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3D SCANNER WORKING PARAMETERS – INFLUENCE ON AN ACCURACY OF MECHANICAL VEHICLE ELEMENT REPRODUCTION

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Abstract

In recent years, the reconstruction based on existing physical objects, plays an increasingly important role in research and everyday life. With the advancement of modern industry, more and more often, including automotive industry, modelling and deformation techniques of objects, based on reverse engineering, are used. One of such example is the reproduction of the geometry of motor vehicles using 3D scans. Damages of motor vehicles, cause local changes in the shape of the product and their size and character are directly related to the occurred reaction. However, to assess the damage extent and qualify the object for further repair, it is necessary thoroughly to know the condition of the object after the damage to select the appropriate technology and repair method. This is the case for reverse engineering, and 3D scanning using structural light.

The aim of the study was to evaluate the influence of the parameters of the 3D scanner on the accuracy of reconstructing the geometry of the selected vehicle element – the rear door of the Skoda Octavia in two variants, non-deformed and deformed. The dimensions of door exceeded the range of the largest measuring area of used 3D scanner, so it was necessary to use the photogrammetric technique in order to generate a point model of the object that was used to compose the individual scans.

Measurements were made with different measuring areas: 1000 x 800 x 800 mm, 500 x 400 x 400 mm and 250 x 250 x 200 mm. For the base field, 500 x 400 x 400 mm, several measurements were repeated in order to determine repeatability.

Keywords: *3D scanning, strain identification, photogrammetry, reverse engineering*

1. Introduction

As technology progress, people increase their curiosity in research activities. This curiosity, together with the availability of ever-increasing sources of knowledge, has led to the commercialization of modern technology and the introduction of ever more advanced measuring devices of common use. This concerns also the field of transferring real objects to the virtual world – reverse engineering. In the reverse engineering process, the starting point is the physical object that is copied or whose geometry is reproduced, modified, or refined.

In nowadays production processes of the equipment and during the assessment of defects and deformation of technical objects, it is often necessary to recreate mass-produced or damaged products. Damage and wear of objects causes local changes in the shape of the product and their size and nature is directly related to the impact resulting damage or wear. The initial state of an object can be determined from the production documentation or the measurement of new object. However, in order to assess the degree of wear, depth of damage and to select the appropriate repair methods and technology, a thorough knowledge of the condition of the object after the failure is necessary. This possibility provides reverse engineering [6, 8, 9].

Despite different interpretations and different concepts for interpreting reverse engineering concept, it is possible to give a broadly defined definition of "reverse engineering" as a process of acquiring information about a physical product and analysing and processing it to develop technical data and produce a new product in the same or improved form [4, 9].

Reverse engineering has many applications, including the use of mechanical devices, quality control, computer simulations, industrial design, sculpture and many other areas requiring knowledge of spatial dimensions. Digital models allow reproducing the documentation of existing objects, allowing estimating the extent of damage or wear. Reverse engineering methods are increasingly being used to evaluate the accuracy of newly manufactured components, during evaluating the degree of machinery wear and various types of technical objects such as matrices used in vehicle body production. During analysis, the mapping accuracy of examined object is very important.

The simplest reverse engineering technique is to make measurements using mechanical measuring tools and create a digital model based on these measurements. When the shape of an object is very complex, such measurements are insufficient to provide data for the model [3]. Other methods of surface mapping are required. Nowadays, more and more methods of optical scanning (white or blue structural light) and laser scanning [1, 2] are used. These methods are very precise, enabling accuracy to be less than 0.001 mm, depending on the scanning technique used.

Depending on the scanner, important parameters, among many others, are [4]:

- scanner resolution – a scanner parameter that determines the density of points on a scanned area or object, which affects the accuracy of the detail of the object being examined [6, 7];
- scanner accuracy – this parameter characterizes the accuracy of the original object as a result of the scanning of the digital image, primarily depending on the "scan volume" and the resolution used in the scanner's detector [5];
- scan volume – measurement area – specifies the size of the area where the scan is taking place;
- repeatability – this parameter demonstrates the degree of compatibility of further measurements performed in the same way;
- scanner resistance to environmental conditions – determines how environmental parameters affect the accuracy of the performed scans;
- scanning speed – determines how fast the scanner compares to other available devices. The scanner performs the measurement and communicates with the unit responsible for processing the data collected on the scanned object.

