CALIBRATION METHOD OF THE RANGEVISION PRO OPTICAL 3D SCANNER USING A CERAMIC STANDARD

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ABSTRACT
The importance of measurement as a practical technical discipline is of crucial significance both in everyday life and across all sectors of industry and science. Accuracy, precision, correct measurement, and reliable calibration of measuring devices play a key role in modern industrial processes. If any of these influential parameters are unreliable, measurement results can lead to serious deviations and undesirable consequences in manufacturing processes. This paper presents the method of calibrating the RangeVision PRO optical 3D scanner using a ceramic standard, in accordance with the requirements of the international standard ISO 10360-13. The focus is placed on the calibration procedure and the evaluation of measurement accuracy using two key parameters: probing error and distortion error. By applying data analysis methods after scanning, using GOM Inspect software, deviations between measured and nominal values were identified, allowing the determination of the mentioned parameters and assessment of the scanner's performance.

Keywords: calibration, optical 3D scanner, refrence standard, ISO 10360:13 standard, RangeVision PRO

1. INTRODUCTION

Nowadays, the use of optical 3D scanners in measurement and research has significantly increased due to the need for fast, accurate and non-contact acquisition of geometric data in three dimensions. Optical 3D scanners enable the digitization of complex shapes in a very short period of time, unlike traditional tactile measurement systems such as coordinate measuring machines (CMMs). However, as with any measuring device, the reliability and accuracy of their measurements largely depend on proper calibration and verification according to relevant standards. Calibration is a set of operations that ensure that instruments provide accurate measurement results. When it comes to optical 3D scanners, calibration is especially important due to their complex nature and the large number of factors that can affect the results, including lighting, object reflection, distance from the sensor, and resolution. Proper and regular calibration can significantly reduce measurement errors, which is crucial in applications where precision is of utmost importance, such as quality control, reverse engineering and metrology. The ISO 10360:13 standard specifically addresses the calibration and verification of optical 3D measurement systems, providing guidelines for evaluating their performance based on the use of spherical artefacts with known spatial distances. The aim of this paper is to present a concrete example of calibrating the RangeVision PRO optical 3D scanner, using a ceramic artefact with four spheres, and to analyze the results obtained based on the requirements of the standard. In addition, through this analysis it is important to point out the importance of regular calibration of 3D scanners in industrial environments, where reliability and accuracy of measurements are essential for ensuring product quality and optimizing production processes.

2. FUNDAMENTALS OF OPTICAL 3D METROLOGY AND REQUIREMENTS OF ISO 10360-13 STANDARD

Three-dimensional (3D) scanning is the process of analyzing an object or real-world environment to collect data about its shape and potentially its appearance. Depending on the data collection method, 3D measuring devices can be classified as contact and non-contact systems.

In contact methods, contact is established between the measuring system via a probe and the object being measured, they are characterized by a high level of accuracy, but are more time-consuming and limited when measuring complex geometry. On the other hand, non-contact methods use technologies such as laser scanning, structured light and photogrammetry to collect data, i.e. a large number of points that actually represent the surface of the object.

Non-contact measuring systems, especially optical 3D scanners, are distinguished by their ability to quickly and efficiently capture complex shapes and surfaces without physical contact. Optical 3D scanners are often portable and can be used in various environments, including manufacturing facilities and field work. They are suitable for scanning large objects or entire systems, where a CMM might be impractical or too large to use. However, although optical 3D scanners have made great progress, they can be subject to variations in lighting conditions, shiny, reflective or transparent surfaces, and high-precision optical scanners can be very expensive.

Optical 3D scanners are commonly used as universal measuring and inspection tools, so users must ensure that their devices operate within the defined accuracy range. In the long term, the only way to maintain this confidence is through the use of traceable criteria, namely calibration and regular inspection of the device.

