REPEATABILITY AND REPRODUCIBILTY STUDIES FOR STRUCTURED LIGHT SCANNING

Leah J. Jacobs[1] and Tony Schmitz[1,2]
[1]Mechanical, Aerospace, and Biomedical Engineering Department
University of Tennessee
Knoxville, TN, USA
[2]Manufacturing Science Division
Oak Ridge National Laboratory
Oak Ridge, TN, USA

ABSTRACT

Structured light scanning is used to create a digital twin of a manufactured part. Features can be extracted from this digital twin to determine if the part meets the designer's intent and required tolerances. This paper describes repeatability and reproducibility studies for a structured light scanning system and measurement artifact.

INTRODUCTION

To quantify the repeatability and reproducibility of structured light scanning measurements in manufacturing environments, a study was performed using a GOM ATOS Q. This scanner is composed of a projector, which projects a structured pattern onto the test object, and two cameras, which capture the distortion in the pattern caused by the object shape. The object shape is identified by analyzing the distortion of the projected pattern after the system is calibrated and the spatial relationship (distance and angles) between the projector and camera is known.

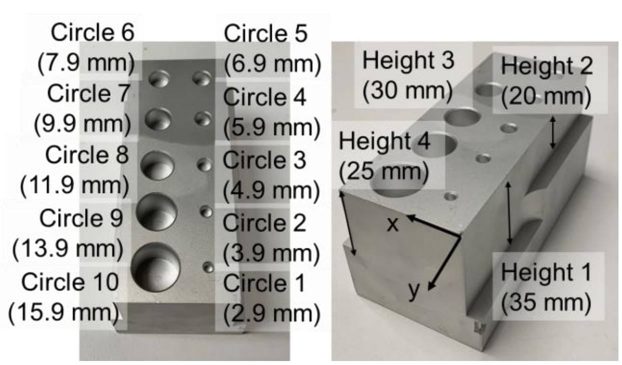

FIGURE 1. Artifact with features and nominal dimensions.

The precision and accuracy of structured light scanners have been evaluated by several researchers using various artifacts. Example artifacts include gage blocks [1], various prismatic volumes [2], multiple different sized precision spheres [3], and a freeform aluminum alloy artifact [4]. These artifacts are used to identify key factors that affect accuracy. These include object and scanner temperature, optical characteristics of the object surface, vibrations during data collection, object orientation, and number of images/scans.

This study evaluates the effects of: repeated scans with no other changes; and the number of scans (orientations) used to define the digital twin (solid model). Other factors were minimized by performing scans consecutively after the scanner reached its recommended operating temperature. Resolution affects the measurement uncertainty and, therefore, the resolution is typically kept constant for repeatability studies [5]. For this effort, the GOM Inspect Professional software and ATOS Q scanner are used to determine the measurement repeatability and reproducibility.

REPEATABILITY STUDY

A 100 mm x 50 mm x 50 mm aluminum artifact was designed and machined with ten holes of varying diameters (2.9 mm to 15.9 mm) and four steps with varying heights (20 mm to 35 mm). The artifact and features with design dimensions are shown in Fig. 1. To avoid reflectivity effects, the part was sandblasted to a satin finish to improve scan quality.

Methods

The artifact was scanned in 15 different positions with five repeated back-to-back scans completed at each position. These data were used to determine scan repeatability by randomly selecting one scan for each of the 15 positions to create a single mesh. This process was repeated 50 times to obtain 50 meshes. Inspections were then performed on these 50 meshes using the GOM Inspect Professional software to measure the diameter for each of the 10 circles, the four heights, the x and y location of the circle centers (with the x-axis along the short edge and the y-axis along the long edge of the part), and the distances between the circle centers. Next, the number of positions was reduced from 15, to 10, to 5 (same data set in all cases) to evaluate the sensitivity to the number of scan orientations. These measurements were then compiled by element in a table in GOM Inspect before being exported as CSV files containing the measurements performed on a single mesh. The measurements of each element are then compiled for each set of positions.

