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Ph.D. DISSERTATION DEFENSE

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Title: Advanced Additive Manufacturing Using Data Analytics for Real-Time Quality Assurance

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ABSTRACT

Additive Manufacturing (AM) has emerged as a promising technology in recent years. However, the complexity of the fabrication process poses significant challenges in ensuring the quality and consistency of AM parts. To address these challenges, this dissertation proposes the utilization of sensors for real-time monitoring and control of the fabrication process, enabling the achievement of quality requirements for a repeatable and reliable process. Given the vast amount of information that can be obtained from embedded sensors, it is crucial to employ data analytics and predictive models for efficient processing of sensory data. The proposed solutions encompass effective methodologies to enhance part quality and machine reliability by integrating sensory data analysis with AI/ML models and closed-loop control systems.

In this study, the part quality attributes are identified by dimensional errors, layer-wise surface anomalies, and abnormal machine vibrations. In addition, the cost of quality and machine reliability are included to provide a maintenance strategy for the AM machine to assure the required quality output. Different methods are developed and investigated for their utility and effectiveness in solving each of these quality problems. Initially, the dimensional accuracy problem is studied using three different analytical models which are compared to compensate for the dimensional deviation resulting from the Fused Filament Fabrication (FFF) process. Secondly, layer-wise surface anomalies in FFF are investigated using real-time quality monitoring and control methods. An online sensor-based monitoring system for FFF is developed to identify layer-wise surface anomalies using a Convolutional Neural Network (CNN) model. Based on the online monitoring results, feedback controllers are designed to improve dimensional accuracy and layer-wise surface quality measures. To study abnormal machine vibrations, a data analytic approach based on a deep neural network is developed. To improve the quality of the AM process, machine maintenance and reliability are critical factors. In this study, a multi-objective optimization model is developed to consider both maintenance cost and machine reliability criteria for improved part quality.

Further, an online monitoring system is developed for the metal Direct Energy Deposition (DED) system. For this system, an image-based gaussian process model is developed to accurately predict the metal melt pool morphological features during the fabrication process. The proposed methodologies in this research offer a comprehensive system and associated models to address the challenges of quality assurance in advanced additive manufacturing and have the potential for wider applications in other manufacturing processes as well as the automation industry.