The ISO 10360:13 standard defines four different tests to assess the performance of an optical device:

1. Probing error - which is divided into probing size error and probing form dispersion error;

2. Distortion error – i.e., deviation from shape;

3. Flat form distortion;

4. Volumetric length measurement error in concatenated measurement volume

The tests are designed to determine the maximum error that an optical sensor can make in a specified measurement volume, consisting of eight voxels, with a maximum enclosed length or distance between two points. The quality parameter of length measurement error is met and the device is successfully calibrated if, taking into account the measurement uncertainty, no length

measurement error exceeds the limit value for the maximum permissible length measurement error (MPE).
During calibration, special attention is paid to environmental conditions, because according to ISO 10360:13 they directly affect the reliability of the results. Therefore, for all tests, the optical 3D coordinate measuring system will operate according to the specified operating conditions and default settings, and if any of the conditions and settings are not specified, the user may freely choose them. Specific areas to be observed include the start-up or warm-up cycles of the measuring device, its qualification, achievement of thermal stability, location, type, number of thermal sensors, software filters applied for data processing, surface characteristics of the material standard (color, roughness, glossiness, light scattering), data registration and fusion settings, and the installed data smoothing function.

2.1. Optical measuring device-3D scanner and artefact for the calibration procedure
The RangeVision PRO optical 3D scanner, a scanner that works on the principle of structured light, was used for realization of the calibration procedure. It uses two high-resolution cameras and specially developed optics for precise measurement. The nominal accuracy of the scanner is up to 0.06 mm, with a resolution of 0.18 mm in the largest measuring range (L). The device provides variable measuring ranges (L, M, S), allowing it to adapt to different object dimensions.#

Figure 1. Optical measuring device – RangeVision PRO 3D scanner

For calibration purposes, artefacts with known geometric characteristics are used. An artefact is a materialized measure, reference material, or measurement system intended to define, realize, maintain, or reproduce a unit or one or more quantity values to serve as a reference [1]. In this study, a ceramic artefact with a ball bar composed of four rigidly connected spheres was used, which allows scanning and verification of multiple dimensions using an optical measuring device1Ceramic was chosen as the material due to its excellent properties such as thermal stability, wear resistance, low reflectivity, and dimensional stability over time. These characteristics ensure minimal deviations in metrological analyses and enable reliable evaluation of the accuracy of the optical scanner.
The artefact has known nominal diameters of the spheres as well as precisely defined distances between their centers, allowing for precise assessment of measurement accuracy in different parts of the measurement range.

Figure 2. Calibration artefact

3. PRACTICAL IMPLEMENTATION OF CALIBRATION AND TESTED PARAMETERS

The calibration of the Range Vision PRO optical 3D scanner was carried out using a ceramic artefact with four spheres, in accordance with the requirements of the ISO 10360:13. Given the characteristics of the available artefact, the calibration was focused on the evaluation of two key errors: probing size error and distortion error. Other test parameters from the mentioned standard are not included in this analysis, since their reliable calculation requires artefacts of different geometry and more complex dimensional relationships. This approach enables a partial, but relevant assessment of the accuracy of the measurement system under real application conditions.

For each scan, it is very important to know the procedure with regard to the final result. To achieve this more easily and without repeating steps, we use the following form:

1. Preparing the object for scanning
2. Connecting the device
3. Defining the axes in which the scanner measures and setting the parameters for scanning
4. Scanning the artefact according to the requirements and positions specified by the ISO standard
5. Scan analysis
6. Creating a measurement report in the GOM Inspect software

Before scanning, the artefact is visually inspected and cleaned with approved agents if necessary, during which the surface is degreased or matted if required for quality scanning..

Before each scan, a short calibration procedure of the rotary table is carried out in order to align its axis with the scanner, which defines the global coordinate system and ensures precise positioning of the object in space. Then, before carrying out the scanning procedure itself, it is necessary to check the already mentioned working conditions and ensure that these conditions meet the requirements of the standard, as well as select the required scanning parameters that relate to the software settings.

