Prediction of Dimensional Changes of Low-cost Metal Material Extrusion Fabricated Parts Using Machine Learning Techniques

Authors: Zhicheng Zhang, James Femi-Oyetoro  Advisors: Dr. Ismail Fidan, Dr. Muhammad Ismail, Dr. Michael Allen

Introduction
Additive manufacturing (AM) is a widely used layer-by-layer manufacturing process [1]. However, it is limited by material options, different fabrication defects, and inconsistencies in part quality. Material extrusion (ME) is one of the most widely used AM technologies [2]. Thus, it is adopted in this research. Low-cost metal ME is a new AM technology used to fabricate metal composite parts using sintering metal in a defined elemental material. Since the materials and the processes are relatively new, there is a need to investigate the dimensional accuracy of low-cost metal ME fabricated parts for real-world applications. Each step of the manufacturing process such as 3D printing of the samples and the sintering will affect the dimensional accuracy significantly. By using several machine learning (ML) algorithms, a comprehensive analysis of dimensional changes of metal samples fabricated by low-cost metal ME process is developed in this research. ML methods can assist researchers in sophisticated pre-manufacturing planning and product quality assessment and control. The findings of this study can help researchers and engineers to predict the dimensional variations and optimize the printing and sintering process parameters to obtain high-quality metal parts fabricated by this low-cost ME process.

Process
The schematic of this research is shown in Figure 1. There are three main sections in the research. The first section is the collection of the data. It was gathered from a CAD model to the slicing software, which then is fed to the sintered parts in the 3D printer. After measuring the non-sintered dimensions, the sintered parts were sintered in the muffle furnace. After cutting, the sintered parts were polished and then measured. The second section is prediction. Prediction algorithms were trained, tested, and evaluated using the collected data. The third section is verification, where the performance of the prediction algorithm is validated via experimental results.

Material & Equipment
In this research, the Sintera SLA system made by The Virtual Foundry was used to print the non-sintered parts and fabricated in an Ultimaker 5 S 3D printer. The slicing process was performed using the prints of a KLM-100K metal furnace. A 3-axis electron microscope was used to take the measurement of the dimensional features before and after the sintering process. The material and equipment are shown in Figure 2. Also, the CAD non-sintered and sintered parts are shown in Figure 3.

Machine Learning Algorithms
The three types of algorithms used in this research were single Linear Regression (LR), Linear Regression with Interactions (LRI) and Neural Networks (NN). In this research, the CAD dimensions in the response variable. The independent variables are layer thickness (L), sintering temperature (ST), Temperature increasing ratio (TR), nozzle temperature (NT), Printing speed (PS) and the final length (L), width (W), and height (H).

Discussion
Figures 5, 6, and 7 show the predicted results of different ML algorithms. The differences are the difference between the predicting CAD dimensions and real dimensions. It is easy to get the point that, closer to zero the difference in measurement accurate the algorithm is. The medians of all three algorithms are closer to zero, but the max errors are different. The LR prediction has the largest error 2mm, LRI has the largest error 1mm and the largest error for NN is 0.3mm. Also, different ML algorithms have different variance. From the boxplot, the variance of NN is much smaller than LR and LRI. The medians are close and the variance is small, from the boxplot, the NN is the most reliable ML algorithm to use in this research.

Conclusion
In this research, the dimensional changes of low-cost metal ME fabricated parts are analyzed by different ML algorithms and these three types of algorithms behave differently in predicting CAD dimensions. The medians of them are all close to zero, but NN has smallest variation. Besides, NN has the smallest MSE and, hence, will be the best algorithm to predict the initial CAD dimensions.

Acknowledgement
This research has been made possible with the help provided by the Additive Manufacturing Research and Innovation Laboratory (Foundation Hall) and Senior Design Laboratory (Brown Hall) in Tennessee Tech University.

References