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A Comparison of the Outputs of 3D Scanners

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Abstract

Various types of 3D scanners are used for digitalization of objects (products, space). These are mostly different types of optic or laser 3D scanners. The presented article deals with the comparison of the Steinbichler Comet L3D optical scanner and the Creaform EXAscan laser scanner. Determination of parameters of both scanners is necessary if we need measure on obtained data and not only use the scanned shape. To make this comparison, a specimen was designed that satisfies scanning criteria using the two types of the 3D scanners; i.e. it does not contain complicated shapes or parts that are not possible to scan using the chosen technologies (deep apertures with a small diameter, corners, etc.). The designed specimen was scanned 3 times using both types of 3D scanners. The obtained images were then cleaned (elimination of unwanted artifacts) and STL files were generated. The obtained scanned data were evaluated using VolumeGraphics VGStudio MAX 2.2 software with the necessary modules. In the comparison selected dimensions, shape and orientational deviations were evaluated and the scanned image obtained was compared to the CAD model.

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1. Introduction

A 3D scanner is a device serving for the conversion of a real object into digital form. During the process of sensing, the scanner collects with the help of different technologies information about the shape and dimensions of the scanned object and depending on the technology can also record, for example, information about the color of the object. The scanned data is made up of so-called point clouds; this means each scanned point has a position in space

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in terms of a coordinate system, possibly also a color. The information obtained can then be used for the creation of a digital three-dimensional model of the scanned object.

The resulting data can be subsequently processed for different purposes through specialized software products. 3D scanners can be divided according to several criteria – for example construction and method of scanning.

Dividing of 3D scanners by construction:

- stationary – they are bound to one place, these are scanners of large dimensions,
- mobile – they have the advantage of being small in size and can be brought to an immovable object. [3, 4, 8]
  They can be divided according to the method of scanning:
- contact – they need mechanical contact with the scanned object for scanning. These are stationary 3D scanners, to a predominate measure coordinate measuring machines (CMM) and measuring arms.
- non-contact – optical, laser and other technologies are used for scanning. [3, 4, 8]

They can also be divided based on the method of scanning:

- optical – they work on the photographic principle. The object is scanned from several angles, and the scans are subsequently combined, to create a digitized 3D image of the object.
- laser – these work on the triangulation principle. Light reflected off the object is sensed and on the basis of the period of return of the light ray and the angle of impact the position of the scanned area in space is determined.
- ultrasound – ultrasonic waves are used for scanning, and as with lasers the period of reflection and the angle of impact are sensed using ultrasonic waves. Unlike laser scanners, they have a lower precision (0.3-0.5 mm).
- x-ray – RTG radiation is used for scanning. Residual radiation falling on the detector after the passing of the scanned object is detected. With this type in addition to the external shape, complete information about the overall volume of the object is obtained (internal geometry, defects of material).
- mechanical – a type of contact scanner. These can be divided into measuring arms and CMM machines. With these types of scanners information is not obtained from the entire surface but from selected points which characterize the given locality of the object.
- destructive – the scanned object is destroyed during scanning. This serves for obtaining the external and internal geometry of the object. During scanning a thin layer of material is gradually skimmed off the object and the exposed surface is subsequently scanned. In this process a model of the entire object is gradually acquired. [3, 8]

Areas of application of 3D scanning:

- reverse engineering – reconstruction of objects
- quality control – control of products during operation, numerical simulation with the use of scanned objects
- architecture – for modeling buildings and their visualization, for designing buildings, visualization of partial modifications or during complete reconstructions for creating virtual models of historical buildings, digitalization of historical objects
- multimedia – use in games, creation of animation in films, for modeling of virtual cities, etc.
- art -– reconstruction of cultural and historical monuments, such as statues, creation of the foundations for replicas.
- medicine – reconstruction and visualization of the human body (prosthetics and orthotics), bones, etc.

2. Scanners

2.1. Steinbichler Comet L3D

The Steinbichler Comet L3D enables non-contact optical scanning. The version used for the comparison has resolutions of 2Mpx and 1600x1200 pixels available (Table 1).