Once the table calibration and verification of the rotation axes are completed, and it is ensured that the device operates under conditions required by the standard, the calibration process of our 3D scanner using the previously described artefact begins. The artefact and the scanner must be positioned according to the standard's requirements. Then, 5 length measurements (distance between spheres) are taken and the average length value is determined, wich is necessary for further calculations.

After scanning the artefact, in single view (single scan), a scan is obtained from which the necessary dimensions are measured in the GOM Inspect software. GOM Inspect is a software for analyzing 3D measurement data from projection or laser scanners, coordinate measuring machines (CMM) and other measuring systems and is used in product development, quality control and production. The spheres should be selected using the Best-Fit Sphere method with a deviation of 1-σ from the ideal geometric shape.

Figure 3. Position of the artefact and the scanner

As already mentioned, the following parameters are tested during calibration:

- Probing size error
- Distortion error

3.1. Probing size error

The probing size error refers to the difference between the actual size and the measured size of the calibrated diameter of the artefact's test sphere. Figure 3.1 on the right, shows the probing size error (PS-probing error size), i.e. the deviation of the diameter of the fitted sphere. The size of the sphere is measured using the Fitting Sphere method. The diameter error is described as the difference between Da- the measured diameter and Dn- the reference diameter.
PS = Da – Dn

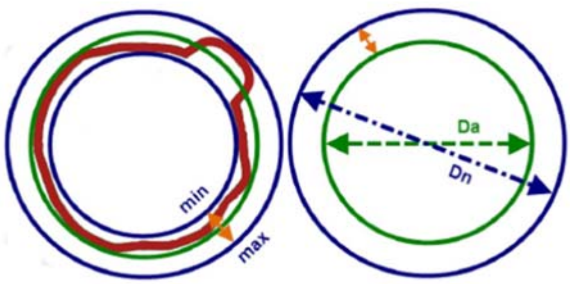

Figure 4. Schematic representation of form deviation and calculation of probing size error

3.2. Distortion error

Distortion error is the indication error when measuring the calibrated center-to-center distance of spheres within the sensor's measurement volume. The distortion test requires a artefact consisting of two spheres calibrated for diameter and center-to-center length: [3]

$$L_p \geq 0.3 \times L_0$$
$$0.02 \times L_0 \leq \emptyset_P \leq 0.2 \times L_0$$

where:

$\emptyset_P$ – diameter of the spheres,

L_p – center-to-center distance,

L_0 - the largest distance within the sensor's measurement volume

Therefore, Lp is the distance between the centers of the spheres used in the test and this distance is what is actually measured to test for distortion.

Distortion error is the difference between the measured and calibrated values of the center-to-center distance of the spheres, obtained by calculating the difference between the measured and nominal values of the length, i.e. the center-to-center distance of the spheres.

4. DATA EVALUATION

After scanning the artefact with four-spheres, data is collected to analyze the performance of the 3D scanner. This data included measurements of the sphere dimensions and the distance between the centers of the spheres. Each data was recorded in digital format and processed using specialized 3D scanning analysis software.

