ASPECTS AFFECTING ACCURACY OF OPTICAL 3D DIGITIZATION

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Use of optical 3D digitization for dimensional and shape inspection of work-pieces has increased during the last few years. However, the quality of data obtained by scanning may be affected by many factors. Digitization accuracy of optical 3D scanners is generally determined by Acceptance Tests compliant with the VDI / VDE 2634 standard. When performing the validation test, all variables and measurement conditions must basically be ideal. Unfortunately, such conditions are usually unavailable in common practice. For that reason, we conducted research finding how may the surrounding conditions and parameters of digitization process affect the dimensional and shape accuracy of optical 3D measurement. The aspects we assessed were for example calibration, exposure, number of images, scanning angle, or quality of used reference points. The measurement was carried out on ATOS optical 3D scanner by GOM and spherical and cylindrical elements were used for the analysis. As found out, used reference points with low quality have a major impact on quality and accuracy of the result. Operators should also pay increased attention to calibration and heat-up the scanner to operating temperature before commencing the measurement.

KEYWORDS

3D optical digitizing, 3D scanner, Calibration, Measurement accuracy, Inspection, Acceptance test, Atos

1 INTRODUCTION

Optical 3D scanning is on a huge rise in industry practice for the last few years. Digitization basically became an integral part of every modern industrial plant. That is primarily due to the requirements of modern manufacturing processes and their upgrade to Industry 4.0 [Kostak 2017]. Measurement speed and accuracy are among such requirements.

The digitization accuracy is affected by a variety of factors. The major factor is the used 3D scanner, its properties to be precise. Accuracy of scanners is declared by so called Acceptance Tests [GOM mbH 2012, GOM mbH 2014]. Test for ATOS products follows specifications of the manufacturer (GOM) and is in accordance with VDI/VDE 2634 – part 3 [VDI/VDE 2634 2008]. The standard describes practical part of the test, defines the calibration gauge blocks, characteristic values, measurement conditions and the evaluation method.

Figure 1. Calibration etalon by GOM for so called Acceptance Test

The etalon consists of a set of very accurate spheres – see the calibration etalon for implementation of so called Acceptance Test (Fig. 1) for optical scanners by GOM.

Another factor affecting the measurement accuracy is temperature, humidity, light conditions, dust, etc. – the environment, in which the measurement is conducted. The digitization procedures and systematic or random errors caused by the operator significantly affects the quality of results as well. There are many recommendations and procedures that should be followed. As the practice shows, when it is impossible to fully exclude the operator's factor, an inspection mechanism should be set as well as a system that will be highly robust to minimize the influence of operator on the measurement results.

Accuracy of 3D digitization was addressed by several authors in the past. The research team of T. Brajlih [Brajlih 2011] conducted research to identify the possibility to inspect machined parts with ATOS II scanner. The dimensional accuracy of the optical scanner was tested using a range of end elements coated with a titanium-powder-based anti-reflective product (TiO2). Quality and thickness of each anti-reflective layer was highly depending on experience of the person performing the coating. Vagovsky [Vagovsky 2015] conducted research of measurement capabilities of ATOS Triple Scan II optical 3D scanner. He was measuring a small object, a very hard steel rod with 12 mm diameter. The objective was to determine the achievable accuracy while utilizing statistical evaluation. After conducting many measurements, he concluded that the system is not able to provide acceptable results when measuring small and highly accurate objects with a narrow tolerance range. Barbero [Barbero 2011] also carried out a more detailed comparison of scanning systems and determined accuracy of 3D scanners. Calibration elements such as spheres, cylinders and end gauge blocks were used to determine the measurement inaccuracy. The experiment yielded measurement uncertainty results for the ATOS 25 µm system. Recently, Dokoupil [Dokoupil 2013] carried out an experimental findings of measurement deviations of the ATOS Triple Scan on objects coated with matting chalk and titanium spray. As described in the paper, objective of the research was to determine measurement uncertainty with objects coated with chalk and titanium powder and identify layer thickness of matte powders. Another important research focused on influence of matte coating on accuracy of measurement by a 3D optical scanner was published by Palousek [Palousek 2015]. He and his team concluded that while the chalk coating may average 44 µm, the titanium-based anti-reflective coating decreases the thickness roughly tenfold to approximately 5 µm. Somewhat extensive own analysis of measurement accuracy of contact-less optical 3D scanners was performed in 2015 [Mendřický 2015]. Consequently, the methodology for evaluation of digitization accuracy of optical 3D scanner was validated in laboratory conditions. The validation was published in 2016 [Mendricky 2016] and includes practical performance of Acceptance Test for ATOS 3D scanner (starting with design and manufacturing of own test etalon, through determining nominal dimension, up to digitization and evaluation) and lists results of several experiments demonstrating the effect of various external factors on correctness of measurement. As the experiments showed, a digitization process has many variables that influence the final accuracy of the digitized model in more or less significant manner. As this issue was not addressed in detail in any of the available literature, we decided to carry out our own experiments and find out what aspects have major influence on accuracy and reliability of optical 3D digitization.

2 METHODS AND MATERIALS

The research was conducted by means of ATOS II optical 3D scanner by GOM with measuring volume of 250 mm (see Fig. 2). Digitization process of this measurement system is based on principles of optical triangulation, photogrammetry and Fringe Projection method. According to Acceptance Test by GOM, the maximum measurement deviation of the said device is 0.017 mm for "Sphere Spacing Error" parameter and 0.004 mm for "Probing Error (Max. Sigma)".

Figure 2. ATOS optical 3D scanner with MV250 measuring volume

2.1 *Principles of Accurate Measurement*

As in any other measurement, following certain principles is recommended during optical digitization. The most important are:

- Adjustment and calibration of the system (scanner).
- Letting the scanner heat up to operating temperature.
- Using original reference points and points with size corresponding to the selected measuring volume.
- Appropriate placement of reference pointsto the measured surface or use of a suitable measuring instruments.
- Providing appropriate light conditions (shutter, exposure).
- Using anti-reflective coating to make a measured part with optically unsuitable surface matte.
- Following the recommended measurement procedures and selecting correct measurement strategy (number of images, camera angles, stable attachment of the measured part, etc.).