Results

The measurements from the 50 meshes for each number of positions were used to determine the mean, standard deviation, and range for each feature. An example histogram is displayed in Fig. 2 for circle 1. The mean is 2.894 mm, the range is 8.1 µm, and the standard deviation, σ, is 2.0 µm. For comparison, Fig. 3 shows the results for circle 10. The mean is 15.944 mm, the range is 2.5 µm, and σ is 0.5 µm. Not surprisingly, the larger circle with more points offers higher repeatability.

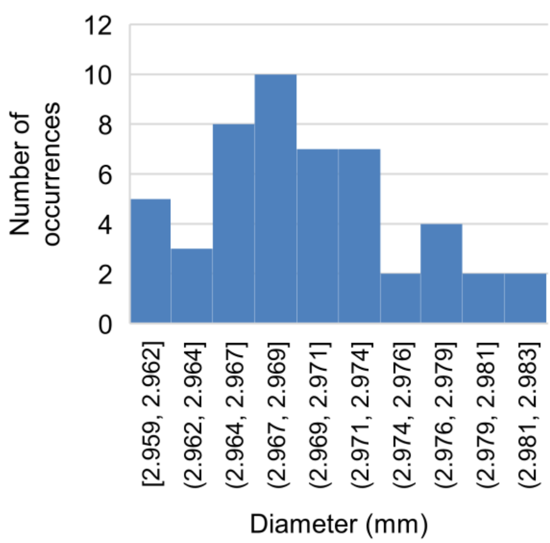

FIGURE 2. Circle 1 histogram for 50 randomly selected scan sets at same 15 positions.

Summary plots for the repeatability of 15, 10, and 5 positions for all 10 circles are provided in Figs. 4 and 5. These plots indicate that using a larger number of positions to create the mesh increases repeatability. Higher repeatability is also obtained for larger circle diameters.

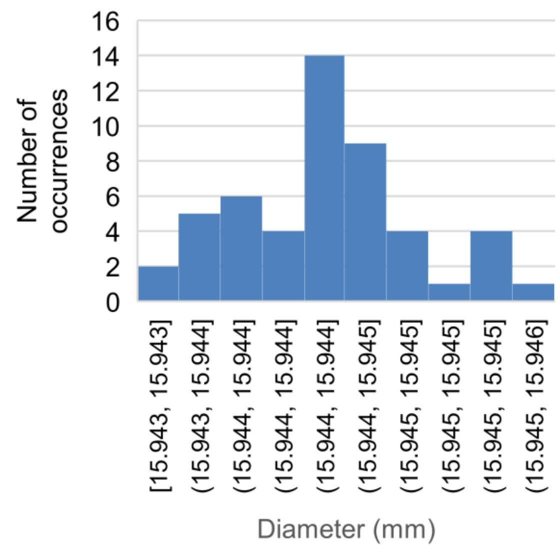

FIGURE 3. Circle 10 histogram for 50 randomly selected scan sets at same 15 positions.

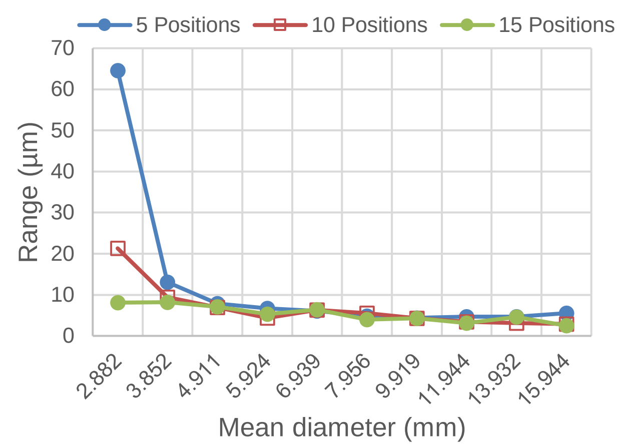

FIGURE 4. Variation in diameter range for all circles with 5, 10, and 15 scanning positions.