Table 1. Steinbichler Comet L3D parameters [6]

Camera Resolution [dpi]	1600x1200
Measuring field [mm]	400
Measuring volume [mm^3]	400x300x250
Point to point distance [µm]	259

This is a portable scanner, where the scanning head is placed on a tripod during scanning. For positioning (rotation) of the measured object it is possible to use a rotating table. The supplied software allows for basic modification of the scanned data, their comparison with a model and export in the IGES, STEP and STL formats (Fig. 1).

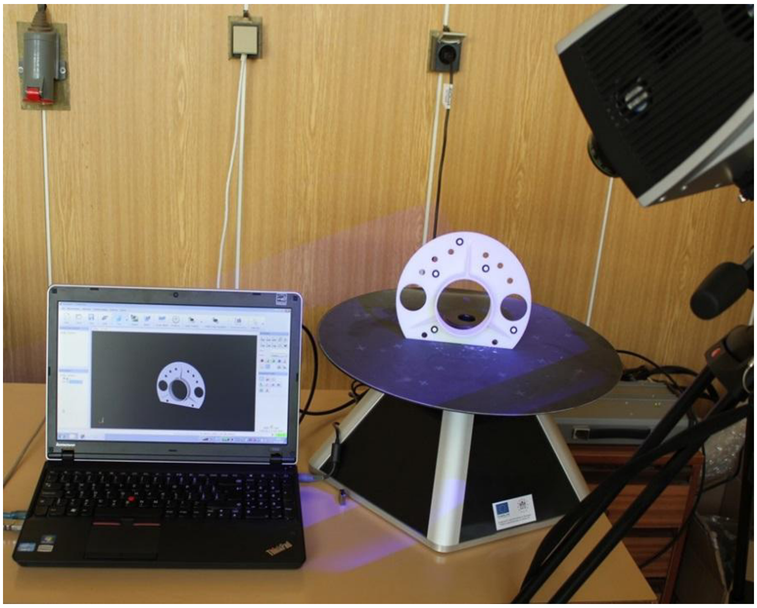

Fig. 1. Steinbichler Comet L3D during scanning.

2.2. Creaform EXAscan

A hand-held portable and self-positioning laser 3D scanner, which is during scanning allows movement of both the scanner and the item being scanned. The scanning position is defined by positional (referential) markers placed on the scanned object; these help ensure the spatial orientation of the scanner (Table 2).

Table 2. Creaform EXAscan parameters [7]

Resolution [µm]	50
Accuracy [µm]	40
Depth of Field [mm]	±150
Measurement Rate [measures/s]	25000
Volumetric Accuracy [mm]	0,020 mm + 0,025 mm/m

The principles of scanning using the Creaform EXAscan scanner are displayed in the picture (Fig. 2).

Fig. 2. Creaform EXAscan.

3. Design of the scanned specimen

For the needs of comparing the scanning systems a specimen was designed and built. In view of the scanning technology used morphologically complex areas were eliminated in the design of the measured object and its size, thickness and the designed holes were set such that it was possible to scan through the entire depth. The shape of the body was designed on the basis of the need for scanning the maximum amount of deviations in the shape, positions, orientation and dimensions. See the picture in Fig. 3.