The scanner is controlled by GOM ATOS Professional during the measurement process. When combined with the scanner, this software features several inspection mechanisms that may notify the user about any irregularities. Those are for example:

- Inspection of sufficient amount of visible reference points.
- *Movement Check* – observes any movement between the camera and the measured object when scanning.
- *Transformation Check* - observes transformation accuracy when forming individual scans into a common coordinate system.
- *Calibration Check* – inspects whether the system requires calibration.
- *Lighting Change* – watches any changes of lighting conditions during the scanning process.
- *Minimum Mask Threshold* – observes whether the contrast is appropriate.

2.2 *Description of Experiments*

With respect to our experience and to these inspection mechanisms and principles of correct measurement, we defined high-risk elements that occur often with the operator (whether intentionally or not) or whose impact on the resulting measurement accuracy is not clear. The following aspects were selected in the research:

a) Calibration of the device
b) Exposure time
c) Number of scans
d) Angle of scanner
e) Heat up process of the scanner
f) Camera shutter
g) Quality of reference points

2.3 *Measuring Gauges*

Two different standard parts were used based on the type of experiment. The first one was a cylindrical bore gauge (with nominal diameter of 48 mm), a metal cylindrical surface with glossy ground surface (Fig. 3). Dimensions and shape were validated at a coordinate measuring machine. Repeated measurement identified that the error of diameter and cylindricity is up to 1 µm. The other etalon featured a set of very accurate metal ground spheres with nominal diameter of 20 mm. Spacing of the spheres was pre-determined to be 115.005 mm (Fig. 4). This etalon is used for Acceptance Tests and its nominal dimensions were validated during the preceding research by the DEA GLOBAL Status 7.10.5 3D coordinate measuring machine [Mendricky 2016]. A thin layer of titanium coating (TiO_2 – titanium dioxide) was applied to both objects to prevent reflections.

Figure 3. Cylindrical measuring gauge with anti-reflective coating

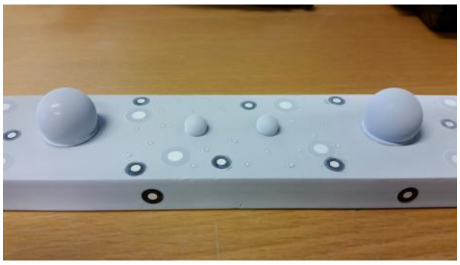

Figure 4. Spherical measurement gauge with anti-reflective coating

2.4 *Measurement Procedure*

The effort was to make the values and the measurement procedure to correspond with the so-called Acceptance Tests as much as possible [GOM mbH 2012, GOM mbH 2014, Mendricky 2016]. Among the parameters evaluated during the test on spherical etalon were the following:

- Probing error form (PF)
- Probing error size (PS)
- Sphere spacing error (SD)

Probing error form (PF) (Fig. 5 – left) shows shape deviations (sphericity). The highest and the lowest deviation from an ideal sphere is identified (from all scan points).

$$PF\ (sigma) = \sigma \quad (1)$$

$$PF\ (range) = |max - min| \quad (2)$$

Probing error size (PS) (Fig. 5 – right) shows dimensional deviation of the fitted sphere. Sphere dimensions are identified by means of *Fitting Sphere* method. The diameter error is described as a difference between measured diameter D_a and reference diameter D_n.

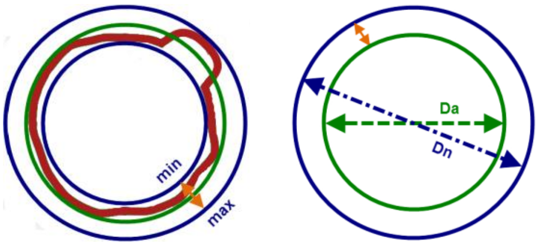

Figure 5. Schematic representation of the „Probing error" calculation [GOM mbH 2014]

$$PS\ (size) = D_a - D_n \quad (3)$$

Sphere spacing error (SD) shows spacing deviation of sphere centres. Used to determine whether the scanner measures on the correct scale on the defined length.

With respect to the above, we selected the following values for our experiments: in case of the sphere-fitted etalon – diameter of both spherical elements, Range parameter (error of sphere – "sphericity") and spacing of spheres (see Fig. 6). The values for cylindrical etalon were its diameter and cylindricity error (Fig. 7). Other measured values were supplementary and not included in the statistical evaluation.

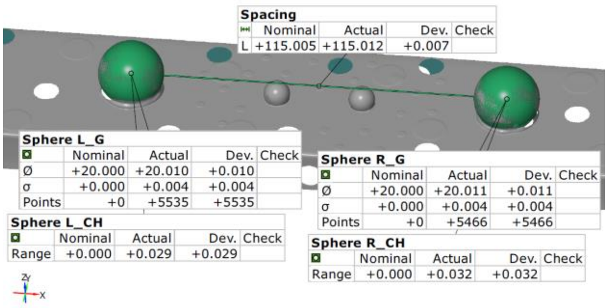

Figure 6. Measured dimensions of sphere-fitted etalon

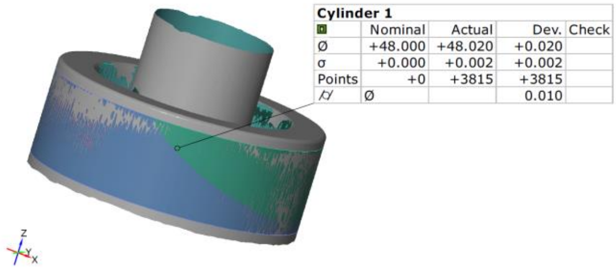

Figure 7. Measured dimensions of cylindrical etalon

In the first phase, we digitized both gauges while strictly following all recommendations and procedures for measurement. Characteristic values, measurement conditions and assessment method that must be complied with are:

- Sensor and all components thereof are set by the manufacturer and must not be changed. That particularly applies to camera and lenses settings.
- The hardware manual must be followed when calibrating the sensor. The given heat-up period is important.
- Measurement is carried out with quality set to "high".
- The exposure time settings must allow the images to be well exposed. Overexposed images are not suitable.
- Scanner should be under 45° angle to horizontal plane of the table; 10 images are taken during the 360° travel.
- When forming the images to a mesh, post-processing is performed with polygonization set to "Standard".
- When calculating the sphere, only points above the defined plane are considered. The plane is parallel with the base plate and comes through the sphere at 10° of its bottom latitude (slightly above half-volume).
- Selection of points throughout the whole cylindrical surface is used for cylinder calculation, except surface that is 1 mm from edges.
- Dimensions of each element (sphere and cylinders diameters) are calculated by the least squares method while using 3 Sigma of all selected points, meaning that approximately 0.3 % of the most deviating points are removed from the selection (Fig. 8).
- Shape error of the elements (cylindricity, sphericity) is calculated from all selected points.
- Ambient temperature and temperature of the element must be identical. Measurement environment must be vibration-free. Ambient light should not be too intensive during the measurement.

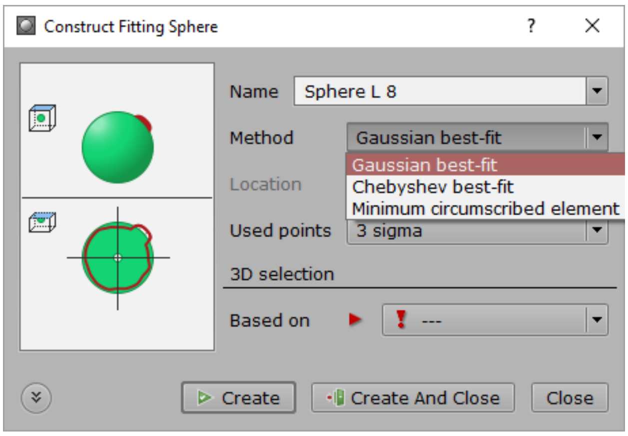

Figure 8. Construct Fitting Sphere window

Results of the initial measurement were applied in other experiments as reference values and used for comparison with the assessed value (element diameter, spacing, etc.) upon change of one of observed elements. Each measurement was repeated several times to exclude any random errors caused by operator. The results were averaged and graphically processed.

3 RESULTS

3.1 *Reference Measurement*

The reference measurement was performed under ideal conditions according to rules mentioned above. The observed aspects were set to optimal values as well.

- The scanner was heated up to operating temperature (20 min.
- Before the measurement started, we calibrated the system by means of "calibration panel" and in compliance with procedure provided by the manufacturer.
- We used original reference points with 3 mm diameter.
- Optimal exposure times was set as well (11 ms for our conditions).
- The scanner was positioned under 45° angle to the horizontal plane.
- A total of 10 images was taken during the 360° travel.

The Acceptance Test comprised of only 3 measurements following the standard (each had difference scanner position). In order to increase reliability, data from 6 etalon measurements were used to determine the reference values. Each result ranged within no more than units of micrometres. Deviations of each observed parameter were calculated (difference between the nominal value and value measured by digitization).

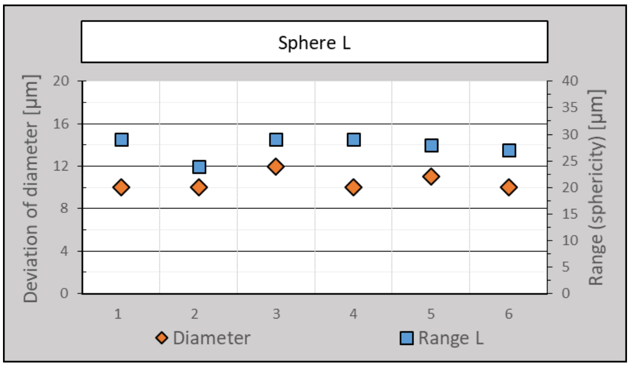

Figure 9. Reference measurement (spherical etalon – left sphere)

As clear from Fig. 9, the average deviation of left sphere dimension was 10 µm, the Range parameter (sphericity) was 29 µm. Results of the right sphere were similar. Reference error of sphere centre spacing was 10 µm. The obtained data correspond with the Acceptance Test carried out with identical gauge elements during the previous research [Mendricky 2016]. Reference values identified in case of cylindrical etalon were: diameter error was 21 µm, cylindricity error was 10 µm. These deviations include imperfection of the optical scanning method as well as the effect of anti-reflective coating. According to other research, layer thickness may range between 5 and 13 µm. Such statement is supported by the measured deviations being positive. The measurement conditions and the anti-reflective coating remained unchanged for all experiments and do not therefore affect further experiments. Reference measurements are pointed as REF in subsequent experiments.

3.2 *Calibration of the device*

The system features a calibration check function and the manufacturer recommends performing a user calibration in regular intervals, after each transport of the device, change of optics or significant change of ambient temperature. When the scanner is used in a laboratory with stable conditions and the system does not warn about any necessarycalibration of the device, the user is tempted to not perform the calibration too often. However, our experience shows that the time of the most recent calibration may have a major impact on accuracy of the device. During our experiment, we performed the measurement 5 and 15 days from the most recent calibration. Results of spherical etalon are clearly shown in the following graphs. The measurement was repeated twice to confirm the result.

