April Bowen
2021
Mechanical Engineering

Physical Properties of Additive Manufacturing to Combat Illicit Use of 3D Printing Technology

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The long-term goal is to trace a generated part to its source (e.g. printer or material) by creating a database which identifies and categorizes 3D printing. The question: Can the source of 3D printed objects be determined through unique physical properties? Experiments were designed to determine parameters which have significant effects at the macro-scale. The hypothesis stated that there are measurable physical differences in 3D printed products generated due to the type of printer, filament material, software used to generate the printed file, and orientation of the printed part. The first step was to test the hypothesis to evaluate whether the factors that were chosen to have significant effects in the process of 3D printing. By separating parameters into individual projects, experiments were conducted measuring the dimensions and mass of 3D printed objects concerning variables such as design units (e.g., G-code and *.stl), orientation and filament material. Four different printers reside at the University of New Haven: MakerBot Replicator 5th Generation, MakerBot Replicator Plus, Stratasys Dimension SST (Soluble Support Technology) 1200es, and Sindoh 3DWOX. The geometric objects originally designed were cubes, hemispheres, cylinders, and triangular and quadrangular prisms. However, only rectangles, cylinders, and wedges were designed for simplicity. The objects designed were converted from a *.stl file - output of computer-aided design (CAD) software - to G-code using computer-aided manufacturing (CAM) software which is specified by each printer. Measurements of mass (grams) and dimensions (x, y, z, inner and outer diameter) were taken of each generated part using a scale and caliper respectively.

Project 1 tested the effect of different printers on the dimensions and mass of generated rectangles and cylinders. In SolidWorks, rectangles and cylinders were designed and saved as a *.stl file. The *.stl file was then converted to G-code using a CAM program. Stratasys, MakerBots, and Sindoh used CAM software call GrabCAD Print, MakerBot Print, and FreeLab respectively. The rectangles and cylinders were then printed by uploading the G-code file to the printer by USB or ethernet cable. Three samples of rectangles and cylinders were printed, and each dimension and mass were measured 3 times. The average of the x, y, z, and ID, OD, and y dimensions was calculated in inches. The average value was subtracted by the expected value to create an accuracy plot.

Project 2 tested CAD Programs such as SolidWorks, and Fusion 360, AutoCAD on the 5th Gen, Plus, and Dimension. A rectangle and cylinder were designed on each CAD program then printed on each separate printer using CAM software. The methods from Project 1 were repeated.

Project 3 tested the orientation of a printed wedge part. The wedge was printed on the bottom, adjacent, and hypotenuse face using a *.stl SolidWorks file. The wedge was also printed on each printer to see multivariable effects. Three samples of wedges were printed, and each dimension and mass were measured 3 times. The average of the x, y, and z dimensions was calculated. The average value was subtracted by the expected value to create an accuracy plot.

Project 4 tested the effect of different filament materials. MakerBot Replicator Plus can print PLA and Tough PLA. Three samples of rectangles were printed using a SolidWorks *.stl file and each dimension and mass was measured 3 times. The average of the x, y, and z dimensions was calculated. The average value was subtracted by the expected value to create an accuracy plot.

A generated part may potentially be traced to a specific printer or model/manufacturer if the parts produced by a single printer (i.e., within the group) have fewer differences/variance than those from different printers (i.e., between-group). If there was no difference between groups, then the null hypothesis would not be rejected and there would be no reason to continue this research using a larger sample size. The analysis of variance (ANOVA) of the physical measurements indicated there are statistically significant differences (p-value less than 0.05) between 3D printed parts that are manufactured with different printers, software, orientation, and material. As the database increases in size, there is a possibility to determine the discriminating potential of physical measurements for the identification and categorization of 3D printing characteristics, which ultimately has the potential to help trace a printed part to its source. I will also investigate if there are identifiable characteristics at the microscopic level (e.g., striations produced during printing) as more parameters and statistical analysis tools are explored.