressure sensor) and not only each attribute on its own. Second, using our tool the engineers are able to readily detect anomalies and explore their sources. Summarized, our visual analytics tool provides promising methods to address the specific problems associated with automotive testbeds: analyzing multivariate time series and finding anomalies in reoccurring processes.

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- AVL List, Austria
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JOINT SUCCESS STORY

Pro2Future
Products and Production Systems of the Future

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: Common Research Programme (CRP), 4 Years, MFP DP1

together with K1 Centre „Austrian Center for Digital Production“

AI <> HI :: ARTIFICIAL INTELLIGENCE MEETS HUMAN INTELLIGENCE

USAGE OF A COGNITIVE HEADGEAR FOR OPTIMIZING PROCESSES IN INDUSTRIAL PRODUCTION.

The COMET K1 competence center Pro²Future, founded at the end of the Industry 4.0 era, addresses research questions of industrial production and product design in the era of **cognitive systems**. The central theme of the center**: Products and production systems of the future "think with you".** More than 25 industry partners - mainly from the thematic sectors AI, mechatronics, mathematics and software - work with around 30 center employees on "cognitive" products and industrial systems that use human-like cognitive skills such as perception, interpretation, understanding, memorization and learning, prediction and conclusions and appropriate cognition-controlled action.

During Pro²Future's research activities, there is a **common research program (CRP**) with the Austrian Center for Digital Production (**CDP**) in Vienna. Different **demo cases** were implemented in this **CRP**, which are summarized in three **demonstrators**. One of these demonstrators is a **cognitive helmet** to support workers (see picture on next page).

For the second funding period (2021-2025), which is now starting, Pro2Future is committed to a central challenge for such systems, namely the confluent cooperation between **humans** and increasingly **AI-powered machines**, and **products with embedded AI**. The projects in preparation are aimed at situation and work step-aware, self-adapting, AI-powered machines that control interaction with human

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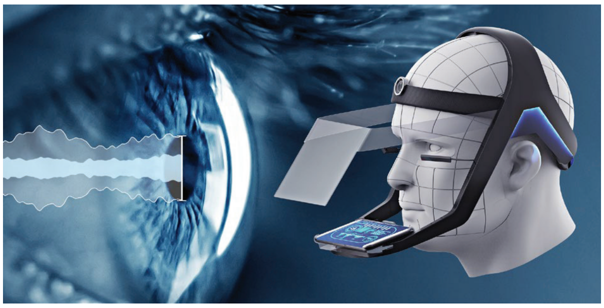
workers based on workers' observations and experiences, skills and abilities. The level and scope of AI-based assistance functions must be adapted individually, context-sensitive and to the minute in the manufacturing process.

A reference implementation of AI-controlled manufacturing systems based on (i) **formal models** of human perception, recognition and understanding, (ii) multi**sensory, unattended recognition architectures** and (iii) **embedded subtle AI support mechanisms** has already been implemented (see pictures). Future industrial manufacturing will combine the special capabilities of AI-controlled robots in terms of strength, accuracy, and efficient execution of repetitive tasks with the flexibility, fine motor skills and intuition and skills of human workers in collaborative environments. The initial motivation for the research work in Pro²Future is the **development of multimodal sensor systems** that enable machines to perceive their environment and their operators and to react to them in a situational manner. The emerging multi-sensor-based AI user interaction platform combines four functional levels: cognitive modeling of the user (**operator models**), evaluation of the experience and ability levels of the user to select the assistance and interaction mode (**recognition component**), knowledge transfer database as a repository of reference processes (**intelligence component**) for triggering and controlling machine control commands and feedback to the assisted worker (**assistant component**).



Illustrations: Institute for Pervasive Computing, JKU Linz

Pro²Future methodically uses cognitive processes in human-machine interaction based on the current state of research (**deep learning, reinforcement learning, perception, attention research, cognitive load modeling**), and strives for a **new generation of assistive collaboration systems** that combine complementary qualities and possibilities of AI and AI.

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- Wacker Neuson GmbH, AT
- Institutes at JKU, Austria
- Institutes at TUW, Austria
- Institutes at TUG, Austria
- ACDP GmbH, AT

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JOINT SUCCESS STORY

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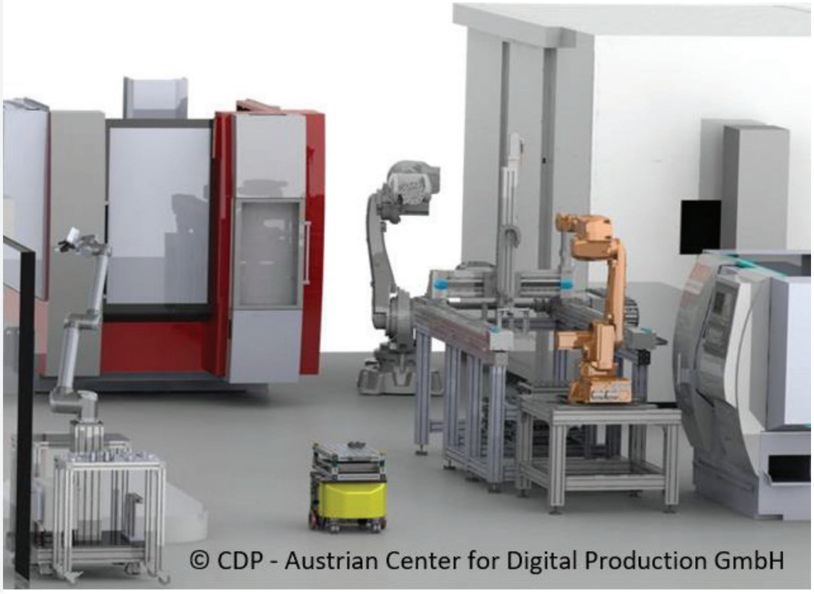
CDP / DP 2/ JUC 2
Austrian Center for Digital Production / Demonstrator Project 2 / Adaptive Loading Station

Programme: COMET – Competence Centers for Excellent Technologies

Programme line: Common Research Programme (CRP), 4 Years, MFP DP2

In cooperation with the K1 Centre "Pro²Future"



ADAPTIVE LOADING STATION

FULLY AUTOMATED LOADING OF PARTS BY COMBINING INTERDISCIPLINARY RESEARCH RESULTS TO A SHOW CASE FOR A BROAD AUDIENCE WITH INDUSTRY RELEVANCE

–

The *Common Research Program* (*CRP*) of the *Austrian Center for Digital Production* (*CDP*) and *Pro²Future* (*P2F*) is a joint research program conducted by the two Austrian competence centers, funded by the FFG, dedicated to topics in the broad perspective of Industrie 4.0. Within the CRP several demo cases, that act as technological building blocks, are developed. One of those is the "*Adaptive Loading Station*", an interdisciplinary showcase carried out by the participating scientific and company partners.

The Loading Station (Figure 1) tackles one of the most significant bottlenecks when it comes to fully automated night shifts in production companies. Typically, the loading process is done by shop floor employees, that have process and manufacturing knowledge about how to load raw parts the correct way. The presented "*Adaptive Loadings Station*" presents a fully automatic solution for placing raw parts for turning machines on pallets. The station consists of an UR10 of the e-Series and a pair of cameras, one for 3D and one for 2D visual recognition. Additionally, an Autonomous Guided Vehicle (AGV) by Neobotix is used to automatically transport the loaded pallet to the tooling center.

A worker can simply prepare the needed raw parts and corresponding trays to the robot loading area. Thanks to visual recognition the parts and trays can be placed anywhere within the designated area. The trays function as mini pallets with form closure. The robot is hovering above the parts and the cameras check for the correct tray and raw parts. Once the parts for the next manufacturing order are identified, the robot checks for the AGV and detects its exact position with the cameras. As soon as the position is

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determined, and a correction matrix calculated (the AGVs have a high position tolerance), the loading starts. First the trays for the order get loaded onto the pallet. Next the raw parts are placed on the trays on top of the pallet, carried by the AGV. The whole visual recognition is handled by the "*XRob*" software developed by the scientific partner *Profactor*.

Once the loading process is completed the AGV is sent to the next manufacturing process according to the workplan. Later in the shift the machined parts return on their specific trays on the AGV and the robot starts with unloading, basically inverting the loading steps, freeing the trays, and loading new parts for the next manufacturing round. The orchestration of the whole process is done by "*Centurio*" a BPMN (Business Process Model and Notation) based process engine, developed by the *CDP* and scientific partners. "*Centurio*" connects to MES or ERP and the field level services and executes the work steps. "*Centurio*" can load any CAD-model of a raw part into the "*XRob*" software for increased adaptability.

Impact and effects

The "*Adaptive Loading Station*" greatly reduces the amount of part carriers (pallets) needed during ghost shifts, as the trays and pallets can easily be reused because the parts are loaded and unloaded automatically. Especially for a High-Mix production system the combination of varying and specialised trays as carriers of the parts on a pallet works very well. In this case the trays are produced by FDM 3D Printers.

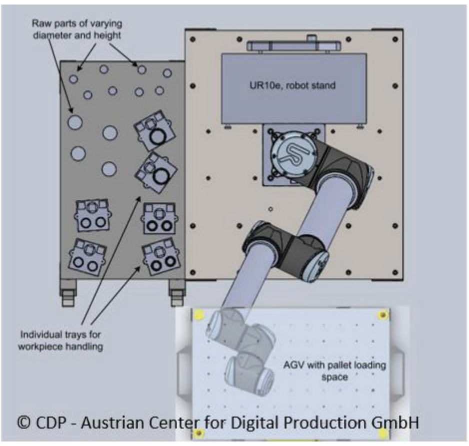

Figure 1: Adaptive Loading Station description

The *Adaptive Loading Station* was presented during the year 2019 and will continue to be a show case within the TU Wien Pilotfabrik Industrie 4.0 in Vienna in the future. It is fully integrated into the Pilotfabrik's manufacturing network and is thereby presented to the numerous interested people that visit the Pilotfabrik each year.

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- Hoerbiger, AT
- TTTech, AT
- Plasmo, AT
- Pro2Future, AT

This success story was provided by the centre management and by the mentioned project partners for the purpose of being published on the FFG website. CDP is a COMET Centre within the COMET – Competence Centers for Excellent Technologies Programme and funded by BMK, BMDW, Wien, Niederösterreich, and Vorarlberg. The COMET Programme is managed by FFG. Further information on COMET: www.ffg.at/comet

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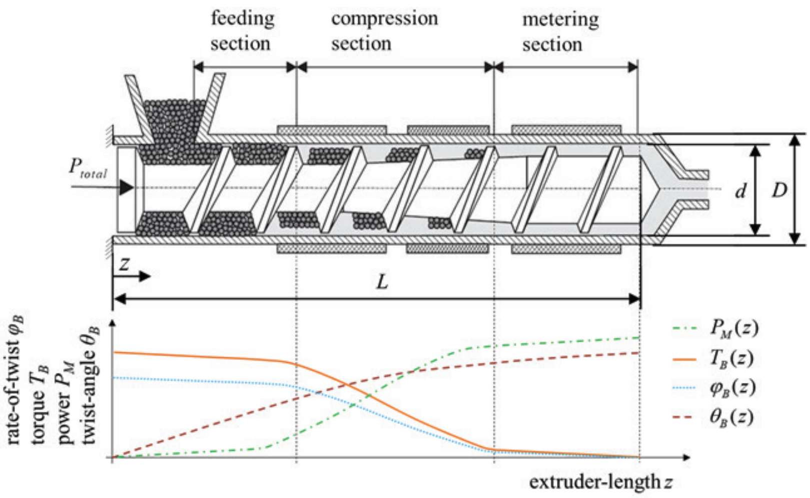
SUCCESS STORY

Pro²Future
Products and Production Systems of the Future

Programme: COMET – Competence Centres for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: E-Manager 1.2, 2 years, strategic



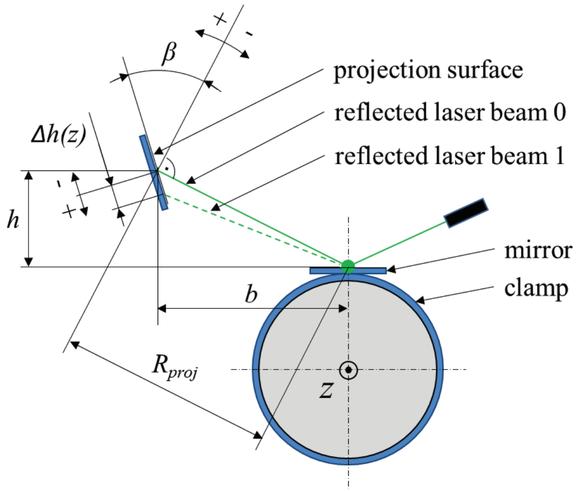
IMPROVED ENERGY EFFICIENCY IN EXTRUSION

NOVEL MEASURING METHOD ENABLES TO DETECT AXIAL DISTRIBUTION OF MECHANICAL ENERGY INPUT ALONG A SINGLE-SCREW EXTRUDER

Global annual plastic production reached approximately 370 million tons for 2020 (statista.com) – more than a third of which is processed by using **extrusion machines**.

Depending on the processing, between **37%** and **48%** of the energy demand is **provided** by the **extruder**. Approximately **80%** of this energy is introduced in the form of mechanical energy due to the **rotating screw**. This mechanical energy input is mainly dependent on screw geometry and design of the extruder and strongly influences the **total energy consumption** as well as the **quality** of the **extruded plastic**.

Researchers at Pro²Future have succeeded in developing a **novel measurement approach** to identify how much mechanical energy is introduced at which **axial extruder position**. The measuring principle is based on the **deformation** of the extruder **cylinder** due to the energy input, which is detected by **laser beam** deflection using a **mirror system**.



Schematic representation of the measurement method

The physical principle is based on the mechanical power being **proportional** to the **screw** respectively **cylinder torque**.

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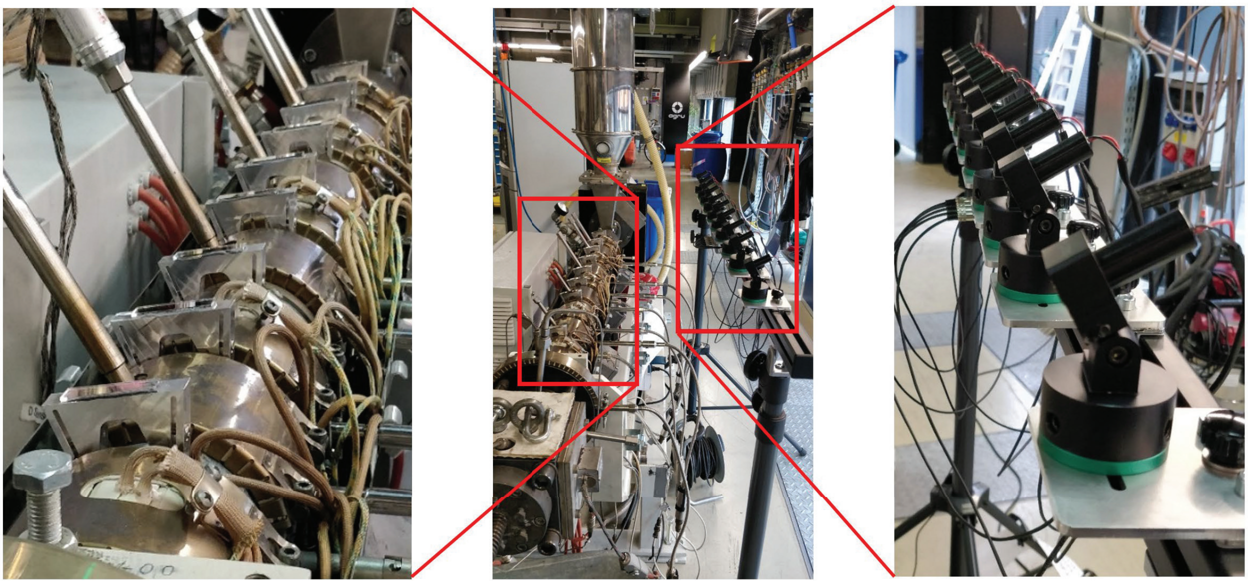

Prototype test setup with 10 measuring points on a single-screw extruder.

Impact and effects

The development of the measurement method is already well advanced, and several **prototypes** have been designed and tested. The prototypes consist of flexible measuring units, with each individual unit consisting of a mirror mount and a laser, which can be placed at any position on the extruder barrel. Recent measurements carried out have shown very promising results. Subsequently, the measuring method and measurement devices will be improved, and it is planned to develop a measuring system for **commercial use**.

The measurement method can be used for **process monitoring**, **design improvement** (characterization of the energy input along the processing unit), and **optimization** and **validation** of simulation models, which means that more **energy-efficient** extrusion screws can be produced. This leads to a more **sustainable screw design** and overall, to an **improved energy efficiency** in **polymer processing**.

—

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Project Partner

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SUCCESS STORY

Pro²Future
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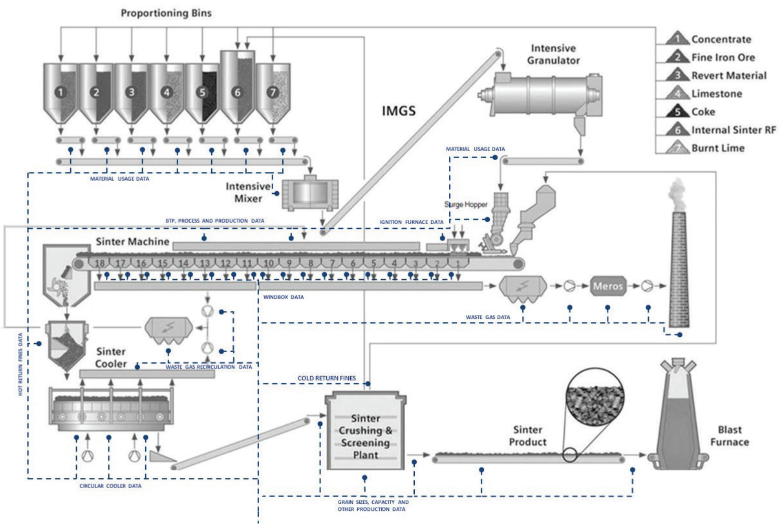
Programme: COMET – Competence Centres for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: SINPRO (Predictive Maintenance for Production Env.) 2,5 years, multi-firm



SINTER PRODUCTION IMPROVEMENT

A FORECASTING MODEL-BASED DISCOVERY OF CAUSAL LINKS OF KEY INFLUENCING PERFORMANCE QUALITY INDICATORS IN SINTER PRODUCTION

Sintering is a **complex** production process where the process stability and product quality depend on **various parameters**. Building a forecasting model improves this process. Artificial Intelligence (AI) approaches show **promising results** in comparison to current physical models, although often considered as black-box models because of their hidden layers. Due to their complexity and **limited traceability**, it is difficult to draw conclusions for real sinter processes and improve the physical models in a running plant. This challenge is addressed by focusing on **detecting causal links** from **AI-based forecasting models** in order to **improve** the **understanding** of **sintering** and **optimizing** existing **physical models**.

In the first step a **forecasting model** was developed to predict the **harmonic diameter** as a central **quality parameter** indicating the grain sizes distribution of the finished sinter. This forecasting model is a **ML** (machine learning) **regression model** based on the **Random Forest** ensemble method. Additionally, approaches such as **Support Vector Machine** regressor, **Multilayer perceptron** and **K Nearest Neighbours** regressor were evaluated. After an optimization step, the model showed a normalized root mean square error of 8.9% (equivalates to 0.2mm) on the prediction of the **target value** (grain size), which is **beyond** state of the art.

The model with the **best performance** was too complex to be interpreted and despite not being a black-box model per se, a control strategy or a new production insight was difficult to infer (see Figure 1). Hence, in the second step, a discovery interview was conducted with the **domain experts** to gather domain knowledge about the use case as well as materialize **implicit knowledge**. More specifically, the diagram of influences was developed as a rough approximation. Finally, the approach was verified through **Visual Analytics** and a **Forecasting Model Analysis** gave an additional insight into the model and its **decision basis** (see Figure 2).