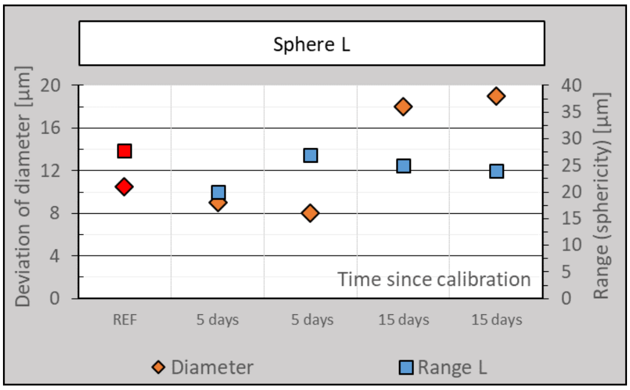

Figure 10. Effect of scanner calibration (spherical etalon – left sphere)

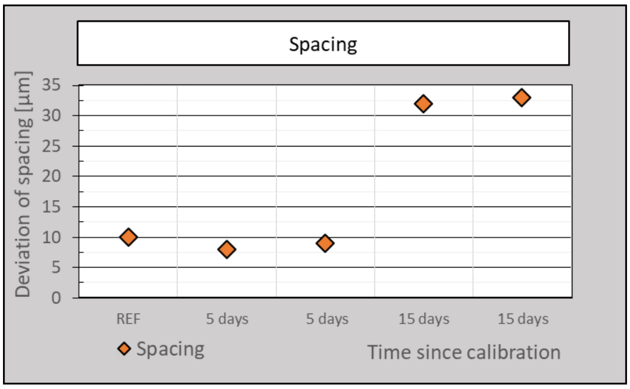

Figure 11. Effect of scanner calibration (spherical etalon – spacing)

The results imply that as the time from last calibration increases, the measurement error increases with small elements (sphere diameter error was double in case of 15 days from calibration) as well as with long-range measurement (sphere spacing error was even triple). Such trend is not regular, as the error changed to negative values in other cases. Effect of time from the last calibration on error of shape was not proved.

3.3 *Exposure time*

Objective of this experiment was to confirm or disprove whether incorrect exposure settings may affect measurement accuracy. Measurements under overexposed (exposure time of 17 ms) and underexposed conditions (exposure time of 2 ms) were compared to the reference measurement (optimal exposure of 11 ms) – see Fig. 12.

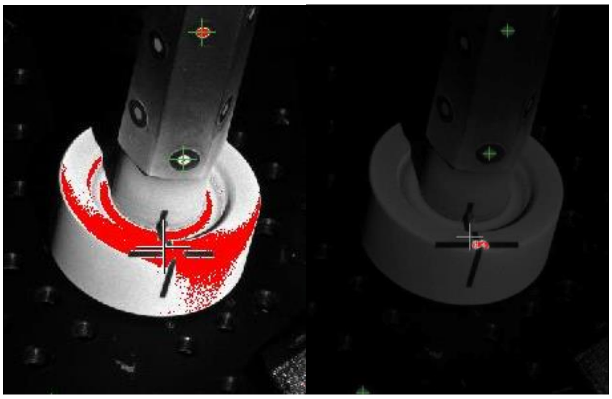

Figure 12. Overexposed and underexposed scene – cylindrical etalon

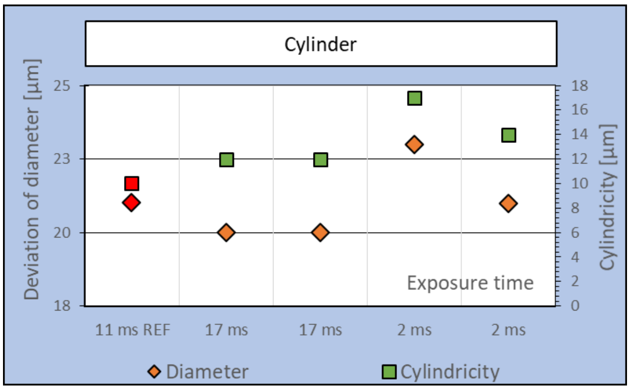

Figure 13. Effect of exposure time (cylindrical etalon)

As clear from the graph in Fig. 13, even major changes of exposure did not have any significant impact on quality and accuracy of measurement and the results are ranging near the reference value. Problems may occur if the object is so overexposed or underexposed that the given area is not scanned at all. Data in the transition area may then be wrongly interpreted and generate error of shape. Such statement is proved in Fig. 14 showing a colour map representing the cylindricity error of 55 µm for severely underexposed object (exposure time of 1.3 ms) compared to colour map of appropriately exposed etalon (11 ms) in Fig. 15, where the cylindricity error is only 10 µm.

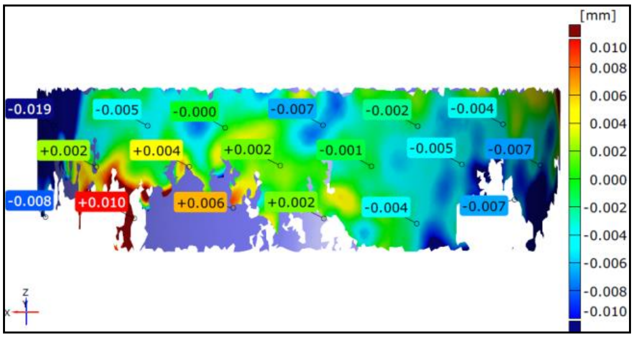

Figure 14. Colour map of cylindricity error (extreme underexposure, exposure time of 1.3 ms)

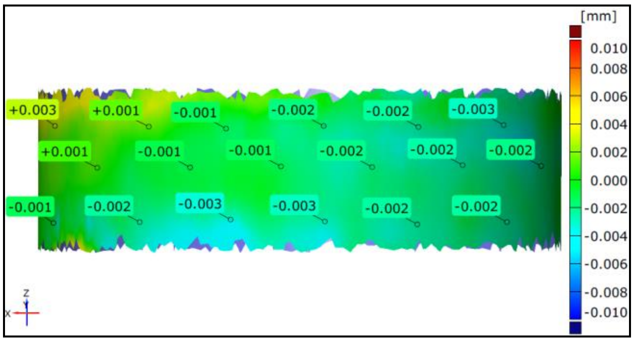

Figure 15. Colour map of cylindricity error (REF, exposure time of 11 ms)

3.4 Number of scans

Objective of this analysis was to determine how the number of images forming the resulting model affect quality of the model. In practice, the minimum number of images highly depends on size and complexity of the measured object. In our case, the reference number was 10 images (in compliance with the Acceptance Test) for spherical etalon. Consequently, we performed measurement with 4 and 30 images evenly distributed around the measured object (see Fig. 16). Results for spherical etalon – left sphere are shown in Fig. 17.