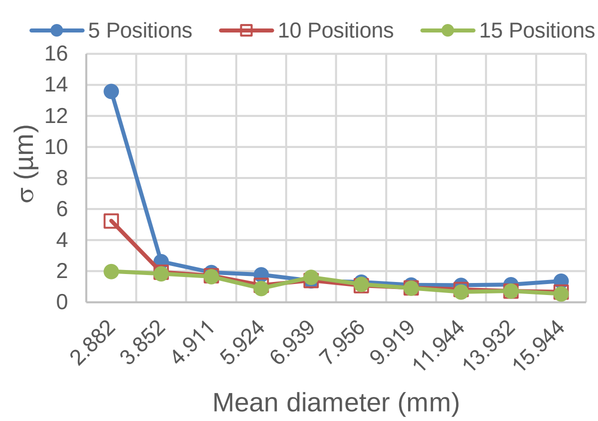

FIGURE 5. Variation in diameter standard deviation, σ, for all circles with 5, 10, and 15 scanning positions.

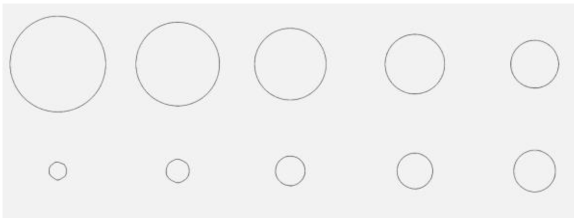

FIGURE 6. Hole cross-sections used to measure diameter.

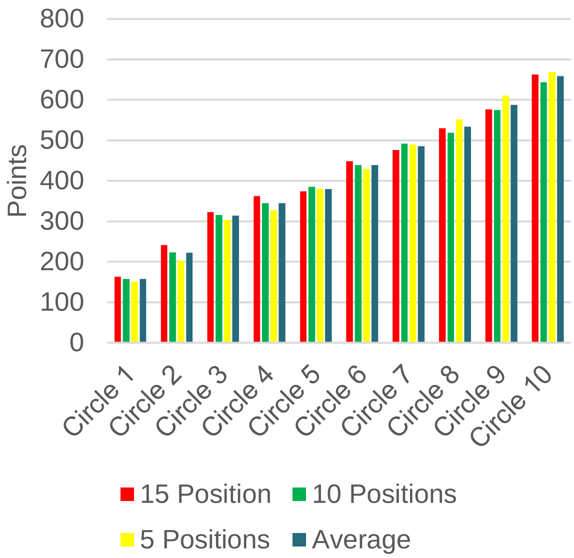

FIGURE 7. Number of points used to create each circle on a cross-section.

Figures 4 and 5 show that a larger number of positions increases the measurement repeatability. For the diameters, it is noted that the larger diameters have smaller ranges and standard deviations. To observe how the number of points used to create a circle affects the range in deviation of measurement, five cross-sections at different depths for each hole were used to create circles. Figure 6 shows one of the cross-sections. Note the difference in apparent roundness for the largest versus smallest hole. The points on the periphery of each of the five cross-sections were counted using GOM Inspect. Figure 7 shows the number of cross-section points that were used to create the circles.

Summary plots for the repeatability of 15, 10, and 5 positions for all 4 heights are provided in Figs. 8 and 9. These plots indicate that using a larger number of positions to create the mesh increases repeatability.

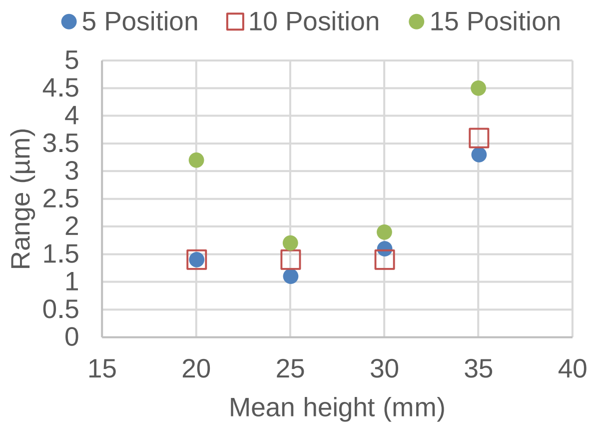

FIGURE 8. Variation in height range for four heights with 5, 10, and 15 scanning positions.