Depends of the user needs and the destination of the scanners, the manufacturers have created many variants of those devices, depends of the degree of complexity and used software. However, some of those features are incompatible with others.

For large objects, whose dimensions exceed the triangularity of the used measuring field, a photogrammetric technique is required to increase the accuracy of the process of combining individual scans into a single scan [3, 4].

Photogrammetry is the process of determining the geometric parameters of an object based on photographic images. This technique allows determining the distance between points (non-coded points) located on a plane parallel to the plane of the photographic image. The values of these distances are determined by the distance information between the points on the taken photograph and the scale information.

2. Aim of the study

The aim of the study was to assess the influence of the 3D scanner's performance parameters on the accuracy of the selected vehicle element geometry – the rear door of the Skoda Octavia. The reproduction of the door element with its dimensions far exceeded the range of average and smallest measuring field of used 3D scanner (Fig. 1a), that's why it was necessary to use the photogrammetric technique in order to generate a point model of the object that was used to make the scans. Measurements were performed by three measuring areas: 1000 x 800 x 800 mm, 500 x 400 x 400 mm (as a base field) and 250 x 250 x 200 mm. The GOM GmbH ATOS IIe scanner was used during the measurements; technical data of the scanner are shown in Tab. 1.

Tab 1. Technical data of the GOM GmbH 3D scanner ATOS IIe

Scanner technology	White structural LED light
Cameras	2 x 1.4 Mpix
Scanned area	38 x 29-2000 x 1500 [mm^2]
Points density	0.02-0.79 [mm]
Working distance	490-2000 [mm]
Point per single scan	1 400 000
Working temperature	5-40°C

2.1. Research program

The first problem was to determine the dependence between the individual parameters of the scanning process and to determine their influence on obtained results. For this purpose, scanning of the object was carried out for various configuration of measuring equipment (field size, photogrammetric technique). The following elements were valuated:

– influence of measuring field size on a accuracy,
– repeatability of a measurements for a measuring field,
– influence of used photogrammetric technique on a repeatability.

To assess the impact of the 3D scanner's performance parameters, the following measurements were performed on the accuracy of the vehicle components:

– measuring the door with a measuring area of approximately the size of the scanned element – 1000 x 800 x 800 mm,
– measuring the door with a measuring area smaller than the size of the scanned element – 500 x 400 x 400 mm,
– measuring the door with a measuring area of a much smaller size to the size of the scanned element – 250 x 250 x 200 mm,
– performed measurements, mentioned above, with use of photogrammetry,
– for a base field, 500 x 400 x 400 mm, four repeats were performer to determine repeatability of measurements.

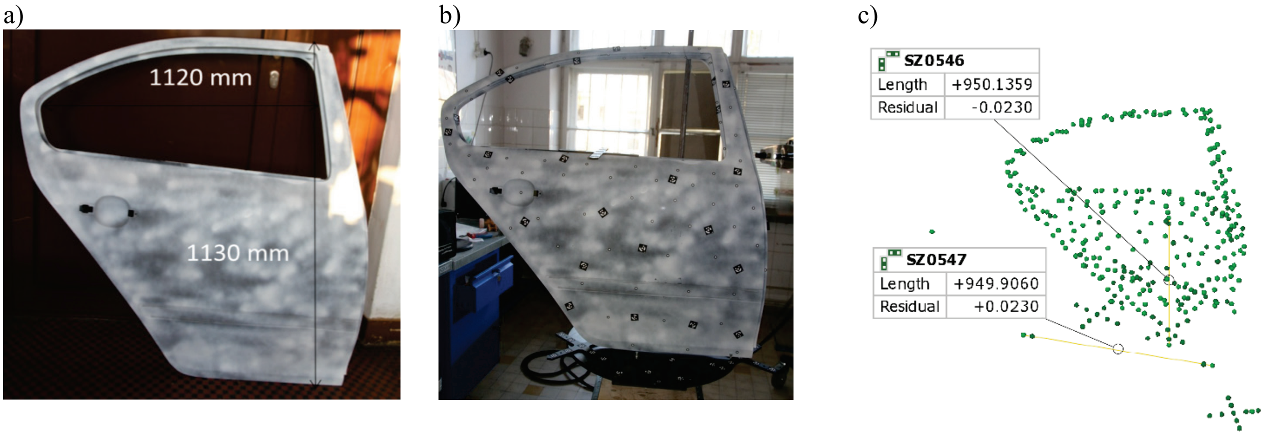


Fig. 1. Measured object: a) main view; b) coded and uncoded points on a surface c) geometry of uncoded reference points

