3D PRINTER DIMENSIONAL ACCURACY BENCHMARK

Todd Grimm

The blend of low cost and ease-of-use has fuelled rapid growth for 3D printers. Designers, engineers and educators have adopted this technology in record numbers, making it the fastest growing segment of the rapid prototyping industry. 3D printers are often used in the earliest stages of design. The models that they produce are the tools for review, evaluation, iteration and innovation and although the life span of these design tools can be measured in minutes or hours, users still want reasonable accuracy that will satisfy the needs of their applications. This article presents a benchmark study of three of the leading machines in this field, and offers readers an insight into the results that can be achieved.

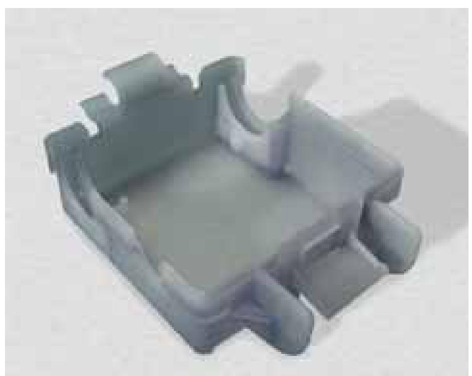

Figure 1: Battery box top from InVision SR.

Figure 2: Battery box bottom from Dimension SST

Figure 3: Fixture base from Dimension SST

Figure 4: Fixture cap from ZPrinter 310.

The Brief

The goal of this benchmark is to analyse and quantify the dimensional accuracy available from the Dimension SST [1], InVision SR [2] and ZPrinter 310 [3]. To compare accuracy, end users of each of the three systems in this benchmark test built four prototypes of the same parts. These prototypes were inspected with quality control tools. Instead of a CMM (coordinate measuring machine), this benchmark used laser scanning and CAI (computer-aided inspection) to analyse the quality of the prototypes. With CAI, the analysis used 200,000 data points per part and the large sample produces a truer representation of the prototypes' accuracy. The results reveal some surprising information, and, in some cases, the data is contradictory to general perceptions.

Parts and Process

Two two-piece assemblies were selected for the accuracy benchmark. The battery box consists of a top and bottom that are joined with a hinge and snap fit. (See Figures 1 and 2). The components measure roughly 2.5 x 2 x 1 in. The second assembly was a light fixture comprised of a base,

	Battery Bottom			Battery Top			Fixture Base			Fixture Cap		
	Dimension SST	InVision SR	ZPrinter 310	Dimension SST	InVision SR	ZPrinter 310	Dimension SST	InVision SR	ZPrinter 310	Dimension SST	InVision SR	ZPrinter 310
Mean	-0.0009	-0.0108	0.0021	0.0001	-0.0011	0.0002	0.0000	-0.0032	0.0015	0.0009	-0.0036	0.0030
Std. Dev. (_)	0.0030	0.0106	0.0041	0.0034	0.0097	0.0050	0.0031	0.0075	0.0044	0.0027	0.0065	0.0054
Max. Error	0.0147	0.0279	0.0303	0.0198	0.0446	0.0345	0.0204	0.0246	0.0221	0.0152	0.0244	0.0294
Min. Error	-0.0151	-0.0373	-0.0167	-0.0167	-0.0299	-0.0235	-0.0297	-0.0252	-0.0148	-0.0098	-0.0151	-0.0137
±1 Std. Dev.	69.10%	69.93%	73.47%	67.64%	67.42%	69.82%	77.83%	53.38%	66.62%	70.87%	56.84%	66.41%
± 2 Std. Dev.	95.44%	93.95%	94.47%	95.97%	96.21%	95.40%	94.78%	99.07%	96.018%	94.34%	98.85%	96.12%
± 3 Std. Dev.	99.44%	99.90%	98.99%	99.59%	99.95%	99.37%	99.04%	99.99%	99.78%	99.59%	99.97%	99.95%
± 4 Std. Dev.	99.96%	100%	99.83%	99.96%	99.99%	99.89%	99.56%	100%	99.99%	99.96%	99.99%	99.99%
± 5 Std. Dev.	99.99%	100%	99.97%	99.99%	100%	99.97%	99.64%	100%	100%	99.99%	100%	100%
± 6 Std. Dev.	100%	100%	99.99%	100%	100%	99.99%	99.72%	100%	100%	100%	100%	100%
Points Captured	213132	201682	212275	245925	226980	223047	260273	241548	266188	264273	242773	254789

Table 1: Accuracy data from laser scanning and computer-aided inspection (CAI).

which holds a light bulb and a decorative cap that screws to the base. (See Figures 3 and 4). These components have diameters of roughly 1.5 in. and heights of 1.5 to 2.0 in. [Ed: The benchmark test was carried out in the US and all measurements for the parts and the results are given in inches].