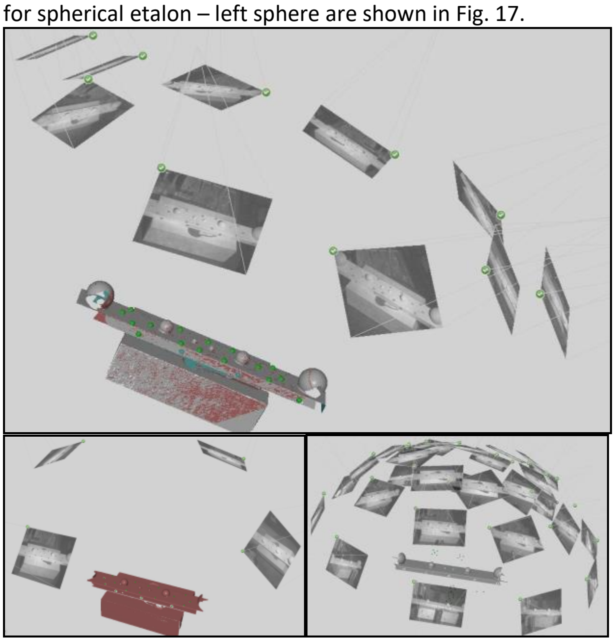

Figure 16. Scanning position (REF 10 images, 4 images, 30 images)

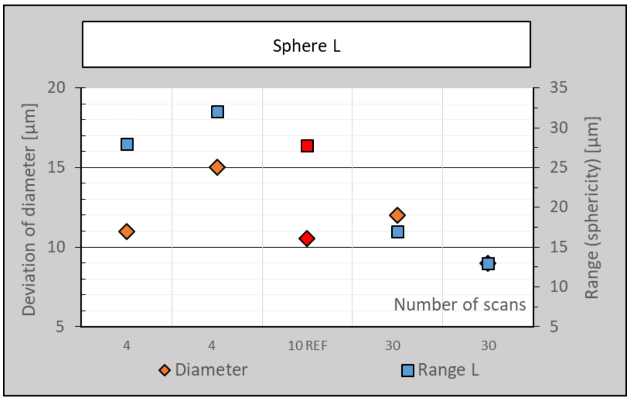

Figure 17. Effect of number of images (spherical etalon – left sphere)

As expected, the spacing of elements does not affect this parameter in any way. This is similar with dimensional characteristics of the elements (diameter of sphere, cylinder). As clear from Fig. 17, the only value that may be affected by the number of images is the shape. While the reference specimen showed sphericity error of 29 µm, the increasing number of images decreased the error to half. However, the decrease was less significant with cylindricity.

3.5 Angle of scanner

This experiment included the effect of scanning angle to the scanned surface on the measurement accuracy. The manufacturer recommends scanner being perpendicular (0°) or under no more than 60° to the measured surface. However, this requirement is hard to ensure as the objects are generally of more complex surfaces and various angles. Our experience shows that the maximum angle that is able to provide a satisfactory scanning sequence is approximately 70°. The cylindrical etalon was used for this experiment. We conducted measurement under angle of 0° (scanner was perpendicular to the measured surface), 20°, 45° (REF), 70° and 75° (Fig. 18).

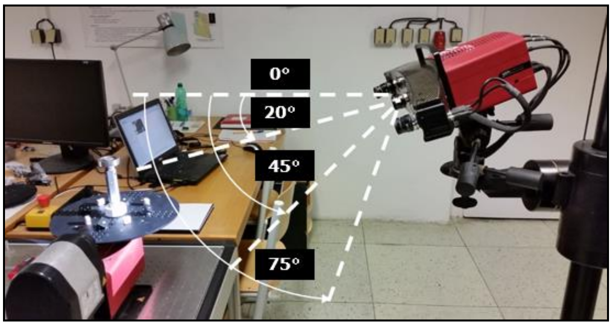

Figure 18. Scanning angle to the measured surface [Maran 2017]

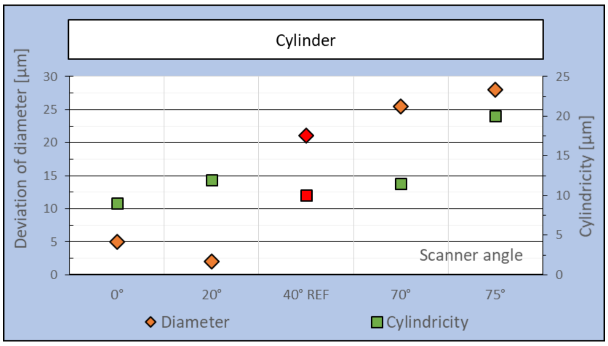

Figure 19. Effect of scanning angle to the measured surface (cylindrical etalon)

The experiment confirmed that scanning angle exceeding 70° may result in increase of shape error. In other words, the scanning angle to the measured surface does not affect this parameter in any way. However, measurement of dimensions yielded higher variance. While angles close to perpendicular perspective showed error below 5 µm (deviation of up to –19 µm from the reference value), angles of 70° or 75° showed error over 25 µm (deviation of up to 6 µm from the reference value). Reference specimen under angle of 45° showed error of 21 µm (Fig. 19). If we subtract the theoretical layer of anti-reflective coating, it appears that measurement at the angle of 45° gives the most accurate values (when considering the layer thickness to be 2 x 10 µm). However, the error values are relatively small for all scanning angles, it can therefore be safe to assume that scanning angle does not severely affect the diameter value.