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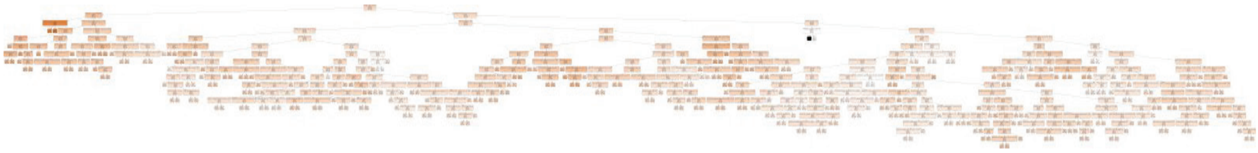

Figure 1: One out of 255 estimators (decision trees) of the Forecasting Model, showing the complexity of the inference model.

Modeling and understanding **interdependencies** in a production process was traditionally tackled through different **first-principle models**. Building these models required profound understanding of the nature of the processes and conducting **randomized controlled experiments**.

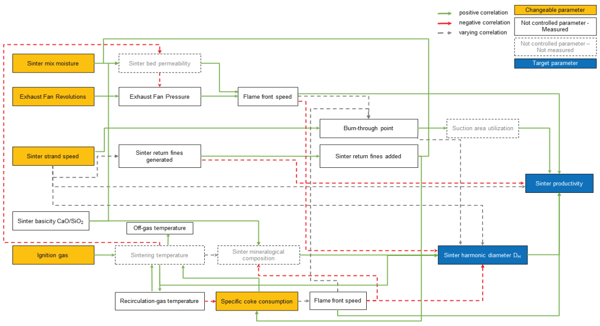

Figure 2: Diagram of influences in the sinter production process

In the sinter plant operation, the **process stability** is paramount which makes large scale experiments impossible to conduct (e.g., breaking the production, requirements for high process stability, supply chain dependencies etc.). Applying our approach **enabled gaining these crucial insights** in a non-obstructive way through analysis of observational data.

Impact and effects

The findings of the project take direct effect in the **production improvement** of **running sinter plants** and show **promising results** in the **prediction** of the **harmonic diameter**, therefore **increasing production** outcome while keeping **high quality** of the **sintered material**.

Applying the developed approach and building a **machine learning model** provided a **detailed insight** into main influences of the **sinter quality** and was used as a basis for a **holistic approach** in which additional models were built and utilized to further **maximize** the **output** and return fines for replacing the added coke in the process.

The results have been published in several conferences and in the renowned **AISTech Journal** of Iron & Steel Technology in March 2021 (details via http://digital.library.aist.org/iron-and-steel-tech.html).

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SUCCESS STORY

Pro²Future
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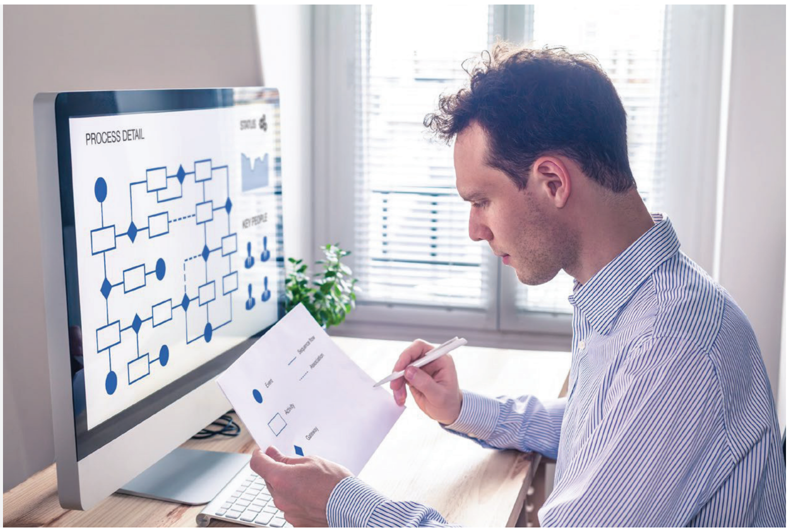
Programme: COMET – Competence Centres for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: CEPS (Cognitive Engineering Project Support)
3 years, multi-firm



EMPOWERING ENGINEERS IN LARGE DEVELOPMENT PROCESSES TO PRECISLEY FOCUS ON THE TASK

A MODEL-BASED APPROACH TO MANAGE PROJECT-SPECIFIC WORKFLOWS IN DOCUMENT-CENTRIC ENGINEERING PROJECTS

The goal of concurrent designs is to have engineering teams—and especially interdisciplinary teams—working in tight interaction on many aspects of the system under design to create **product innovations** in **shorter development cycles**.

To carry out such a development process, dozens of engineers from many domains perform tasks on parts of the **final products**, so-called **artifacts**. Artifacts range from user requirements to design, over hardware and software, to tests; thus, products potentially involve thousands of artifacts. After a task is finished, the resulting artifacts can be passed on to another engineer for the next task. In order to have smooth progress on the development, it has to be clear who is able to work when on which artifact and what needs to be done. Furthermore, the engineers need to know, from which person to receive the necessary inputs, when the **quality of their task** is **fulfilling the requirements**, and to whom to forward the results. The exact rules change over time and differ based on context, resulting in hundreds of variations resulting in complexity that needs to be managed.

The **development of changing products** will require different engineers, and not all engineers will be available at all times. Thus, each project will follow a different path to achieve its goal. Requiring each engineer to be aware of each project plan draws a lot of focus to boring and **avoidable topics**, draining their energy. Also, it is prone to **human errors**, which then lead to unnecessary iterations and the need for rework.

For these scenarios, **Pro²Future,** together with partners from the industry, namely the **Robert Bosch** AG and **MethodPark** by UL, as well as the **Institute of**

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Software Systems Engineering at **JKU Linz**, developed an approach and **tool support** to (i) **model the engineering process for a specific project**, and then (ii) **provide the engineers** the reminders, information, artifacts, and **quality criteria** for their given task.

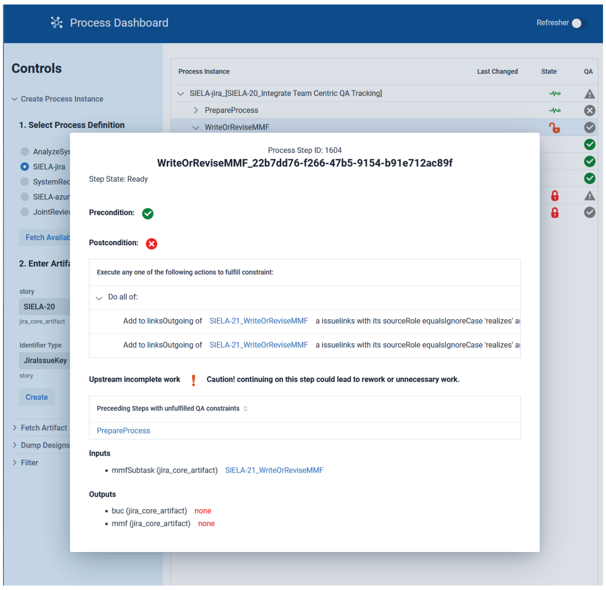
This newly developed approach uses information from artifacts to decide on the readiness of an artifact to be passed to the next engineering step. The information is directly accessed in the engineers' tools; thus, each engineer stays in his/her **favored tool environment**.

The approach has been implemented in a **first prototype** and is **integrated** with an **engineering tool** and the **process models** used in the STAGES software by Method Park. This **first experiment** with users at Robert Bosch AG has shown that **engineers** using the prototype find it **easier and less frustrating** to follow the process and **quality assurance** regulations compared to just using typical engineering tools.

Impact and effects

The approach has been integrated with one major engineering tool so far and shows **great potential benefits** to the users. The integration enables users to **access the relevant tasks and readiness criteria** without lengthy navigation across multiple artifacts.

The possibility to integrate the approach with a variety of engineering tools works well with the seamless workflows required in concurrent engineering.



Repair suggestions as process guidance in an example process

Another benefit is the **availability of the used processes in the form of models** that can be analyzed, refined, and optimized to improve the engineering team's performance in future development projects.

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Project partner

- Robert Bosch AG, Austria
- MethodPark by UL, Germany
- Johannes Kepler University Linz, Austria

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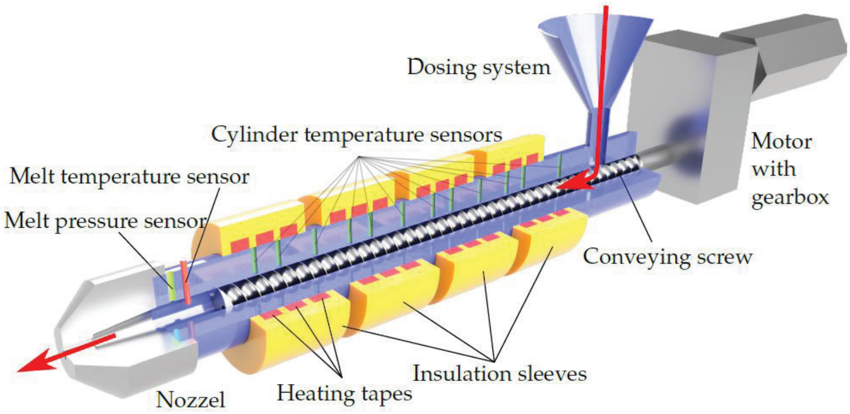
SUCCESS STORY

Pro²Future
Products and Production Systems of the Future

Programme: COMET – Competence Centres for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: CoExCo 2 (Cognitive Polymer Extrusion and Compounding 2)
4 years, multi-firm



MODELLING AND CONTROL OF PLASTICS EXTRUSION MACHINES

AN INNOVATIVE MODEL-BASED CONCEPT FOR EFFICIENT AND ENERGY-SAVING PRODUCTION OF PLASTIC ARTICLES

An important process for the **production** of plastic products such as **packaging, pipes etc.** is the extrusion process. In this process, a plastic **granulate** is filled into a machine called an extruder, conveyed through the extruder cylinder by a complex screw and **melted** using pressure and heat. The heat required for melting is generated by friction and heating elements, the pressure by the screw. The **pressure, mass flow** and **temperature** of the melt are to assume **values** that can be specified at the outlet. **The newly developed control system allows the extrusion process to run faster, more efficiently and in a more environmentally friendly manner, while at the same time ensuring optimal product quality.**

This process should be as energy-efficient and environmentally friendly as possible, but also be able to extrude a wide variety of types of granules in such a way that the end products are of high quality. Today's **challenges** are doing without active cooling and **processing of granules with fluctuating properties, eg. in recycling**. The standard is that experienced staff use recipes to adjust the extruder in such a way that the best possible behavior is achieved under the same conditions. Changes over time due to defects or **changes in the composition** of the granules **cannot be specifically taken into account**. Recipes also have to be created in a complex manner. Modern extrusion is an extremely complex process that varies greatly over time, and the best possible settings have to be learned.

To meet these challenges, **Pro²Future** has developed a new model-based control system together with partners from industry (**Soplar.sa)**, the **Institute of Polymer Processing and Digital Transformation** and the **Institute of Automatic Control and Control Systems**

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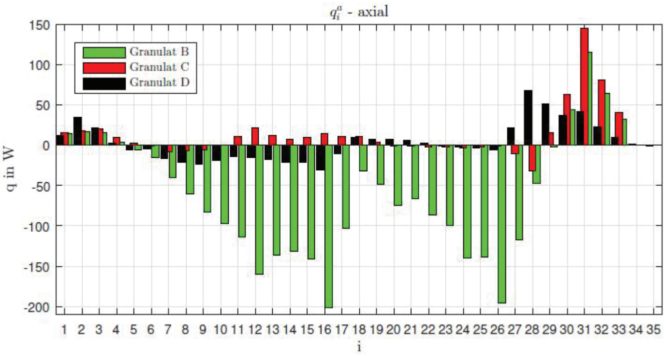
Technology (both of them JKU-LINZ). The newly developed control system **continuously analyzes** the thermal effect of a **granulate** mixture and **adjusts** the **production process** accordingly, compensating for any fluctuations that occur and thus **ensuring consistently high product quality**. The analysis of the plastic mixture is carried out by a developed **smart sensor**. This smart sensor is able to **estimate** the **heat flows** that act between the extruded plastic and the extruder.



Heat flow estimation of the Smart Sensor during processing of 3 different granulates on an industrially used extruder.

Impact and Effects

With the innovative **temperature management, optimal production conditions** are achieved quickly, thereby **reducing rejects**. By using the **model-based controller**, all essential process variables are recorded, **system-related limitations** are observed and safe operation is thus ensured. This makes it possible to operate well-insulated and thus energy-efficient extruders **without additional cooling devices**.

The **new control system** thus allows **recycled and/or new bio-based material** from the plastics industry to be **processed** very **efficiently** by **quickly** achieving and maintaining optimal production conditions and has already been demonstrated under production conditions.

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- Soplar sa and others

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3D-Reconstruction and Localisation

Providing Location Sensitive Support to workers on the factory shop floor

Pro²Future

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MOTIVATION & GOALS

Provide **cognitive intelligence just in time and space for human**:

- **Digitalisation** of analog production areas
- **Localisation** of Worker (Self) on Shop Floor
- Semantic annotation of work area
- Process and workflow-sensitive, embedded, accompanied assistance
- Multi-modal, direct, unobtrusive user feedback
- Battery powered AI-wireless devices
- Providing Worker Path Tracing
- Enabling Work Space Optimisation

Project FactBox

Project Name Guide/3D-Recon
Project ID DP1.2/MFP1.2-2
Duration 39 Months

Area 1
Perception and Aware Systems

Project Lead
Prof. Dr. Alois Ferscha

APPROACH

Using **Structure from Motion** Principles

- Generate Features in Camera Frames
- Find Correspondence between Frames
- Remove Local Outliners
- Compute Trajectories to Reconstruction Camera Motion and 3D Environment

and further optimizations in our **Embedded SLAM AI Algorithm** in our **Cognitive Headgear** we trace enable workers to trace themselves on the factory shop floor

Cognitive Headgear

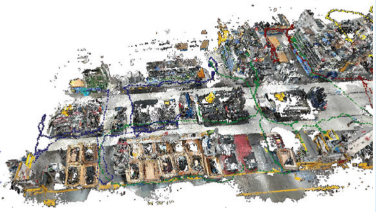
Head-mounted, cognitive assisting unit driven by NVIDIA Jetson TX2 embedding multimodal feedback and sensor data:

- Peripheral led stripes for minimal obtrusion
- 8 vibration motors evenly distributed around the head for haptic feedback
- Intel RealSense D435 RGB-D depth camera with 77° FOV
- High-speed mobile eyetracker @200 Hz

Reconstructed 3D-Model of Factory Used for Localisation

Localisation

Current Camera Frame



2D Top Down Path on Factory Floor

3D Path in on the fly created 3D-Model On Shop Floor

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184), Wacker Neuson and RSA FG.

RSA FG Research Studios Austria Forschungsgesellschaft · WACKER NEUSON all it takes!

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Cognitive Products

Fischer4You

Cognitive Skiing Products

Pro²Future

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MOTIVATION & GOALS

The aim of this work is to develop a sensor set up and an algorithm to assess skill level of recreational alpine skiers, which is feasible for home use.

- Finding the best position for detecting skiing skills
- Automatic analysis of skiing activities
- Communication of assessment feedback
- Coaching suggestion
- Recommendation for equipment change

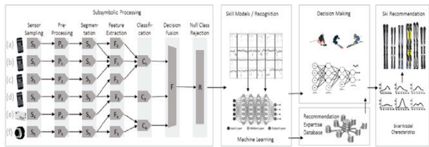
Project FactBox

Project Name Fischer4You
Project ID DP1.2-1
Duration 27 Months

Area 1
Perception and Aware Systems

Project Lead
Prof. Dr. Alois Ferscha

APPROACH



CONTRIBUTION

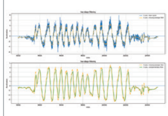
Scientific contribution
Unsupervised Activity Recognition
High Dynamic Technique Recognition
Two-stage Filtering and Sensor Fusion
Data-Driven Assessment Model

Economic contribution
Costumer satisfaction
Costumer binding

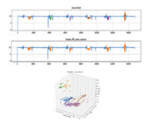
SYSTEM ARCHITECTURE

Data Collection
Collecting data from various part of the body using Xsens and Smartphone sensors.

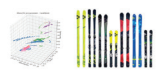
Preprocessing
fusing accelerometer and gyroscope to reduce the vibration to be minimum.



Unsupervised Machine Learning
Training unsupervised models to detect active sessions of skiing and distinct techniques.



Skill Assessment
Rating skiers and recommending them appropriate equipment based on their skills.



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Fischer Sports.

FISCHER

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Workflow Tracking for Industrial Manufacturing

WorkIT – Workflow and Tool Process Modelling

Guide – Guidance and Assistance

Pro²Future

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MOTIVATION & GOALS

Workflow Tracking is an important and complex stepping stone for the implementation of cognitive industrial **assistance and quality assurance** systems. Knowledge of the current work step enables **correlation of the worker's observed activities** with the **scheduled tasks** and thus decision making with respect to assistance provisioning and monitoring.
In the frame of the WorkIT and Guide projects, such a workflow tracking system was successfully instantiated for **industrial assembly and manufacturing**. The goal of this system is to automatically determine the current work step during assembly of industrial digging machines based solely on the **workers' hand movements and noises** in their surrounding.

Project FactBox

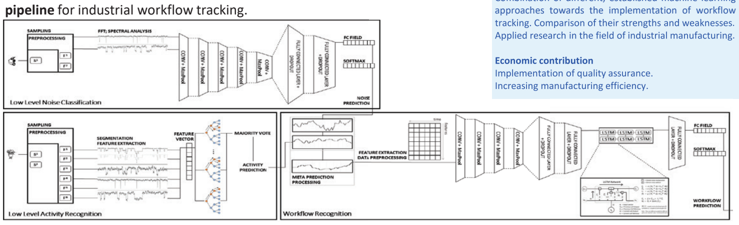
Project Name WorkIT/Guide
Project ID DP1.6/DP1.1
Duration 36 Months

Area 1
Perception and Aware Systems

Project Lead
Prof. Dr. Alois Ferscha

APPROACH AND ARCHICTECTURE

Combination and **comparison** of different **machine learning approaches** (deep learning; ensemble classifiers) towards implementation of a **classification pipeline** for industrial workflow tracking.



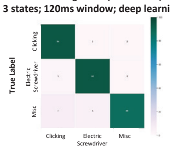
CONTRIBUTION

Scientific contribution
Combination of different, established machine learning approaches towards the implementation of workflow tracking. Comparison of their strengths and weaknesses. Applied research in the field of industrial manufacturing.

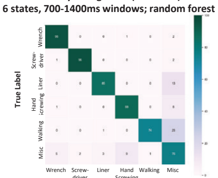
Economic contribution
Implementation of quality assurance.
Increasing manufacturing efficiency.

RESULTS LOW LEVEL RECOGNITION

Noise Recognition (audio data)
3 states; 120ms window; deep learning

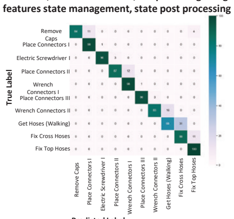


Activity Recognition (IMU data)
6 states, 700-1400ms windows; random forest



RESULTS WORKFLOW RECOGNITION

10 states, 10000ms window; deep learning using features state management, state post processing



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Wacker Neuson.

WACKER NEUSON all it takes!

JKU Johannes Kepler Universität Linz · TU Graz · AVL · Fronius · UAR Upper Austrian Research GmbH · Bundesministerium Verkehr, Innovation und Technologie · Bundesministerium Digitalisierung und Wirtschaftsstandort · FFG · ober österreich · Das Land Steiermark · SFG

SKILL-LEVEL DETECTION FOR WELDERS

GUIDE – Guidance and Assistance

Machine Learning on IMU Data

Pro²Future

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MOTIVATION & GOALS

Our partner Fronius is working with IMU expanded welding machines, enabling to collect different data streams during welding. Based on this data a new developed workflow reveals the skill level of the welder. For Fronius this result enables them to adapt their machines for the expertise of the user.

