AN EVALUATION OF NON-CONTACT LASER SCANNER PERFORMANCE USING CALIBRATED ARTIFACTS

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INTRODUCTION

Compared to traditional measuring techniques, non-contact laser scanning has the potential to offer industry a cost-effective method for quality assurance inspection, reverse engineering, and in-process metrology. However, establishing non-contact laser scanning measurement uncertainty is challenging due to multiple factors which affect scan results, including optical properties of the scanned surface, orientation of the surface within the work volume, and lighting conditions [1]. In this paper, evaluation of the resolution and repeatability is presented for selected non-contact scanning systems. This evaluation was completed through a statistical evaluation of multiple measurements and comparison of the mean values for feature dimensions to calibrated measurement artifacts. The selected non-contact laser scanning systems include the ROMER Absolute Arm 7525SI with integrated scanner (ROMER) and ATOS Core 300 (ATOS). This effort is the outcome of a two-semester senior design project sponsored by the UNC Charlotte Center for Precision Metrology Affiliates and, therefore, represents a combination of research and education efforts at the university.

Two artifacts were designed and manufactured by the senior design team to test the non-contact laser scanner resolution and repeatability. The point cloud data sets obtained from the laser scanners were processed using two different software packages: Geomagic Studio and GOM Inspect, to examine potential differences in reported results. The feature dimensions extracted from the software analyses were then compared to the measurements obtained using a Zeiss Prismo 7 Navigator coordinate measuring machine (CMM).

VERIFICATION ARTIFACTS

Artifacts were designed and test procedures defined to obtain both qualitative and quantitative data regarding the performance of the laser scanning systems. Factors which are identified in the results include the instrument resolution, measurement volume, and time-to-scan [1]. Furthermore, artifact properties, such as orientation within the work volume, thermal expansion, surface features, and material were considered [2].

Two artifacts were designed and constructed. The step cube artifact displayed in Fig. 1 was designed for both qualitative and quantitative assessments. The face with the smaller holes (left view) was designed to determine the smallest feature (hole) that could be identified in a scan in order to establish the resolution of the laser scanning system. The larger holes (right view) and the step heights (top surface in both views) were used to quantify step heights, hole diameters, and center-to-center distances of the holes.

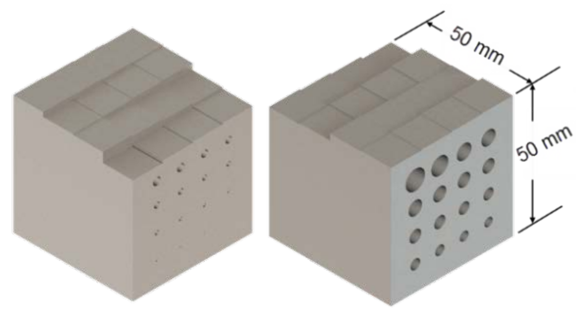

Figure 1. Step cube artifact.

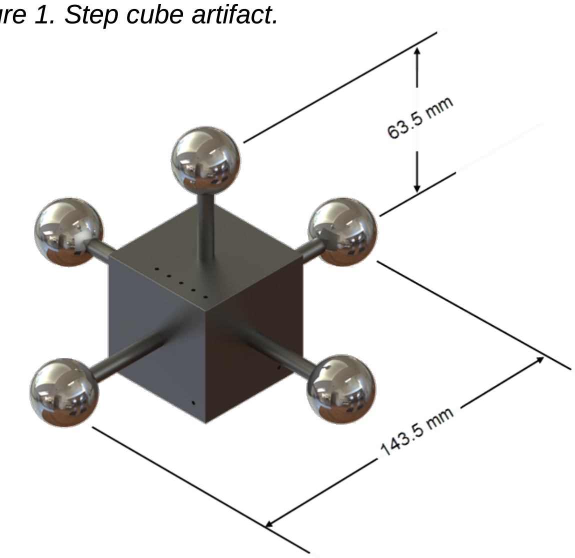

Figure 2. Ball cube artifact with 440 stainless steel spheres. The spheres are labeled 1-5 using holes on the corresponding surface for inspection purposes.

