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Toward Explainable Transfer Learning for Cross-Material Surface Roughness Prediction in Machining

Gennisse Forte and Christian Zamiela, PhD
Department of Industrial and Systems Engineering
Auburn University
Auburn, Alabama, USA
gyf0001@auburn.edu, cez0003@auburn.edu

Alice E. Smith, PhD
Departments of Mechanical Engineering and Computer Science
University of Alabama
Tuscaloosa, Alabama, USA
alice.smith@ua.edu

Abstract

In subtractive manufacturing, surface roughness serves as an important quality indicator, directly affecting product performance, dimensional accuracy, friction, wear, and overall functionality. Predicting it accurately is therefore essential for quality control. However, in CNC machining, most machine learning models are developed and validated on only a single material. As a result, these models are typically unreliable when the material changes, limiting their practical use in real manufacturing environments. In addition, training a model for each new material increases costs, time, and data requirements. To address this challenge, our ongoing study proposes a transfer learning framework combined with explainable artificial intelligence to improve cross-material prediction performance. This approach will allow knowledge learned from one material to be reused to predict surface roughness in another material, while maintaining model fidelity and interpretability. During CNC milling, multi-sensor signals and cutting parameters are collected as inputs, and surface roughness is the output for two materials. In the preliminary experimental phase, the model is trained using data collected from the source material, then transfer learning will be employed to adapt the learned representations to another material. Explainability techniques can then be used to identify which features remain invariant and transferable across materials and which features are material-sensitive. The expected outcome of this project is a robust, interpretable, and data-efficient modeling framework capable of adapting across materials with minimal retraining. This work aims to contribute to both academic research and industrial practice by advancing scalable, trustworthy, and generalizable AI solutions for intelligent manufacturing systems.

Keywords
Explainable Transfer Learning, Cross-Material Surface, Roughness Prediction, and Machining.

Biographies
Gennisse Forte is a doctoral student in Industrial and Systems Engineering at Auburn University. She earned a dual Master of Science in Supply Chain Engineering from the Georgia Institute of Technology and Universidad Tecnológica de Panamá, and a Bachelor's degree in Mechanical Industrial Engineering from Universidad Tecnológica de Panamá. Before beginning her doctoral studies, she gained extensive professional experience in Panama, serving in leadership positions as Purchasing and Logistics Manager, where she oversaw supply chain operations, supplier negotiations, inventory planning, international transportation, customs activities, and process improvement. Alongside

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her industry experience, she served as an adjunct professor for eight years in the Department of Logistics of the School of Industrial Engineering at Universidad Tecnológica de Panamá, teaching courses in purchasing, warehousing, transportation, international logistics, customs regulations, and supply chain management. She currently serves as a graduate teaching assistant at Auburn University. Her research interests include advanced and smart manufacturing, machine learning, explainable artificial intelligence, and intelligent decision-support systems. She is also involved in developing manufacturing applications that integrate large language models, retrieval-augmented generation, and multiagent AI systems to support engineering decision-making. Her broader interests include process optimization, supply chain engineering, human-centered artificial intelligence, and the practical implementation of data-driven technologies in industrial environments.

Dr. Christian Zamiela is an Assistant Professor in the Department of Industrial and Systems Engineering at Auburn University. His research integrates artificial intelligence and systems engineering to improve data-driven decision-making in advanced manufacturing. His work advances model-based enterprise integration and adoption through manufacturing process monitoring, quality assurance, digital threads, and connected digital engineering ecosystems. He collaborates with industry, academic, and government partners to improve digital engineering technologies and connected manufacturing systems. His research has been published in peer-reviewed journals and conference proceedings in advanced manufacturing and systems engineering. He is a member and active contributor to IISE, INFORMS, and INCOSE communities.

Dr. Alice E. Smith is Endowed Shelby Distinguished Professor of the Departments of Mechanical Engineering and Computer Science at the University of Alabama. Dr. Smith's research focus is analysis, modeling, and optimization of complex systems with emphasis on intelligent computation inspired by natural systems integrated with traditional operations research and statistical approaches. She holds one U.S. patent and has authored publications which have garnered over 19,000 citations and an H Index of 54. Dr. Smith is the outgoing Editor in Chief of *INFORMS Journal on Computing* and an Area Editor of *Computers & Operations Research*. Dr. Smith has been a principal investigator on over $12 million of sponsored research with funding by Department of Homeland Security, NASA, U.S. Department of Defense, Missile Defense Agency, National Security Agency, NIST, U.S. Department of Transportation, Frontier Technologies Inc., Lockheed Martin, Adtranz (now Bombardier Transportation), the Ben Franklin Technology Center of Western Pennsylvania, and U.S. National Science Foundation, from which she has been awarded 18 distinct grants. Dr. Smith is a member of the National Academy of Engineering (NAE), a Life Fellow of the Institute of Electrical and Electronics Engineers (IEEE), a Fellow of the Institute for Operations Research and Management Science (INFORMS), a Fellow of the Institute of Industrial and Systems Engineers (IISE), a senior member of the Society of Women Engineers, a member of Tau Beta Pi, and a Registered Professional Engineer.

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