TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue Special IV, December, 2021

PHOTOGRAMMETRY ACCURACY EVALUATION THROUGH 3D SCANNING AND MEASUREMENT OF A CUSTOM-DESIGNED GAUGE

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Abstract: This paper presents the design of a gauge that can be used to evaluate the accuracy of photogrammetry. It was manufactured of aluminum on NC equipment and then measured on a CMM machine to obtain its absolute values, both dimensional and angular. Due to the limitations of photogrammetry, among which its inability to obtain a true-to-scale 3D model, only the angles measured between flat surfaces were considered for the accuracy evaluation. These are not influenced by the scale at which the object is generated. The entire mesh obtained by photogrammetry was then manually scaled and compared with a model recreated using data from the CMM measurements.

Keywords: *Photogrammetry, 3D scanning, calibrated gauge, deviation analysis*

1. INTRODUCTION

In latest years, there has been an increased interest in 3D digitization technology using photogrammetry, mainly because of its cost-effectiveness and high fidelity regarding the captured texture of the digitized object; however, there are several drawbacks associated with it, as well.

Among these disadvantages, the varying accuracy can be considered the primary deficiency. The high digitization time, ambient lighting dependency, and lack of true scale of the digitized object [1] are also related shortcomings. However, it should be noted that if a proper digitization process is fine-tuned (assuring necessary ambient lighting; manually adjusting the scale of the object, acquiring data with high-resolution equipment and/or sensors, etc.), the results are similar with state-of-the-art high-performance laser and structured light scanners.

Due to the limitations that the photogrammetry 3D digitization technology has and because skepticism still exists regarding its reliability [1],[3], it's mainly deployed for: large scale structures, such as buildings or monuments [4],[5], (for which the accuracy factor can be acceptable even at lower levels - 2-3mm); entire outdoor surface areas, where the digitization process is undertaken with the help of drones or UAVs (unmanned aerial vehicles) [6]-[8]; objects where the texture must be hyper-realistic and is considered more important than the accuracy of the scanned object's surfaces, such as paintings [9],[10] or different types of textiles [11]; and finally small and micro-scaled objects, such as archaeological artifacts between 50-100mm in diameter or even insects [12],[13], where the digitization is facilitated by very high-resolution cameras and with high optical zoom.

Thanks to the increased popularity of photogrammetry, over the past few years, multiple studies have assessed its accuracy [5],[14]; however, because of the technology's inability to precisely determine the scale of the digitized object, this was not correctly addressed.

In the current paper, the authors evaluate the accuracy of photogrammetry by explicitly designing a gauge for this purpose, containing multiple planes disposed at various angles. By measuring only the angles on the gauge, the accuracy evaluation can be achieved independently from the scale of the digitized object, thus reducing potential error sources to a minimum that can influence the evaluation process.

2. DATA ACQUISITION

The paper aims to validate a gauge dedicated to evaluating the accuracy of photogrammetry. The gauge (Fig. 1), was designed and made of special aluminum to evaluate the accuracy of digitization operations. It consists of simple essential elements: plane, cone, cylinder, and sphere, which can be easily "recognized" by software used in reverse engineering.

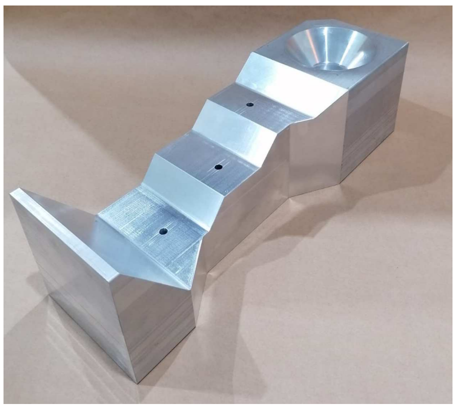

Fig. 1 *Physical Gauge*

The algorithm for evaluating the accuracy of the photogrammetry is shown in (Fig. 2); the data acquisition steps are marked in blue.