Equipment manufacturers did not participate in this benchmark. End users were carefully selected for their experience with the technology and their lack of bias. These users constructed the four pieces with the intent of delivering the best accuracy. However, the companies were limited to one build for each part so that iterations could not be used to improve the results. The parts were post processed to the minimum standards, which included support removal, depowdering and infiltration. Sanding and finishing were not permitted.

Upon receipt, the parts were randomly labelled S1 to S12. By eliminating any reference to the systems, the labelling enabled a blind study. The parts were not matched to the system that produced them until all inspection analysis was complete.
The parts were inspected with an LDI 150 laser scanner. For each part, the scanner's output yielded a point cloud with an average of 237,000 individual points. Using PolyWorks software, the point cloud data was compared with the STL files from which the parts were built. This CAI data produced the colour maps and accuracy summaries presented in this report.

The colour maps (see figures 5 and 6) illustrate the deviation of the sample parts from the STL files used to produce them. The colour scale, which is different for each part, indicates the range of dimensional error. Green areas are nearest to the nominal dimension, while yellow/red shows the highs and cyan/blue shows the lows.

A summary of these results is presented in table 1 and figure 7. Table 1 lists the mean (average), standard deviation and minimum/maximum error. The combination of the mean and the standard deviation documents the range of error for approximately 66 percent of all the data points. Figure 7 is a graphical representation of the data in table 1. This chart shows the ±1 standard deviation (σ) as a solid bar. The vertical lines above and below indicate the maximum deviation for all data points.

Results – By Part

Battery Box

For both the bottom and top parts of the battery box, the Dimension SST has the best overall accuracy, as seen in the colour maps. The $\pm 1\sigma$ error is impressive, with both parts having a range of just 0.006 in. While the maximum errors are -0.017 and 0.020 in., 99% of all data points fall within a range of -0.010 to 0.010 in.

The second best accuracy results are from the ZPrinter 310. The $\pm 1\sigma$ error is 0.008 in. for the bottom and 0.010 in. for the top. For the bottom, the error range for 99% of the points approached that of the Dimension SST (-0.010 to 0.014 in.), but the top's error band is twice the size (-0.020 to 0.020 in.). The top also has a wide maximum error range of -0.024 to 0.035 in.

The InVision SR demonstrates the poorest accuracy of the three technologies. For both parts, the range of dimensional inaccuracy is quite large when compared with the other systems. The two parts have $\pm 1\sigma$ error bands of 0.021 and 0.020 in. 99% of the data points fall within a range of -0.042 to 0.028 in. The extent of this error band is significantly broader than that of either the Dimension SST or ZPrinter 310.

Fixture

The Dimension SST also had the best accuracy for the fixture base and fixture cap. As with the battery components, the $\pm 1\sigma$ error range is only 0.006 in. for both parts. Also consistent, the 99% range of values are between -0.009 and 0.009 in. The Dimension SST did show an interesting difference in minimum/maximum error for the base and cap. The base had the biggest maximum error range of any Dimension part (-0.030 to 0.020 in.), while the cap had the best (-0.010 to 0.015 in).

The ZPrinter 310 once again has the second best accuracy performance, and the fixture base was the best of all ZPrinter 310 parts. The $\pm 1\sigma$ error for these parts are 0.009 and 0.010 in. respectively. The base has a standard deviation range of -0.003 to 0.006 in., and the cap has a range of -0.002 to 0.008 in. Of all data points for these parts, 99% fall between -0.013 and 0.019 in.

