

Pro²Future :: Cognitive and Sustainable Products and Production Systems of the Future

Programme: COMET – Competence Centres for Excellent Technologies

Programme line: COMET-Centre K1

Type of project: VIVARIUM II, multi-firm



Fig. 1.: Detailed multimodal exploration interface for time series and visual data

VISUAL ANALYTICS FOR MULTIMODAL WELDING DATA A FRAMEWORK FOR EFFICIENT AND TRANSPARENT ANOMALY DETECTION IN WELDING PROCESSES

Modeling and analyzing modern welding processes is **highly challenging** due to the large volume of **high-frequency, multidimensional** data as well as the **complex temporal dynamics** of the underlying process. In addition to time series data, image data of weld seams provides valuable information about **process quality** but is difficult to integrate into conventional analysis approaches.

Due to these challenges, relevant patterns and anomalies are often not directly observable, and manual inspection and labeling of data remains **time-consuming** and **inefficient**. Existing approaches typically analyze data modalities in isolation or rely on aggregated features, limiting their ability to capture the full complexity of the process.

This motivated the development of a data-driven and visual analytics-based framework for the integrated analysis of multimodal welding data, with the goal of **improving anomaly detection** and **reducing the**

manual labeling effort. Within this project, methods for **combining** time series and image data were developed. Image data was processed using object detection approaches such as YOLO to identify relevant regions, followed by feature extraction using **pre-trained models, including ResNet and EfficientNet**. In parallel, time series data was modeled using **Temporal Convolutional Networks** to capture **complex temporal dependencies**. A late-fusion strategy was applied to combine both data modalities and leverage their complementary information.

In addition, a visual analytics framework was developed to support efficient data exploration and annotation. This includes a calendar-based overview for identifying **temporal patterns**, guidance mechanisms for prioritizing relevant anomalies, and interactive detail views for **in-depth multimodal analysis**. The integration of labeling functionalities directly into the analysis process enables a **more efficient generation of ground truth data**.

SUCCESS STORY

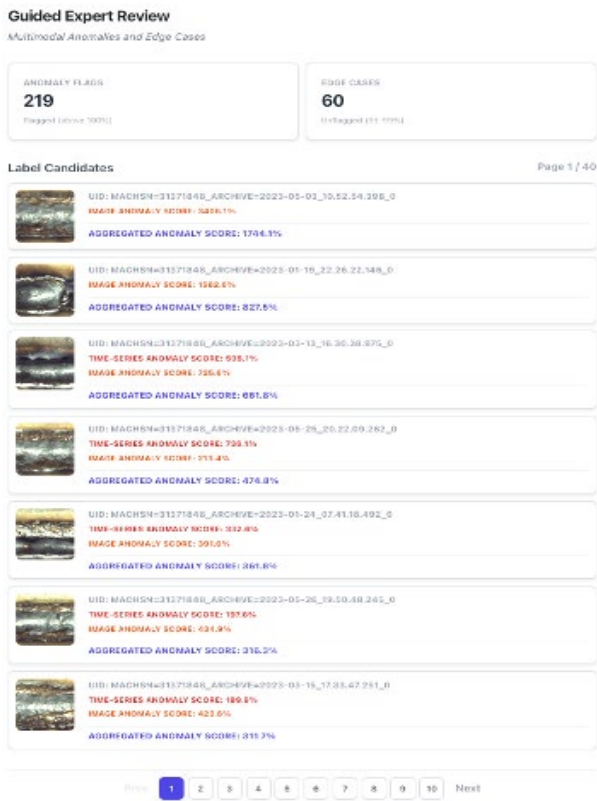


Fig. 2.: Guidance View recommends faulty welds for detailed analysis.

Impact and effects

The project demonstrates that the combination of visual analytics and multimodal data-driven methods **significantly improves** the analysis of welding processes. The integration of time series and image data enables a more comprehensive understanding of process behavior, as both modalities provide complementary insights into temporal dynamics and visual quality characteristics. At the same time, guidance mechanisms **support users in identifying** relevant anomalies and navigating large and complex datasets.

Another key outcome of this project was the demonstration that robust machine learning models can be developed to perform well even when trained on partially labeled data. This significantly reduces the overall labeling effort and makes the approach more feasible for real-world applications. Furthermore, the tight integration of interactive visualization techniques with machine learning enables users to better interpret model results and actively contribute to the analysis process. Overall, the developed methods enhance both the efficiency and transparency of welding data analysis and provide a strong foundation for future integration into industrial systems and workflows.

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