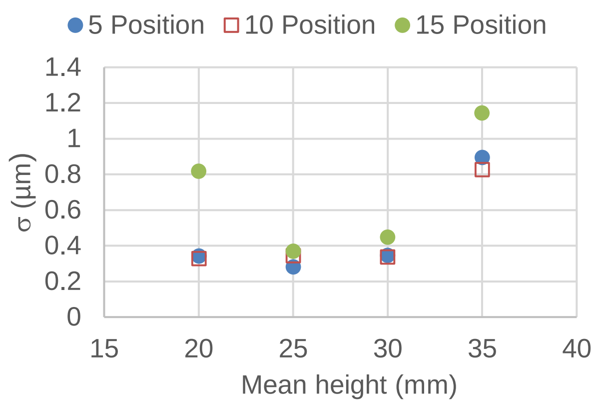

FIGURE 9. Variation in height standard deviation for four heights with 5, 10, and 15 scanning positions.

REPRODUCIBILITY STUDY

The same artifact was used to perform the reproducibility study.

Methods

The artifact was scanned a total of 30 times, 10 times each for 15, 10 and five positions using different locations around the part for each set of scans. These scans were then used to measure the circle diameters, step heights, distance between circle centers, and x and y locations of circle centers. The sets of 10 meshes were analyzed to determine mean, standard deviation, and range of the measurements for each element.

Results

Summary plots for the reproducibility of 15, 10, and five positions for all 10 circles are provided in

Figs. 10 and 11. These plots indicate that using a larger number of positions to create the mesh increases reproducibility. Higher reproducibility is also obtained for larger circle diameters which correlates directly with repeatability trend.

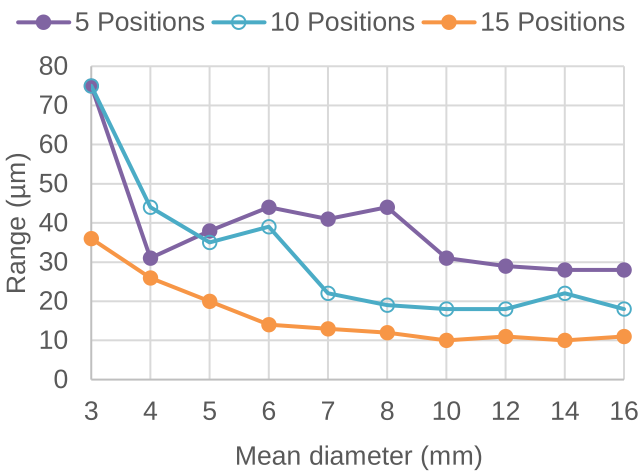

FIGURE 10. Variation in diameter range for 10 circles with 5, 10, and 15 scanning positions for reproducibility.

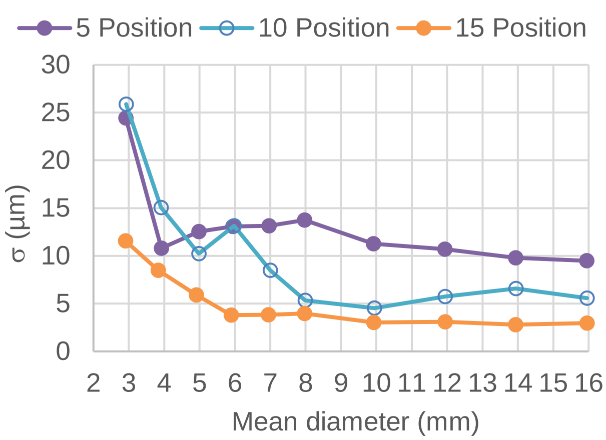

FIGURE 11. Variation in diameter standard deviation for 10 circles with 5, 10, and 15 scanning positions for reproducibility.