3.6 Heat up process of the scanner

After the SW system starts up, it tells the user to wait for about 20 minutes. During this time, the device heats up. However, this step is often ignored by operators, so we became interested about the effect of insufficient heat-up sequence on the measurement results.

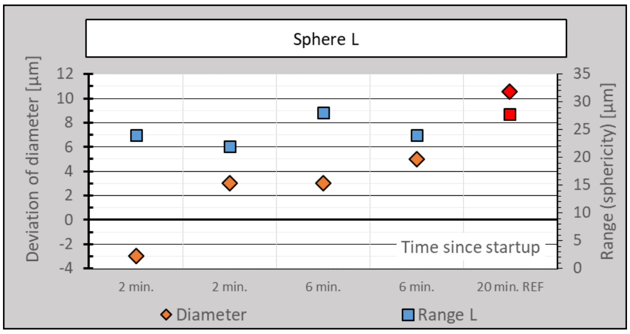

Figure 20. Effect of scanner's heat-up period (spherical etalon – left sphere)

The spherical etalon was digitized roughly 2 and 6 minutes after starting the system. Again, the results were compared with the reference value representing measurement after standard heat-up sequence (more than 20 minutes). The results are shown in Figure 20 and 21.

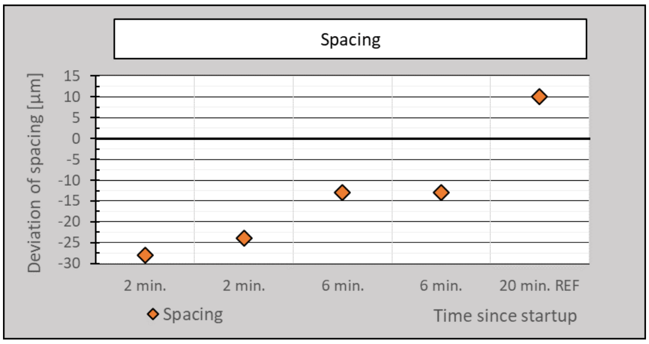

Figure 21. Effect of scanner's heat-up period (spherical etalon – spacing)

Results of the analysis show quite clear negative effect of insufficient heat-up sequence on the resulting dimensional accuracy. As the heat-up period decreased, the negative deviation of sphere's deviation from reference valued increased (up to -13 µm with 2-minute heat-up). This trend manifested even more with larger dimensions. The 6-minute heat-up sequence showed spacing error of -23 µm when compared to the reference value, 2-minute heat-up show error of -35 µm. Nevertheless, the shape ("sphericity") was not affected in any way.

3.7 Camera shutter

Correct adjustment of scanner hardware is one of important principles of correct measurement. Those are for example settings of measurement distance, focus of cameras and projector, settings of camera and projector shutters, adjustment of polarizing filters, etc. It is important to set the camera shutter to an appropriate value, however, setting both cameras to same values is even more important. The adjustment algorithm is very sensitive and even the slightest difference in shutter value of left and right camera will be manifested. Such adjustment is carried out rather rarely in practice, so we were curious about whether eventual differences of shutter values affects measurement results. To find out such effect, we intentionally increased the shutter of right camera by 1 exposure value (EV) when compared to the left camera, and measured the etalon with these settings.

Figure 22. Change of shutter value from 8 to 11 for the right camera (+1 EV)

Despite the manufacturer’s declaration that even slight changes greatly affect the measurement accuracy of this device, our experiment showed that all the observed parameters (sphere diameter, sphericity, spacing) changed only slightly and corresponded to the reference value with minor variations.

3.8 Quality of reference points

Before the digitization process is initiated, the measured object, its vicinity or the measuring instrument must be fitted with reference points. These are self-adhesive or magnetic points with defined dimensions and geometry (white point on black background). The points are used for transformation of individual images into one common coordinate system. There are two types of points: coded and uncoded.

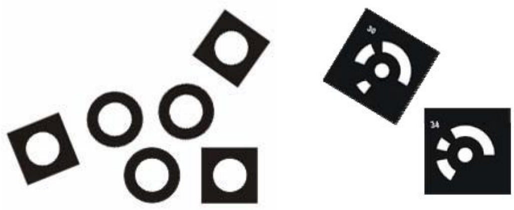

Figure 23. Uncoded and coded reference points [GOM MBH 2012b]

Size of the points should be selected in compliance with manufacturer’s recommendations and based on used measuring volume. The recommended points for our system and MV 250 are points with 3 mm diameter. However, quality of the point is equally important (base paper, perfect circularity, contrast of black and white). It is a well-known fact that manufacturers usually recommend their own reference points meeting the requirements on accuracy of dimensions and shape. And due to high price of these points, we often encounter effort to supplement these points with “homemade” ones. The objective of this experiment was to validate if the quality of points is as important for accurate 3D digitization as is said.

For the experiment, we selected the original points (REF measurement), own points (specimen A) with 3 mm diameter printed on high-quality photo paper (highly resistant paper by Avery Zweckwork with high resistance to water, grease and temperatures from -20°C to +80°C, printed on Konica Minolta Bizhub C35) and points printed on a standard self-adhesive paper by OCÉ (printed on HP LaserJet Pro MFP M 125nw laser printer). Additionally, the points were printed with the required diameter of 3 mm and with diameter smaller and higher by several tenths of mm. The effect of black background was observed as well (see Table 1 and Fig. 24).

Label	*ø [mm]*	*Description*
REF	3	Original point
A	3	Non-original point, high-quality paper
B	3	Non-original point, standard paper
C	2.8	Non-original point, standard paper
D	3.2	Non-original point, standard paper
E	3	Same as B, more black background

Table 1. The used reference points

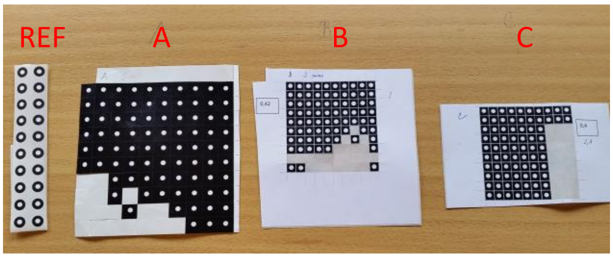

Figure 24. Demonstration of used reference points

The dimensions and quality of print were proved by measurement on optical microscope – see Fig. 25.