Project FactBox

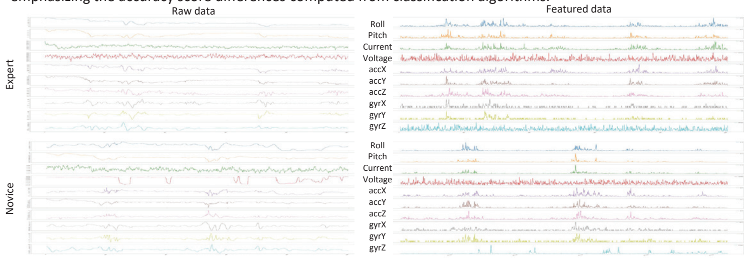
Project Name GUIDE
Project ID DP1.6
Duration 33 Months

Area 1
Perception and Aware Systems

Project Lead
Prof. Dr. Alois Ferscha

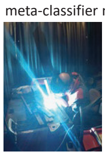
DATA TRANSFORMATION

These IMU data streams include all axis of both accelerometer and gyroscope, voltage, current, pitch and roll with distance of 20ms. To distinguish between an expert and novice welder, the raw data streams were not sufficient (left diagrams). Thus, sliding windows compute new features via standard deviation (right diagrams) or variance, emphasizing the accuracy score differences computed from classification algorithms.

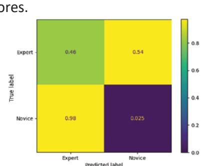


APPROACH

Evinced by experiments, a window with size of 2 (independent of offsets 1, 2 and 5) in combination with an applied random forest results in the most decisive model so far. This model reaches accuracy scores for experts around 45 to 55% (upper confusion matrix) and for novice welders under 10% (lower confusion matrix). Last a meta-classifier makes the final decision based on these accuracy scores.



→ IMU raw data streams (above) → Feature with standard deviation sliding windows → Classify with random forest →



→ Meta-classifier for final result

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Fronius.

Fronius

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Cognitive Products in Railways

RTEAS

Cognitive Rail Track Error Analysis Support

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MOTIVATION & GOALS

The aim of this project is to develop a pipeline to support operators in rail track error assessment

- by **sensor data processing** and **feature extraction**,
- **unsupervised clustering** to find local outliers,
- **visualization Techniques** supporting decision finding and
- creating **persuasive reports**, which measures to takes e.g.
    - Increase maintenance interval
    - Replace ballast bed
    - Redo Tamping
    - Keep as it is

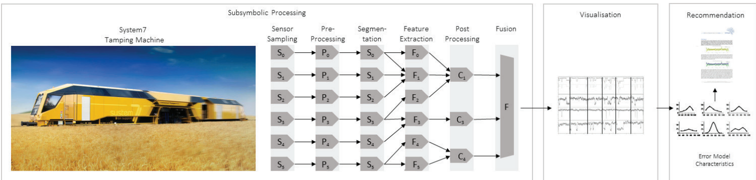
Project FactBox

Project Name RTEAS
Project ID DP1.2-3
Duration 12 Months

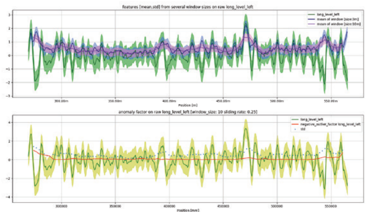
Area 1
Perception and Aware Systems

Project Lead
DI Michael Haslgrübler

APPROACH



VISUALISATION



CONTRIBUTION

Scientific contribution
Unsupervised Clustering for Error Spotting
Multi-Stage Filtering and Sensor Fusion
Data-Driven Error Spotting and Action Recommendation Engine

Economic contribution
Rail Road Maintenance Cost Reduction
Costumer Binding and Support
New Business Model with
After Sales Support

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COGNITIVE INDUSTRIAL SYSTEMS

WorkIT/Guide/SeeIT

Workflow Recognition and Guiding

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MOTIVATION & GOALS

- Recognition of micro activities e.g. Screwing detection in industrial processes.
- Collaboratively behaviour of human and machine.
- Capturing Workflow - Human Activity Recognition using: (Wearable- & Biometric-Sensors, Eye- & Hand-Tracker)
- Identification of bottlenecks within the assembly procedure.
- Quality Control of the manufacturing operation by providing guidance and support to novice workers in distracting or vague situations.
- Confirmation for the successful completion of a task.

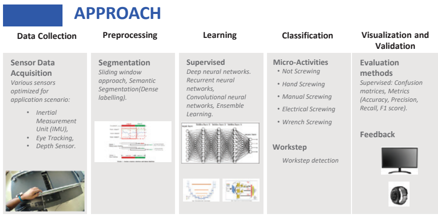
Project FactBox

Project Name WorkIT
Project ID MFP1.1/DP1.1
Duration 39 Months

Area 1
Perception and Aware Systems

Project Lead
Prof. Dr. Alois Ferscha

APPROACH

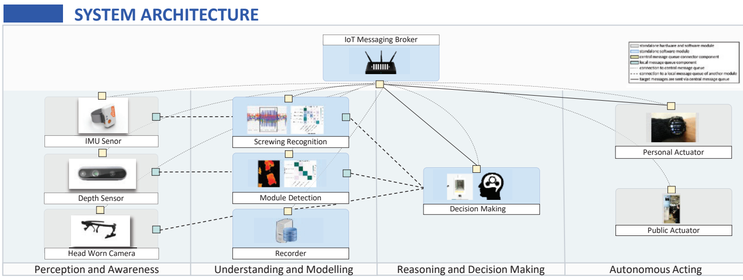


CONTRIBUTION

Scientific contribution
Detection of micro-activities(small movements with hands) in the filed of human activity recognition using mainly IMUs. Furthermore detecting the stage of the assembly process, based on depth sensors.

Economic contribution
Reduce training time for novice workers
Reduce the cost of rework for the companies

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and KEBA AG.

COGNITIVE INDUSTRIAL SYSTEMS

WorkIT – Workflow and Activity Recognition for Trumpf

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MOTIVATION & GOALS

- Device independent preparation of information
- Workflow detection for industrial processes
- Activity recognition based on human localization with respect to relative objects in the scene
- Sensor driven recording of the working environment and human factors

Project FactBox

Project Name WorkIT
Project ID DP 1.1
Duration 39 Months

Area 1
Perception and Aware Systems

Project Lead
Prof. Dr. Alois Ferscha

APPROACH

Data Collection

Sensor Data Acquisition
Various sensor sources optimized for application scenario:

Depth Sensor

Bending Machine

Processing

Depth Sensor preprocessing *E.g. object detection using segmentation or bounding box*

Scene Analyzing
Human, Computer, Machine, Tool Table, Bending Area, Computer Area, …

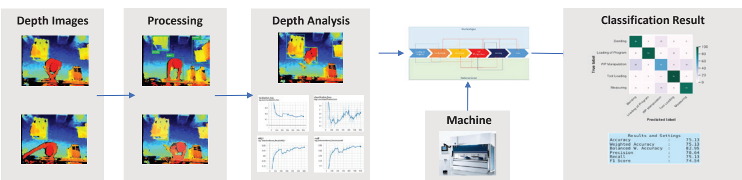
Classification

Depth Sensor specific classification *E.g. human in bending area, human in computer area, …*

Bending Machine specific information
PROGRAM_LOADED, UPPER_TOOL_CLAMP, FOOT_SWITCH_PRESSED, …

System Final Classification
Combination of both classes from previous sensors

PROTOTYPE



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184), Fronius, KEBA, Wacker Neuson and Trumpf.

AUTOMATED PROCESS DEVIATION DETECTION

Human-Intensive Assembly Processes

Based on indirect and incomplete shopfloor observations

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MOTIVATION & GOALS

- The move towards high customizable products in small lot sizes at the costs of mass production.
- **Assembly workers** remain an **integral part** of production systems assuring flexibility on the shopfloor. They perform subtle **optimization techniques** to overcome minor disturbances on the shopfloor.
- It is necessary to **monitor** the production process for **timely detection of deviations**.
- Legal regulations and union policies often limit the use of sensors for direct observations of human activities.
- Assembly process monitoring needs to rely on **indirect and incomplete observations** from the shopfloor

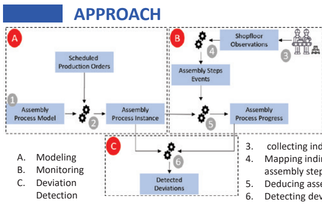
Project FactBox

Project Name A2PS
Project ID MFP 2.5-1
Duration 21 Months

Area 2
Cognitive Robotics & Shopfloors

Project Lead
Dr. Christoph Mayr-Dorn

APPROACH



1. Modeling the assembly process , needed resources and layout with variability features
2. Instantiating the process for a particular product variant
3. collecting indirect shopfloor observations
4. Mapping indirect shopfloor observations to assembly step events
5. Deducing assembly process progress
6. Detecting deviation based on the prescribed process

A. Modeling
B. Monitoring
C. Deviation Detection

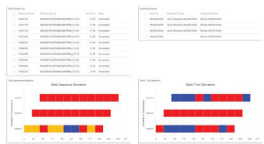
CONTRIBUTION

Scientific contribution
A flexible modelling approach for human-intensive assembly covering assembly layout, resources and assembly processes in all variants.
A privacy-respecting monitoring and deviation detection approach based on indirect and incomplete observations from the shopfloor

Economic contribution
An insight on the assembly progress on the shopfloor and a deviation analysis cloud dashboard based on privacy-respecting shopfloor observations.

RESULTS

- Evaluated based on **real assembly data** from our industry partner Wacker Neuson
- Using Part Picking events as indirect observations, our approach is able to predict step completion times for key steps accurately within **1,12% of the assembly tact time**.
- We correctly identify **89%** of the **delaying steps, 71%** of the **delaying stations**.
- The approach is able to detect the sequence deviations with the error of **0.07** for one station and **0.33** for another (depending on the station's flexibility and constraints)



A Fabasoft cloud dashboard summarizing the daily scheduled processes progress and the detected deviations (sequence deviations, delaying steps and delaying stations)

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184), Wacker Neuson GmbH and Fabasoft.

Flexible Production based on OPC UA

Making Production Machinery ready to fit into the next generation of shopfloors

Pro2Future

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MOTIVATION & GOALS

Manufacturing faces a clear trend towards **customized mass production**, that is **series production** of rapidly changing **variants** of a specific product, down to **lot size 1**. In addition, the pressure to **innovate** products leads to **shorter** production **life cycles**, together with changing production process and plant layouts. These two trends are to be met in the future by production machinery, which

- accepts **changes** to the production **sequence** online
- works as an **autonomous** unit
- embraces **reconfiguration** to adapt to new plant layouts

Project FactBox

Project Name APS.net
Project ID DP2.1-1
Duration 39 Months

Area 2
Cognitive Robotics & Shopfloors

Project Lead
Prof. Dr. Alexander Egyed

APPROACH

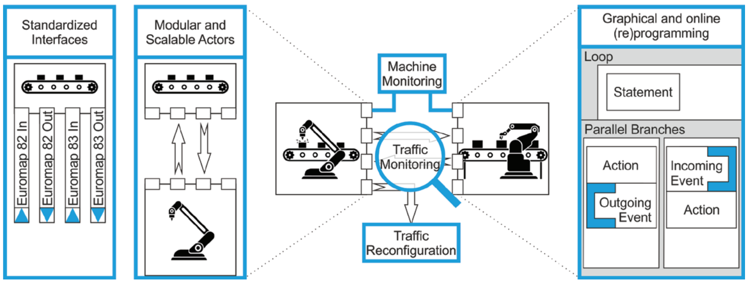
OPC UA is the **protocol** standard for machine-to-machine **communication** in Industry 4.0.
Its structured nodeset allows detailed models that are readable to other machines.
Abstracting from machine functionality to **capabilities** provides a unified environment for machines.
Mappings between capabilities provide and internal functions **decouple** interface and implementation.
Reconfiguration is possible at the mapping layer.

CONTRIBUTION

Scientific contribution
Publication of architectures for cyber physical production systems at European Conference on Software Architectures (ECSA2019)
Publication of a framework for capability-based control at Emerging Technologies in Factory Automation (ETFA2020)

Economic contribution
Shorter Time-To-Market
Support for Debugging
Prevention of Errors leads to quicker Set-Up/Reconfiguration
Cheaper Development by Reuse of Components

RESULTS



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Engel Austria.

COGNITIVE LINE BALANCING SUPPORT

Based on Similarity Detection and Prior Data

Pro2Future

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MOTIVATION & GOALS

- Assembly line balancing is a **complex** and **time-consuming** process
- Experts rely on **tacit** knowledge of **prior balancing solutions** and assembly **requirements** (tasks dependencies, resources availability, etc.)
- **Explicitly modelling** all dependencies is not only a **very costly** (because time consuming) task but also **quickly outdated**.
- Instead, our goal is to rely on **prior balancing solutions** to find **similar situations,** and produce a baseline balancing solution

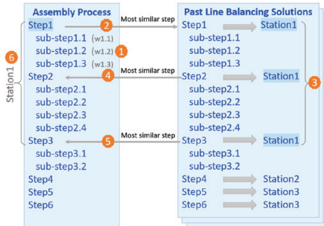
Project FactBox

Project Name LineTACT
Project ID MFP 2.5-2
Duration 24 Months

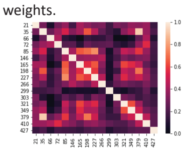
Area 2
Cognitive Robotics & Shopfloors

Project Lead
Dr. Christoph Mayr-Dorn

APPROACH



Related steps are clustered together based on structural similarity calculations with accorded weights.



A heatmap portraying the similarity calculated between steps.

CONTRIBUTION

Scientific contribution
A novel approach for Line Balancing Support reusing prior balancing solutions for different products and extracting similarities.

Economic contribution
This approach will considerably reduce the time and effort currently invested by manufacturing assembly companies, including our industry partner Wacker Neuson, to initially balance new product processes and rebalance existing processes.

PROTOTYPE

- Creates a baseline balancing solution after applying a set of similarity metrics
- The solution can then be refined by the experts
- Station recommendations can be requested for individual steps
- Grouping of related steps (based on the similarity metrics) and allocation to the recommended station
- Warnings are raised in case the new allocation violates some implicitly learned step dependency.

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184), Wacker Neuson GmbH and D-MTM.

ConMon

Anomaly Detection on Cyclic Industrial Sensor Data

Pro2Future

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MOTIVATION & GOALS

- Huge amounts of (timeseries) data are generated in durability tests of engines
- Each test in divided in multiple cycles
- In each cycle, hundreds of sensors measure different signals: multivariate timeseries
- These data can be used to analyse/predict the condition of the engines
- E.g., to identify anormal behaviour in advance to avoid unplanned breakdowns
- To support engineers with the analysis, we provide an interactive visual analytics tool for anomaly detection in multivariate timeseries data

Project FactBox

Project Name ConMon
Project ID MFP 3.2.2
Duration 36 Months

Area 3
Cognitive Decision Support

Project Lead
Dr. Belgin Mutlu
Prof. Dr. Tobias Schreck

APPROACH

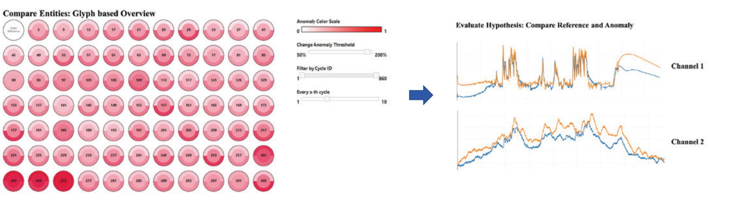
- Interactive visual analytics tool which combines several anomaly detectors
  - regression-model-based
  - causality-based
  - correlation-based
- Glyph-based approach enables the exploration of anomalies in cyclic data
- Interactive labelling through a user interface captures engineers domain knowledge for further processing

CONTRIBUTION

Scientific contribution
- Applied research in anomaly detection on real life testbed data
- Multiple user studies and design studies with the domain experts
- 1 accepted paper, 3 papers to be submitted

Economic contribution
Our user study with the domain experts has revealed the effectivity and efficiency of our tool for in a real life setting.

PROTOTYPE



Exploration of Anomalies in Cyclic Multivariate Industrial Time Series Data for Condition Monitoring

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and AVL List GmbH.

DEFCLAS & EPCOS

Advanced Defect Classification Preparation & Ex-Post Analysis

Pro2Future

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MOTIVATION & GOALS

- **Automatic optical inspection** (AOI) in **semiconductor industry** is an extremely important and demanding task for detecting significant errors on the **wafer fab process** within the Quality Process Control pipeline.
- **Yield deviations** can more seamlessly identified and engage the engineers to locate the exact source of error with the numerous complex process steps.
- With the advanced analytic techniques (e.g. **Deep Learning**) as well as **parallel computing** (deployment of GPU servers) it is possible to **classify** and **label** the **errors** on the **chip surface** by feeding large **images datasets** to Neural Networks

Project FactBox

Project Name EPCOS/DEFCLAS
Project ID MFP3.1-1/-2
Duration 12 Months

Area 3
Cognitive Decision Support

Project Lead
Prof. Dr. Stefan Thalmann

METHOD

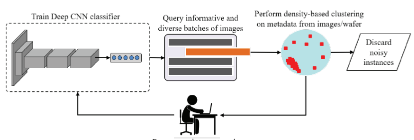
- Extract chip images with the defect centered
- Identify the relevant parts of the images
- Apply methods to analyze whether the chip images contain the appropriate context in terms of defect structure
- Propose an iterative active learning framework of a convolutional neural network to classify defects

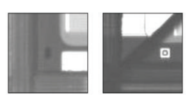
CONTRIBUTION

Scientific contribution
- 1 scientific publication accepted
- 1 scientific publication under review

Economic contribution
- A specially designed convolutional neural network for defect classification in a real wafer fabrication site
- Less effort and time is required by the process engineer for labelling the defect images

SYSTEM ARCHITECTURE





Sample images of two types of chip defects

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and EPCOS TDK.

GuFeSc

A Multi-Component Systems Perspective towards Predictive Maintenance

Pro²Future

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MOTIVATION & GOALS

As a result of a large number of product **variants and options**, optimal maintenance and support is **challenging**. To provide a **high quality** of support for all products, it is required to **invest considerable time** by humans involved in all different product stages (testing, maintenance, repair etc.). This is as cost intensive for the manufacturer as it is cumbersome for the worker. This leads to the need of new promising approaches, such as a **Multi-Component Systems (MCS)** perspective toward **predictive maintenance**.

- Cognitive decision support for welding systems
- Data-Driven Predictive Maintenance
- Challenge of high variety of components and options to combine them
- Analysing the interdependencies of variants

Project FactBox

Project Name GuFeSc
Project ID MFP 3.2-1
Duration 39 Months

Area 3
Cognitive Decision Support

Project Lead
Dr. Patrick Ofner

APPROACH

Fully data-driven approach which follows four different phases:

- Pre-processing, data exploration, and feature engineering
- Trend Detection, Change Point Detection, Pattern Recognition, and Modelling Interdependencies
- Predictive Model (RUL and Confident interval estimation)
- Model interpretation (xAI)

CONTRIBUTION

Scientific contribution

- "Cognitive Decision Support for Industrial Product Life Cycles: A Position Paper." COGNITIVE 2019
- "Taking complexity into account: A structured literature review on multi-component systems in the context of predictive maintenance," EMCIS 2019.
- "How to deal with missing usage data in defect prediction? A case of a tool supplier in the welding industry", HICSS 2021

Economic contribution

- Improved Finale Test System
- Better products, higher reliability, less costs
- Improved end products performance & usability
- Less costs and better performance of workers (decision support for works)

SYSTEM ARCHITECTURE

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Fronius International GmbH.

OnDaA

On-line Predictive Analytics In Continuous Casting

Pro²Future

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MOTIVATION & GOALS

Identification of correlation based on process parameters

- Pattern extraction from time series
- Classification model for predicting dynamic phenomena from mold level fluctuation sensors
- No labelled cases available
- Visual analytics on large streams of time-series data

Project FactBox

Project Name OnDaA
Project ID MFP 3.1-3
Duration 23 Months

Area 3
Cognitive Decision Support

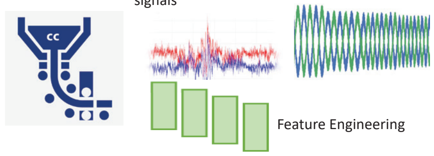
Project Lead
DI Heimo Gursch

APPROACH

Continuous casting

Mold level fluctuation signals

Synthetic Data

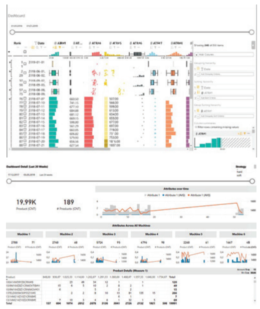


Feature Engineering

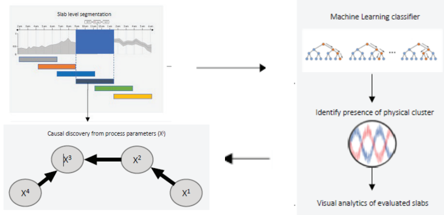
CONTRIBUTION

Scientific contribution
Identified specified phenomena and their influence on each slab
Forecast intensity of critical phenomena within each slab
Development of visual analytics application in Microsoft Power BI
Development of custom visual for exploring ranking of items based on a set of heterogeneous attributes

Economic contribution
Delivered a fully functional visual analytics prototype for gaining insights into the process
Through our predictive analytics tool downtime or shutdown of the process can be prevented and even eliminated



ANALYTICS FRAMEWORK



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and voestalpine Stahl GmbH.