The ball cube artifact is shown in Fig. 2. This artifact includes spheres so that diameters and center-to-center distances can be measured. The lines that define the center-to-center distances between the spheres of the ball-cube form a measurement pyramid which enables a geometric assessment of accuracy within the measurement volume [1]. See Fig. 3.

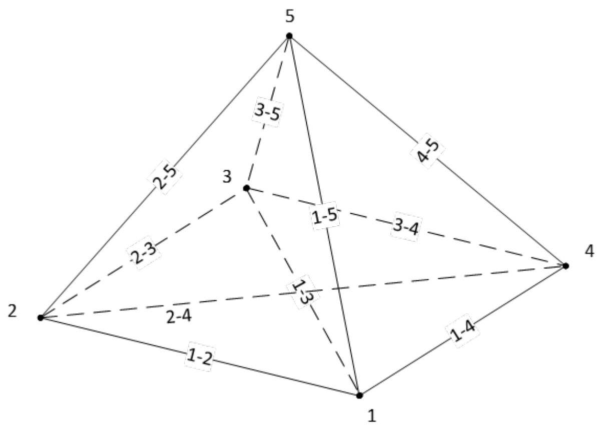

Figure 3. Measurement pyramid.

The step cube and ball cube artifact material was 316 stainless steel. Due to the measurement limitations imposed by the high reflectivity, an *i*-PrOH-TiO_2 [3] solution was sprayed on the artifacts prior to scanning. Therefore, dimensional changes were incurred due to the variation in particle distribution across the artifact surface. To potentially investigate this effect, the ball cube artifact was designed to enable the stainless steel spheres to be replaced by aluminum oxide spheres.

Scans were performed and the measurement point clouds were analyzed to compare artifact dimensions, including sphere/hole diameters, sphere/hole center-to-center distances, and step heights, to CMM measurement results.

STEP CUBE ARTIFACT

Analysis of the step cube artifact included a qualitative inspection of the face of the artifact with the smallest hole array; see Fig. 4. An array of 16 holes with nominal diameters ranging from 3.2 mm to 0.2 mm were used to determine the ability of the laser scanning system to detect small features. This experiment was completed in order to observe difference in resolution between the two scanning systems. Note that GOM Inspect was used to process point cloud geometries due to factors which are discussed later in this paper.

As shown in Fig. 4, five scans were completed using the ROMER scanning system. The scanner was able to identify the 0.4 mm hole two out of five times, while it was unable to identify the 0.2 mm hole in its point cloud in any scan. All other holes were observed in all five scans.

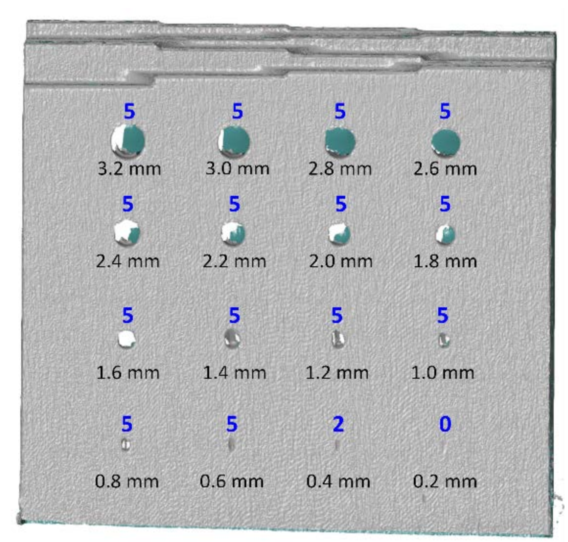

Figure 4. A representation of a ROMER point cloud generated for qualitative inspection of the step cube. A series of five scans were completed and a visual inspection was performed on the corresponding point clouds.

The qualitative analysis of the small hole array for the ATOS is presented in Fig. 5. Of the five scans, the 0.4 mm hole was visible 1 out of 5 times. As before, the scanning system was unable to identify the smallest hole at 0.2 mm.