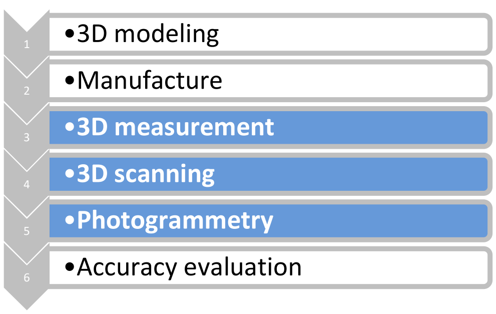

Fig. 2 *Photogrammetry accuracy evaluation algorithm*

After manufacturing the gauge, it's measured on a coordinate measuring machine (CMM) to certify the actual values obtained from the manufacture of the gauge. It is then scanned to obtain the digital version equivalent, by employing two techniques: photogrammetry and structured light scanning. Next, the two models are evaluated through the prism of angles made of flat surfaces. The mesh obtained by photogrammetry is then scaled to the nominal size (the measured one), and then a global comparison is made using the Deviation Analysis tool, in the CATIA V5-6R2019 software.

2.1 Photogrammetry data acquisition

The data for the gauge was obtained with a Canon 5DSR DSLR camera paired with the Canon macro 100mm lens mounted.

For assuring proper ambient lighting 4 sources with LEDs were used, that are capable of 475 [Lx], measured from about a 200 [cm] distance from the gauge; they were placed on tripods at the height of 180 [cm] for good dispersion. The lighting was measured using a Sekonic C-700 device and the acquired data is presented in Fig. 3.

Fig. 3 *Light measurement with Sekonic C-700*

The position of the light sources as well as of the gauge is presented in Fig. 4.

A total of 75 photos have been taken with the help of a tripod. Three sets of photos at different heights were shot to cover all surface areas of the gauge; these are presented in Fig. 5, placed around the digitized object.

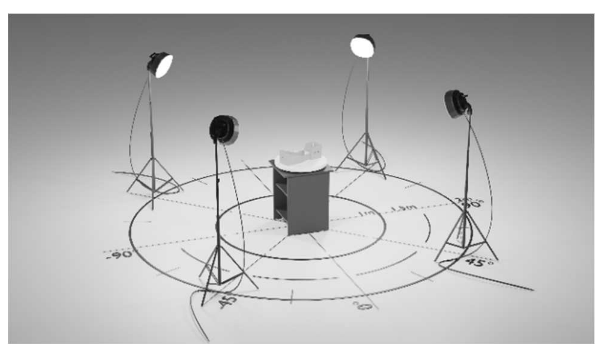

Fig. 4 *Photogrammetry set-up*

The authors decided to use a tripod for the camera to speed up the photogrammetry process. Thus, a rotating table was required to rotate the gauge at different angles. In addition, the camera setting was done manually to have better control; the ISO was set at 2000, the aperture stop f/25, and the exposure time ranged between 1/4 up to 1/5; to obtain a sharp images and prevent blur.

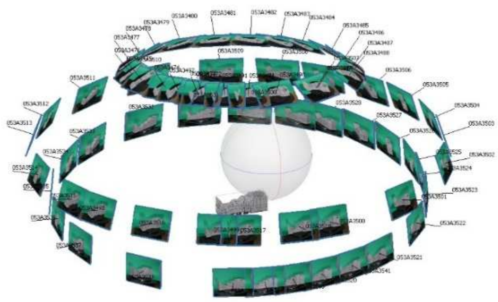

Fig. 5 *Distribution of photos in the photogrammetry process in Agisoft*

Two specialized photogrammetry software were used to generate a 3D mesh with the same set of photos (Agisoft and Pix4d), thus enabling a comparison regarding mesh quality and deviation against the 3D measurement model; in the following two figures (Fig. 6 & Fig. 7) the mesh resulting from the two software is showcased.