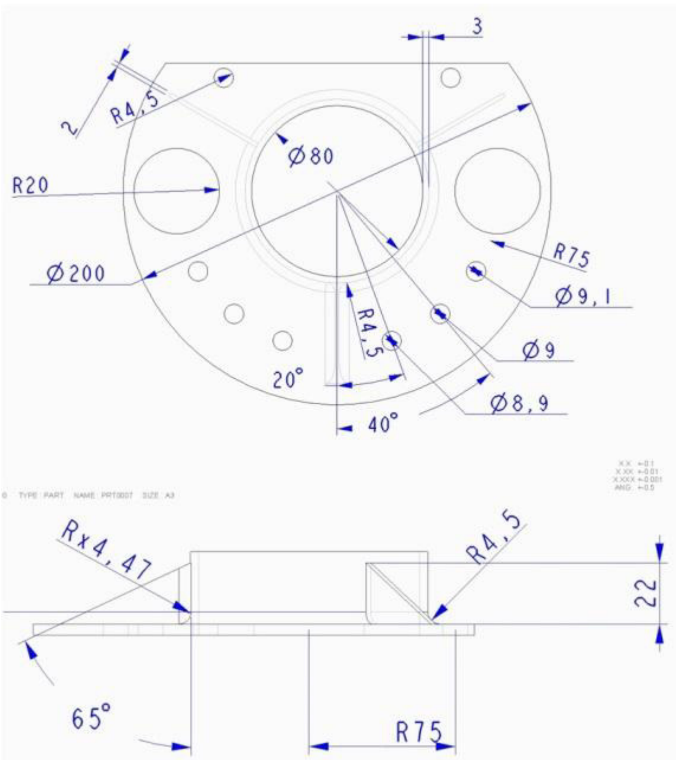

Fig. 3. The dimensions and the shape of specimen.

The designed object was consequently made by the method of rapid prototyping on the Objet Eden 250 device from the material Vero White.

4. Scanning methodologies

4.1. Conditions of the environment

During scanning it was necessary to keep the basic parameters of the surroundings unchanged – temperature, humidity and lighting. A change of the first two parameters can cause a change in the dimensions of the scanned object as well as a change in the parameters of the scanning system. The lighting in the room has a major impact on the calibration of the scanning device as well as on the scanning itself. A change of lighting during scanning can cause a worsening of the scanning conditions – errors during scanning and the time-demand of the scanning is prolonged. With scans using the Creaform EXAscan device it is not possible to change the parameters of the laser beam during scanning; the Steinbichler Comet, in view of its different technology, does allow a change of parameters during scanning. (Fig. 4)

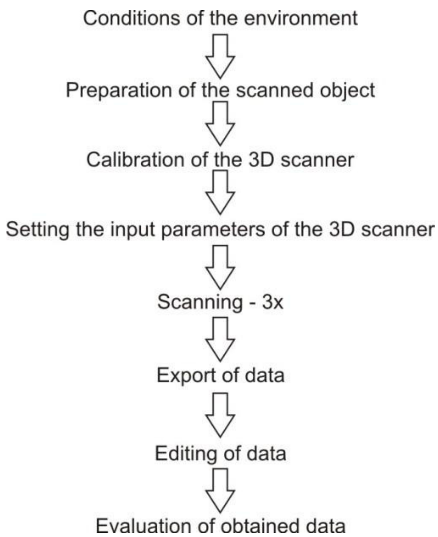

Fig. 4. Scanning methodology.

4.2. Preparation of the scanned object

It is necessary before the scanning itself to leave the scanned object in the room in which the scanning is to take place in order to stabilize it thermally. If the object has a shiny surface it is necessary to modify it, e.g. with powdered chalk in spray form. Subsequently, the positional markers are put onto the object and/or its surroundings. Their density and placement depends on the size and shape of the scanned object. The tabs are placed such that an irregular triangle mesh is created.

4.3. Calibration of the 3D scanner

Before each measurement, or group of measurements, it is necessary to perform a calibration/verification of the 3D scanner. In the case of a laser and optic 3D scanner, this consists of scanning a calibration board at different distances and inclinations.

4.3.1. Setting the input parameters of the 3D scanner

In the case of the EXAscan scanner, the intensity of the laser beam emission is set as is its frequency of scanning and resolution.

With Steinbichler Comet scanners parameters for lighting the object are set during scanning such that no overexposure or underexposure occurs.

4.4. Scanning

The designed specimen was scanned three times on each scanning system with the set input parameters. Creaform system is using continuous data acquisition. The Steinbichler creates the resulting point clouds by assembling self-rotated/shifted scans. The reconstructed point clouds after scanning contain a multitude of artifacts from reflections or from the scanned surrounding surfaces.

