A SIMPLE NON-CONTACT METHOD TO EVALUATE HIGH DEFORMABLE BODIES DEFORMATION

Ioan TAMAȘAG[1*], Irina BEȘLIU-BĂNCESCU [1], Ilie MUSCĂ[1]

[1] „Ștefan cel Mare" University of Suceava, 13 Universității, 720229, Suceava, Romania,
**Corresponding author: Ioan TAMAȘAG, e-mail: ioan.tamasag@usm.ro*
.

Abstract: In engineering, the evaluation of high deformable bodies deformations is a common problem, which if not handled properly can lead to substantial measurement errors. The present paper presents a method for measuring the deformations of easily deformable materials such as rubber, using 3D scanning and reverse engineering techniques and specialized software, that can facilitate multiple analysis and measurement methods for deformations. By using the proposed methods, the obtained results indicate high accuracy measurements, exceeding the limits of traditional measurement methods. This approach has significant applications in engineering, helping to develop more reliable products and improve quality in various industrial fields.

Keywords: *Reverse Engineering, Point Cloud, Measurements, Scanning*

1. Introduction

Part measurements are an important issue in engineering. The problem becomes more difficult for low rigidity parts, easily deformable. Even the low measurement force exerted by the stylus used to perform 3D measurements on coordinate measuring machines or by the levers of the measuring instruments that ensure the contact of the measuring instruments with the part surface can lead to local deformations that can cause a rather significant measurement error.

An example of the above problems is the measurement of the deformations of rubber or polyurethane foam bodies.

A solution for such a problem is given by Melciu, [1], for the deformation of a rubber sleeve upon impact. It uses a method of fast filming followed by superimposing an approximate curve over the recorded digital image. This method is subjected to a high degree of subjective component for points selection (the number of points, their position and their actual location).

The present work proposes a method that is much more precise and without subjective errors. The method consists of applying reverse engineering through non-contact measurement (scanning). In the specialized literature, there are a number of studies using this measurement procedure applied in various fields such as medical, [2], automotive, [3], aerospace, [4], civil constructions, [5], etc., especially in mechanical engineering or car manufacturers, [6, 7]. In the main, the studies carried out involve research on the reproduction of parts and quality control, [8], but also the study of defects emerged from different manufacturing processes, [9].

2. Experimental setup

The method consists of scanning the undeformed part and after that scanning the deformed part and comparing the two scanned bodies.

A poly-articulated FARO Edge 7.5 arm, normally used in reverse engineering, was used for the scanning purpose.

To simplify the problem, the volume and contact deformations were studied for a rubber sphere (figure 1).

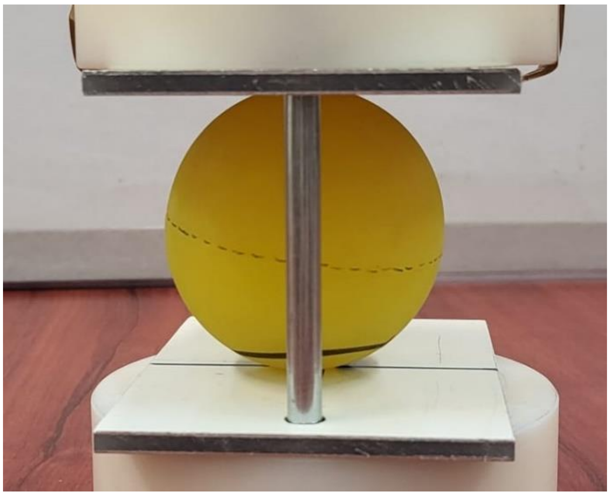


Figure 1: *The rubber spherical body situated between two plates*

The spherical body used, with a diameter of 54.4 mm, was compressed diametrically between two parallel plates with a certain value, as it can be seen in figure 1. Two different deformation situations were considered:

1. Bringing closer the plates by moving them with 3mm and
2. Bringing closer the plates by moving them with 12mm.

After the immobilization between the two plates, the assembly was scanned. The points cloud was processed in Faro CAM 10 software, related to the poly-articulated arm and a triangulated "mesh" type format of the scanned bodies was obtained (figure 2).