RedUsa

Visual Data Analysis of Production Quality Data for Aluminium Casting

Pro²Future

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MOTIVATION & GOALS

- Demand for high-quality material in aluminum products
- Manufacturing industry is shaped by the vision of Industry 4.0 which is to increase the number of individual goods while keeping the cost and the production time at a minimum
- Increasing the production quality comes at the cost of continuous monitoring and adjustments of the entire process
- The development of new methods and tools to support domain experts in production data exploration and identify meaningful relationships and patterns, which could help to better understand such complex processes and define methods to improve the quality of the production process
- Advanced Visual Analytics for quality and yield improvement

Project FactBox

Project Name RedUsa
Project ID MFP_3.1
Duration 36+3 Months

Area 3
Cognitive Decision Support

Project Lead
Dr. Belgin Mutlu

APPROACH

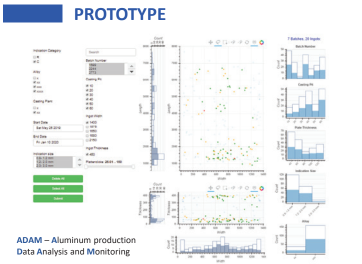
- Development of visual data analysis tools to support exploration and detection of patterns in large data, enabling e.g., production engineers to identify opportunities for process improvements
- Supporting data production analysis in an interactive way, supporting the search for dependencies and patterns in data with different analytics approaches

CONTRIBUTION

Scientific contribution
Visual data analysis approaches promise innovative and valuable insights into a complex and long-running production process. Identifying methods and models in real production datasets and gaining reliable knowledge from data leads to process improvement.

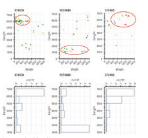
Economic contribution
Identifying the production parameters which influence the production quality and recognition of specific patterns that may indicate critical process deviations in the early stage of aluminum casting will increase product quality and production yield.

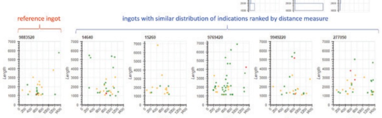
PROTOTYPE



ADAM – Aluminum production Data Analysis and Monitoring

The purpose of ADAM is to help monitor, analyze and determine influence parameters in the production process with interactive cross-filtering, followed by multiple views of production data. The tool supports data exploration and visual comparison, enabling users to gather information concerning detecting special patterns, distribution of indication and correlation with process data.





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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and AMAG GmbH.

SINPRO

Predictive Maintenance for Production Environments Application on Sinter Machines

Pro²Future

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MOTIVATION & GOALS

- **SINTERING** is a process with **significant energy consumption** in the steel and iron production process.
- Nature of main drivers of research efforts is mostly **economical** but often **environmental** and **regulatory**.
- Due to the increasing pressure to **reduce conversion costs**, the iron- and steel-making industry is continuing the efforts to **optimize the production** and the processes.
- **Use case 1:** Understanding **influence parameters** for optimizing the harmonic Diameter
- **Use case 2: Optimizing the BTP** towards the end of the sinter strand

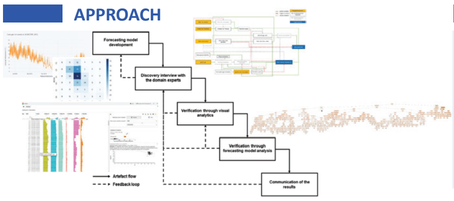
Project FactBox

Project Name SINPRO
Project ID MFP 3.1-5
Duration 27 Months

Area 3
Cognitive Decision Support

Project Lead
Dr. Belgin Mutlu

APPROACH



CONTRIBUTION

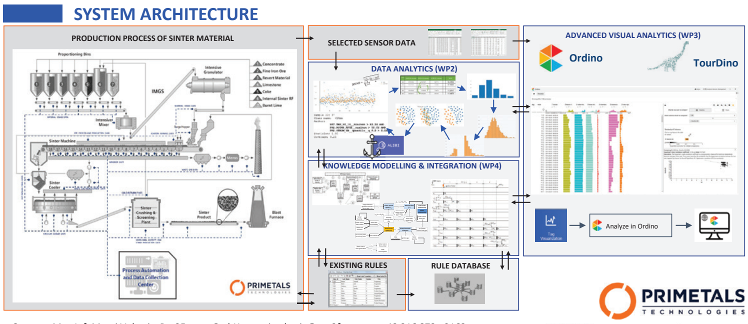
Scientific contribution

- ML based forecasting model
- Verification of the model and correlation information through visual analytics
- Automatic strand speed control for optimizing the concentration of BTP around the BTP setpoint

Economic contribution

- Gained insights from the production process
- Delivered fully functional visual analytics prototype for better insights into the process data
- Improved approach for the process control

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Primetals Technologies Austria GmbH.

SUPCODE

Supporting Cognitive Decision Making

Pro²Future

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MOTIVATION & GOALS

Industry 4.0 as the "fourth industrial revolution"

- fully **automatizes** the **production**
- **optimizes** the **collaboration** of **workers** and **machines**
- Using different helping operators e.g., **decision support assistance systems**

To support **human decision making**, we define the following objectives:

- Combine data-driven approaches, configuration management methods & simulation environments for a **reliable**, **trustworthy (data) basis** for decision making
- Provide decisions to **humans** considering their **cognitive capabilities,** context and **situation** (e.g., within production process versus design process) in order to ensure timely and optimal decisions.
- Provide a secure connection (**Secure Data Transmission**) to the system

Project FactBox

Project Name SUPCODE
Project ID StratP 3.4.1
Duration 36 Months

Area 3
Cognitive Decision Support

Project Lead
Dr. Belgin Mutlu

APPROACH

- Define methods for integration of model-based and data-based approaches into a **hybrid system**
- Define methods for **personalize** and **contextualize** decision making for timely and optimal decisions
- Application of data **transmission security** in decision support assistance systems to protect company data
- Definition **visual- and data analytics** methods to support **transparency** in decisions made by decision-support systems

CONTRIBUTION

Scientific contribution

- 13 scientific publications
- Scientific collaboration with University of Utah, University of Vienna, FH St. Pölten
- Extensive state-of-the-art analysis on how to analyze interaction provenance data
- Definition of design guidelines for guidance approaches

Economic contribution

- Secure data transmission of company data
- Open black-box AI for Industry
- New insights about application possibilities of data- visual analytics methods in industrial applications

OUTCOME

- A data analytics tool which **adapts** the **information space** to what the **user prefers** and **needs**
- **Interactive** data **classification** and **comparison** methods for **high-dimensional data** analysis
- Concepts for user **guidance** in complex visual data exploration applications
- Visual Analytics tools allowing users to statistically confirm **visual patterns**
- A **hybrid approach** which combines **data-driven approaches** with **simulation approaches** to determine the impact of changed configurations on the production systems
- Proposal for a **distributed parallel algorithm** (Distributed PrePostPlus) to utilize the computational power of **multi-core CPUs** used in complex machines
- A **secure data connection** framework

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184).

Cognitive AVL – Smart Development

Integrated Product Lifecycle Knowledge in Complex Industrial Processes

Pro²Future

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MOTIVATION & GOALS

Each of the wide variety of **processes**, that are performed along the **product lifecycle yield information**. In the future this information can be utilized to **extract valuable insights** about the **product and the production process**, as:

- Data enriched with **context information** (relevant metadata) enables **efficient interpretation** thereof,
- Well-interpreted information is relevant for **process optimization**,
- A model-driven approach enables the **extraction of useful knowledge** from data,
- Analysis and good interpretation of **hidden knowledge** can turn it into **accessible, monetizable knowledge**.

Project FactBox

Project Name Cognitive AVL
Project ID MFP 4.1.1-1
Duration 36 Months

Area 4.1
Cognitive Products

Project Lead
Dr. Konrad Diwold

APPROACH

Store information:
- contextual information about product and processes,
- processes generated information.

Semantic Web

Process data using data analysis, context-specific reasoning and AI planning algorithms.

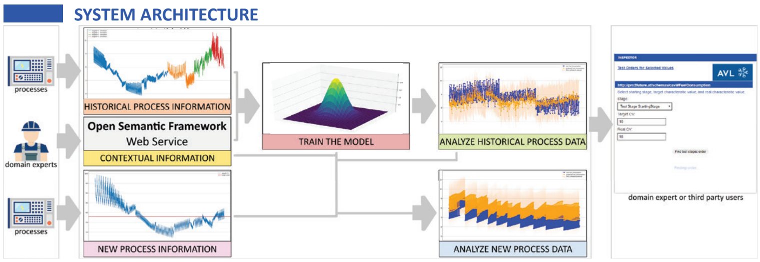
Develop the framework which enables access to knowledge to domain experts/different third parties.

CONTRIBUTION

Scientific contribution
This project will result in novel approaches to extract knowledge over the product lifecycle.
A paper *Enabling Knowledge Management in Complex Industrial Processes Using Semantic Web Technology* is published at TAKE 2019.

Economic contribution
Our work will enable turning hidden knowledge into accessible knowledge that will help optimising industrial production processes. It will combine contextual information (domain constrains) with process knowledge.

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184), AVL List GmbH and Hochschule St. Gallen.

CONVENIENCE

Cognitive building automation infrastructure and services

Pro²Future

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MOTIVATION & GOALS

- **Home automation** is a growing market, gaining more and more importance in our life's
- HMI-Master GmbH successfully started its business 8 years ago and aim for
  - staying **competitive**
  - further advancing in technology and the improving **maturity level** of products
- The project aims for elevate existing solutions towards leverage state-of-the-art regarding **security, software architecture** and **infrastructure**.
- In addition the project investigates how **IoT** communication protocols and devices can further enhance the technology stack and service portfolio of HMI
- Research is conducted in the context of **real use case** scenarios (e.g. apartments or offices)

Project FactBox

Project Name CONVENIENCE
Project ID MFP 4.1.3-3
Duration 12 Months

Area 4,1
Cognitive Products

Project Lead
Dr. Konrad Diwold

APPROACH

- Utilizing open-source frameworks in the context of HMI's home automation
- Redesign of **communication interfaces** and **protocols** to enable dependable communication within the system
- Investigation of further benefits to be achieved with the application of **wireless communication** in the context of intelligent home automation systems and services

CONTRIBUTION

Scientific contribution
The scientific contributions of the work in CONVIENCE are experiments of state-of-the-art technologies on real use cases and to investigate the applicability in open-source frameworks and HMI hardware.

Economic contribution
As an economic contribution, upgrading the products of HMI by state-of-the-art and novel technologies can increase their competitiveness in the national, but also international market. Also, the reliability of their products can profit through our work.

SYSTEM ARCHITECTURE

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and HMI masters.

COGNITIVE SMART GRIDS

Dependable Wireless Communication Solutions for Smart Grid Operation

Pro²Future

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MOTIVATION & GOALS

- **Deploying substation equipment** is a **complex** task, which often requires a lot of **configuration** and **engineering effort**
- **Smart grid automation features** usually depend on **communication**, a change in **connection quality** requires an **adaption of functionality/communication**

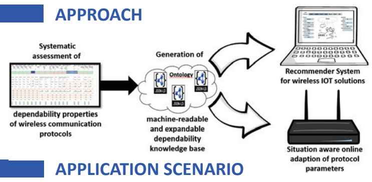
Project FactBox

Project Name CSG
Project ID MFP 4.1.3-2
Duration 12 Months

Area 4.1
Cognitive Products

Project Lead
Dr. Konrad Diwold

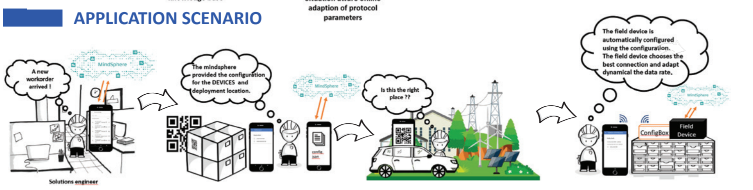
APPROACH



CONTRIBUTION

Scientific contribution
Within the project new methods for **adaptive wireless communication** are developed, which minimize engineering efforts while providing **dependable communication** for **system critical automation systems**
Economic contribution
For our partner SIEMENS this will result in **dependable** and **reliable communication** for their **substation automation solutions**.

APPLICATION SCENARIO



1: Worker get a workorder which he/she must complete

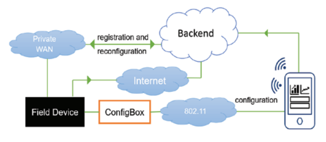
2: Worker search the proper device and scan the UUID and get the proper configuration

3: Worker drive to the substation and verifies the location

4: Worker install the FD at the substation and configure the Device with the configuration he/she got

SYSTEM ARCHITECTURE

The system consists of a **Backend**, a **Field Device**, a **ConfigBox** and a device which content the configuration (e.g. **Smartphone**). The **Field Device** is in general a Black Box with **different communication interfaces**, which **provides the dependable communication** of the substation. The **ConfigBox** is the device with which the Field device will be configurated. And the **Smartphone** is used to get **configuration parameters** from the Backend to the Field Device over the ConfigBox.



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Siemens AG Austria.

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DRIWE

Dependable RF Communication Systems for In-Car Wireless Sensors

Pro²Future

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MOTIVATION & GOALS

- Dependable reliable wireless communication the goal of any sensor-based system
- Wireless systems are very difficult to implement in certain environments
- Attain **reliable** wireless communication systems in **harsh environments**
- Systems can be **tailored** and **automated** towards specific harsh application environments
- Use accurate **EM simulation models** to estimate wireless communication parameters
- Achieve a **high reliability** and **throughput** based on simulations
- Validation of simulated data in **real environments**
- Software **tool** that gives **parameter recommendations** for each individual scenario

Project FactBox

Project Name DRIWE
Project ID MFP 4.1.3-1
Duration 36 Months

Area 4.1
Cognitive Products

Project Lead
Dr. Konrad Diwold

APPROACH

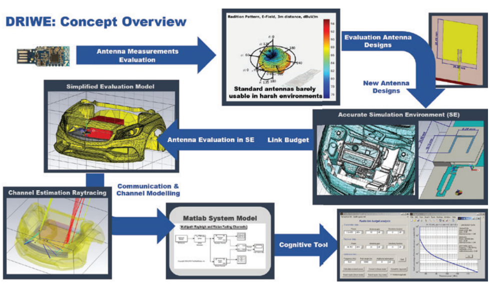
Evaluation of existing systems and components by measurements and simulations
Verification of results in real testbeds (demonstrator setup & engine compartment)
Implementation of a Matlab/Simulink model to simplify the whole calculation process
Creation of a **cognitive tool** with generated results

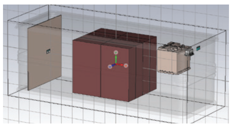
CONTRIBUTION

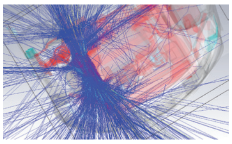
Scientific contribution
Development of new methods to optimize a wireless communication system and all the required parameters in a harsh environment. The methods are applicable for a wide range of industrial applications.

Economic contribution
The resulting cognitive tool will enable technicians to pick the best components and positions for wireless communication systems without the requirement of additional expertise.

SYSTEM ARCHITECTURE




Simulation setup of the demonstrator box


Raytracing applied in an engine compartment model

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and AVL List GmbH.

SIMATIC FAILSAFE 4.0

Predictive Failsafe: Improving the Safety of Industrial Environments

Pro²Future

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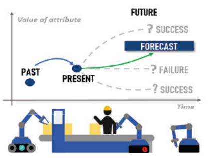
MOTIVATION & GOALS

- **Flexible and intelligent automation environments** feature the **seamless collaboration of workers and machines**
- Traditional (static) fail-safe concepts are not suitable for such dynamic environments
- Developing of novel **"data-driven" predictive fail-safe** concepts allow to **detect and prevent faults** in dynamic production environments.
- **This** improves the **safety and** increases **maintainability, availability** and **reliability** of the automation system.



Project FactBox

Project Name Simatic Fail-Safe
Project ID MFP 4.1.2-1
Duration 36 Months

Area 4.1
Cognitive Products

Project Lead
Dr. Konrad Diwold

APPROACH

- **Identify data sources** which may contribute to maintainability, availability, reliability and safety!
- **Apply** advanced **analytics** to data obtained from the system (data analysis, predictive features…).
- Together with industrial failsafe devices **create predictive failsafe systems**.
- Predictive failsafe systems are able to **mitigate or prevent failures.**

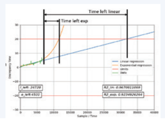
CONTRIBUTION

Scientific contribution
By exploring safety-critical devices we collected a lot of safety - relevant data that can be processed and analysed. Different algorithms are developed and applied to safety-related data in the goal to improve existing safety architectures.

Economic contribution
Reliability, maintainability, and availability are increased, thus reducing the costs and making maintenance easier. In addition, the predictive component allows the provisioning of new services and unique intelligent features for future automation systems.

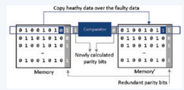
SYSTEM ARCHITECTURE

Input/Output decision support:
- Discrepancy time
- Read-back time
- ADC instability



Temperature analysis :
- Change point detection
- Prediction
- Gradient

Memory management:
- Redundant Parity
- Just-in-time



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Siemens AG Österreich.

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ASP 2 – Adaptive Smart Production 2

Fuel-Cell Components Assembly & High-Speed Bearing System Improvement

Pro²Future

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MOTIVATION & GOALS

This project deals with two use-cases, fuel-cell component assembly and high-speed bearing system improvement, and has following goals:

- To develop **innovative fuel cell designs** enabling production cost decrease and performance increase
- To **adapt production line** for high-voltage battery assembly and fuel cell stack assembly
- To **investigate the influence of manufacturing and assembly tolerances** on the bearing system behavior, e.g. noise, vibration, harshness, load-based bearing system temperature and the testbed behavior in general
- To investigate the general conditions and new opportunities to use the **classification algorithms based on image data** in the field of testbed monitoring combined with mechanical measurands.

Project FactBox

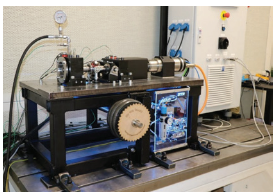
Project Name ASP 2
Project ID MFP II 4.2.3-2
Duration 36 Months

Area_4.2
Cognitive Production Systems

Project Lead
Dr. Markus Brillinger

APPROACH

Developed testbed for investigating the **influence of manufacturing and assembly tolerances** on high-speed bearing system behaviour.



CONTRIBUTION

Scientific contribution
What is the impact in terms of production tolerance to reduce production costs?

Economic contribution
How to optimize fuel cell design for efficient production?
How to adapt existing production lines to follow market uptake?
How far production processes from other domains can be used for fuel cells systems?

OUTCOME / EXPECTED RESULTS

Considering the use-case fuel-cell component assembly, innovative fuel-cell designs (based on design for efficient assembly), which enables a **decrease in production costs** will be developed. Furthermore, a strategy for **production line adaptation** for high-voltage battery assembly, fuel cell assembly, e-motor and fuel-cell can be derived.

Considering the use-case testbed and test procedures for high-speed bearing systems for electric powertrains systems, a beyond state-of-the-art testbed will be developed to investigate the **influence of manufacturing and assembly tolerances** on the bearing system behavior. The generated data assists to optimize the assembly line towards increasing **quality and flexibility**. On the top of that, we will acquire knowledge about the conditions under which classification algorithms based on image data can be used combined with mechanical measurands.

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and AVL List GmbH.