Summary plots for the reproducibility of 15, 10, and five positions for all four heights are provided in Figs. 12 and 13. These plots indicate that using a larger number of positions to create the mesh increases reproducibility. This is because less data is available when using fewer positions.

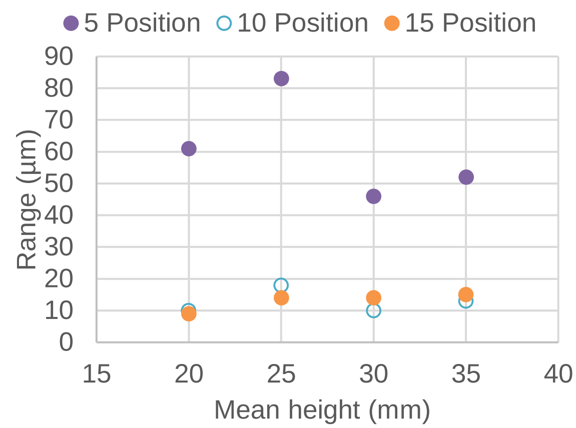

FIGURE 12. Variation in height range for four heights with 5, 10, and 15 scanning positions for reproducibility.

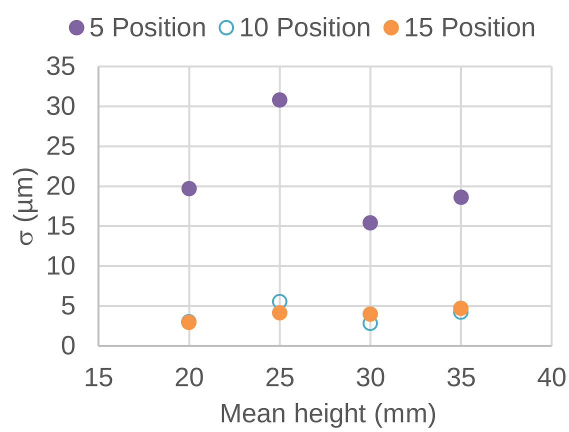

FIGURE 13. Variation in height standard deviation for four heights with 5, 10, and 15 scanning positions for reproducibility.

CHALLENGES DURING THE STUDY

At several points during the study, issues arose that had the understandable effect of skewing the histogram results significantly. The first of these issues was the fact that some of the meshes did not properly align to each other. To address this issue, the alignment had to be manually adjusted for each mesh. The second issue comes from GOM Inspect pre-set unit preferences. The default unit preferences are pre-set so that only two decimal places are visible for a measurement. This was not sufficient for the study, so the setting had to be adjusted for all measurements to display four decimal places each time; the table of measurements was exported as a CSV file.

SUMMARY

Repeatability and reproducibility studies were completed for measurements performed on a digital twin produced by structured light scanning. Initial results identified the repeatability due to scanning alone. The sensitivity to number of scan positions was also evaluated. It was shown that repeatability increases with the number of scan positions.

REFERENCES

[1] C. Bernal, B. de Agustina, M. M. Marín and A. M. Camacho, "Performance Evaluation of Optical Scanner Based on blue LED Structured Light," *Procedia Engineering,* vol. 63, pp. 591-598, 2013.

[2] S. Martínez-Pellitero, E. Cuesta, S. Giganto and B. J., "New procedure for qualification of structured light 3D scanners using an optical feature-based gauge," *Optics and Lasers in Engineering,* vol. 110, p. 2018, 2018.

[3] R. Mendricky, "etermination of measurement accuracy of optical 3d scanners," *MM Science Journal,* pp. 1565-1572, 2016.

[4] M. McCarthy, S. Brown, A. Evenden and A. Robinson, "Npl freeform artefact for verification of non-contact measuring systems," *Three-dimensional imaging, interaction, and measurement,* 2011.

[5] M. E. Polo, A. Cuartero and A. M. Felicisimo, "Study of uncertainty and repeatability in structured light 3d scanners.," pp. 1-9, 2019.