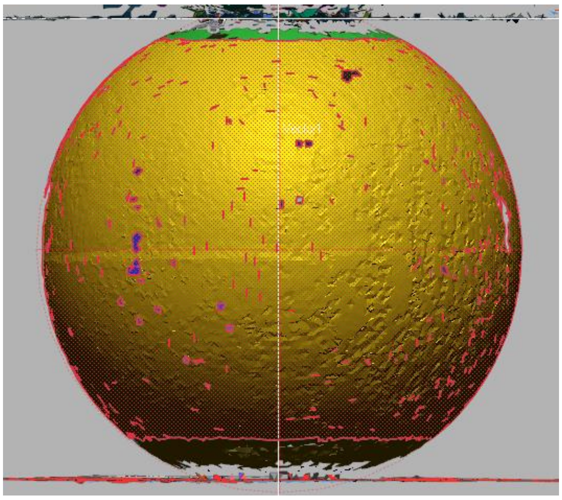


Figure 2: *The mesh obtained after the triangulation of the point cloud*

The mesh was generated by using a radius search filter method with a value set at 0.05 mm for an accurate mesh. The radius search method sets a specific radius around a point and chooses all neighboring points within that radius as neighbors. In this stage no other filters were used. After this, a CAD (Computer Aided Design) format object was obtained.

The generated ISO file was imported into a CAD environment, for example in Geomagic Design X. After inserting the mesh and aligning it in the Cartesian system, the deformations can be measured by several methods:

1. The measurement of some specific regions

From the imported mesh body, a series of regions automatically identified as primitive geometries (sphere, cylinder, plane, cone, ring) can be subtracted and for which the dimensions of interest can be measured (figure 3).

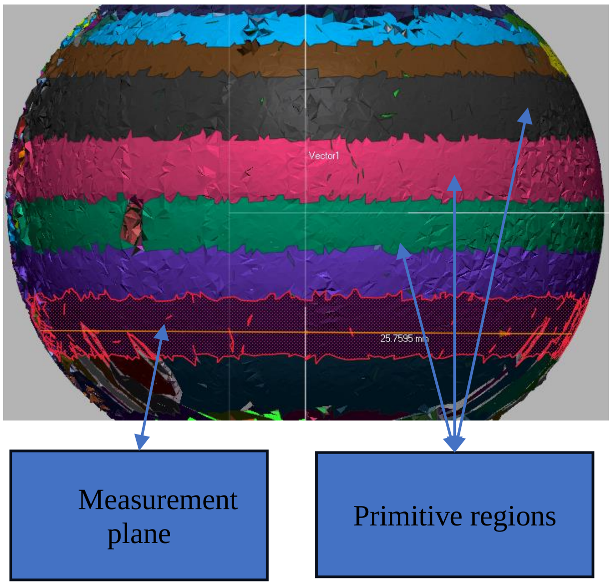
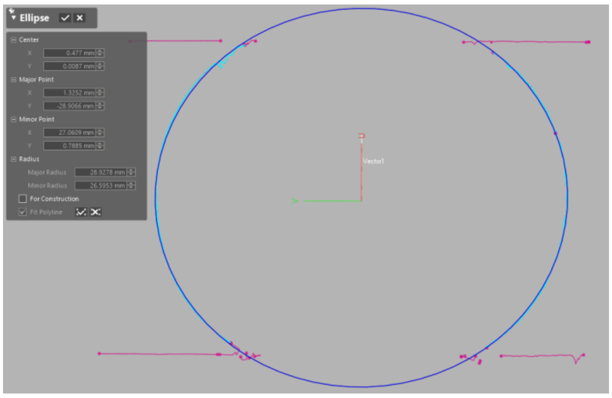


Figure 3: *The selection and measurement of regions dimensions*

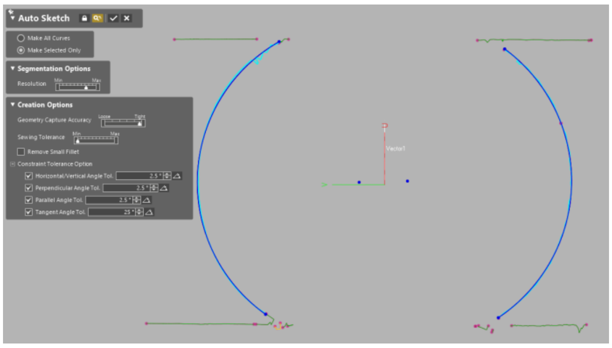
2. The sectioning of the mesh and creating the generating curve

This procedure is the main method used to obtain the CAD format of the deformed scanned geometries. The method involves creating a new sketch in a selected plane, in the present case in a plane tangent to the axis of symmetry of the spherical body, followed by the creation of the generating curve.

As in the previous case, the generating curves can be identified depending on their primitive shape (figure 4.a), or the automatic generation of the contour of the scanned body by a string of polyline type lines (figure 4.b.), method chosen depending on the constructive version of the scanned part. For example, in the case of organic type surfaces, the version shown in figure 4.b is used more often.



a.



b.