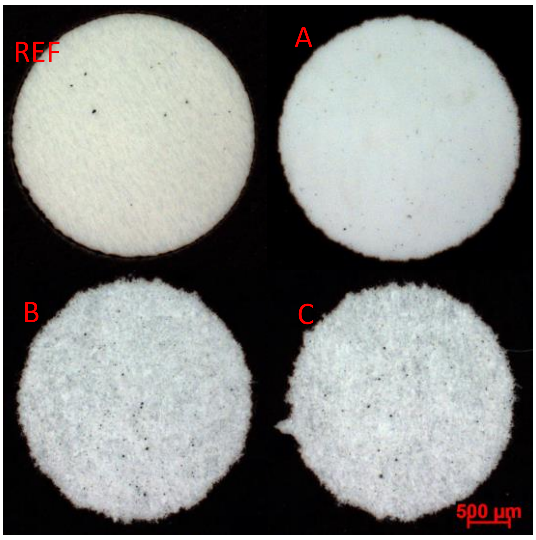

Figure 25. Reference pointsREF and A, B, C under optical microscope

When not magnified, all the pointsseem very similar. However, analysis by optical microscope showed major differences. Above all, points printed on regular paper (points B – E) showed highly blurred contours (see Fig. 25).

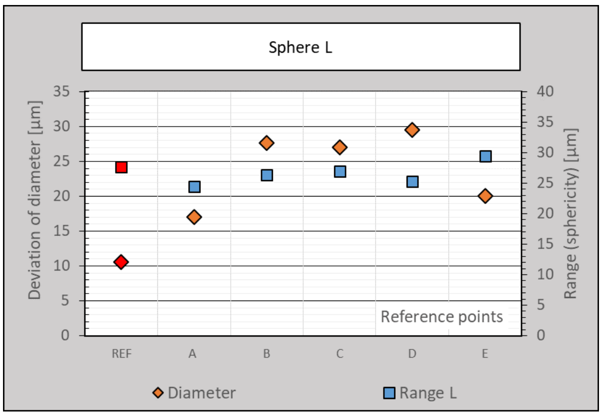

Figure 26. Effect of used reference points (spherical etalon – left sphere)

Results of this analysis brought interesting facts. The shape (Range – sphericity) or spacing of the element was not affected in any way by the various reference points. For all 5 "low-quality" points, the measured values did not deviate from the values measured with original points by more than 3 µm. However, the situation is different with dimension-related values, as proved in Fig. 26. The deviation of sphere diameter increased with deteriorating quality of the reference point. The A point deviated by 7 µm from the reference value, the deviation with points B through D ranged around 18 µm. Slight improvement was observed with point E which has the same properties as points B through D, but had more black background. It is therefore safe to assume that diameter of the point does not affect any of the observed parameters. All deviations (including sphere diameter) with points C (ø 2.8 mm) and D (ø 3.2) were comparable with point B (ø 3 mm).

3.9 Summary of Results

Results of every instance of measurement were averaged for each analysis. Calculation for spherical elements included data identified for the right and the left sphere. Summary of performed analysis is shown in the graphs below.

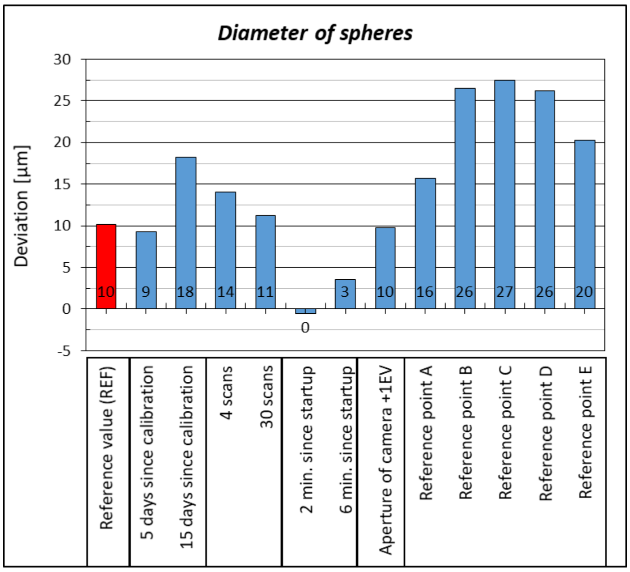

Figure 27. Overall summary (spherical etalon – diameter of spheres)

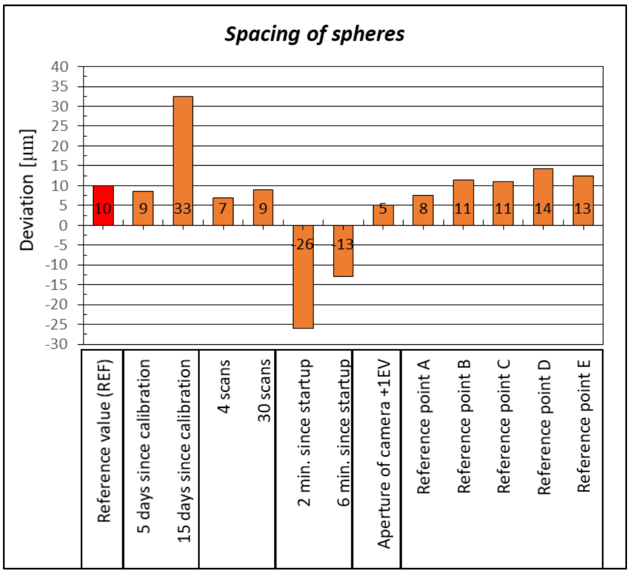

Figure 28. Overall summary (spherical etalon – spacing of spheres)