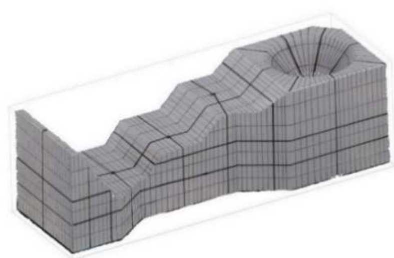

Fig. 6 *3D mesh resulting from photogrammetry with Agisoft software*

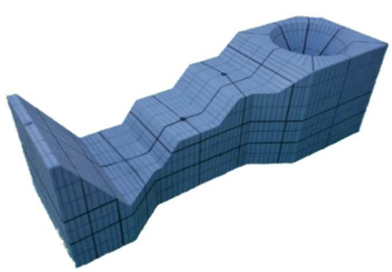

Fig. 7 *3D mesh resulting from photogrammetry with Pix4D software*

2.2 3D scanning data acquisition

The scanning of the gauge was performed using a structured light scanner from Creaform – Go!Scan 50 (Fig. 8). According to the device's technical specifications, the resulting mesh has an accuracy of at least 50 µm and it was used as a baseline for comparison with the mesh resulting from photogrammetry. To reduce errors and noise as much as possible, the scanning was done from a single position.

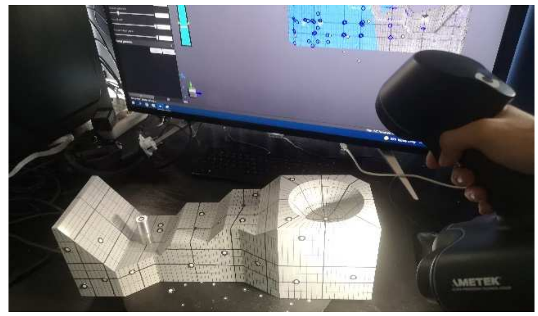

Fig. 8 *3D scanning of the caliber using Creaform Go!Scan and VXelements software*

The mesh resulting from the scanning (Fig. 9) was processed to eliminate the base surface on which the gauge was placed; in addition, a series of filters, specific for reverse engineering, were applied to further reduce errors and increase scan quality.

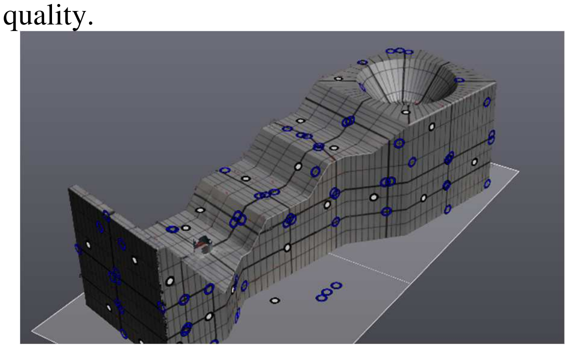

Fig. 9 *Mesh resulting from 3D scanning VXelements*

2.3 3D measuring data acquisition

The validation of the 3D model obtained using photogrammetry has been done using a CMM, this process is illustrated in Fig. 10.

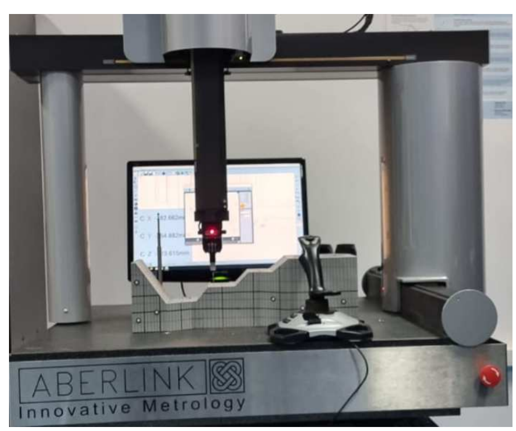

Fig. 10 *Calibration measurement with CMM*

By measuring the gauge, the CMM obtains the actual angular values of the gauge and implicitly the difference between the CAD model and the physical model (Fig. 11).