4.5. Export of data

It is possible to export raw data into several types of files, most often into *.STL due to the universality of its use. This involves a surface triangle mesh.

4.6. Editing of data

The exported data also contains unnecessary data errors in the surface of the triangle mesh (tiny openings, areas with a faulty normal, ...), which need to be removed or repaired. This is most often done in independent software serving for the modification of such data. For data correction and reparation we using INUS Rapidform XOR2. The rapaired data are again exported into STL file and load in the visualization and measuring software VolumeGraphics VGStudioMAX 2.2.

4.7. Evaluation of obtained data

The obtained surface mesh is interpreted in the VolumeGraphics VGStudio MAX 2.2 software. For the evaluation 23 characteristics were selected, including:

- dimensions
- deviations in shape and orientation (Fig. 5)

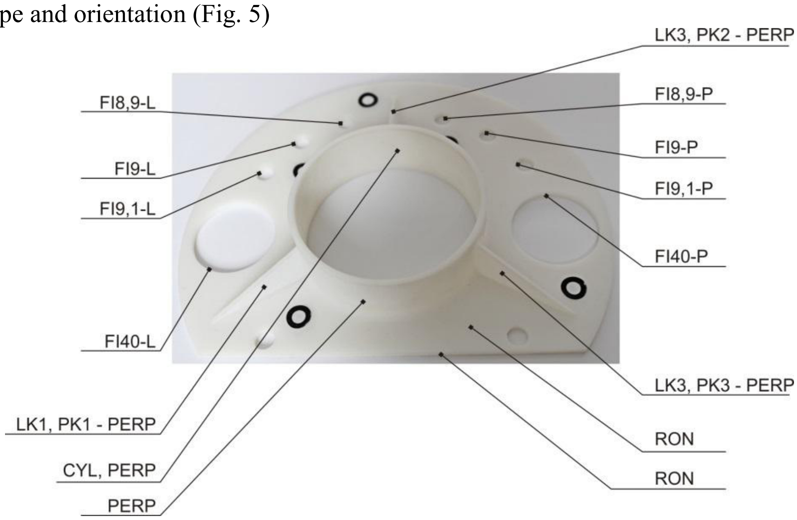

Fig. 5. Evaluated dimensions and deviations.

Deviations between the CAD model of the specimen and the obtained mesh were evaluated independently.

For optimizing the process of evaluation a template was created which included all of the evaluated and supporting characteristics.

All dimensions were evaluated by the method of smallest squares (Gauss). Evaluation of the angles between the ribs is created from the symmetries between the surfaces of the ribs. The tolerance value was set to 0.1 mm; they serve only as information for the software. After the evaluations the data were exported into the XML and XLSX file format for easier processing and evaluation. (Table 3)

Table 3. Comparison of obtained data.

		Creaform EXAscan			Steinbichler Comet L3D		
Name	Type	X_p [mm/deg]	R [mm/deg]	R_p [mm/deg]	X_p [mm/deg]	R [mm/deg]	R_p [mm/deg]
Upper surface	RON	0,1393	0,001		0,1393	0,001	
Side surface	RON	0,134	0,005	0,0020	0,1017	0,049	0,0180
Center cylinder	CYL	0,139	0		0,1377	0,004	
FI8,9-L	DIA	9,0163	0,701		8,6257	0,745	
FI8,9-P	DIA	9,071	0,827		8,6193	1,241	
FI9,1-L	DIA	9,0363	0,047		8,8177	1,02	
FI9,1-P	DIA	9,0873	0,382		8,8243	1,275	
FI9-L	DIA	8,9097	0,078	0,7454	8,6623	1,153	1,1701
FI9-P	DIA	9,0827	0,626		8,7337	1,222	
FI40- P	DIA	39,3893	1,668		39,798	1,415	
FI40-L	DIA	39,2277	2,337		39,725	1,146	
FI- 80	DIA	79,902	0,043		78,959	1,314	
LK1 to upper surface	PERP	0,2197	0,076		0,1597	0,07	
LK2 to upper surface	PERP	0,195	0,087		0,232	0,02	
LK3 to upper surface	PERP	0,2067	0,079		0,185	0,046	
PK1 to upper surface	PERP	0,18	0,033		0,1817	0,018	
PK2 to upper surface	PERP	0,1893	0,047	0,0551	0,1867	0,037	0,0434
PK3 to upper surface	PERP	0,1883	0,099		0,1907	0,103	
Center cylinder (inner surface) to upper surface	PERP	0,069	0,005		0,0767	0,03	
Center cylinder (outer surface) to upper surface	PERP	0,0513	0,015		0,0507	0,023	
Angle 1	ANG	120,0017	0,087		120,051	0,228	
Angle 2	ANG	120,1633	0,109	0,0930	120,1807	0,271	0,3070
Angle 3	ANG	119,8337	0,083		119,7687	0,422	