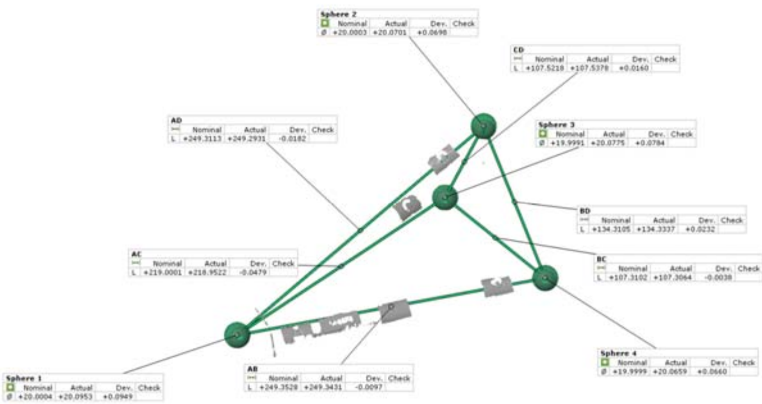

Figure 5. Measured distances between sphere centers and sphere diameter values

Table 1. Measurement results

Parameter	Measured value	Calibrated value of artefact [mm]	Deviation [mm]
Length (A-B)	249,3431	249,3528	-0,0097
Length (A-C)	218,9552	219,0001	-0,0479
Length (A-D)	249,2931	249,3113	-0,0182
Length (B-C)	107,3064	107,3102	-0,0038
Length (B-D)	134,3337	134,3105	+0,0232
Length (C-D)	107,5378	107,5218	+0,0160
Sphere A diameter	20,0953	20,0004	+0,0949
Sphere B diameter	20,0659	19,9999	+0,0660
Sphere C diameter	20,0775	19,9991	+0,0784
Sphere D diameter	20,0701	20,0003	+0,0698

In order to check whether the measured deviations fall within the tolerance of the maximum permissible deviation, the following expression is used:

$$|E| \leq |MPE_E| + U$$

Therefore, for the purpose of a complete evaluation of the measurement accuracy, the values of the expanded measurement uncertainty (U) were also taken into account. These represent the interval in which the true value of the measured quantity is expected to lie with a defined level of confidence. In this case, the expression used to calculate the measurement uncertainty was:

$$U = 107{,}22\mu m + 2{,}8 * 10^{-6} * L \ ; k = 2$$

By inserting the obtained error values, i.e. deviations, measurement uncertainty values, and MPE into the given expression, it was determined that both the distortion errors and the probing size errors are within the permissible limits. Therefore, based on the conducted tests, it can be concluded that the optical 3D scanner operates within the specified tolerances, which therefore confirms its accuracy in operation.

As previously explained, the probing size error is the difference between the measured diameters of the test spheres and their calibrated values and is calculated as the difference between the measured diameter and the nominal diameter value. The nominal diameter of each sphere is given in Table 1 as well as the measured diameter values which varied slightly. The probing size error was calculated for each sphere individually, and the maximum deviation was 0.0949 mm.

The distortion error is the difference between the measured and calibrated center-to-center distances of the spheres. After applying the expression for calculating the distortion error, the maximum obtained distortion error was 0.0479 mm.

Table 2. Comparison of calculated errors and maximum permissible error

Parameter	Calculated errors [mm]	$\lvert MPE \rvert + U$ [mm]
Length (A-B)	-0,0097	0,16
Length (A-C)	-0,0479	0,16
Length (A-D)	-0,0182	0,16
Length (B-C)	-0,0038	0,16
Length (B-D)	+0,0232	0,16
Length (C-D)	+0,0160	0,16
Sphere A diameter	+0,0949	0,16
Sphere B diameter	+0,0660	0,16
Sphere C diameter	+0,0784	0,16
Sphere D diameter	+0,0698	0,16

The obtained distortion errors and probing size errors are all within the maximum permissible limits, Table 2, which confirms the accuracy of the device for further use in precise measurements.

5. CONCLUSION

This paper analyzed the calibration procedure of an optical 3D scanner according to the ISO 10360:13 standard, with a focus on key measurement errors, i.e., distortion error and probing size error that can be determined using a ceramic standard. Therefore, using the available standard, two parameters were tested, and the results obtained indicate that the scanner meets the specified accuracy criteria, confirming the accuracy of the device for further use in precise measurements.

The obtained results show that the given optical 3D scanner can be used for precise measurements within the specified tolerances, although the calibration only included certain aspects of the scanner's accuracy, such as probing size errors and distortion. A more detailed assessment of the overall scanner performance can be performed by testing other parameters, such as the volumetric length measurement error in concatenated measurement volume and the flat form deviation. Ultimately, the calibration results confirm the correctness, or rather the accuracy and reliability of the optical 3D scanner's operation in the context of the measured parameters, thus enabling its daily use in purposes that require high measurement accuracy.

6. REFERENCES

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