Cognitive Polymer Extrusion & Compounding

Numerically and Experimentally Driven Analysis of Flow Instabilities in Multilayer Co-Extrusion

Pro²Future

Alexander Hammer[1], Wolfgang Roland[1], Maximilian Zacher[2], Bernhard Löw-Baselli[1]
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MOTIVATION & GOALS

Co-extrusion is a highly efficient process technology that allows **targeted combination** of individual polymeric materials within a **multilayer structure**. **Interfacial flow instabilities** are a typical **limiting factor** for the **maximum production rate**. Profound knowledge of **critical flow situations** offers possibilities in **optimizing die** and **process design**. The **goals** of this project are:

- Initiation and detection of interfacial flow instabilities under controlled flow situations
- Characterization of co-extrusion flow situations
- Identification of critical parameters causing flow instabilities and determination of their limiting values
- Implementation in co-extrusion flow simulations to predict critical flow situations

Project FactBox

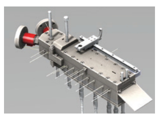
Project Name CoExCo
Project ID MFP 4.2.1
Duration 48 Months

Area 4.2
Cognitive Production Systems

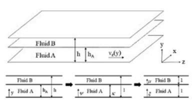
Project Lead
Mag. Bernhard Löw-Baselli

APPROACH

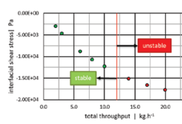
Co-extrusion Experiments → **Simulations** → **Data Analysis** → **Validation**



- Two-layer co-extrusion flow in demonstrator
- OCT / Ultrasonic sensor



- Velocity profile
- Interfacial shear stress
- Viscosity ratio, …

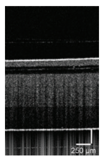


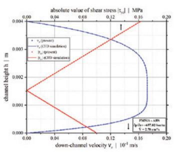
- Statistical analysis of experimental and simulation data

- Application of findings to multilayer products

RESULTS

- Co-extrusion **demonstration die** developed
- **Measurement system** to detect interfacial flow instabilities
- **Numerical solver** to evaluate two-layer co-extrusion die flows





CONTRIBUTION

Scientific contribution
Co-extrusion demonstration die
OCT and ultrasonic sensor technology
Numerical co-extrusion flow solver
Novel models for interfacial flow properties

Economic contribution
Expertise in co-extrusion process technology
Experience of critical flow situations
Material and equipment for model validation

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Soplar sa.

Cognitive Polymer Extrusion & Compounding

Model predictive control and disturbance observer for plastics extrusion

Pro²Future

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Motivation & Goals

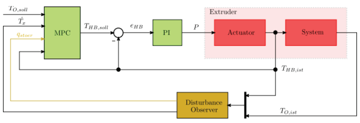
- Improve product quality: Estimate the temperature distributions within the extruder, as well as the heat flow between melt and barrel - Disturbance Observer based on precise process model
- Optimize the production process: Optimal control of the nonlinear heating system guarantees the required temperature distribution a mass flow - MPC (Model Predictive Control) for start up, as well as set point and material change.
- Improve the basic automation: Optimized algorithms for the implementation subordinate control loops

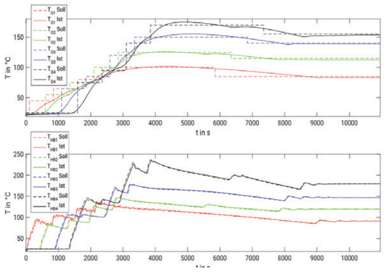
Project FactBox

Project Name CoExCo
Project ID MFP 4.2.1
Duration 48 Months

Area 4.2
Cognitive Production Systems

Project Lead
Mag. Bernhard Löw-Baselli



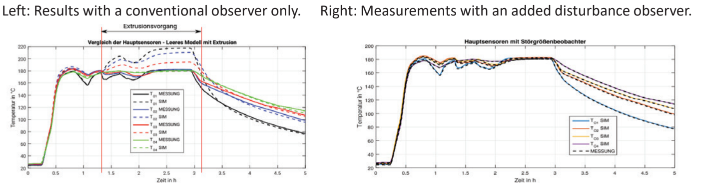


Simulation Results - MPC

The MPC's suitability was proven by several simulation Studies and lab tests (Results on the right). Reference trajectory were specified to check the MPC controller, which determined the optimal heating strategy. The plots compares the sensor values (T) of a production with simulation results.

Simulation Results - MPC with Disturbance Observer

Left: Results with a conventional observer only. Right: Measurements with an added disturbance observer.



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and soplar sa.

Cognitive Polymer Extrusion & Compounding

Hybrid Modelling of Pressure-Throughput Relationship for Kneading Blocks in Co-rotating Twin-Screw Extruders

Pro²Future

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MOTIVATION

- **Twin-screw extruders** are one of the most used machineries in **polymer processing**
- Co-rotating twin-screw extruders are typically **operated in starve-fed mode**
- **Back-pressure length** and **material distribution** are key process parameters
- **Kneading blocks** are commonly approximated **as conveying elements**

GOALS

- **Generalized Pressure-Throughput model for kneading blocks**
- For **various** commonly used **offset angles, diameter ratios, kneading disc sizes** and **undercuts**
- **Easy handling** of the model
- **Prediction of the material and pressure distribution** along the screw

Project FactBox

Project Name CoExCo
Project ID MFP 4.2.1
Duration 48 Months

Area 4.2
Cognitive Production Systems

Project Lead
Mag. Bernhard Löw-Baselli

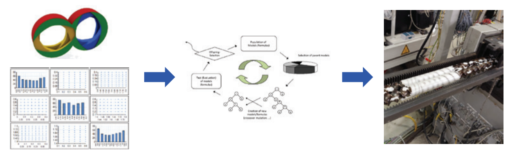
APPROACH

Dimensional Analysis | CFD-Parametric Study | Regression Analysis | Validation

$$\Pi_D = \frac{D_a}{D_s}$$

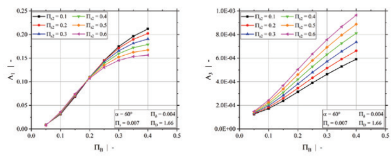
$$\Pi_{p/L} = \frac{D}{\eta N}\frac{\partial p}{\partial L}$$

$$\Pi_{\dot{Q}_{Diss}/L} = \frac{1}{D^2 N^2 \eta}\frac{\partial \dot{Q}_{Diss}}{\partial L}$$



RESULTS

- We developed symbolic **regression models** for the **dimensionless conveying parameters A_1** and **A_3**.
- Our models can be used for e.g. **screw design, digital twin, model based control** and **process optimization**.



CONTRIBUTION

Scientific contribution
Accurate Pressure-Throughput prediction of kneading blocks
All gap regions were taken into account
First valid modelling approach for non-conveying elements
Novel power consumption model for kneading blocks

Economic contribution
Geometry specifications
Material and Equipment for model validation
Expertise of the twin-screw extrusion process
Guidelines for the range of the parameters

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Leistritz Extrusionstechnik GmbH.

ENERMAN-1

Power Measurement Prototype via Laser Beam Deflection

Pro²Future

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MOTIVATION & GOALS

Injection molding and **extrusion** are the most common processing techniques in polymeric processing. Most of the **energy requirement** of these processes is **provided by the screw**. However, up to now, **no satisfying measurement technique** exists for measuring the **length-based torque** for single-screw extruders, which would provide profound insights for the process and can be used for **optimization**. Therefore, we developed a **laser beam deflection** screw torque measurement prototype and carried out a feasibility study.
Approached results:

- Very good agreement with the maximum screw torque given by the control system.
- New developed prototype for full axial measurement.

Project FactBox

Project Name Enerman-1
Project ID StratP 4.2.3
Duration 27 Months

Area_4.2
Cognitive Production Systems

Project Lead
Dr. Markus Brillinger

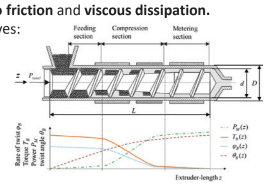
APPROACH

The screw drive power is **transferred** to the polymeric material, which is heated **due to friction** and **viscous dissipation.**
The torque balance gives:

$$T_S(z) = T_B(z)$$

$$T(z) = G \cdot I_P \cdot \varphi(z)$$

$$\varphi(z) = \frac{\partial \theta(z)}{\partial z}$$



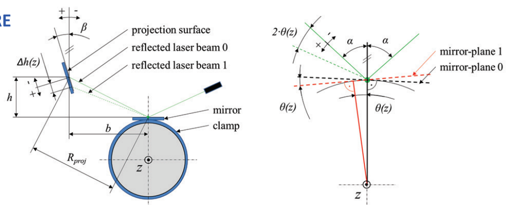
CONTRIBUTION

Scientific contribution
Investigation method for axial energy input of the extruder, which gives a better insight in the extrusion process.
Validation method for new extruder models and screw designs.
Scientific publication of the measurement principle submitted

Economic contribution
New screw designs or screw designs tailored to a specific problem.
More energy efficient process control due to additional process information.
New models for efficient process settings.

SYSTEM ARCHITECTURE

Rate of twist is determined by **measurements of twist angle $\theta(z)$** on different axial positions.
This is done by a laser beam, which is reflected by a mirror attached to the barrel. In case of a change of $\theta(z)$, the change of the mirror plane would deflect the laser beam.



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184).

SUPRA-1

Sustainable Production and Assembly Technologies in Future Production Systems

Pro²Future

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MOTIVATION & GOALS

High variances in electric power demand of a production site must be provided from power supplier and result in high electric power connection to the power grid. Machine downtimes and unproductive set-up time decreases the machine efficiency. Both is and cost factor in production sites which cannot be neglected.

The goal of this project is a holistic approach to **reduce variances in power demand** of production sites and **reduce machine downtimes** and finally **saving costs**.

Project FactBox

Project Name SUPRA-1
Project ID MFP II 4.2.2-1
Duration 4,5 Years

Area_4.2
Cognitive Production Systems

Project Lead
Dr. Markus Brillinger

APPROACH

ENGINEERING

Pro²Future

Objective Functions

$$C = T \cdot R_M + E \cdot R_E + PD \cdot R_{PD}$$

Constraints

$$PD = max\left\{\frac{1}{n+1}\sum_{i=0}^{n} P_i\Big|_0^{15min}\right\}$$

Solution

$$PD = P_b \pm \sqrt{\frac{E_{kin}}{R_{PD}} \cdot (R_M + P_b \cdot R_E)}$$

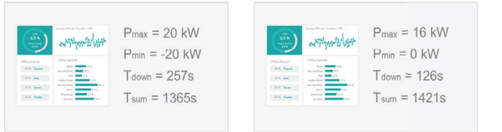
CONTRIBUTION

Scientific contribution

- 4 scientific publications planned
- Scientific collaboration with TU Graz
- Extensive state-of-the-art analysis on how to reduce energy consumption and power demand of production facilities
- New power smoothing algorithms

Economic contribution

- Smoothing power demand of production facilities
- Decrease in power grid volatility
- High cost saving potential
- Approach to Green Manufacturing



EVALUATION

Cost Saving Potential:

1.173 € p.a.

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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Fuchshofer Präzisionstechnik.

CRP: Cognitive Products

Common Research Programme: Demonstrator Project 1
Enabling direct interaction and data acquisition

Pro²Future

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MOTIVATION & GOALS

Bringing **cognitive intelligence** (Cognitive Human-Worn Devices) **closer** to the **human**:
- Human-Machine interaction based on implicit interaction
- Process and workflow-sensitive, embedded, accompanied assistance
- Assistance based on skill level
- Sensor selection according to work situation
- Multi-modal, direct, unobtrusive user feedback
- Digitalisation of analog production areas, semantical annotation of work area
- Battery powered wireless devices

Project FactBox

Project Name CRP DP1/SeeIT
Project ID DP1.2/MFP1.4
Duration 39 Months

Area 1
Perception and Aware Systems

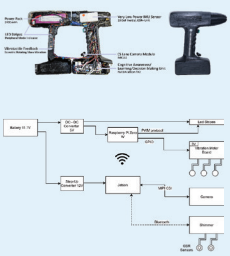
Area X
Common Research Programme

Project Lead
Prof. Dr. Alois Ferscha

PowerTool

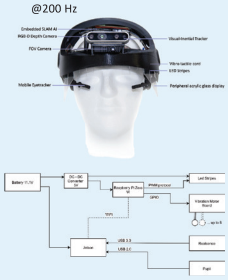
Drilling unit embedded with assistive intelligence driven by NVIDIA Jetson TX2 providing:
Multimodal user feedback:
- 18 individually addressable RGB-LEDs
- 3 individually controllable vibration motors

Sensors:
- IMX185 Camera 1080p@60fps
- Shimmer 9DOF inertial measurement sensor with GSR+ Unit



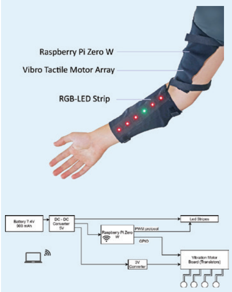
Cognitive Headgear

Head-mounted, cognitive assisting unit driven by NVIDIA Jetson TX2 embedding multimodal feedback and sensor data:
- Peripheral led stripes for minimal obtrusion
- 8 vibration motors evenly distributed around the head for haptic feedback
- Intel RealSense D435 RGB-D depth camera with 77° FOV
- High-speed mobile eyetracker @200 Hz



Cognitive Armsleeve

Low-cost, unobtrusive, lightweight, multimodal feedback unit embedding:
- 6 individually addressable peripheral led stripes
- 4 individually controllable vibration motors
- Adjustable for different arm sizes
- Powered by 900 mAh LiPo battery



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and Fronius, Wacker Neuson, KEBA and Trumpf.

CRP: Adaptive Production Systems

Common Research Programme: Demonstrator Project 2
A Joint Initiative with the Center for Digital Production

Pro²Future

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MOTIVATION & GOALS

Research in adaptive production systems supports production companies in Europe to be able to provide customized goods for local customers at low costs. Recent developments, in **Industrial Internet of Things**, and **Cyber Physical Production Systems**, require interactive machines. Interface technologies for interoperable systems-of-systems and engineering support is missing.
In addition to adaptivity on the shop floor, feeding production-process data analysis back into the automated design process will enable production process improvements in terms of production quality and cost.

Project FactBox

Project Name CRP DP2 / APS
Project ID DP2
Duration 48 Months

Area 2
Cognitive Robotics & Shopfloors

Area X
Common Research Programme

Project Lead
Prof. Dr. Alexander Egyed
Dr. Christoph Mayr Dorn
Dr. Georg Weichhart

APPROACH

A **Model-Driven Systems** approach has been taken, combining **flexible production planning** with a **work-flow and process based systems architecture**.

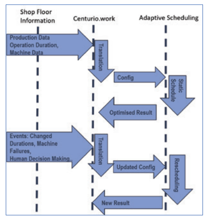
It combines an actor-based reactive scheduling system with the centurio.work process engine developed at the center for digital production (CDP).

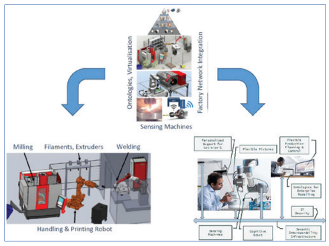
CONTRIBUTION

Scientific contribution
Computer Vision for Object Identification
Flexible Robot Control handling heterogeneous parts
Flexible Production Planning and Control for Re-Scheduling
Workflow-based Systems

Economic contribution
Automation of production for small lot sizes and / or parts with high variability supports Austrian Manufacturing SMEs in benefitting from automation.

SYSTEM ARCHITECTURE





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Acknowledgement: This work was supported by Pro²Future (FFG, 854184), PROFACTOR, CDP, and JKU.

CRP: Data Analytics for Industry

Common Research Programme: Demonstrator Project 3
Data Analytics for Industrial Process Improvement

Pro²Future

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MOTIVATION & GOALS

- Collect and analyze large amount of sensor data on manufacturing equipment in an Industry 4.0 environment
- Many manufactures are not yet able to use analytics beyond a tool to track historical performance
- Knowing what happened and why is not enough and does not exploit the full potential of the data: manufactures need to know what happens next and what actions to take in order to get optimal results
- Investigation of interoperability concepts of several smart factories to transfer novel concepts and technologies

Project FactBox

Project Name CRP DP3
Project ID DP3
Duration 48 Months

Area 3
Cognitive Decision Support

Area X
Common Research Programme

Project Lead
Prof. Dr. Christian Huemer

APPROACH

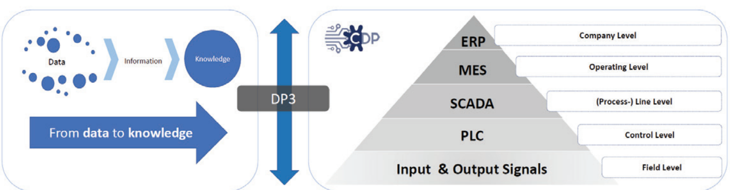
- Process-model-based visual analytics approach to analyse production data
- Visually highlighting interesting data points supporting engineers in their decision making
- Product quality prediction to optimize production process

CONTRIBUTION

Scientific contribution
The scientific contributions of the work on DP3 are manifold. Several concept, visual analytics and data analytics papers have been submitted and accepted in close collaboration with the colleagues from CDP.

Economic contribution
As an economic contribution the techniques applied in the pilot factory in Vienna offers an optimization of the production process. For example, the bottleneck quality control process can be skipped, if so forecasted by the data-driven quality prediction model.

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and CDP Center for Digital Production.

smartfactory@tugraz

3D-RECON

Novel 3D Reconstruction Methods
for 3D Models from Camera Shoots

Pro²Future

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MOTIVATION & GOALS

The goal is the **analysis, development and evaluation** from methods for high quality **3D reconstructions methods** by making use of **semantic information** and modern **machine learning methods**.
- Data driven Multi-View Stereo
  - View synthesis for Multi-View Stereo (MVS)
  - MVS without cost-volumne
  - Semantic (planar) bias for depth completion
- Data driven Structure-From-Motion

Project FactBox

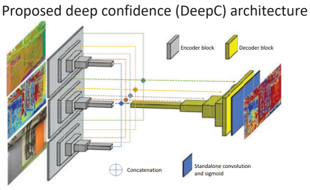
Project Name 3D-Recon III
Project ID MFP II 1.1
Duration 12 Months

Area 1
Perception and Aware Systems

Project Lead
Ass.-Prof. Dr. Fraundorfer
DI Michael Haslgrübler

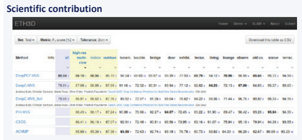
METHOD

Proposed deep confidence (DeepC) architecture

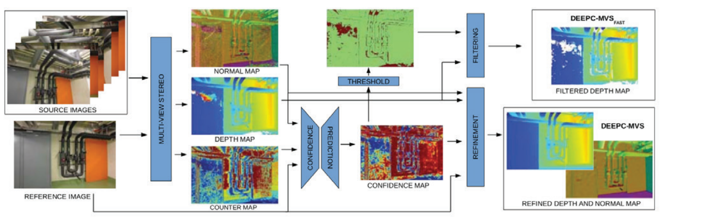


CONTRIBUTION

Scientific contribution



SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and Sony Europe B.V.

SONY

APECGR

Artificial Personality for Cognitive Guidance and Recommendation Systems

Pro²Future

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MOTIVATION & GOALS

- Improve **interaction** quality between worker and machine/arc welder
- Support arc **welder maintenance** for the worker
- Provide feedback **quality & guidance** through the welding processes

- Catalyze an **artificial personality** to enable adaptive communication
- Reveal **occuring problems** during the welding process
- Recommend **corrective actions** to the welder during the work process

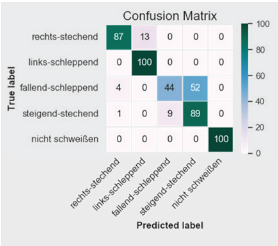
Project FactBox

Project Name APECGR
Project ID MFP II 1.2
Duration 36 Months

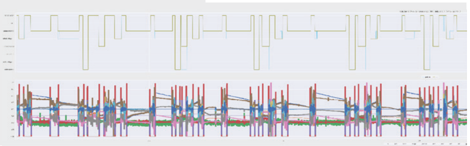
Area 1
Perception and Aware Systems

Project Lead
Univ.-Prof. Dr. Alois Ferscha

PRELIMINARY RESULTS



- Recognition of welding technique for workflow detection was well achieved.
- Results inform recognition of problems during welding process as well as provision of feedback.