Figure 4: *Creating the generative curves: a – By approximation of the primitive form, b – by polyline method*

After generating the CAD model, the part can be analyzed to determine the accuracy obtained by coloring the deviations of the surfaces from the CAD to those of the triangulated model (figure 5).

In this way, the deformed shape of the sphere was obtained by a non-contact method, with a precision comparable to that provided by the poly-articulated arm.

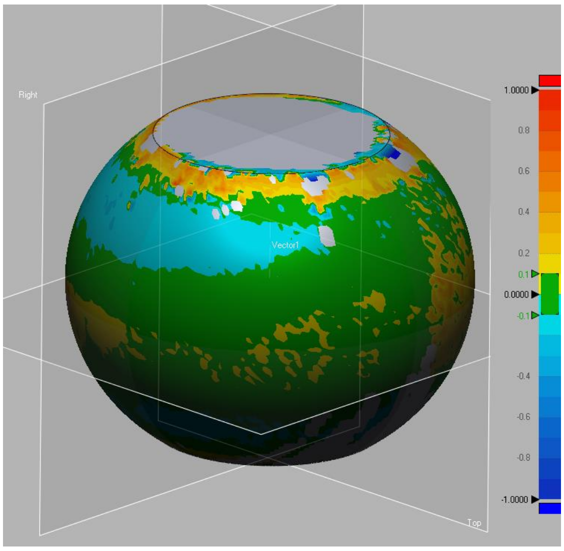
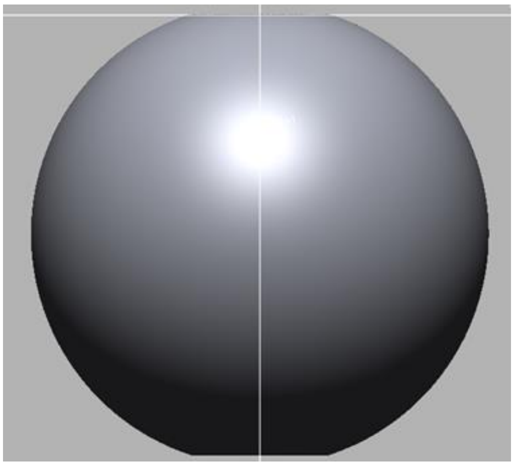
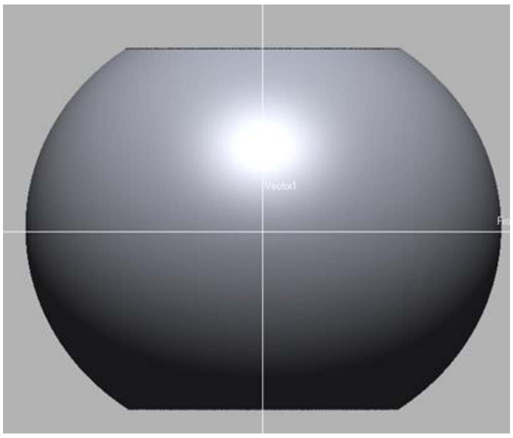


Figure 5: *Analysis of deviations of CAD surfaces from scanned part surfaces*



a.



b.

Figure 6: CAD model of the deformed sphere: a – The sphere deformed by the displacement of the plates with 3 mm, b – The sphere deformed by the displacement of the plates with 12 mm 12mm

The technical characteristics of the 3D scanning module in the Faro Edge arm construction are shown in Table 1.

Table 1: Faro Edge 7.5 scanner module technical specifications

Accuracy	±25μm
Repeatability	25μm
Stand-off	115mm
Depth of field	115mm
Effective scan width	Near field 80mm Far field 150mm
Points per line	2000 points/line
Minimum point spacing	40μm
Scan rate	280 frames/second 280fps x 2000points/line = 560000 points/sec
Laser	Class 2M
Weight	485g

3. Results and discussions

The deformations were evaluated from several points of view.

1. Volumetric assessment.

A first method to validate the working mode is to check the differences between the volume of the undeformed sphere and the volume of the deformed sphere, knowing that solids are non-deformable.

The CAD application provides the values obtained for the two cases in table 2.

Table 2: The volume values of the spherical body

Part	Volume	Relative error
Undeformed sphere (Vsf)	84290 mm^3	-
The sphere deformed by the displacement of the plates with 3 mm (V_3)	87495 mm^3	$\delta = 5.8\%$
The sphere deformed by the displacement of the plates with 12 mm 12mm (V_{12})	89212 mm^3	$\delta = 3.8\%$

2. Evaluation of contact deformations.

The contact deformations are characterized by the radius of the circles of the flat surfaces. They were also measured by another contact method, obtaining the values in table 3.