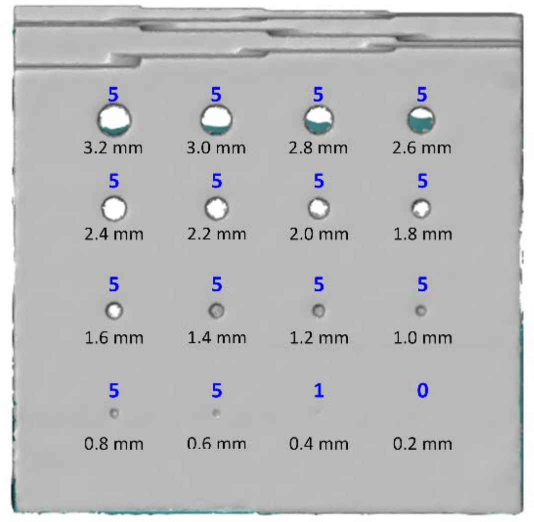

Figure 5. A representation of an ATOS point cloud generated for qualitative inspection of the step cube.

Figure 6 displays a comparison of deviations in hole diameter from the CMM values for the two scanning systems. The diameter was realized by cylindrical fitting elements for the holes. The hole diameter numbering system is shown in Fig. 7 with hole 16 being the smallest hole relative to the reference hole 1. The ATOS error bars, which represent the 95% confidence intervals from repeated measurements, are smaller between the two scanning systems.

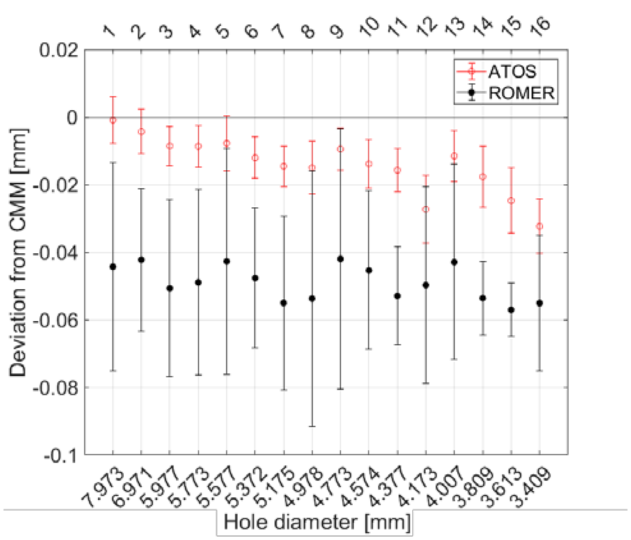

Figure 6. Mean values and 95% confidence intervals for step cube hole diameters. There were five sets of tests for the ATOS scanner and four sets for the ROMER scanner.

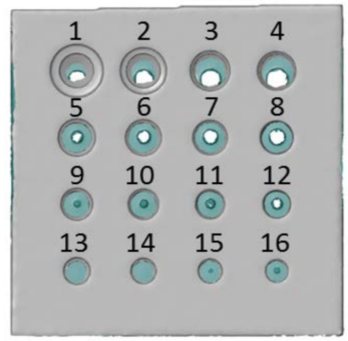

Figure 7. Hole diameter identification for the step cube artifact.

The cylindrical fitting elements were used to determine center-to-center distances between holes as well; see Fig. 8. The ATOS system again exhibited higher repeatability.

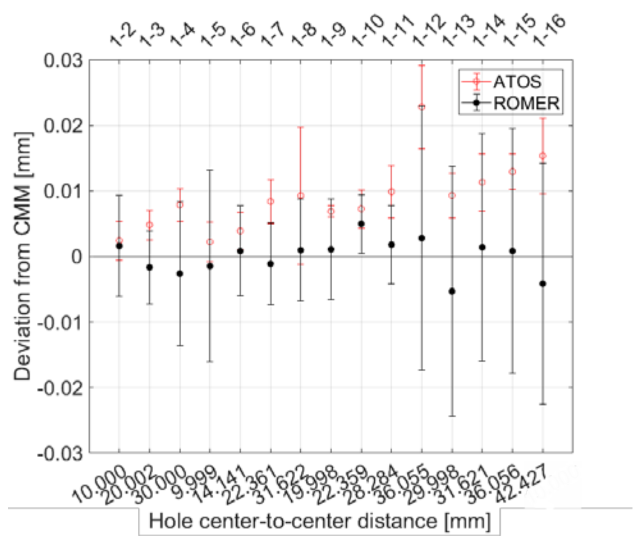

Figure 8. Mean values and 95% confidence intervals for hole center-to-center distance of the step cube artifact.

