Capability Testing of the UNH uPrint® Rapid Prototyping Machine (3D Printer)

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Abstract

The dimensional accuracy of parts produced on the uPrint rapid prototyping machine (3D printer) was evaluated using a Starrett AV300 Vision System (3D scanner). This project builds upon work performed previously by faculty and student researchers at UNH to determine machine capability in producing certain types of part features. The ability to measure feature dimensional accuracy is greatly improved by the addition of a Galileo AV300 Vision System, which was installed in the industrial and system design lab during the summer of 2013. The Starrett AV300 Vision System works by importing SOLIDWORKS files into the machine software and then comparing design dimensions to actual dimensions of parts produced on the 3D printer. The system has the stated capability to measure complex features to 3.5 + 5L/1000 micron accuracy in the X-Y plane and 2.5 + 5L/1000 micron accuracy in the Z direction. This capability was tested by producing a benchmark part on the uPrint 3D printer that contains important common features that are used in typical engineering design projects at the university. The highest level of dimensional accuracy, or best performance, according to average percent error occurred for the overall length of the part at -0.1819 %. Seven other features actually had lower average errors, but the error is divided by a smaller overall feature size. Radius 6 and Edge 3 had large average percent error rates occurring at 3.22% and 8.75%, respectively, which should be investigated further to determine if the error is due to the prototyping process or the measurement method and system. A presentation was created that can be used to train other engineering faculty and students on use of the Starrett AV300 Vision System.

Introduction

During the engineering design process, a problem is identified or defined, ideas are generated, criteria are developed and used to “down-select” to a few, or one, possible solutions to further pursue. Models or prototypes are built to refine the design and then a concept is built, tested, and eventually sent to a mass production process to produce thousands or millions of parts. Rapid prototyping (RP) technology is a key step in that process, allowing for testing and validation of designed components and systems. What was once a limited and expensive resource is now easily accessible and affordable (Rottman, 2013).

When RP technology was first introduced in the 1980s, it was mainly used for “throwaway” prototypes. Parts were built to communicate their “fit, form, and function,” and then tossed because they were produced from wax or other inferior materials. Today, the technology is being used for production-ready parts produced in limited quantities, which can withstand actual testing and implementation. One can imagine a time in the future where custom parts (a hip joint, a knee cap, etc.) can be generated and implanted into the patient. Dental implants are already being produced with this technology.

RP technology is becoming more widely used thanks to its ability to speed-up product development time in many different types of industries. Lately, there has also been much discussion of a “maker” movement where households are able to design and produce their own designs and parts in their own homes (Rottman, 2013). The quality of a prototype depends upon the machine design, process, process settings, material used, and other factors (Thompson et al., 2011). The uPrint 3D printer automatically constructs 3-dimensional physical objects using fused deposition modeling (FDM) technology. As shown in Figure 1, FDM produces prototypes from plastic materials, such as ABS, by laying tracks of semi-molten plastic filament onto a platform in a layer-wise manner from bottom to top (Lee et al., 2005). Several attempts have been made to improve the quality of a prototype part in aspects such as part accuracy, surface finish, strength, etc. (Sood et al., 2010). Moreover, those studies also attempt to improve rapid prototyping technology.

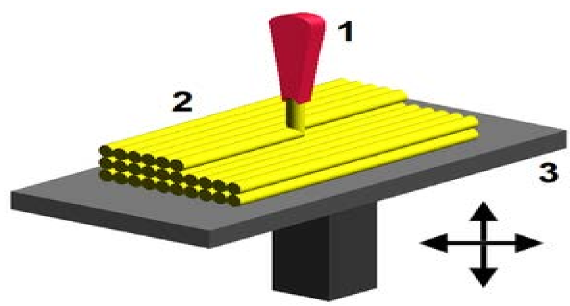

Figure 1. Visual of fused deposition modeling (FDM) process.

The goal of this project was to test the dimensional accuracies of certain features produced by the uPrint 3D printer using the Starrett AV300 Vision System. The AV300 Vision System works by importing SOLIDWORKS files into the machine software and then comparing design dimensions to actual dimensions of parts produced on the 3D printer. The system has the capability to measure complex features to 3.5 + 5L/1000 micron accuracy in the X-Y plane and 2.5 + 5L/1000 micron accuracy in the Z direction. By measuring different features on a benchmark part, as in Figure 2, that could be replicated using the uPrint 3D printer, results could be compared to those of the original computer file that the 3D printer used to create the parts.

Figure 2. Original benchmark part (top) next to a replicated part from the uPrint 3D printer (bottom).

Materials and Methods

The material used to create prototype parts in the uPrint 3D printer is ABS plastic. This plastic is melted and deposited in layers by the 3D printer to create the prototype part desired. The programs used to create the prototype parts were AutoCAD and SOLIDWORKS. Microsoft EXCEL was used primarily in compiling the data acquired and analyzing it for results. Catalyst EX was used to send the digital files of the prototype parts to the 3D printer to be printed. The original prototype part was dimensioned using AutoCAD to determine the nominal dimensions.