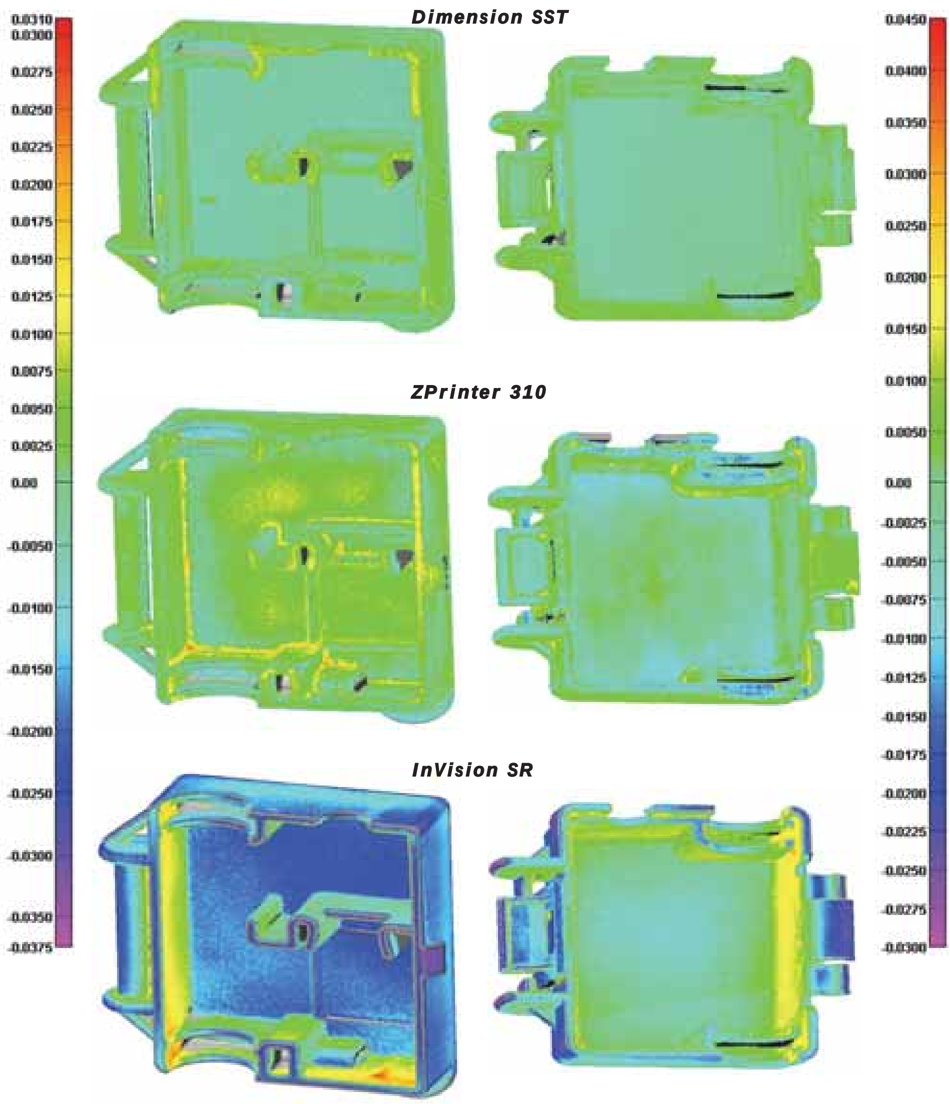

Figure 5. Results – By Part: Colour map of dimensional accuracy for battery box bottom (left) and battery box top (right).

While the accuracy of the fixture components from the InVision SR is better than that for the battery box, the results were the poorest of the three systems. The $\pm 1\sigma$ error bands are 0.0013 and 0.015 in.—50% larger than that of the ZPrinter 310 and more than double that of Dimension SST. Although the accuracy of the fixture cap approaches that of the ZPrinter 310, the 99% error range is much broader (-0.023 and 0.016 in.).

Results – By System

Dimension SST

The Dimension SST outperformed both the ZPrinter 310 and InVision SR in all but one measure. The analysis shows that Dimension SST has a narrower range of tolerance deviation and that the high and low deviations are centred about the nominal value. For prototype parts of similar size, this analysis shows that ±0.003 in. is a reasonable expectation for many measurements and that most should fall between -0.010 and 0.010 in.
One factor that impacts overall accuracy and quality is that the Dimension SST may leave a narrow gap between the faces of small features. These gaps arise when the system cannot fill the space without adding excess material. The gaps are included in the accuracy data and can be seen in the colour maps.

Yet, the level of dimensional accuracy and the consistency of the results rival that of rapid prototyping systems that cost much more.