Table 3: The radius values measured for the spherical body

Part	The radius of the scan CAD model	Contact radius measured by another method	Relative error
The sphere deformed by the displacement of the plates with 3mm (R3)	8.3mm	7.93mm	$\delta = 4.6\%$
The sphere deformed by the displacement of the plates with 12 mm (R12)	16.4mm	14.67mm	$\delta = 11.8\%$

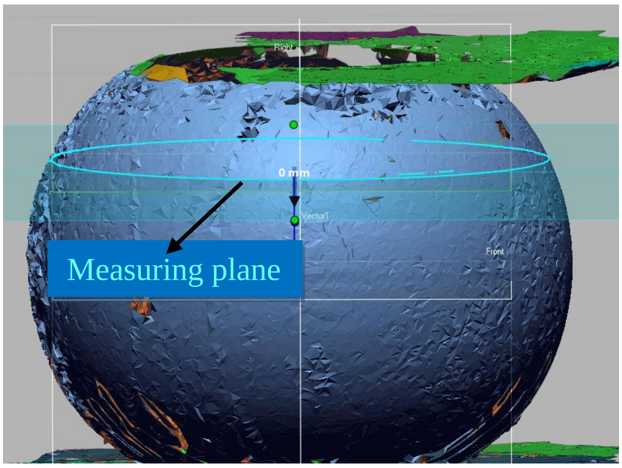


Figure 7: *Establishing the position of the measuring plane*

4. Evaluation of the deformed median extended diameter.

This diameter gives us the outer dimension obtained from the deformation of the toroidal portion.

From the analysis of these parameters, it can be concluded that the evaluation of the dimensions is sufficiently accurate. The higher errors obtained are determined by the scanning process limitations when dealing with narrow areas as the sphere-plane contact area (figure 8).

Table 4: The diameter values measured for the deformed body

Part	Diameter obtained for the scanned CAD model	Contact diameter	Relative error
The sphere deformed by the displacement of the plates with 3mm (R_3)	54.93mm	55mm	$\delta = 1.4\%$
The sphere deformed by the displacement of the plates with 12 mm (R_{12})	57.78mm	57.5mm	$\delta = 0.5\%$

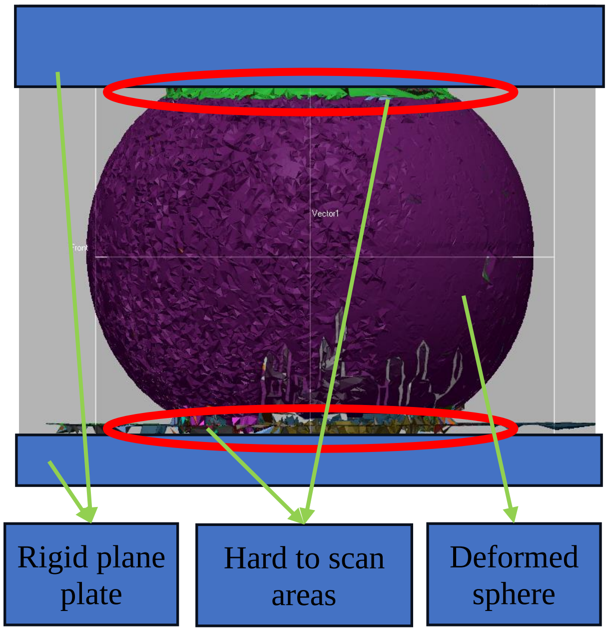


Figure 8: *Scanning limitations*

5. Effective evaluation of deformations.

Effective assessment of deformations can be done by measuring deviations of the scanned part versus the undeformed part. In this sense, the cloud of points obtained after scanning the deformed spheres is superimposed with the CAD shape of the undeformed piece, having coaxial symmetry axes. Subsequently, the differences in deflections at any point on the surface of the spherical body can be measured.

In figure 9, the analysis of deviations was made for the part deformed by the pressure exercised by the movement of the planes closer with 12mm. It can be seen that in the contact area with the flat surfaces the deviations are small, within ±0.04mm, they increase towards the median diameter of the toroidal portion, where a deviation of up to 2mm could be observed.