Three prototype parts were created with the uPrint 3D printer at the settings with the highest density of the ABS plastic and support material. The parts were then analyzed using the Starrett AV300 Vision System. The benchmark part used was chosen due to its multitude of features that could be analyzed; including its slots, thru-holes, fillets, and the range of sizes of its features. Having a metal part produced by a stamping process could also be used for relative comparison of dimensional accuracy. To begin, the original AutoCAD file was dimensioned to provide nominal (target) measurements. These dimensioned features are shown in Figures 3, 4, and 5.

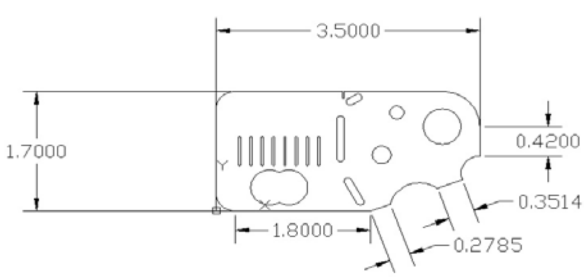

Figure 3. Length and edge features in the original CAD file (inches).

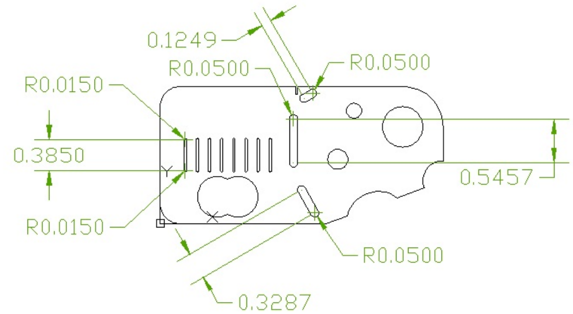

Figure 4. Slots in the original CAD file (inches).

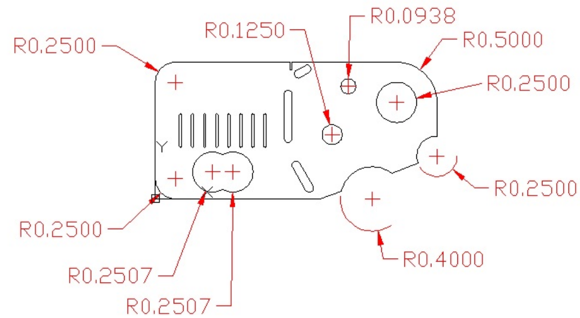

Figure 5. Fillets, curves, and circles in the original CAD file (inches).

After the features of the prototype parts were measured using the Starrett AV300 Vision System, the data was exported to Microsoft EXCEL where it could be analyzed and compared to the original AutoCAD or SOLIDWORKS file. Compiling the data in Microsoft EXCEL allowed for each of the measurements of the multiple prototype parts to be compared to the original AutoCAD file and for the error and percentage error of each of the features to be calculated.

An additional goal of this project was the creation of a presentation that could be used to train other engineering faculty and staff on use of the Starrett AV300 Vision System (Figure 6). The presentation compiles information from the manufacturer's training manuals, self-experience, and training seminars. The subjects include starting up the Starrett AV300 Vision System, setting up coordinate axes to measure parts, measuring features of 2D parts, measuring features of 3D parts, and recording a program, or macro, that can be used to measure the same part for multiple tests or measure multiple parts that are very similar. This presentation will be used to teach interested faculty in the Tagliatela College of Engineering the basics of how to properly use the Starrett AV300 Vision System.

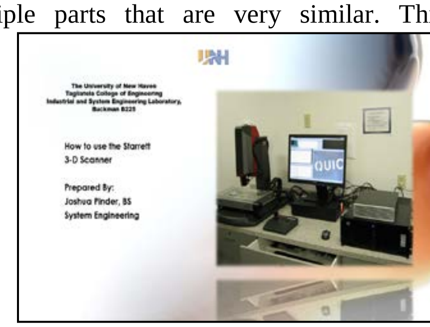

Figure 6. How to use the AV300 vision system.

Results and Discussion

Table 1 shows dimensional accuracy results for 12 selected features. These features include the overall length and width of the part, slot radii, thru-holes, circle radii, and edge lengths. A positive sign indicates either an expansion in the part or other manufacturing error and a negative sign indicates shrinkage of the part or other error. This study did not analyze how measurement error may impact the error found, and would be part of future work related to determining capability of the prototyping process.

Average error measures the average deviation of a dimension from its target, or nominal dimension. This measure is in absolute terms, and does not take into account the overall size or dimension of the feature. The percent average error measure takes into account the size of the feature and determines the dimensional accuracy in relation to the feature. Given these definitions the average percent error for long features usually is quite small because the error is divided by the long size of the feature. For instance, the highest level of dimensional accuracy according to average percent error occurred for the overall length of the part at *-0.1819 %*. Seven other features actually had lower average error, but the error is divided by a smaller overall feature size. Radius 6 and Edge 3 had large average percent error rates occurring at *3.22%* and *8.75%*, respectively, which should be investigated further to determine if the error is due to the prototyping process or the measurement method.

