Advanced Explainable Machine Learning (XML) Approaches and Their Applications in Advanced Manufacturing Processes

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ABSTRACT

Manufacturing is at the forefront of technological advances, and machine learning techniques offer unprecedented opportunities for process optimization, quality improvement, and predictive maintenance. However, the complexity of modern manufacturing processes often leads to machine learning models or complex deep learning models being viewed as black-boxes that lack transparency and interpretability. This opacity raises concerns about trust, accountability, and the ability to understand the underlying decision-making process. In this paper, we deeply dive into how to incorporate explainable machine learning methods into the manufacturing domain. We focus on bridging the gap between complex machine learning models and human understanding, ultimately facilitating the seamless adoption of these models on the shop floor. We explore two well-known interpretability techniques: Locally Interpretable Model-Ignostic Interpretation (LIME) and SHapley Additive exPlanations (SHAP). We show how to better understand microstructural properties and machinability from optical microscopic images in manufacturing processes through a LIME-based explainable machine learning approach. The results show that this explanation method can provide a comprehensive investigation of the effect of microstructure heterogeneity on the resultant behaviors of machining behavior for sustainable material machining and finds the causality of the fibrous structures' heterogeneity to the resultant machining forces. The SHAP-based approach investigates mechanism explanations for the vibration-assisted Atomic Force Microscope (AFM)-based nanomachining via acoustic emission (AE) signals and unravels the fundamental understanding of vibration-assisted nanomachining. Those techniques improve transparency and allow manufacturing professionals to customize materials and processes confidently. The transparent insights provided by these interpretable methods enhance trust in machine-learning models, facilitate collaboration among domain experts, and encourage informed decision-making. Additionally, these technologies lay the foundation for building regulatory-compliant, responsible and ethical production processes that will propel the entire industry into an era of smart and transparent production. In summary, the integration of LIME- and SHAP-based explanations into manufacturing processes paves the way for a symbiotic relationship between advanced machine learning models and domain expertise. By revealing the intricate relationship between microstructural properties and machinability, these techniques elevate manufacturing practices to new levels of transparency, innovation, and optimization.