ZPrinter 310

The accuracy results for the ZPrinter 310 seem contradictory to previous accuracy studies and general perceptions. This system performed well, and the results are reasonable for a system in the 3D printer class of rapid prototyping technology. Users of the technology, when constructing parts of similar size, can reasonably expect to see dimensional tolerances that are on the order of ±0.005 in. Overall, the test parts show that most dimensions should fall between -0.015 and 0.015 in.

However, the ZPrinter 310 did show a tendency to produce dimensional inaccuracies that exceed the ±0.015 in. range. A contributing factor may be part post processing. Unlike the other two technologies, the ZPrinter 310 requires manual depowdering and infiltration of the prototypes. When enlarged, the point cloud shows that most surfaces have high and low spots that deviated significantly from the bulk of the surface. This is likely to be the result of an excess or shortage of powder and infiltrant.

It is important to note that the battery bottom, which was infiltrated with cyanoacrylate, was broken in three places. A snap fit was broken off when the part was removed from the powder bed. If allowed to build the part a second time, the end user indicated that this could have been remedied. Additionally, in transit to the inspection company, two corners were broken off of the part. While these missing features were not included in the dimensional analysis, they would detract from the overall part accuracy when used as a concept model or prototype.

InVision SR

The InVision SR faired poorly in the study of dimensional accuracy. It is difficult to state what can be expected from the system, since the dimensional accuracy varied significantly by part. However, it appears that a reasonable range is -0.010 to 0.005 in. and that most dimensions will fall between -0.020 and 0.020 in. With the exception of the battery top, the features tend to be undersized.

These results show that the InVision SR may be acceptable as a concept modeller, but for more demanding applications, the technology may be unable to satisfy accuracy requirements.

Conclusion

From this study of four parts, the Dimension SST has shown that it can deliver the accuracy needed for prototype components. The ZPrinter 310 also performed well, although the range of tolerance error is broader than that of the Dimension. Surprisingly, the InVision SR did poorly in spite of its high resolution.