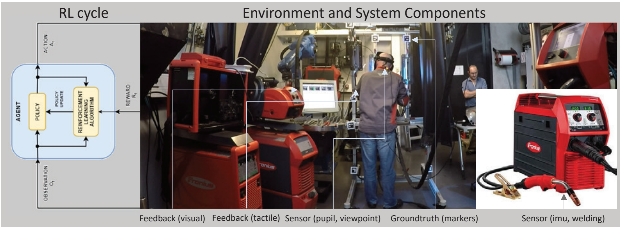


CONTRIBUTION

Scientific contribution
Skill level detection of industrial welders using IMU data

Economic contribution
Reinforcement learning to improve man-machine interaction
Feedback system via embedded actuators & screens

ENVIRONMENT & SYSTEM ARCHITECTURE



Observation:
Realtime multi-sensor data
Metadata derived from AI algorithms

Action:
Active interactions with arc welder
Active interaction with feedback system
Passive reactions to real time feedback

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and Fronius International GmbH.

Fischer4You2

Active Learning Alpine Skiing Activities for Cognitive Enhanced Skiing Products

Pro²Future

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MOTIVATION & GOALS

The aim of this work is to crowd source the **recognition of alpine skiing activities** on **body worn smartphones** with their respective **embedded IMUs**, which should provide

- Reliable detection of skiing activities
- Detection of Skiing Style
- **Skiing Skill Analysis**
- Communication of **Assessment feedback**
- Correction of Assessment by Providing Additional Information from Users
- **Causal Discovery** of Data Anomalies and User or Environmental Setting

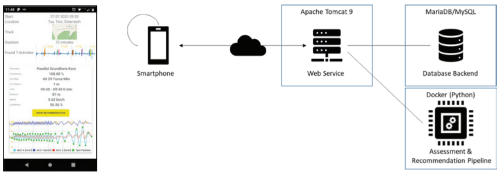
Project FactBox

Project Name Fischer4You2
Project ID MFP II 1.3
Duration 12 Months

Area 1
Perception and Aware Systems

Project Lead
DI Michael Haslgrübler

SYSTEM ARCHITECTURE

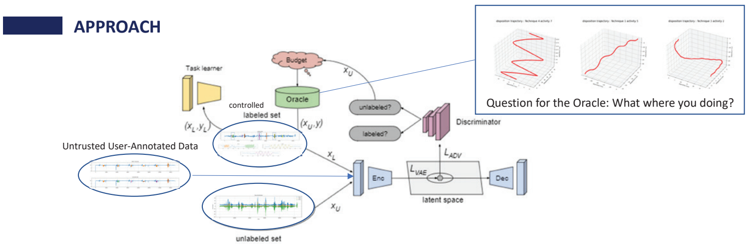


CONTRIBUTION

Scientific contribution
- Unsupervised Activity Recognition
- High Dynamic Technique Recognition
- Multi-Stage Filtering and Sensor Fusion
- Data-Driven Assessment Model

Economic contribution
- Consumer Information
- Costumer satisfaction
- Costumer binding

APPROACH



Adapted from: Sinha, Samarth, Sayna Ebrahimi, and Trevor Darrell. "Variational adversarial active learning." In Proceedings of the IEEE/CVF International Conference on Computer Vision, pp. 5972-5981. 2019.

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and Fischer Sports.

GUIDANCE FOR ASSEMBLY PROCESSES

Cognitive Worker and Tool Guidance for Assembly Processes

Pro²Future

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MOTIVATION & GOALS

- Recognition of **micro activities** e.g., Screwing detection in industrial processes
- Workflow detection and **Human Activity Recognition** for industrial scenarios
- Sensor driven recording of the **working environment** and human factors
- **Quality Control** of the manufacturing operation by providing guidance and support to novice workers in distracting or vague situations
- **Adaptive Model** based on personalized data (Retraining/Online)
- Omission of the necessity for labelling data

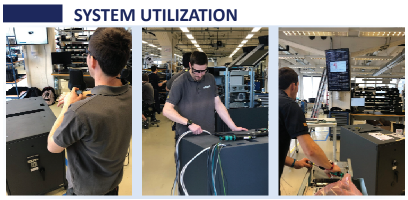
Project FactBox

Project Name GAP
Project ID MFP II 1.2
Duration 12 Months

Area 1
Perception and Aware Systems

Project Lead
DI Michael Haslgrübler

SYSTEM UTILIZATION

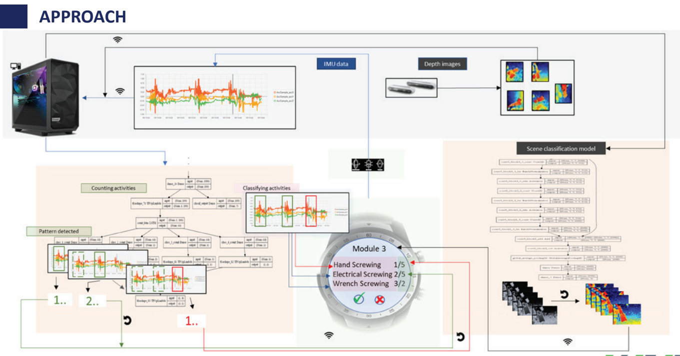


CONTRIBUTION

Scientific contribution
Development of a privacy preserving system that identifies macro\micro-activities. IMUs and depth camera sensors are integrated in our system for human activity recognition and workflow detection.

Economic contribution
- Reduce training time for novice workers
- Reduce the cost of rework for the companies
- Reduce the error detection time

APPROACH



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Acknowledgement: This work was supported by Pro²Future (FFG, 854184) and KEBA AG.

KEBA
Automation by innovation.

RAIL TRACK ERROR LEARNING

Supporting Railroad Maintenance with Cognitive Methods for Rail Track Error Learning

Pro²Future

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MOTIVATION & GOALS

The aim of this project is to support operators and managers of railroad maintenance machines by suggesting maintenance options during or after use.

- by **sensor data processing** and **feature extraction**,
- **machine learning powered data analysis**,
- **visualization techniques** supporting recommended actions and
- establish **knowledge** pool based on crowd sourced information from simultaneously working **multiple operators across the globe**

Project FactBox

Project Name RTEL
Project ID MFP II 1.2
Duration 36 Months

Area 1
Perception and Aware Systems

Project Lead
DI Michael Haslgrübler

APPROACH

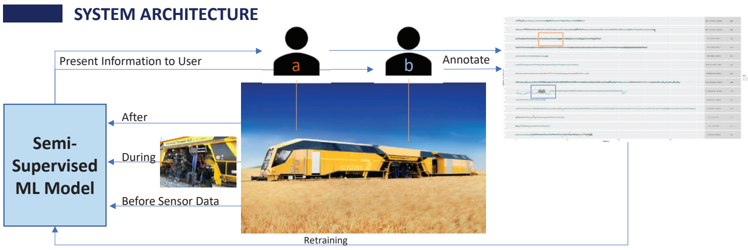
- Collect Sensor Data from Multiple Operating Stages of the Track
- Use Semi-Supervised ML (e.g. Deep VAE) for Distribution Analysis (within/outside norm)
- Prepare Data Visualisation and suggest recommended actions for Users
- Lets users use suggestion, correct actions or provide other form of feedback
- Provide Interaction information to ML for Retraining

CONTRIBUTION

Scientific contribution
- Unsupervised ML for Error Spotting
- Multi-Stage Filtering and Sensor Fusion
- Multi-Layer Active/RL Learning

Economic contribution
- Railroad Maintenance Cost Reduction
- Costumer Binding and Support
- Data Driven New Business Model

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and System 7 Rail Support.

CoSma

Product and Production Cosimulation for Smart Manufacturing

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Project FactBox

Project Name CoSma
Project ID MFP II 2.2
Duration 30 Months

Area 2
Cognitive Robotics and Shop Floors

Project Lead
DI Michael Mayrhofer

MOTIVATION & GOALS

Production of **complex products** requires many production steps. Detection of **deviations** t in early production steps and **prediction** of their impact on final **product quality** are key enablers to **skip obsolete work** on semi-finished, already broken products. Also, if possible, it is easier to fix problems by **reworking** directly after the deviation happened.

Following the main goals of the project
- Integrate several flows of measurement data
- Learn relationship between measurements and product quality
- Define and calibrate estimation models used for quality prediction
- Integrate quality prediction into production workflow

APPROACH

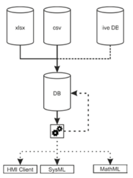
Measurement data is stored to a single data warehouse to guarantee uniform access.
Machine learning, as well as statistical measures are employed to identify relations between measurement data and product quality.
Discovered **relations** are calibrated using numeric measurements to create a model for product quality in continuous space.

CONTRIBUTION

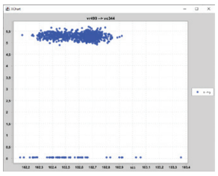
Scientific contribution
- Comparison of numeric methods against machine learning
- Combined use of mathematical modelling and machine learning
- Comparison of quality measures
- Use case for quality prediction

Economic contribution
- Feed-forward estimates allow to optimize testing schemes
- Feed-back to stations allows to deal with quality drifts
- Higher throughput und First-Pass-Yield
- Increased preservation of raw material

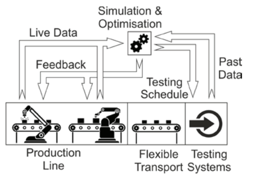
ONE FRAMEWORK ...



...to host measurement data



...to process data and visualise results



...to integrate evaluations with production

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844), JKU-ISSE, PROFACTOR, and Fronius.

COGNITIVE LINE BALANCING SUPPORT

Recommending Assembly Work to Station Assignment & Dependency Mining based on Historical Data

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Project FactBox

Project Name Line TACT
Project ID MFP II 2.2 CSA
Duration 24 Months

Area 2
Cognitive Robotics and Shop Floors

Project Lead
DI Michael Mayrhofer

MOTIVATION & GOALS

- Assembly line balancing is a **complex** and **time-consuming** process
- Experts rely on **tacit** knowledge of **prior balancing solutions** and assembly requirements (tasks dependencies, resources availability, etc.)
- **Explicitly modelling** all dependencies is not only a very **costly** (because time consuming) task but also **quickly outdated**.
- Instead, our goal is to rely on **prior balancing solutions** to find similar situations, and produce a baseline balancing solution and learn the assembly dependency graph

APPROACH

- Investigating multiple **metrics** to calculate **similarities** to available balancing solutions of **different products**.
- **Recommendations** of assembly work to **station assignment** based on the calculated similarities.
- On average our approach provides recommendations for **91.5%** of assembly tasks at **82%** precision.
- **Mining** of assembly **dependencies** between tasks based on different tacts and available similar products.
- Assembly task **sequence recommendation, inconsistency detection**, and **repair** based on the mined dependency graph.
- Integrating error **feedback** from users.

CONTRIBUTION

Scientific contribution
A novel approach based on structural similarities between assembly tasks of different previously balanced products to recommend task to station assignments and learn assembly tasks dependencies.

Economic contribution
This approach considerably reduces the time and effort currently invested by manufacturing companies to initially balance new processes and rebalance existing ones. The mining approach automatically produces a dependency graph, otherwise outdated, incomplete, or altogether unavailable for manufacturing companies.

PROTOTYPE

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844), Wacker Neuson GmbH and D-MTM.

PREDICTIVE MAINTENANCE ON HOIST COMPONENTS

Health Index Extraction of a Wire Rope from Multivariate Time Series

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Project FactBox

Project Name PREMAC-2
Project ID MFP II 3.1.3
Duration 24 Months

Area 3
Cognitive Decision Making

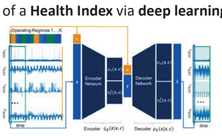
Project Lead
DI Dr. Belgin Mutlu

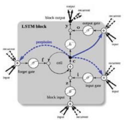
MOTIVATION & GOALS

Condition monitoring of hoist components is **essential** within an industrial process not only for the overall load carrying task but also to guarantee **personnel safety**. Inspection techniques of **very complex mechanical components**, such as wire ropes, are **quite costly**, as they require expensive testing equipment and usually **downtimes** are inevitable. Exact monitoring of **internal wire rope breakages** is of paramount importance, as it may dictate the right time for wire rope replacement, thus **increasing** the reliability and **decreasing** the maintenance costs. By exploiting the existing monitoring data (e.g., torque, load, velocity), we extract a robust **Health Index** for the wire rope, which accurately **quantifies** the structural degradation of the wire rope. Further, based on the past degradation pattern we build a **prediction model** for **online** deployment of our proposed approach.

APPROACH

Develop an end-to-end algorithm for **time series segmentation**, **causal selection** based on an interventional channel defined from **domain knowledge** and construction of a **Health Index** via **deep learning** techniques.



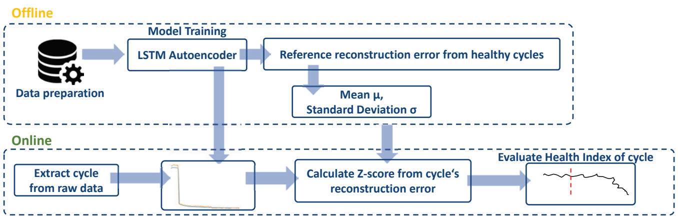


CONTRIBUTION

Scientific contribution
- Channel selection via causal strength quantification
- Health index extraction with deep learning techniques
- Wear monitoring of structural components with high accuracy
- Failure prediction based on past time series data

Economic contribution
- Prevent unexpected accidents with potential loss of human lives
- Reduce overall operational costs from regular inspections
- Optimize decision making for maintenance planning activities
- Eliminate downtimes of production flow process

FRAMEWORK



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844), voestalpine Stahl GmbH, and MUL-WBW.

PreMoBAF

Data-driven Methods for Predicting and Monitoring the Behavior of Blast Furnace and Electric Arc Furnace

Matej Vukovic[1], Georgios Koutroulis[1], Belgin Mutlu[1], Josef Küng[2], Stefan Thalmann[3]
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Project FactBox

Project Name PreMoBAF
Project ID MFP II 3.1.2
Duration 48 Months

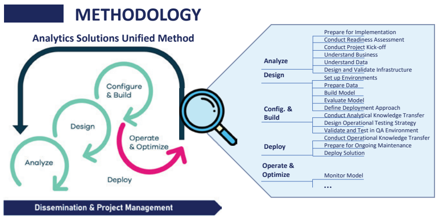
Area 3
Cognitive Decision Making

Project Lead
DI Dr. Belgin Mutlu

MOTIVATION & GOALS

- **Blast furnace (BF) and electric arc furnace (EAF)** are **key processes** in the iron and steel production. **Stability** of these processes is **crucial** due to the complexity of the physical and chemical processes that take place during the operation.
- **Overall dynamics** of these processes are **difficult to model** as the processes inside of the furnaces are **barely accessible for direct measurements**.
- **Data-driven approaches** have been applied to model the complex behavior **with limited success**. Existing models could capture some of the process dynamics **but give no insight to the underlying mechanisms**.
- Goal of this research is to utilize **data-driven and explainable AI (xAI) methods** to **better understand the inner dynamics** of the blast furnace and electric arc furnace operation.

METHODOLOGY

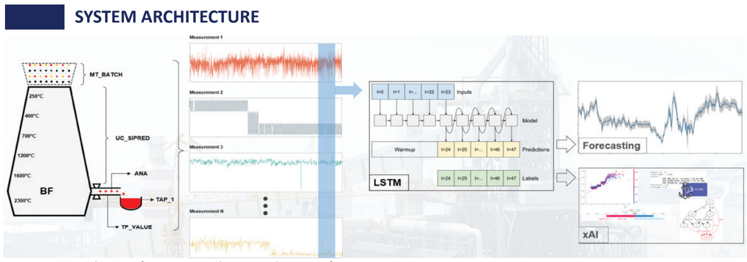


CONTRIBUTION

Scientific contribution
- Application of deep learning (DL) models in production scenarios
- Methods for knowledge discovery from ML/DL models
- Research on factors crucial for acceptance of ML/DL models in industry (xAI, causal AI, integration of domain knowledge)
- Application of causal discovery in complex industrial process

Economic contribution
- Modelling domain knowledge from data-driven methods in BF and EAF processes
- Integration of ML/DL models in automated decision making
- Improvements in process control

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and Primetals Technologies Austria GmbH.

VISUAL ANALYTICS FOR PRODUCTION SYSTEMS

Supporting Digitalization of Industry by Using Visual Analytics for Production Systems

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MOTIVATION & GOALS

The goal is to help in the **digitalization** of the steel industry by using **visual analytics** tool such as **Microsoft Power BI** to enhance the understanding of the whole production process. By interactively exploring and analyzing e.g., surface defects through knowledge-based decision-support systems, the time from data to action can be reduced. Thus, we aim for a

- Unification of the reporting architecture (static and interactive)
- Fast and frequent visual analysis of process parameters across the whole production chain
- Exploratory analysis of surface defects

Project FactBox

Project Name VAPS
Project ID MFP II 3.1.1 VAPS
Duration 48 Months

Area 3
Cognitive Decision Making

Project Lead
DI Dr. Belgin Mutlu
Prof. Dr. Marc Streit

APPROACH

For unifying the system architecture, we use **Microsoft Power BI** to statically and interactively show process parameters. The interactive exploratory process is supported via the development of process-specific custom visuals within the Power BI framework. This enables the user to visually detect defects on their products more readily using a direct connection to the database and specially designed data model.

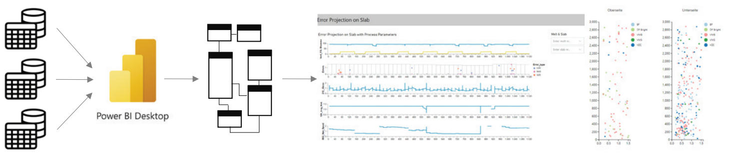
CONTRIBUTION

Scientific contribution
- Identifying barriers to adoption of a new BI landscape
- User-specific methods to onboard interactive dashboards
- Uncertainty visualization of production-based data
- Cause-effect analysis of empirical data

Economic contribution
- Early detection of errors in slab and coil to save time and costs
- Fast and automatic generation of reports to save time
- Closed-loop and knowledge-based decision-support system

SYSTEM ARCHITECTURE

Pre-processed data is added to Power BI, which provides an interface for creating a model and allows the user to explore the data interactively through graphs and other interactive features.



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and voestalpine Stahl GmbH.

voestalpine ONE STEP AHEAD.

PREDICTIVE MAINTENANCE

Maintenance Event Detection based on time-series data of welding devices

Milot Gashi[1], Heimo Gursch[2], Stefan Thalmann[3]
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MOTIVATION & GOALS

Fronius offers a large portfolio of **welding devices** to customers all over the world. The large number of welding products' variants and options in combination with the **different operating conditions** at the customers of Fronius, makes it challenging to determine **ideal maintenance times**. Thus, current maintenance strategies are often cost intensive for the manufacturers using the devices and cumbersome for the maintenance workers. This project aims **at automatically determining ideal maintenance times** to:
- Provide cognitive **decision support** for welding workers
- **Predict** required **maintenance** based on past maintenance actions
- **Reduce and focus** maintenance **efforts**

Project FactBox

Project Name ZEWAS
Project ID MFP II 3.3.1
Duration 9 Months

Area 3
Cognitive Decision Making

Project Lead
DI Heimo Gursch

APPROACH

Inputs
- Sensor data describing the welds over time
- Past maintenance logs

Challenge
- Maintenance logs are incomplete or missing

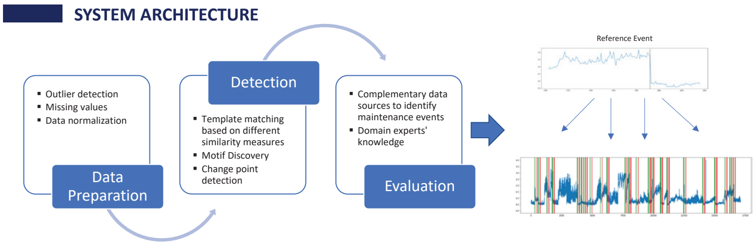
Outcome
- Learn to identify of maintenance needs from incomplete training data

CONTRIBUTION

Scientific contribution
- "Cognitive Decision Support for Industrial Product Life Cycles: A Position Paper" - COGNITIVE 2019
- "Taking Complexity into account: A structured literature review on multi-component systems in the context of predictive maintenance" - EMCIS 2019
- "Dealing with missing usage data in defect prediction: A case study of a welding supplier" - Computers in Industry

Economic contribution
Improved Welding Quality and welding products leading to better products, higher reliability, less costs, better performance of workers due to decision support

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844), Know-Center, Fronius, and Universität Graz.