x_p, - average value, R – variation range, Rp – average variation range, RON – flatness, CYL – cylindricity, DIA – diameter, PERP – perpendicularity, ANG - angle

The comparison of a 3D scan against the model was performed on the basis of the BEST-FIT function, where the first step involved a rapid, rough alignment and the next step a precision adjustment. A value of 1 mm was set as the evaluation distance (search distance for surface detection). In the graphic processing the color scale was set to ± 0.2 mm; values over and above this boundary are denoted as only Bordeaux (purple). (Fig. 6) [5]

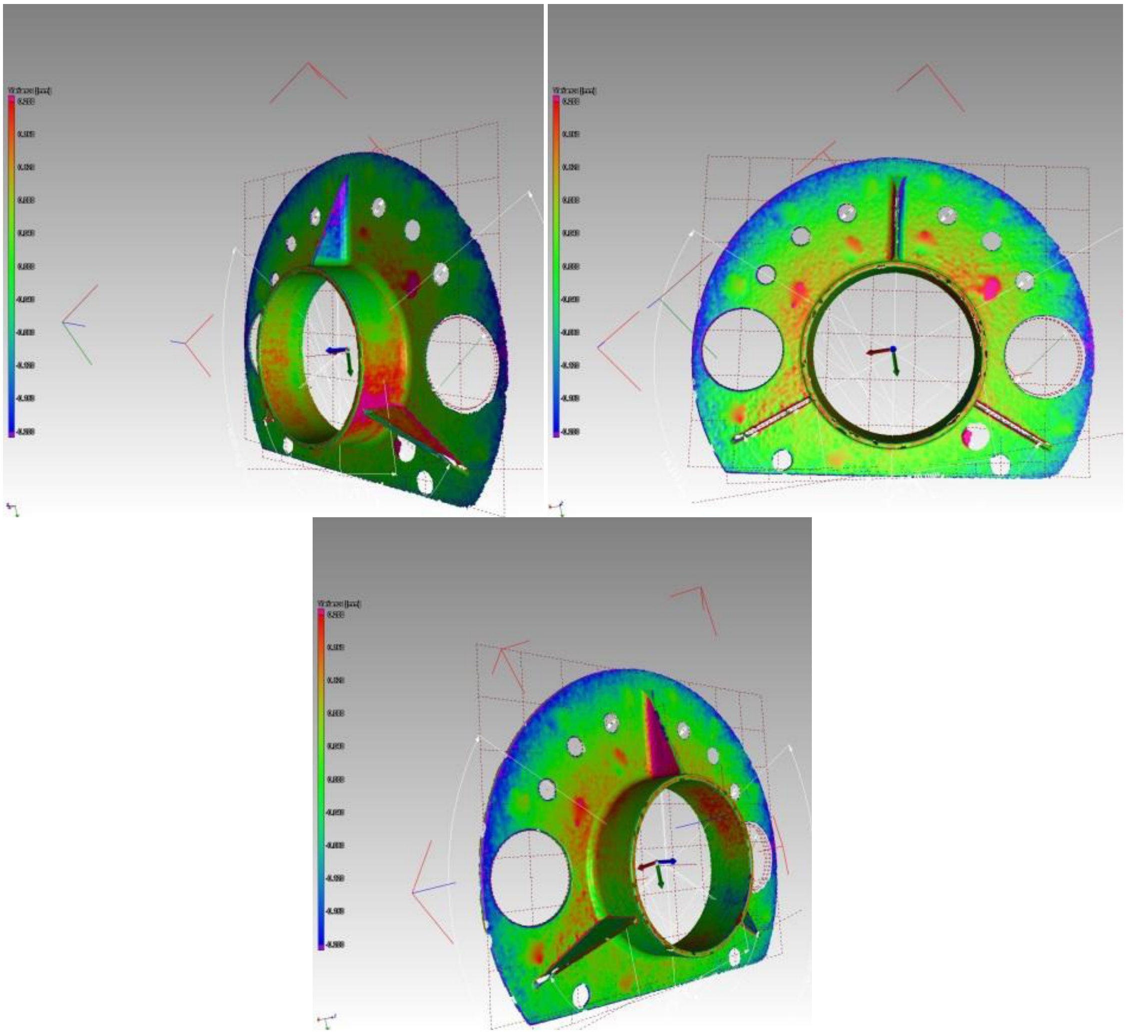

Fig. 6. Deviations between 3D scan an CAD model.

5. Conclusion

At the present time are not studies that compare the selected types of 3D scanners, because the number of manufacturers and scanner types is too high. The closest study is from Barbero et al, which compare the Creaform EXAscan with optical scanner GOM ATOS. ATOS work in the same principle as COMET, but in the test used lens for smaller acquisition area (point to point resolution is better). For the dimension evaluation Barbero used simple objects (sphere, cylinder and gauge block). The result of the study is that the scanners using white lite (Comet, Atos) have greater accuracy than other types of 3D scanners. [1]

In our comparison for dimension measurement we obtained better results (smaller variation range) for EXAscan. The results for holes Φ8.9, Φ9.0, Φ9.1 and Φ40 may be affected by the depth of the hole. The cylinder Φ80 for EXAscan have variation range 0,043mm and for Comet 1,314mm. Because we don't have lens with smaller field of view for Comet, it is not possible determine the impact of lens type into scanning. Barbero not evaluate the deviation for shape, position, orientation and also not compare the surface deviation between the scan and the CAD model.