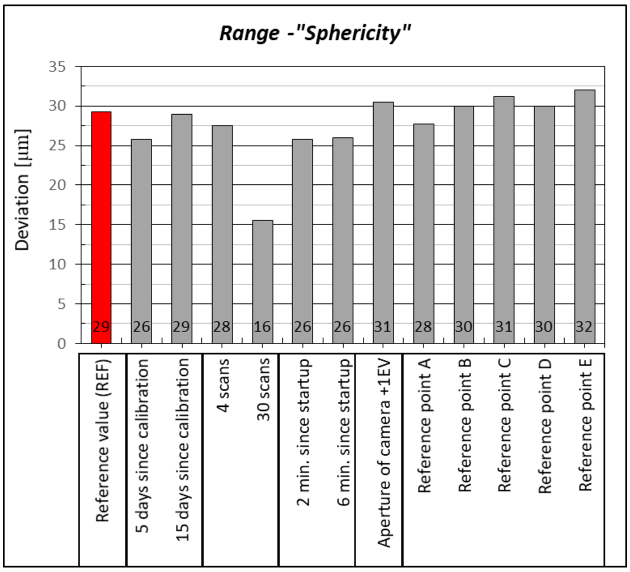

Figure 29. Overall summary (spherical etalon – Range, "sphericity")

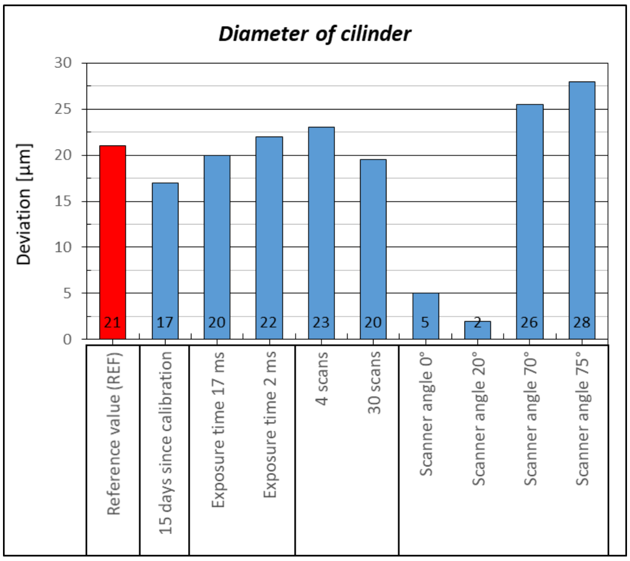

Figure 30. Overall summary (cylindrical etalon – diameter of cylinder)

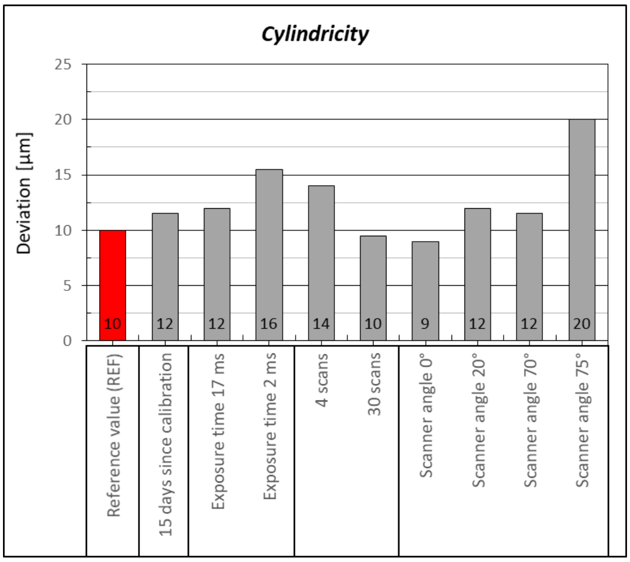

Figure 31. Overall summary (cylindrical etalon – cylindricity)

4 DISCUSSION

The research focused on complex evaluation of how various settings and external conditions affect the accuracy of optical 3D digitization.

The experiments showed that failure to follow the proper heat-up sequence, irregular calibration and low-quality reference points had the highest impact on accuracy of elements (such as diameter of sphere or cylinder) (see Figs. 27 and 30). Also, the test with non-original points showed that measurement accuracy is not affected by diameter of the point as much as by the quality of the used paper and print quality. Calibration and proper heat-up sequence also significantly affected the reliability of sphere spacing measurement (Fig. 28). Conversely, the effect of other observed parameters (number of images, different shutter between the left and right camera, correct exposure during measurement) has not been proved. Result of the analysis observing the effect of scanning angle is disputable. When considering the thickness anti-reflective coating, it seems that the most accurate values were achieved with approximately 45°. Contrariwise, too perpendicular angle resulted in negative deviations from reference values.

The impact of shape values is negligible with almost all the observed parameters. Extreme values of each aspect very rarely distorted the stable cylindricity and sphericity values (Figs. 29 and 31). In one case, the cylindricity severely deteriorated with high scanner tilt (75° from normal line of the measured surface), in the other case, the increase of number of images positively affected the Range parameter (sphericity). As proved by other analyses, shape characteristics are highly susceptible to quality of anti-reflective coating.

Results of the research are important for practice, especially since it concluded that most parameters do not significantly affect the measurement accuracy and shows high robustness of the system.It turned out that measurements by ATOS optical 3D scanner is not very susceptible to influence of external factors and errors caused by operator. Even with extreme change of settings, none of the seven observed aspects influenced the error of shape or accuracy of dimensions by more than 30 μm. On the other hand, it should be noted that combination of several negative factors might have a significant impact on reliability of the device. Therefore, one should pay increased attention to the recommended principles and procedures. In order to achieve as accurate measurement as possible, the system should be regularly calibrated, regardless of seemingly faultless operation, properly heated up. Also, high-quality reference points should be used.

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