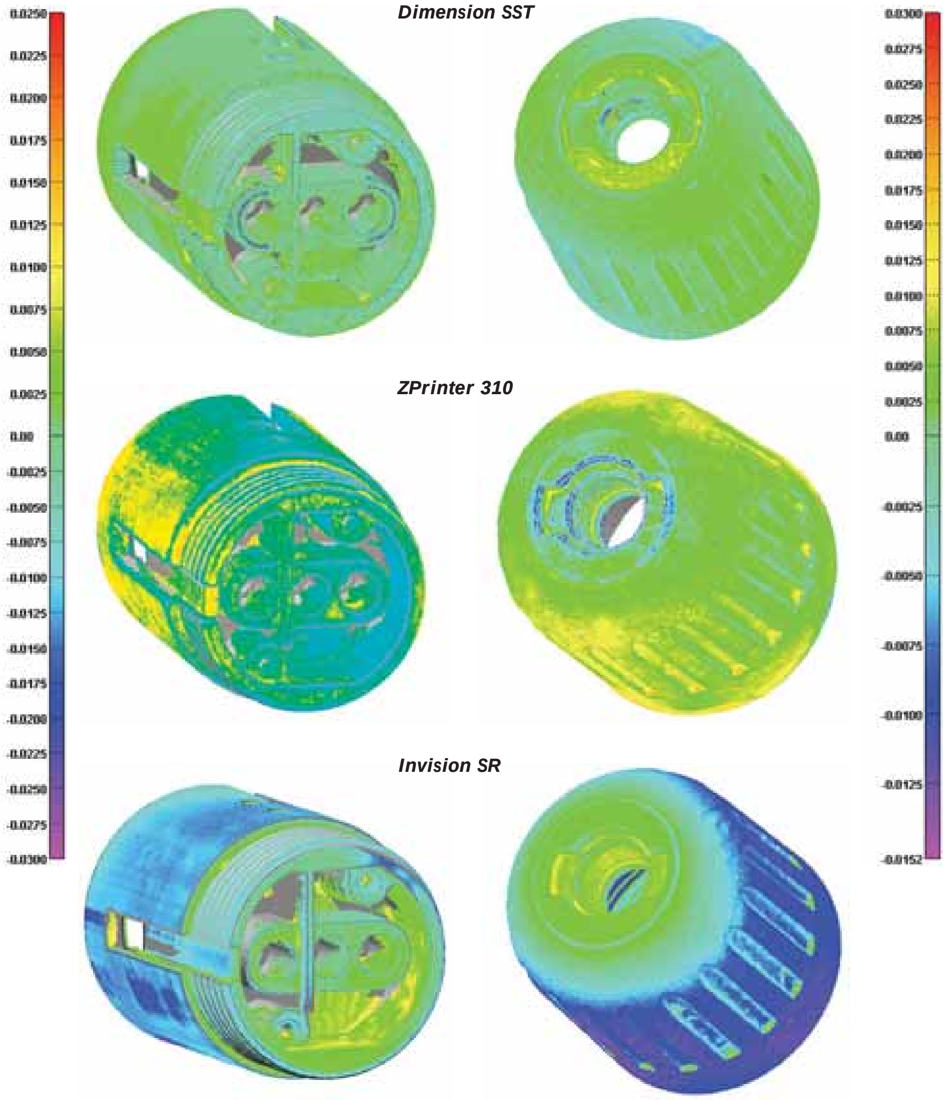

Figure 6: Colour map of dimensional accuracy of fixture base (left) and fixture cap (right).

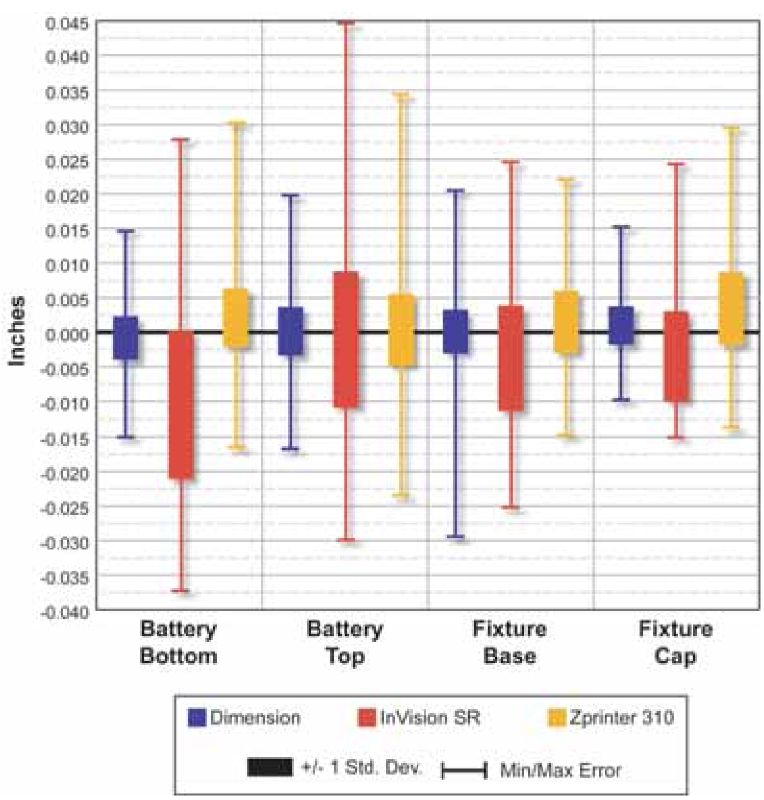

Figure 7: Accuracy chart showing ±1 σ and minimum/maximum error.

Caution is merited when using these results. As any user will state, the quality of a rapid prototype, including dimensional accuracy, is a function of the part, the system, the build parameters, the material and the operator. Therefore, use this data only as an indicator of the possible accuracy for small prototype components.

Acknowledgements

The ZPrinter 310 prototypes were supplied by Sherpa Design (www.sherpa-design.com). The Dimension SST and InVision SR prototypes were supplied by end users that wish to be unnamed. Part measurement and inspection was performed by QC Inspection (www.qcinspect.com).

References

1. The Dimension SST is manufactured by Stratasys Inc.
2. The InVision SR is manufactured by 3D Systems.
3. The ZPrinter 310 is manufactured by ZCorporation.

Todd Grimm is president of T. A. Grimm & Associates, Inc., an independent consulting firm that focuses on rapid prototyping and reverse engineering. Todd has worked in the field of rapid prototyping since 1990. He is the author of "Users Guide to Rapid Prototyping." Todd is a member of the TCT Europe Editorial Advisory Board, serves on the Society of Manufacturing Engineers' Rapid Technologies and Additive Manufacturing steering committee and he chairs the 3D Data Capture/Reverse Engineering technical group.