To determine the usability of the photogrammetric technique, the measuring tool TRITOP of GOM GmbH Company was used to recreate the geometry of the element. The first step was to place markers on the test element and around it. At a further stage, those elements enabled to correct spatial orientation of the specific reference points (Fig. 1b). Next, a series of images of the examined element was made, along with markers of lengths that allowed the software to process the images received by the TRITOP system. On the basis of the photographs obtained in this way, a spatial model was created (Fig. 1c).

Measurements were made under the same conditions and by the same operator, each time after changing the lens for changing the scanning field, the device was calibrated using calibration patterns.

As a result, a number of images were created, allowing them to be optimally connected while avoiding empty areas. After obtaining the model and removing unnecessary information, the data was exported in the .stl format.

2.2. Method of the results interpretation

The following factors were not taken into account when evaluating the results – it was assumed that they did not affect the final result:

- operator experience – measurement were always performed by the same experienced operator, with appropriate training in both the precise and optimal setting of the scanner's operating parameters and the most appropriate position of the scanner in relation to the surface being measured;
- environmental conditions – the room where the measurements were performed was adequately isolated from the external environment and atmospheric conditions;
- temperature change – when calibrating the device, the exact temperature in the measurement room was took into account, but only its approximate value;

Measurements were stored in *.stl* files of GOM Inspect software. The defects seen on the imported models were then supplemented. Losses result from the local discontinuity of the matting material.

After performing these tasks, the models derived from individual measurements were compared. The individual "supplemented" grid models were imported and analysed for deviations. Two types of legend were used for this purpose: the legend, which defines the difference between the individual scans, and the legend tolerance, which describes the areas within the tolerance range.

To determine the appropriate tolerance limits, all obtained results were analysed for the maximum difference between the results of the measurements and the model, and the optimum range of the data was chosen which includes the full spectrum of the differences. The accepted limit was 0.1 mm, and then the range was divided as following: 0-50%, 50-100%, 100%-150% and over 150% of differences accepted as a base. The results were presented as > 0.150 mm; 0.100-0.051 mm; 0.050-0.000 mm, 0.000-0.050 mm, -0.051-0,100 mm, -0.100-0.150 mm and < -0.150 mm.

Tolerance is defined as the range of values in which differences in distance between the dimensions of the individual homologous points of the underlying model and the measurement compared. Area value is an absolute value that corresponds to the sum of the surfaces of the individual planes constituting the model of the object. The ratio of the surface area of a given range to the total area of the object is expressed in percent.

3. Results

Fig. 2, 3 and 4 presents the first case – evaluation of repetition and evaluation of the use of photogrammetric technique on accuracy of restoration of the examined object geometry. The deviation map presents the measurement – each point is described in three dimensions (X, Y, Z), and the fourth value represents the deviation. The baseline model and the results obtained during the individual studies were compared.

Based on the analysis of obtained results, it can be seen that the tendency to differentiate the negative character of the surface mapping has increased. On the outer side of the door, negative deviations occur mainly in the right corner of the object and on the upper doorframe (Fig. 2). On the inside of the door, occur around the internal hole of the door (Fig. 3).

Positive differences in dimensions occur mainly on the convex surfaces of the front of the door, which are remnants of the slats attached here, and in places with small radiuses of the outer plating. They are noticeable on the inside of the door on the lower part and on the frame. As for the comparison of the base model with the results obtained without the use of photogrammetric technique, it can be seen that with the same values of the scale and the comparison parameters of the results, there are considerably greater differences between the models. Table 2 summarizes the results of the scanning repeatability assessment using the 500 mm field and the photogrammetric technique.