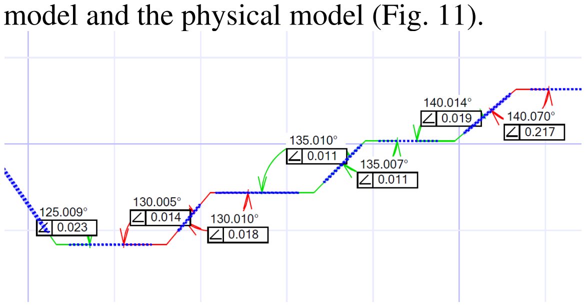

Fig. 11 *Capture from CMM measurement software*

3. DATA PROCESSING

The data processing is completed in CATIA V5; here, the 3D mesh is converted into elementary surfaces (planes, cylinders, cones, or spheres), which can then be used for dimensional verification of the gauge.

Because monocular photogrammetry doesn't allow the generation of a 1 to 1 scale object, only the angles between the gauge surfaces were analyzed in this study. These are not influenced by the scale at which the 3D mesh is generated.

Understanding and obtaining the required form tolerances represent a mandatory step for the proposed reverse engineering process. As presented by other researchers, the use of modern VR technologies can provide a better form of understanding tolerances [15]. The first step in mesh processing is to convert certain sections of it to flat surfaces, is given in Fig. 12.

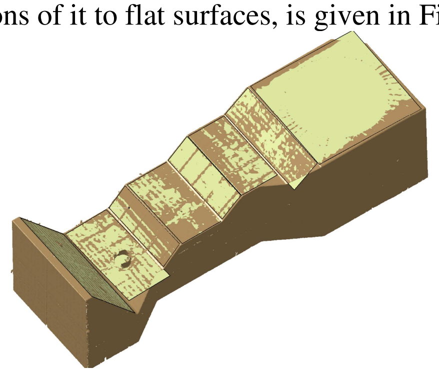

Fig. 12 *Face generation in Catia V5*

After generating the surfaces, various sets of tools are used to create a surface body, to be finally compared with all gauges, generated with different methods: photogrammetry, 3D scanning, 3D measurement.

Deviation analysis (Fig. 13) was performed between all gauges obtained from different digitization methods and a fundamental gauge model, that was recreated using the 3D measurement data (this characterizes the actual physical model).

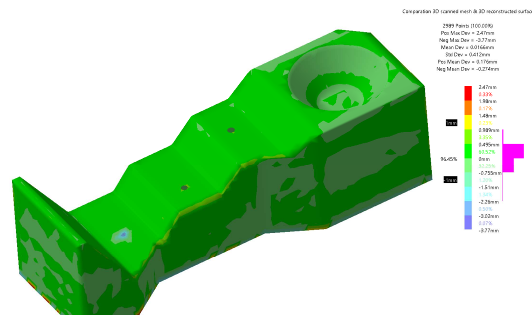

Fig. 13 *Deviation analysis (Catia V5) between photogrammetry (Agisoft) and the generated model based on the CMM data*

4. RESULTS

The gauge was measured, 3D scanned, and digitized by photogrammetry (Fig. 14) to validate the gauge as a tool for analyzing the accuracy of photogrammetry.

Because monocular photogrammetry doesn't generate a real-scale mesh, in the first stage, a set of seven angles was defined (Fig. 15), which was compared (Table 1) with the actual values of the angles measured on the CMM.

The differences between the values measured on the CMM, 3D scanning, and photogrammetry are less than 0.3% (Table 2). Furthermore, in only 4 out of 7 cases, 3D scanning was more accurate than photogrammetry.