CORVETTE

Cognitive Sensing Framework for Vehicle-Fleet Driven Data Services

Katarina Milenkovic[1], Daniel Kraus[1], Konrad Diwold[1], Peter Priller[2], Olga Saukh[3]
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MOTIVATION & GOALS

The project aim is to **develop an infrastructure for cognitive vehicle fleet monitoring**, which includes the **collection**, **evaluation**, **interpretation** and use of **vehicle data** in the context of various **data-driven services**. Several **services** and **use cases** for data-driven support/expansion of development processes as well as the provision of services on the vehicle (e.g., predictive maintenance) were identified in the project concept phase and will be covered in the project. The fleet data can be utilized to detect new trends in mobility.
- Rapid **prototyping** of onboard measurement for **fast data collection** and **method development**
- **Modular device design** to capture use-case specific data and enable future extensions (sensor & services)
- Capture, interpret and preprocess data on device -> produce smart data for further analysis

Project FactBox

Project Name CORVETTE
Project ID MFP 4.1.1
Duration 36 Months

Area 4.1
Cognitive Products

Project Lead
Dr. Konrad Diwold

APPROACH

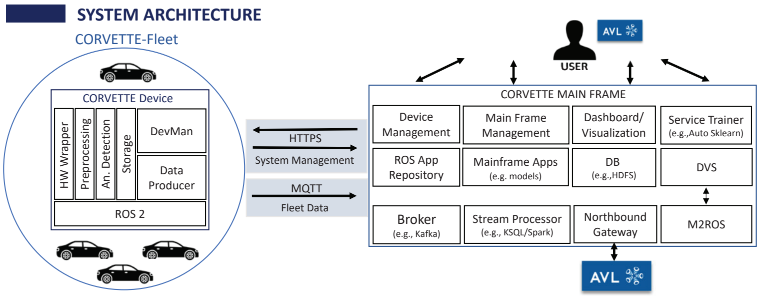
Development of **rapid prototype** for **data collection**
Development of **scalable backend for training, interpretation and service integration**
Research on **model adaptivity, robustness and stability**
Research on **novelty detection in multimodal data streams**
Automated ML model training development for deployment
Test & demonstration of developed methods in real-life use cases

CONTRIBUTION

Scientific contribution
Development of new methods to achieve fast data collection in automotive applications. Design and development of novel algorithms and programs tailored for application in automotive environments.

Economic contribution
Implementation of a modular device with the according software which can be deployed in a highly dynamic environment.

SYSTEM ARCHITECTURE



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and AVL List GmbH.

CompEAS

Enabling Dynamic Composition in Embedded Automotive Systems of the Future

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MOTIVATION & GOALS

1. **Long-term Maintenance** of Basic Software (BSW)
   - **Portability and verification** of low-level software (operating systems, drivers, etc.)
2. Generic Support for **Non-Functional Requirements** (NFR)
   - **Management** of changing application requirements (timing, energy, etc.)
3. **Compositional** Application Software (ASW)
   - **Automatic integration** of modular software (e.g., during updates)

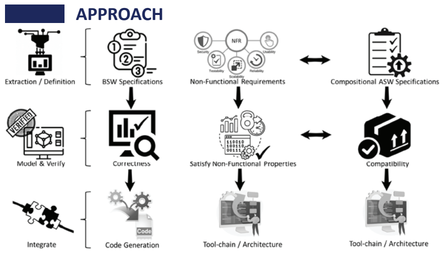
Project FactBox

Project Name CompEAS
Project ID MFP II 4.1.2.1-2
Duration 53 Months

Area 4.1
Cognitive Products

Project Lead
Prof. Dr. Marcel Baunach
Dr. Konrad Diwold

APPROACH

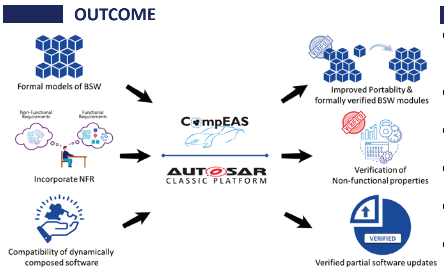


CONTRIBUTION

Scientific contribution
Bring new and innovative technical concepts into embedded automotive systems, focusing on verification, long-term operation, and maintenance of Classic and Adaptive AUTOSAR environments.

Economic contribution
The conventional EAS development approaches validate the software functionally and rely on costly bug fixes at later stages. The research aims on improving reliability and maintainability of the software by focusing on correctness by construction and incorporating non-functional requirements.

OUTCOME



KEY HIGHLIGHTS

- Transform conventional automotive software development into a **generative** approach
- Formal specification of **non-functional requirements**
- **Modelling of low-level** hardware aspects for software **verification**
- **Transform validated or tested** software into **verified** software using formal methods
- **Migrate from monolithic** software updates to **partial** software updates in the field
- Automatic **compatibility** checks through formal methods **before** deployment

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Acknowledgement: This work is supported by Pro²Future (FFG, 881844) and Elektrobit GmbH.

DIGITAL TWIN – VIRTUAL COMMISSIONING

Digital Twin enabled Commissioning and Testing of Future Failsafe Automation Systems

Pro²Future

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MOTIVATION & GOALS

Due to the complexity of automation systems, a great deal of on-site engineering is often required during installation, commissioning, and maintenance. The digital twin emerges as new approach that allows engineers to remotely design, install, and maintain automation systems that comply with defined standards and regulations without hardware equipment.

The goal is to reduce commissioning and maintenance time while maintaining consistency of the system and its features (e.g., safety). **Strategic goal** (long-term): Identify technologies that could become the main drivers of industrial and process automation in the coming years.

Project FactBox
Project Name TWIN-Solution
Project ID MFP II 4.1.2.2
Duration 36 Months

Area 4.1
Cognitive Products

Project Lead
Dr. Konrad Diwold

APPROACH

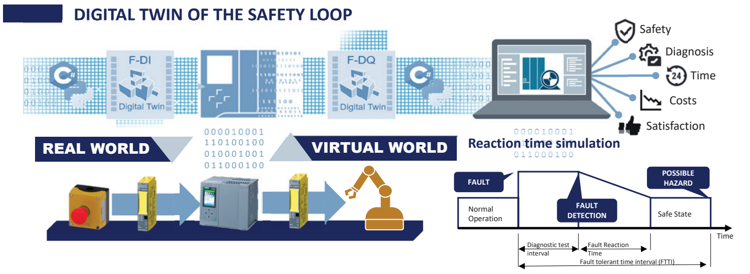
- Getting familiar with **Siemens' fail-safe devices** and their functionalities.
- Use current Siemens' virtual portfolio as the starting point (PLCSIM Advanced v3.0, SIMIT tool, etc.) for developments.
- Incorporate **norms** & **regulations** as **guidelines**.
- **Develop** digital **twins** for different failsafe devices / systems.
- **Demonstrate** the applicability of digital twins to speed up development, testing, certification and deployment.

CONTRIBUTION

Scientific contribution
Research a new approach to industrial automation, which allows for data acquisition, testing and deployment without hardware. Come forward with new approaches for development, testing certification and commissioning of future industrial automation systems.

Economic contribution
Enable fast testing and certification thus reducing risks in and speeding up the development phase. Enable pre-test and preconfigure of automation solution for deployment to foster fast, cost-effective, and remote deployment procedures.

DIGITAL TWIN OF THE SAFETY LOOP



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and Siemens AG Austria.

ADAPTIVE COBOT INTEGRATION

High-Flexible Workplace Design with Collaborative Robots for Low-Occupational Stress Assembly Operations

Pro²Future

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MOTIVATION & GOALS

The goal of the research project "Adaptive Cobot Integration (**ACTION**)" is **to design high-flexible but low occupational stress workspaces** for assembly operations based on the use-case of **riveting operations**. In this context following research questions will be answered:

How can manual work processes be supported by **using cobots** and sensor technology?
How can workplaces be designed **flexible and worker-friendly with low occupational stress**?
What added value do such technologies offer in the context of **occupational safety** and quality improvement?
How must the **safety concept** be designed?

Project FactBox
Project Name ACTION 2
Project ID MFP II 4.2.3-2
Duration 24 Months

Area 4.2 & 4.1
Cognitive Production Systems
Cognitive Products

Project Lead
Dr. Markus Brillinger
Dr. Konrad Diwold

METHOD

Hypothesis: Two **simple KPIs** are related to physical and cognitive load as well as flexibility which can be used in workplace design phase.

$$PLR_i = \frac{WL_i}{HM}$$

$$CLR_i = 1 - \frac{N_{Ai} * n_A + N_{Bi} * n_B}{\sum_{i=1}^{10}(N_{Ai} * n_A + N_{Bi} * n_B)}$$

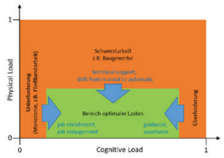

Figure 1: Load Matrix for workspace design.

CONTRIBUTION

Scientific contribution
- New hypothesis about worker-friendly workplace design
- Guidelines for high-flexible lead time calculation
- Influence of human-cobot collaboration on human's stress
- Pulse and heart variability rate as stress indicator

Economic contribution
- Use-case for human-cobot enabled digitalization
- Contribution to low-stress work
- Support to workplace design for sliver society
- Enhancement of existing safety concepts

SYSTEM ARCHITECTURE

To **validate the hypothesis**, a set-up is designed, where a human and a cobot **assemble and rivet parts together**. The human uses **wearable sensors** which detect pulse and heart variability rate. This data are used to analyse human's vital state and **controls** cobot's **velocity** as well as suggested breaks during work to avoid low performance and part defects.

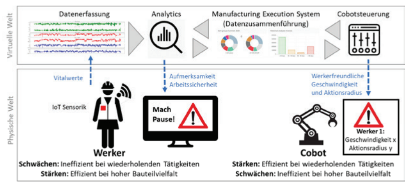

Figure 2: System architecture to elaborate occupational stress in human-cobot interaction.

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and Antemo, sanSirro & AUVA.

QUALITY ASSESSMENT OF PELLETISED MATERIALS

In-line Quality Assessment of Pelletised Materials based on Fourier Descriptors

Pro²Future

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MOTIVATION & GOALS

In the production of pelletised plastics, the **quality** of the resulting pellets is highly dependent on various **machine parameters**. Amongst others these are the **temperature** of the molten prime material and the **cooling** water, the **sharpness** of the cutters, and the **pressure** of the molten prime material.
The resulting reduced **production quality** is reflected by a change in colour or transparency and a change in the shape of the pellets.
Our goal was to **introduce parameters** to asses the pellets' shape in order to **determine** the **pellets' quality** and in a further step to control the production process in combination with other machine parameters to decrease the share of low quality output.

Project FactBox
Project Name AI Gran 2
Project ID MFP 4.2.1-1
Duration 36 Months

Area 4.2
Cognitive Production Systems

Project Lead
Dr. Wolfgang Roland

APPROACH

For the analysis we used a B&R Vison System Camera to take images of pellets from the pellet **output stream** of the machine. **Changes** in colour can easily be detected by evaluating the mean grey-value.
For the analysis of the shape we used the so called **Fourier Descriptors** of each detected pellet's contour. We used the distribution of the relative magnitude of the Fourier Descriptors to assess general form and smoothness of the pellets' contour.

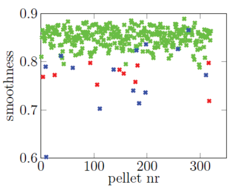
CONTRIBUTION

Scientific contribution
With this project the use of Fourier Descriptors as general shape descriptors was investigated. The result being that they can be applied to get a general description of the quality of an object's shape as well as an estimate of the specific shape (round, triangular, etc.).

Economic contribution
The preliminary results of this project showed, that it is possible to asses the pellets quality in a potentially cheap way. The subsequent control of the machine parameters may lead to a reduction of defective produced pellets and hence the connected costs.

OUTCOME

Depending on the intended shape of the pellet we used the sum of the **relative magnitudes** of a certain selection of lower order **Fourier Descriptors** to obtain a parameter for the smoothness. With this parameter a categorisation in high and low quality pellets was possible with similar results as was obtained by a categorization "by hand". This is shown in the image on the right with a threshold of approximately 0.79.
With the data of the **Fourier Descriptors**, other parameters obtained by the **image processing algorithms**, and the machine data the control of the **production quality** is the goal in the next step of the project, which will be conducted in collaboration with the Institute of Automatic Control and Control Systems Technology.



Left: Smoothness values (first order Fourier Descriptor) for 30 test images of spherical pellets (image on the right). The colours are based on a categorisation „by hand" in high quality (green), low quality (red) and multiple (blue).

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and ECON GmbH.

DEVELOPMENT OF FUEL CELL ASSEMBLY SYSTEMS

Developing Adaptive and Future Assembly Systems for Fuel Cell Assembly along with Battery Pack Assembly

Pro²Future

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MOTIVATION & GOALS

E-mobility is perceived to be the future of mobility. But with low demand, high product variability, and mass customization, new **innovative and modular assembly techniques** must be researched upon. In ASP2, we focus on:

- Development of an **adaptive assembly layout** for fuel cell assembly, which is adaptable for battery pack assembly
- Developing, thereby, a **flexible handling technology**, i.e., grippers for the assembly process of cells
- Addressing the **need for a clean environment** for the stacking process in both, fuel cell as well as battery packs
- Thus, development of **modular cleanroom** concept for individual specific assembly station

Project FactBox
Project Name Adaptive Smart Production 2 (ASP2)
Project ID MFP II 4.2.3
Duration 24 Months

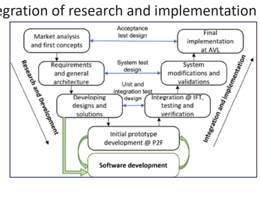
Area 4.2
Cognitive Production Systems

Project Lead
Dr. Markus Brillinger

APPROACH of STUDY

The depicted **V-model** describes the integration of research and implementation for grippers and cleanroom.

- **3D-printed end-effectors** with varying design are experimented.
- **Sensory system** with the help of **HEPA filter** (High Efficiency Particulate Air) is used to develop a modular cleanroom approach.



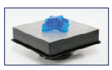
CONTRIBUTION

Scientific contribution
The provision of resource-efficient cleanroom technology (to ensure the longevity of fuel cells) and the adaptation of current handling technology (to ensure the greatest possible flexibility for new product designs).

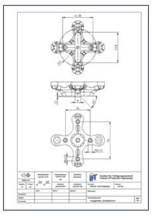
Economic contribution
Cleanrooms are energy consuming spaces. Developing station-specific cleanroom could save over 70% of the energy costs.

OUTCOME

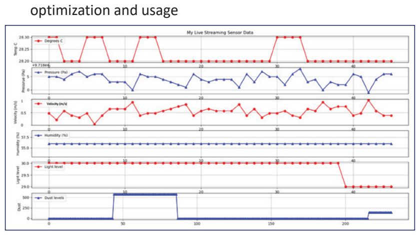
Innovative design and development of **vacuum end-effector** for gripping technology



3D-printed end-effector models



Real-time monitored cleanroom concept for effective optimization and usage



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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) and AVL List GmbH.

SMART COEXTRUSION BLOW MOLDING

In-Situ Detection of Co-Extrusion Flow Instabilities using Optical Coherence Tomography and Ultrasonic Techniques

Pro²Future

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MOTIVATION & GOALS

Co-extrusion is a widely used processing technique for combining various polymers with different properties into a tailored multilayer product. In these processes, **interfacial flow instabilities** are observed under certain conditions leading to **undesired product quality** such as optical and mechanical defects. For **systematic investigation** of these instabilities an **in-situ ultrasonic (US)** and **optical coherence tomography (OCT)** measurement system were developed:

- **Two-layer co-extrusion die** enabling controlled flow conditions
- **Exchangeable die cover** with glass window for OCT and direct coupling for US
- **Real-time evaluation** of flow instabilities
- Definition of **objective and reliable classification criteria**

Project FactBox

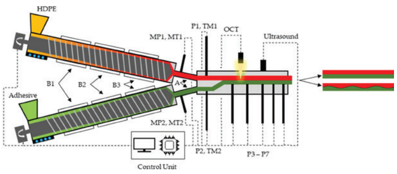
Project Name SmartCoExt
Project ID MFP II 4.2.1-3
Duration 48 Months

Area 4.2
Cognitive Production Systems

Project Lead
Dr. Wolfgang Roland

APPROACH

Experimental co-extrusion tests with US and OCT

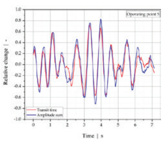


CONTRIBUTION

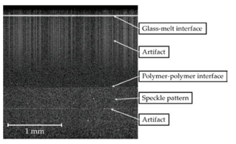
Scientific contribution
- Co-extrusion demonstration die
- OCT and ultrasonic sensor technology
- Evaluation of OCT measurement system
- Automatic classification of process stability

Economic contribution
- Expertise in co-extrusion process technology
- Experience of critical flow situations
- Material and equipment for experiments

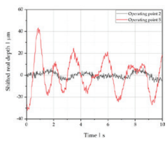
RESULTS



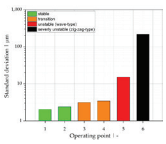
Relative change of transit time and amplitude (intensity) for US detection of flow instabilities



B-scan of OCT measurement during co-extrusion showing glass-melt and polymer-polymer interfaces



Real depth position of the polymer-polymer interface as function of time for an stable and unstable operating point



Process stability indicated by standard deviation of real depth position of the polymer-polymer interface

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844), JKU-IPEC and Soplar sa.

ADAPTIVE SMART PRODUCTION 2

Setting the ISO standards for fuel cell stacking process – Development of modular cleanroom based on ISO 14644

Pro²Future

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MOTIVATION & GOAL

The **focus** towards the Sustainable Development Goals and Circular Production is addressed by the ASP2 Project. At ASP2, the **goal** is to develop a resilient adaptive system of the **fuel cell stacking process** that must be integrated with the existing battery stacking process. The concept of **ISO standard cleanroom** for stacking process is also **prototyped** at the institute. In ASP2, we focus on:

- Development of **flexible handling technology** for gripping of BPP and MEA layers
- Analysing the **necessity** of a clean environment, i.e., cleanroom for the stacking operation
- Development of a **modular cleanroom** with ISO standards
- A **GUI** (Graphical User Interface) of **real-time monitoring** of cleanroom, which also indicates the **control environment** of the filtering and high-efficiency blower system

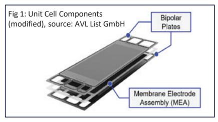
Project FactBox

Project Name ASP 2
Project ID MFP II 4.2.3
Duration 24 Months

Area 4.2
Cognitive Production Systems

Project Lead
DI Dr. Markus Brillinger

Fig 1: Unit Cell Components (modified), source: AVL List GmbH



APPROACH of STUDY

The basic approach is to **utilize** the data generated from the **sensory system** to enhance the stacking process via the developed user model.

- **3 sensory capsules** with **6 sensors in each capsule** record the data and displays it on a **GUI with real-time monitoring and control**
- Temp – **°C**, humidity – **%**, pressure – ***Pa***, velocity of airflow – ***m/s***, light intensity – ***lux***, and particulate matter – ***µm*** are monitored.
- Through the GUI, **airflow** – ***m³/hr*** is controlled.

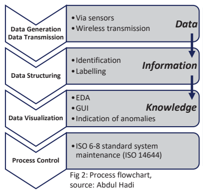


Fig 2: Process flowchart, source: Abdul Hadi

CONTRIBUTION

Scientific contribution
The provision of resource-efficient cleanroom technology (to ensure the longevity of fuel cells) and the adaptation of current handling technology (to ensure the greatest possible flexibility for new product designs).

Economic contribution
Cleanrooms are energy consuming spaces. Developing station-specific cleanroom could save over 70% of the energy costs.

SYSTEM ARCHITECTURE & PROTOTYPE DEVELOPMENT

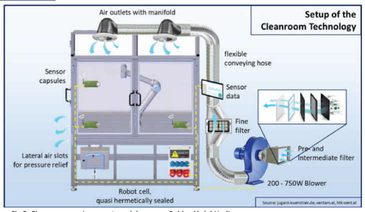


Fig 3: Cleanroom environment model, source: Bahle, Abdul Hadi

Fig 4: GUI and visualization environment, source: Abdul Hadi, Gashi

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844) TU Graz, and AVL List GmbH.