Figure 9 displays the deviations in step heights from the CMM values for the step cube. Planes were fit to each of the (nominally) flat steps and differences in step heights were measured with respect to a reference plane. The step height numbering system is displayed in Fig. 10 with step height 16 being the lowest step relative to the reference plane 1.

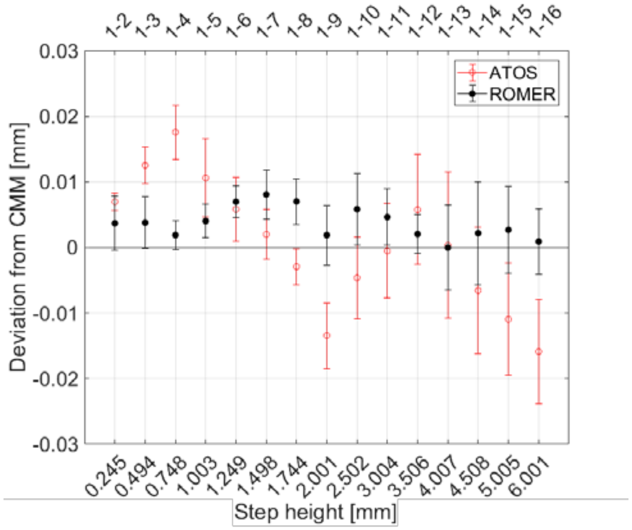

Figure 9. Mean values and 95% confidence intervals for the differences in step heights of the step cube artifact. There were five sets of tests for the ATOS scanner and five sets for the ROMER scanner.

Figure 10. Step height identification for the step cube artifact.

BALL CUBE ARTIFACT

Figure 11 displays the deviation in sphere diameters from the CMM measurements for the two scanning systems. Preliminary results demonstrate a bias for both systems relative to the CMM. The ATOS yielded sphere diameters which were 24 µm to 30 µm smaller than the CMM results. Conversely, the ROMER gave sphere diameters which were 31 µm to 40 µm larger.

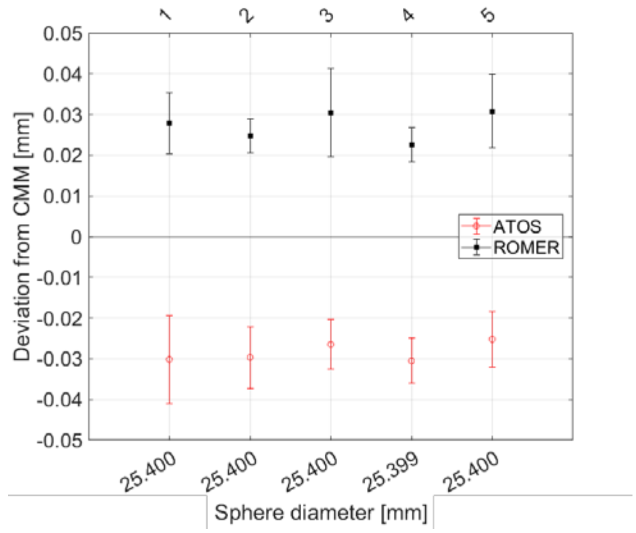

Figure 11. Mean sphere diameters for the stainless steel ball cube artifact. Values were obtained by averaging the results obtained from five point clouds for the ROMER and ATOS scanners.

Figure 12 displays deviations in center-to-center distances between the ball cube spheres. The measured distances from the ATOS and ROMER systems follow similar trends.

