Towards a Digital Twin Framework in Additive Manufacturing: Machine Learning, Bayesian Optimization and Model Predictive Control

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Multidisciplinary concurrent materials, geometry and manufacturing process optimization involves many computational challenges such as high-dimensionality associated with location dependency, material heterogeneity, multi-modal information, and nonlinear material behaviors such as large deformations and plasticity. The recent growth of using physics-based machine learning creates opportunities for incorporating data-driven methodologies with physical models into design. Furthermore, digital twin is an emerging technology in the era of Industry 4.0 that holds promises for real time optimization of manufacturing processes and quality control. We will present in this talk a digital twin framework that facilitates a bidirectional information exchange between virtual and physical systems in complex manufacturing processes. Using laser directed-energy deposition (DED) as an example in additive manufacturing (AM), we will first present the development of a time-series machine learning (ML) model of DED process to predict temperatures across various spatial locations of the DED-built part while taking dynamic processing conditions as inputs. With the uncertainty quantification using Monte Carlo dropout methods and a reduced dimensional representation, we introduce a Bayesian Optimization (BO) method for Time Series Process Optimization. We will then present a simultaneous multi-step Model Predictive Control (MPC) framework for real-time decision-making, using a multi-variate deep neural network (DNN), Time-Series Dense Encoder (TiDE), as the surrogate model. TiDE allows one-shot forward propagation and auto-differentiation for rapid decisions therefore proactive control over melt pool temperatures, while mitigating porosity defects by regulating laser power to maintain melt pool depth. Overall, the proposed MPC framework offers as a powerful tool for future Digital Twin applications and real-time process optimization .

Bio

Dr. Wei Chen is the Wilson-Cook Professor in Engineering Design and Chair of Department of Mechanical Engineering at Northwestern University. Directing the Integrated DEsign Automation Laboratory (IDEAL- http://ideal.mech.northwestern.edu/), her current research involves the use of statistical inference, machine learning, and uncertainty quantification techniques for design of emerging materials systems including microstructural materials, metamaterials and programmable materials. She serves as the Design Thrust lead for the newly funded NSF Engineering Research Center (ERC) on Hybrid Autonomous Manufacturing, Moving from Evolution to Revolution (HAMMER), where she works on digital twin systems for concurrent materials and manufacturing process design. Dr. Chen is an elected member of the National Academy of Engineering (NAE) and American Academy of Arts and Sciences (AAA&S). She served as the Editor-in-chief of the ASME Journal of Mechanical Design, the Chair of the ASME Design Engineering Division (DED), and the President of the International Society of Structural and Multidisciplinary Optimization (ISSMO). Dr. Chen is the recipient of the 2022 Engineering Science Medal from the Society of Engineering Science (SES), ASME Pi Tau Sigma Charles Russ Richards Memorial Award (2021), ASME Design Automation Award (2015), Intelligent Optimal Design Prize (2005), ASME Pi Tau Sigma Gold Medal achievement award (1998), and the NSF Faculty Career Award (1996). She received her Ph.D. from the Georgia Institute of Technology in 1995.