DATATOPIA

The World of Unlimited Industrial Data and Exploration

Pro²Future

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MOTIVATION & GOALS

Currently **deep learning** in industrial use cases is **held back** by the **security** concerns linked to production line data. One such concern is that confidential **process specific knowledge** can be inferred from raw sensor data. Thus, such data is closely held. Furthermore, it is **seldom annotated**, which greatly restricts supervised learning methods.

A solution to data scarcity is using **generative methods** to enhance available datasets. While generating data solves data availability, the **contained information** will still be similar. In order to increase a datasets information content, we aim to include **domain expertise**. The generated data will be presented in an interactive framework. Using this framework, the employed generative methods can be enriched with **human experience**.

Project FactBox

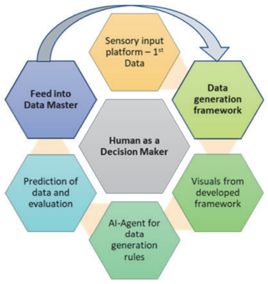
Project Name Datatopia
Project ID StratP SX200
Duration 10 Months

Area 1
Perception and Aware Systems
Area 2
Cognitive Robotics & Shopfloors
Area 3
Cognitive Decision Making
Area 4.1
Cognitive Products
Area 4.2
Cognitive Production Systems

Project Lead
Christina Pichler

FRAMEWORK

Starting from **sensor input** data, generative methods are **learned**. In order to improve the contained information, rules for generation are set. Then generation can be **reiterated** upon to improve results further.



APPROACH

Generative:
- Autoregressive (GAN, VAE)
- Generative modelling (Gaussian copula)

Interactive:
Including domain expertise in the quality control of generated data

Secure:
- Masking process specifics
- Exposing minimal data
- Using black box models

CONTRIBUTION

Scientific contribution
- Generative AI (Time Series, Ultra-Wide Band)
- General representations for industry specific data

Economic contribution
- Increase industrial data privacy and availability
- Establish process security

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Acknowledgement: This work was supported by Pro²Future (FFG, 881844).

REWAI – Reducing Energy and Waste using AI

Building Explainable and Trustworthy AI-Solutions for Even More Sustainable Fiber Production

Pro²Future

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MOTIVATION & GOALS

We want to **reduce the carbon and material footprint** of the textile industry by reducing energy and material consumption by building **Reliable, Trustworthy and Energy-Efficient AI Solutions** for Industrial Processes Analysis capable of **forecasting and anomaly-spotting**.

To this end, we want to **empower Human Operators** in making informed and more timely decision on near real-time data from continuous processes.

Project FactBox

Project Name REWAI
Project ID FFG No. 892233
Duration 36 Months

Area 1 & Area 3
1 - Perception & Aware Systems
3 - Cognitive Decision Making

Project Lead
DI Dr. Michael Haslgrübler
DI Dr. Belgin Mutlu

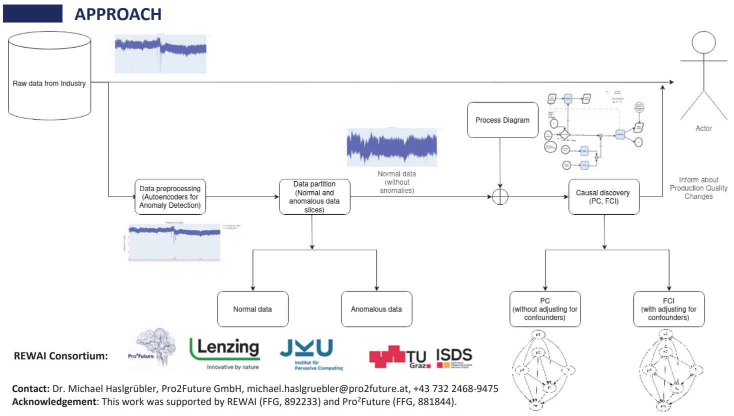
SCIENTIFIC CONTRIBUTION

- Algorithmic framework for recovering lagged causal relationships in complex industrial processes
- Counterfactual reasoning: "What-if" scenarios & AI models are used to predict the outcomes of different scenarios to make informed decisions based on the predicted outcomes
- Improving interpretability in time series by reducing dimensionality and complexity

ECONOMIC CONTRIBUTION

- Minimizing time and energy wastage in the analysis process by efficiently extracting essential features
- Improving resource utilization by reducing the computational cost
- Empowering human operators to make informed decisions

APPROACH



REWAI Consortium:

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Acknowledgement: This work was supported by REWAI (FFG, 892233) and Pro²Future (FFG, 881844).

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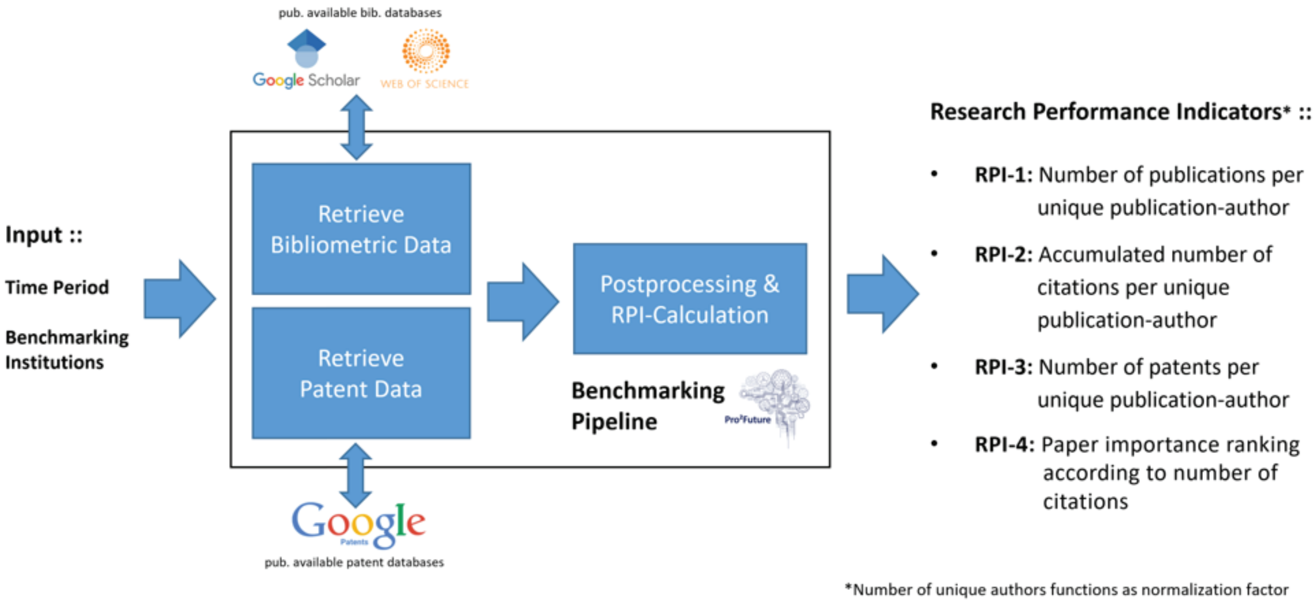
INTERNATIONAL BENCHMARKING

As indicated as one of the Requirements resulting from the Mid-Term-Evaluation, a reasonable **international benchmarking process** has to be defined and completed, and results of the first two years of FP2 have been reported to the FFG. Resulting, an **International Benchmarking Strategy** was defined and first results are presented. As one of the outcomes of the developed strategy, Pro²Future is now able to generate up-to-date benchmarking values and results by just "pushing a button" at any time. Furthermore, benchmarking in general becomes even more important in terms of being **comparable** and showing the competitiveness of the centre.

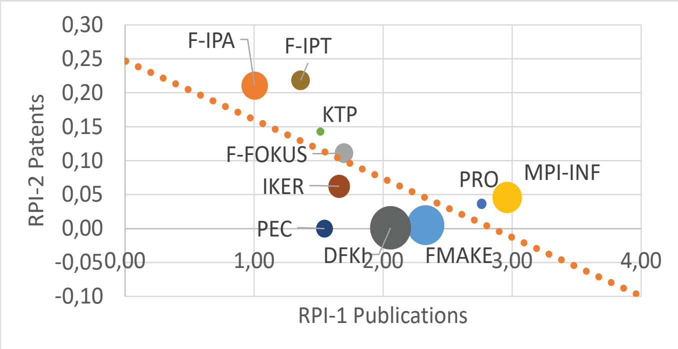
The developed benchmarking strategy was applied in the context of **nine different institutions**. While the center shows a **competitive performance** regarding in terms of the amount of research output per unique author the analysis of Pro²Future's research network based on publications highlights that the center needs to **increase its international collaborations**. This need of **internationalization**, which is reflected in the internationalization efforts, as well in a revised publication strategy, which was developed and established before starting FP2, which focuses on a careful selection of publication venues and journals to increase the international outreach of Pro²Future's research results.



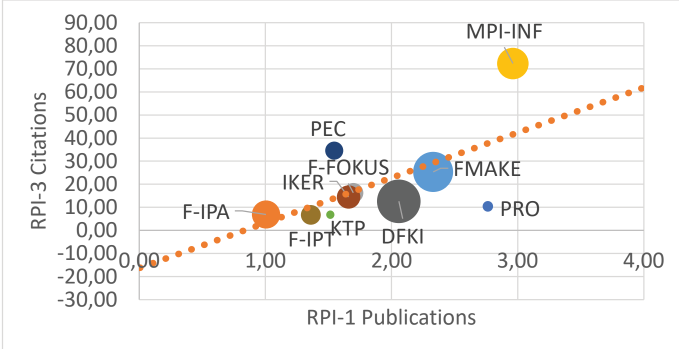
The Benchmarking Framework (see above) uses information provided from several other benchmarking institutions, retrieves bibliometric data from the Web of Science and Google Scholar, and retrieves patent data from Google patents. This information is refined/postprocessed and used in the Pro²Future Benchmarking Pipeline for the calculation of the significant RPIs (Research Performance Indicators).

Country	Institution	Rel. size to max [%]	RPI-1 Publications	RPI-2 Patents	RPI-3 Citations	RPI-4 (Citations)						
						mean	p50	p90	p95	p97.5	p99	max
AT	PRO	5,74%	2,76	0,04	10,42	3,77	2	8	12	29	43	43
DE	F-IPA	41,61%	1,01	0,21	6,86	6,83	2	16	25	39	66	138
DE	F-FOKUS	20,65%	1,70	0,11	16,27	9,59	2	20	36	55	134	565
DE	MPI-INF	52,14%	2,96	0,05	72,30	24,41	4	54	123	200	365	968
NL	FMAKE	84,15%	2,33	0,00	25,35	10,88	3	26	39	63	131	1077
DE	KTP	3,65%	1,51	0,14	6,80	4,49	1	15	26	29	38	38
US	PEC	17,00%	1,55	0,00	34,58	22,37	11	52	77	142	228	326
ES	IKER	28,47%	1,66	0,06	14,48	8,73	3	18	29	59	105	410
DE	DFKI	100,00%	2,06	0,00	12,61	6,13	2	14	24	36	71	373
DE	F-IPT	20,54%	1,36	0,22	6,73	4,95	1	12	20	39	53	70
		Sum/Authors	2,02	0,06	24,09							

Research performance indicators RPI-1, RPI-2, RPI-3, and RPI-4 . These RPIs represent amount of research output and its average influence on the academic field. The relative size of the institution is calculated as its number of unique authors divided by the maximum number of unique authors among benchmarking institutions.



Scatter plot of RPI-2 vs RPI-1, the marker sizes correspond to the relative size of the institution and their labels to the short-name of the institutions. A linear trend line for RPI -2 vs RPI-1 was calculated and plotted in orange.



Scatter plot of RPI-3 vs RPI-1, the marker sizes correspond to the relative size of the institution and their labels to the short-name of the institutions. A linear trend line for RPI-3 vs RPI-1 was calculated and plotted in orange.

Institutions used for comparing Pro²Future in the benchmarking process: F-IPA (Fraunhofer Institute for Manufacturing, Engineering and Automation, DE), F-FOKUS (Fraunhofer Institut für Offene Kommunikationssysteme, DE), MPI-INF (Max-Planck-Institute for Informatics, DE), FMAKE (Flanders Make, BE), KTP (Kunststofftechnik Paderborn University, DE), PEC (Poylmer Engineering Center University Wisconsin-Madison, US), IKER (IKERLAN, SP), DFKI (Deutsches Forschungsinstitut für Künstliche Intelligenz, DE), F-IPT (Fraunhofer Institut für Produktionstechnologie, DE).

The results of the Benchmarking process are visualized by showing the RPI 1, 2 and 3. The scatter plots indicate, that Pro²Future is well positioned in the field of publications (well distributed on basic research publications and industrial focused publications) but needs more focus on patents.

Regarding the research excellence (citations of publications), the centre's publications are not cited as often as publications from bigger and more experienced centres. Establishing the Publication Strategy and the IPR Strategy, the centre is gaining momentum in these areas.

Graphs top next page: Each curve represents a benchmarking institution. A curve nearer the top and right borders of the plots corresponds to a more excellent research institution. The X-axis measures the publications percentile according to the number of citations of all publications included in our datasets (higher means more citations). That is, for each percentile there is a corresponding number of citations, and the curves show which percentage of publications of the institution have that number of citations or more.

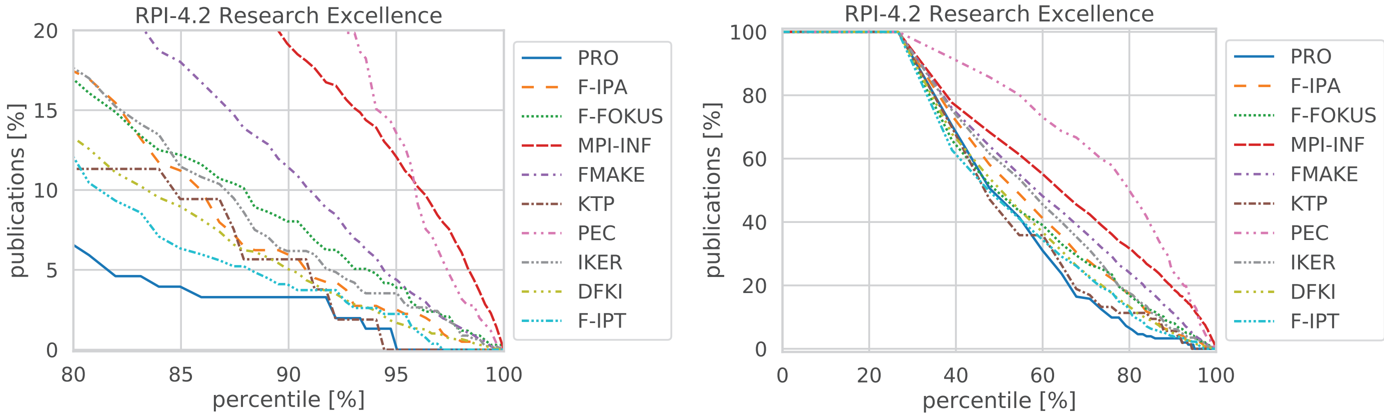
Graph bottom next page: Visualization of Pro²Future's research networking using data extracted from the Web of Science. The connections between nodes represent publications with co-authorships, the node sizes represent the number of the publications in total by listed research institutions.

Conclusion

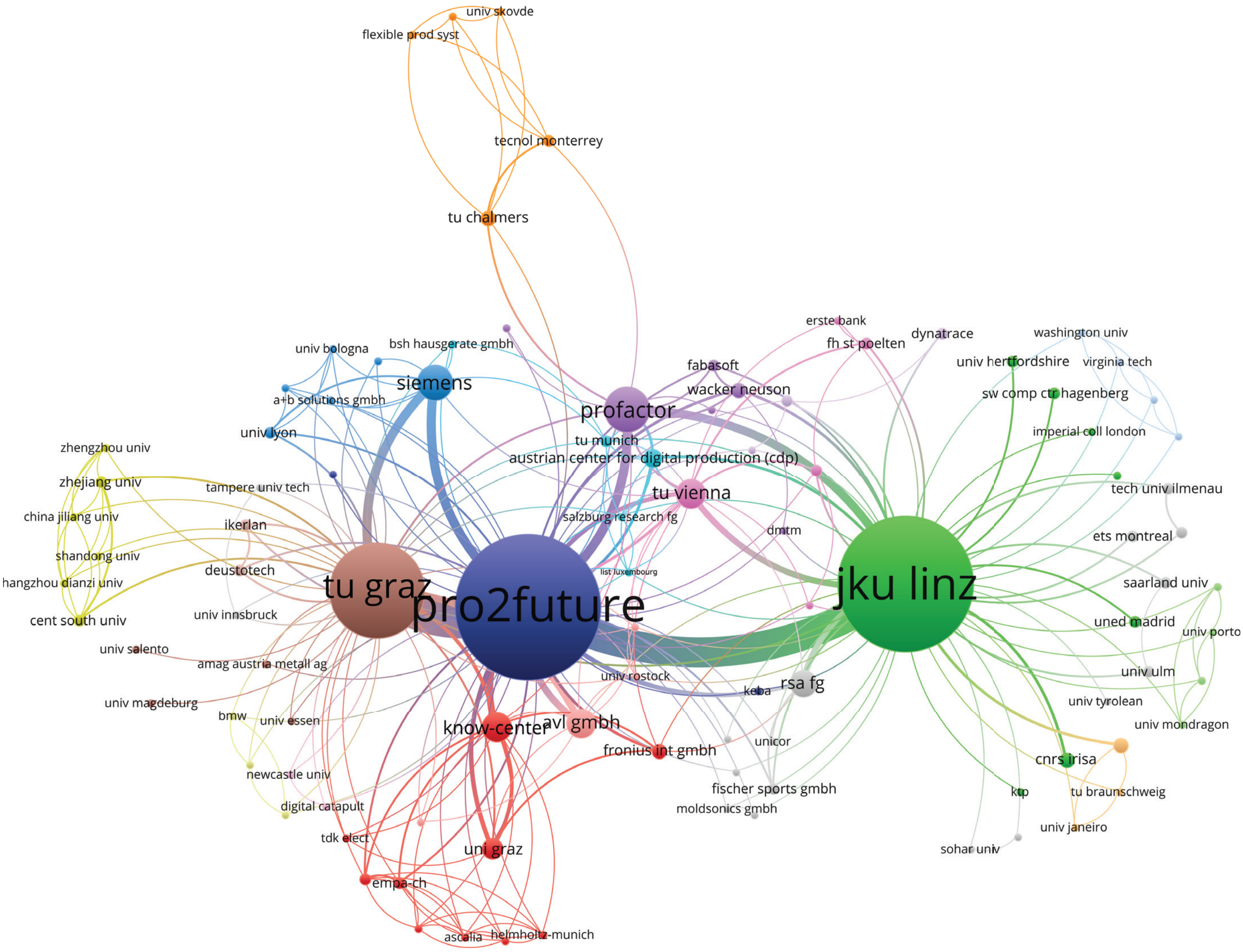
Our collaboration network shows that Pro²Future achieves a wide number of second collaborations thanks to its close work with JKU Linz, TU Graz, Siemens, Profactor, TU Vienna, Know-center, AVL GmbH, Uni Graz, Fronius Int GmbH, Austrian Center for Digital Production and TU Munich.

It is interesting to see, how the collaboration network is divided strongly by the TU Graz and JKU Linz. Pro²Future has offices at both locations, and the separation in the research network is therefore also geographical. It may further indicate that the collaboration between these two Pro²Future offices can be strengthened, and that Pro²Future can provide the opportunity for increased collaborative research between the research institutions JKU Linz and TU Graz in our fields of interest.

This visualization also depicts room for improvement on the center's internationalization strategy as (in contrast to strong national collaboration), international collaboration is only partially available and there-fore needs to be intensified. This is currently addressed in the center via the submission of research pro-posals on a European level as well as further tightening the collaborations with our international scientific partners.



Research performance indicator RPI-4.2. Each curve represents a benchmarking institution. A curve nearer the top and right borders of the plots corresponds to a more excellent research institution. The X-axis measures the publications percentile according to the number of citations of all publications included in our datasets (higher means more citations). That is, for each percentile there is a corresponding number of citations, and the curves show which percentage of publications of the institution have that number of citations or more. For instance, 90% of the publications have less than 18 citations.



Visualization of Pro²Futures research network using VOSViewer, using the data for Pro²Future extracted from the Web of Science (WoS). The connections between nodes represent publications with co-authorships. The node sizes represent the number of the publications in total by listed research institutions.

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