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Applicable and Generalizable Machine Learning for Intelligent Welding, from Quality Prediction to Robotic Automation

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Abstract: In the last decade, the manufacturing sector has adopted Industry 4.0 innovations, including edge and cloud computing, Artificial Intelligence (AI), and Machine Learning (ML), enhancing production visibility, quality, automation, productivity, and safety. This presentation highlights novel ML applications in welding processes, through case studies in Resistance Spot Welding (RSW), laser welding, and arc welding.

The case study of RSW focuses on process sensing and modeling for quality prediction and defect detection. This study not only employs data-driven modeling but also utilizes ML to uncover physical insights into the RSW process, enhancing feature extraction and developing a more generalizable model for predicting quality and defects. It also introduces a new ML approach to create virtual signals for force and displacement using dynamic resistance measurements, addressing the lack of novel process sensing in facilities due to high costs. The case study of laser welding tackles feature engineering, i.e., from sensing data characterization to feature selection, to improve the model generalizability and decision-making efficiency in a plant production scenario. Transfer learning is also investigated to enable the ML models to adapt to dynamically changing welding conditions. The third case study targets the robotic automation of arc welding. To enable robotic operational adaptivity, a hybrid ML-based process characterization, and online adaptive control framework are developed for robotic arc welding to automatically and efficiently achieve the desired weld pool condition, given any initial conditions. These case studies showcase significant potential for advancing welding processes to new levels of efficiency and effectiveness.

Biographical Sketch: Dr. Peng (Edward) Wang is currently an Associate Professor in the Department of Mechanical and Aerospace Engineering at Case Western Reserve University (CWRU). Dr. Wang has extensive experience in developing novel ML methodologies for machine condition monitoring and diagnosis, process modeling and quality prediction, and collaborative robots. Dr. Wang is the recipient of the CAREER award from the US National Science Foundation in 2023, Young Investigator Award from the International Symposium of Flexible Automation in 2024, Outstanding Young Manufacturing Engineer Award from the Society of Manufacturing Engineers (SME) in 2022, the Best Paper Award from the 2023 Manufacturing Science and Research Conference (MSEC), Outstanding Technical Paper Award from the SME North American Manufacturing Research Conference (NAMRC) in 2017, 2020, and 2021, and other best paper awards. Dr. Wang is an Associate Editor of the IEEE Sensors Journal and Journal of Intelligent Manufacturing.

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