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Ph.D. Dissertation Defense

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Title: Integrating Physics-based Thermal Simulations, Real-time Process Monitoring and Machine Learning Methods for Developing Quality Prediction Models in Additive Manufacturing

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ABSTRACT

Ensuring part quality in Additive Manufacturing (AM) remains a critical challenge, particularly in processes such as Fused Filament Fabrication (FFF) and Directed Energy Deposition (DED), where interlayer bonding, melt pool stability, and dimensional accuracy govern performance. This dissertation integrates real-time process monitoring, physics-based simulations, and machine learning (ML) to develop predictive models for part quality across multiple AM processes.

In FFF, an infrared (IR) camera monitoring system was implemented to capture thermal histories during cooling and reheating in thin-wall prints. Experimental datasets are used to analyze the thermal trends as a result of different process parameters. Thermal simulations are then introduced to quantify weld time above the glass transition temperature, enabling bond-strength prediction overcoming experimental limitations.

In DED, single-track studies combined point-cloud surface scans and ML models to predict subsurface melt pool depth, offering a non-destructive route for geometry assessment. A physics-based thermal simulation was then built to expand training data, producing melt pool surface temperature maps to be used for pretraining a hybrid convolutional neural network. In data-scarce conditions, we implement Sim-to-Real Transfer Learning by pretraining the model on simulation data and fine-tuning it with limited IR data. The robustness of this model is tested in comparison to a model solely pretrained on a limited set of experimental data to predict melt pool width and depth of single-track prints in real-time. Expanding on the single-track study, the dimensional accuracy of a multilayer print is studied. Data from a multi-sensor system integrating a coaxial and infrared camera monitoring the process in real-time is used to develop a dimensional tolerance classification model.

Future work will advance towards developing quality predictive models of multilayer, multitrack complex AM parts. These models will allow prediction of part quality through the reliance on limited experimental datasets in combination with simulations. By predicting part quality, these models could also be used to classify part defects in real-time.