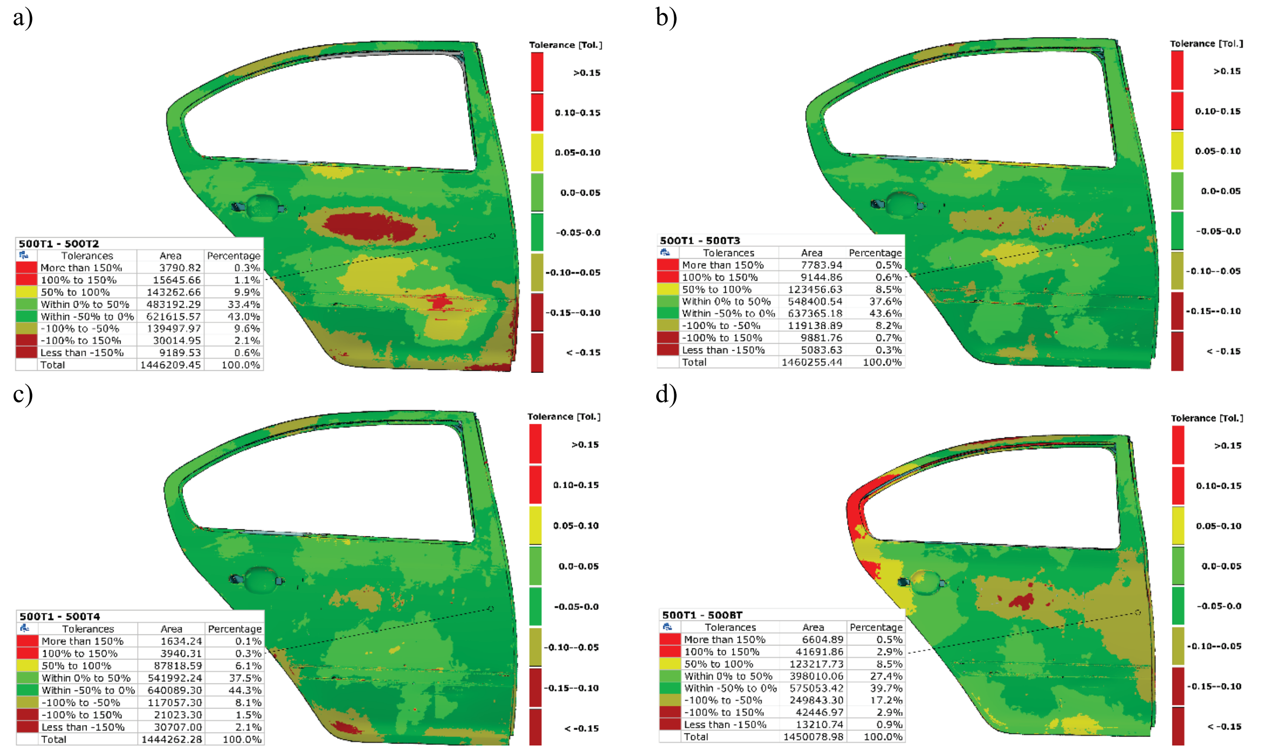


Fig. 2. Evaluation of scan repeatability using base field 500 mm, comparison of results with the base model – external door side: a) measurement V2; b) measurement V3; c) measurement V4; d) measurement without photogrammetry