Table 1. Features and their dimensional accuracies.

Feature	Nominal Dimension in inches (from CAD design file)	Stamped Metal Part (inches)	Error (inches)	% Error	uPrint ABS Part 1 (inches)	uPrint ABS Part 2 (inches)	uPrint ABS Part 3 (inches)	Variance (inches^2)	Average Error (inches)	Average % Error
Part Dimension										
Part Width	1.7000	1.6936	-0.0064	-0.3765	1.6919	1.6946	1.6885	9.34E-06	-0.0083	-0.4902
Part Length	3.5000	3.4926	-0.0074	-0.2114	3.4901	3.4977	3.4931	1.47E-05	-0.0064	-0.1819
Average Error			**-0.0069**	**-0.2939**					**-0.0073**	**-0.3361**
Variance			**5.00E-07**	**0.0136**					**1.93E-06**	**0.0475**
Slots										
Slot	0.2507	0.2437	-0.0070	-2.7922	0.2474	0.2500	0.2521	5.54E-06	-0.0009	-0.3457
Slot	0.2507	0.2434	-0.0073	-2.9118	0.2484	0.2493	0.2479	5.03E-07	-0.0022	-0.8642
Average Error			**-0.0071**	**-2.8520**					**-0.0015**	**-0.6050**
Variance			**4.50E-08**	**0.0072**					**8.45E-07**	**0.1344**
Thru-Holes										
Thru-Hole	0.1250	0.1172	-0.0078	-6.2400	0.1224	0.1226	0.1227	2.33E-08	-0.0024	-1.9467
Thru-Hole	0.0938	0.0868	-0.0070	-7.4627	0.0921	0.0916	0.0919	6.33E-08	-0.0019	-2.0611
Thru-Hole	0.2500	0.2426	-0.0074	-2.9600	0.2477	0.2502	0.2475	2.26E-06	-0.0015	-0.6133
Average Error			**-0.0076**	**-4.6000**					**-0.0020**	**-1.2800**
Variance			**1.60E-07**	**5.4213**					**2.03E-07**	**0.6478**
Radius										
Radius 6	0.4000	0.4017	0.0017	0.4250	0.3951	0.3696	0.3967	2.31E-04	**-0.0129**	**-3.2167**
Radius 7	0.2500	0.2508	0.0008	0.3200	0.2384	0.2468	0.2363	3.09E-05	-0.0095	-3.8000
Average Error			**0.0008**	**0.3200**					**-0.0095**	**-3.8000**
Variance			**4.05E-07**	**0.0055**					**5.67E-06**	**0.1701**
Edge										
Edge 1	1.8000	1.8162	0.0162	0.9000	1.8402	1.8586	1.8404	1.12E-04	**0.0464**	**2.5778**
Edge 2	0.2785	0.2707	-0.0078	-2.8007	0.2733	0.2748	0.2755	1.26E-06	-0.0040	-1.4243
Edge 3	0.3514	0.3443	-0.0071	-2.0205	0.3308	0.3344	0.2968	4.30E-04	**-0.0307**	**-8.7460**
Average Error			**0.0046**	**-0.5602**					**0.0078**	**-3.0841**
Variance			**1.87E-04**	**3.8056**					**1.53E-03**	**32.9751**

Conclusions

The results reported can be used to determine shrinkage or expansion rates when designing parts. For instance, if it is known that on average the overall length of a part is approximately 3.5 inches in size, then the user may want to increase the length by 0.182 % in order to try to achieve higher levels of accuracy on the prototyped part. This is assuming the part length may shrink by about 0.182% based upon our study data. If this can be performed for other features, a more accurate prototype part can be produced. The long term goal of the project is to create a Design for Prototype guideline that UNH students may use when designing and building engineered parts for course projects and capstone projects.

Future Work

A student in Mechanical Engineering began a project with Dr. Carnasciali during the summer of 2012 to computationally redesign and optimize wind turbine blades. A form of renewable energy production, wind turbines produce energy from wind passing over the blades and forcing the blades to rotate. Rotational motion is then translated to a generator to produce electrical power. The shape of the blades influences the efficiency of the turbine. The validation of computer models necessitates experimental data. In order to validate the models generated by Hamilla & Carnasciali, we propose to build small-scale prototypes of the wind blades and test them in the Mechanical Engineering wind tunnel. The complex shapes and intricate details of the scaled wind turbines will require precision prototyping and measurement. It is the goal of future studies to determine if the uPrint 3D printer has the capability to produce the needed shapes.

More advanced analysis and future work will determine the error that results from use of the measurement device, the Starrett AV300 Vision System, and error estimates for the manufacturing process will subtract out the measurement error to isolate error caused by the prototyping process of the uPrint 3D printer.

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Biography

Josh Pinder will graduate in May 2016 with a B.S in System Engineering.