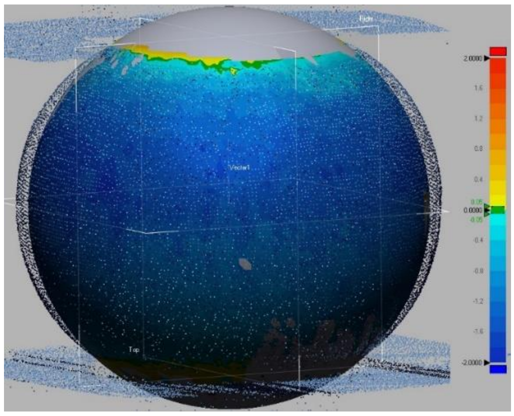


Figure 9 *Analysis of deviations of the CAD surfaces of the undeformed part compared to the point cloud of the deformed part - 12mm deformation*

In the case of the sphere deformed by the pressure exerted by moving the plates closer with 3mm (figure 10), it can be seen that the deviations are small, with a maximum deviation of 0.3 mm on the area of the maximum diameter.

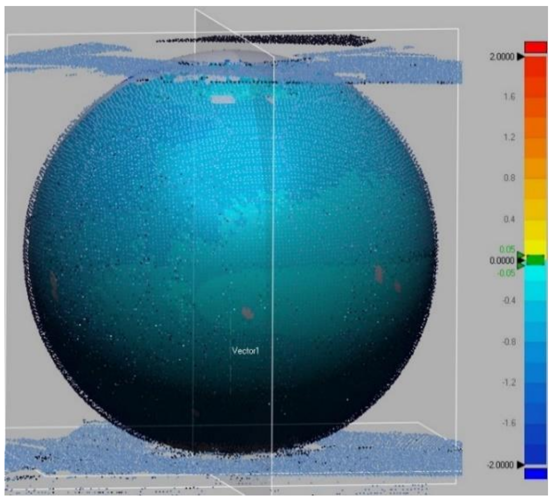


Figure 10: *Analysis of deviations of the CAD surfaces of the undeformed part compared to the point cloud of the deformed part - 3mm deformation*

4. Conclusions

The results obtained for the particular case presented in this paper highlight the increased measurement accuracy using the presented reverse engineering method. In this case, the high degree of confidence was confirmed by the size of the measurement errors, which were between 0.5% and 1.4% for the maximum diameter values, between 4.6% and 11.8% for the circle radii of flat surfaces and between 3.8% and 5.8% for the values of the volume of the spherical body.

For the circle radii the higher error occurs due to the difficulty to scan into the narrow areas (sharp corners).

References

1. [Melciu, 2019] Melciu I.C., *Procese de expulzare repetitive în medii complexe*, Teză de doctorat, București, 2019, p216.
2. [Haleem, 2019] Haleem A., Javaid M., *3D scanning applications in medical field: A literature-based review*, Clinical Epidemiology and Global Health, 7(2), 2019, https://doi.org/10.1016/j.cegh.2018.05.006
3. [Ameen, 2018] Ameen W., Al-Ahmari A.M., Hammad Mian S., *Evaluation of Handheld Scanners for Automotive Applications*, Applied Sciences, 8(2):217, 2018,

   https://doi.org/10.3390/app8020217
4. [Brügge, 2023] van Brügge, L., Çetin, K.M., Koeberle, S.J. et al. *Application of 3D-scanning for structural and geometric assessment of aerospace structures*, CEAS Aeronaut J, 14, 455–467, 2023,

   https://doi.org/10.1007/s13272-023-00654-1
5. [Li, 2021] Li, Y.; Liu, P.; Li, H.; Huang, F. *A Comparison Method for 3D Laser Point Clouds in Displacement Change Detection for Arch Dams*. ISPRS Int. J. Geo-Inf., 10, 184, 2021,. https://doi.org/10.3390/ijgi10030184
6. [Dúbravcík, 2012] Michal Dúbravcík, Štefan Kender, *Application of reverse engineering techniques in mechanics system services*, Procedia Engineering, 48, 96 – 104, 2012, doi: 10.1016/j.proeng.2012.09.491
7. [Eslami, 2017] Eslami, A. M., *Integrating Reverse Engineering and 3D Printing for the Manufacturing Process*, ASEE Annual Conference & Exposition, Columbus, Ohio, 2017, 10.18260/1-2--28558
8. [Robin, 2021] Robin H. Helle, Hirpa G. Lemu, *A case study on use of 3D scanning for reverse engineering and quality control*, Materials Today: Proceedings, 45(6), 2021, pp. 5255-5262,

   https://doi.org/10.1016/j.matpr.2021.01.828
9. [Yang, 2022] Yujing Yang, Xin Liu, Chen Kan, Point cloud based online detection of geometric defects for the certification of additively manufactured mechanical metamaterials, Journal of Manufacturing Systems, 65, pp. 591-604, 2022, https://doi.org/10.1016/j.jmsy.2022.09.011