The results obtained from the evaluations of individual scans were processed and summarized into Table 3. The full degree of data is not included in the article due to its extensiveness. The comparison of the scanning with a CAD model is represented by selected images.

From Table 3 it follows that the cylindricity and flatness show in the case of EXAscan more consistent values with significantly lower scattering.

Comet has better results for perpendicularity - smaller variation range. Its value significantly increases the perpendicularity for the third scanned rib.

The variation range for angles is smaller in the case of the Creaform EXAscan system. The values are more consistent.

EXAscan for diameters have a lower average variation range, but the variation range for both systems is significantly higher as the variation range for shape, orientation and position deviations.

In actual nominal comparison of the CAD model with the input obtained by scanning the object are visible places after removed positional markers. From the outputs it follows that the more uniform distribution of deviations between the individual scans was achieved for the Creaform EXAscan device. In the case of the Steinbichler Comet device the distribution of deviations is equal but more marked local deviations occur between the scans. When in the EXAscan we used higher resolution (smaller point to point distance) the acquired surface has higher roughness.

The variation range for evaluated dimensions and deviations is small, it seems the measurements and results evaluation are interpreted correctly.

For a more exact evaluation it is necessary to increase the number of scans for each system in order to eliminate possible operator errors and to perform repeated comparisons. The next step is compare obtained results with results from measuring devices with higher accuracy: industrial CT Carl ZEISS Metrotom 1500 and coordinate measuring machine Carl Zeiss Contura G2.

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