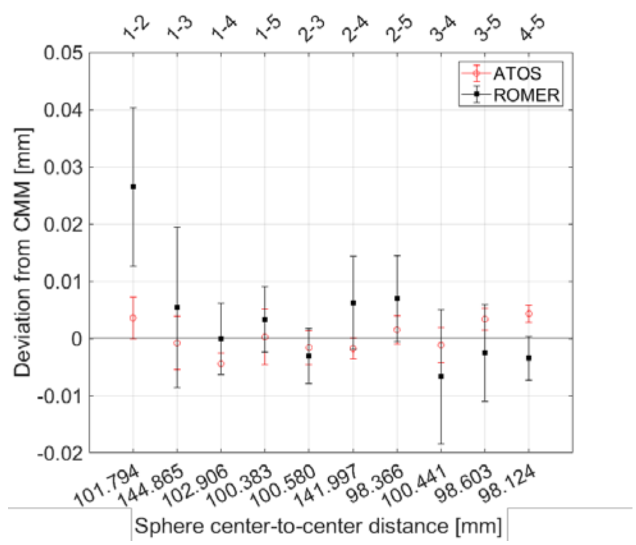

Figure 12. Mean values and 95% confidence intervals for center-to-center distances between spheres for the ball cube artifact.

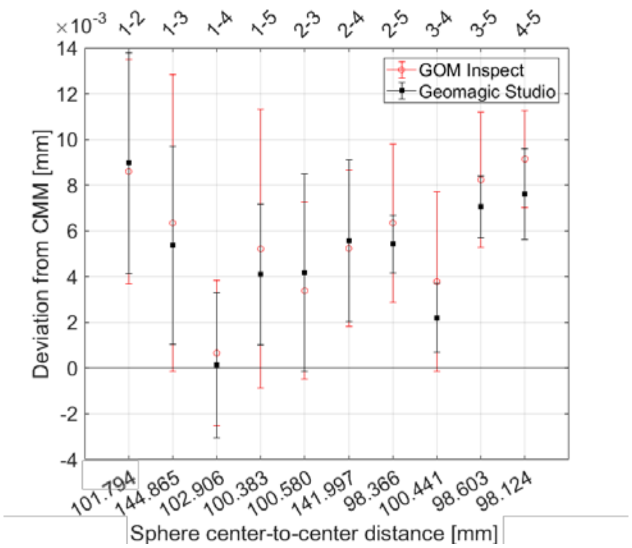

Figure 13. A comparison was performed using a single point cloud from the ball cube. The point cloud was analyzed five times using both Geomagic Studio and GOM Inspect by the same operator.

ADDITIONAL TESTS

The repeatability for dimensional analyses completed using the Geomagic Studio and GOM Inspect software packages is demonstrated in Fig. 13. For this study, a single point cloud data file (obtained using the ATOS system) was analyzed five times by a single operator using both software platforms. It was observed that there was a significant difference in the time needed to complete the analyses. To fully analyze one point cloud in Geomagic Studio, it required, on average, 10 minutes. The time was approximately 4 minutes for the same operator to analyze the scan in GOM Inspect.

The stainless steel gage spheres were replaced with aluminum oxide spheres in an attempt to eliminate the application of the *i*-PrOH-TiO_2 [3] solution. Initial tests were performed on the two scanning systems resulting in an incomplete point cloud. The aluminum oxide spheres, therefore, did not improve the restrictions imposed by high reflectivity.

CONCLUSIONS

The purpose of this project was to assess the measurement resolution and repeatability for two non-contact laser scanning systems using calibrated artifacts. Two systems were considered: the ATOS Core 300 and ROMER Absolute Arm 7525SI. The laser scanning systems measured three-dimensional point clouds from the artifact surfaces. Measurement challenges included artifact orientation within the work volume and surface reflectivity. The artifacts were designed to enable measurement of various geometrical features, including hole diameter, sphere diameter, and distance between feature centers.

The dimensions obtained from point cloud data depend on the fitting techniques used in the geometric modeling analysis software. GOM Inspect and Geomagic Studio were evaluated in this study. While point cloud software can be traceable to standards organizations, the geometric modeling process can result in measurement variation between operators.

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