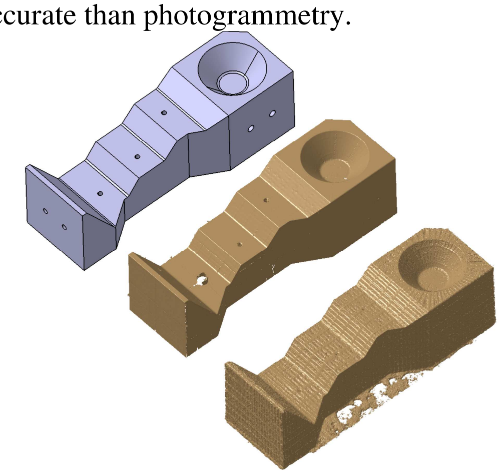

Fig. 14 *Gauge: CAD model, 3D scan mesh, 3D mesh generated by photogrammetry with Agisoft*

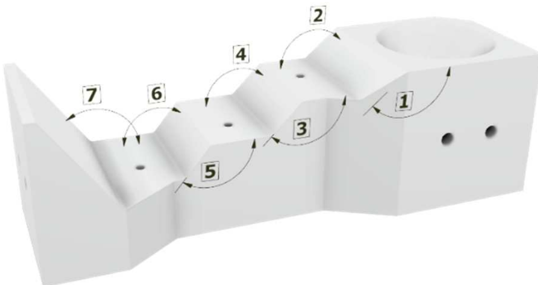

Fig. 15 *Defined angles for the measurement*

Table 1 *The resulting data*

Angle nr.	CAD	3D meas.	3D scan	Photogrammetry	
				Agisoft	Pix4D
1	140°	140.07°	139.949°	140.032°	140.023°
2	140°	140.014°	139.916°	140.038°	140.151°
3	135°	135.007°	135.109°	135.240°	135.005°
4	135°	135.010°	135.038°	135.115°	135.108°
5	130°	130.010°	130.095°	129.825°	130.265°
6	130°	130.005°	130.038°	129.674°	130.316°
7	125°	125.009°	124.957°	124.743°	124.927°

Table 2 *Angular deviations in the case of photogrammetry and 3D scanning*

Angle nr.	3D measurem.	3D scan	Photogrammetry	
			Agisoft	Pix4D
1	140.07°	0.121	0.038	0.047
2	140.014°	0.098	-0.024	-0.137
3	135.007°	-0.102	-0.233	0.002
4	135.010°	-0.028	-0.105	-0.098
5	130.010°	-0.085	0.185	-0.255
6	130.005°	-0.033	0.331	-0.311
7	125.009°	0.052	0.266	0.082

5. CONCLUSIONS

The designed and executed gauge was validated for the purpose of evaluating the accuracy of photogrammetry. By digitizing the gauge using the photogrammetry method, data was obtained that can be compared with 3D scanning, from the angular values' perspective. The comparison between the dimensional values is subjective and cannot be considered as baseline for evaluating the accuracy of this method, because it can't provide a 3D model at scale. As a result, the quality of the mesh obtained by photogrammetry is poorer in terms of surface quality.

6. ACKNOWLEDGMENT

This work was supported by a Romanian Ministry of Research and Innovation grant, CCCDI – UEFISCDI, project number TE 132 15/09/2020 - PN-III-P1-1.1-TE-2019-2203 (Atop), within PNCDI III.

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EVALUAREA PRECIZIEI FOTOGRAMETRIEI UTILIZÂND MĂSURAREA ȘI SCANAREA 3D A UNUI CALIBRU PROIECTAT PERSONALIZAT

Rezumat: Lucrarea prezintă proiectarea unui calibru care poate fi utilizat pentru a evalua acuratețea fotogrammetriei. A fost fabricat din aluminiu pe echipamente CN și apoi măsurat pe o mașină MMC pentru a obține valorile sale absolute, atât dimensionale, cât și unghiulare. Datorită limitărilor fotogrammetriei, printre care incapacitatea acesteia de a obține un model 3D la scară, pentru evaluarea acurateței au fost luate în considerare doar unghiurile măsurate între suprafețele plane. Acestea nu sunt influențate de scara la care este generat obiectul digitizat. Întreaga suprafață obținută prin fotogrammetrie a fost apoi scalată manual și comparată cu un model recreat folosind date din măsurătorile MMC.

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