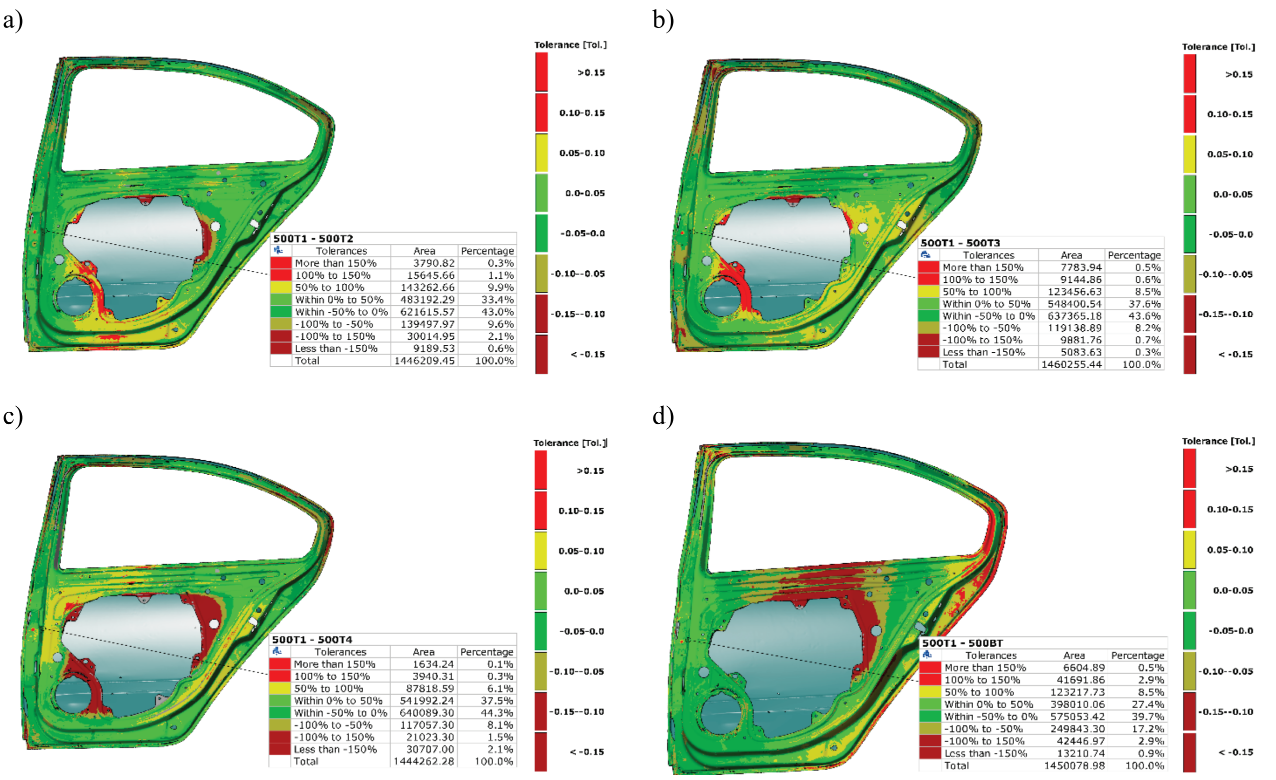


Fig. 3. Evaluation of scan repeatability using base field 500 mm, comparison of results with the base model – internal door side: a) measurement V2; b) measurement V3; c) measurement V4; d) measurement without photogrammetry

Tab. 2. Summary of the reproducibility of measurements using a 500 mm field and photogrammetric technique

Tolerance		Surface area in the measuring range [mm]				Percentage field participation [%]			
[%]	[mm]	V2	V3	V4	BT	V2	V3	V4	BT
> 150%	> 0.150	3790	7783	1633	6606	0.3	0.5	0.1	0.5
100%-150%	0.101-0.150	15644	9145	3940	41689	1.1	0.6	0.3	2.9
50%-100%	0.051-0.100	143265	124455	87819	123215	9.9	8.5	6.1	8.5
0%-50%	0.000-0.050	483192	548400	541988	398023	33.4	37.6	37.5	27.4
-50%- 0%	-0.050-0.000	621614	637365	640094	575025	43.0	43.6	44.3	39.7
-100%-50%	-0.100- -0.051	139497	119136	117053	249845	9.6	8.2	8.1	17.2
-150%- -100%	-0.150- -0.101	30015	9886	21021	42457	2.1	0.7	1.5	2.9
< -150%	< -0.150	9189	5082	30709	13214	0.6	0.3	2.1	0.9

When measuring with a 500 mm measuring field without photogrammetric technique, a significant increase in absolute deviation in the range 0.051-0.100 mm – Fig. 2d and Fig. 3d occur. This is due to an increase in inaccuracies resulting from the lack of reference points used to merge individual scans. The deviation value increases as the distance from the starting point of the scans increase. The largest deviation is visible on the inside of the door – the farthest area where the scan has started – Fig. 3d.

Comparing the obtained results using the photogrammetric technique, high repeatability is observed (Fig. 4. – measurement P1, P2, P3). This technique also provides a higher accuracy of the surface of the examined element, as evidenced by the smaller proportion of tolerance fields with high deviation – above 0.100 mm.

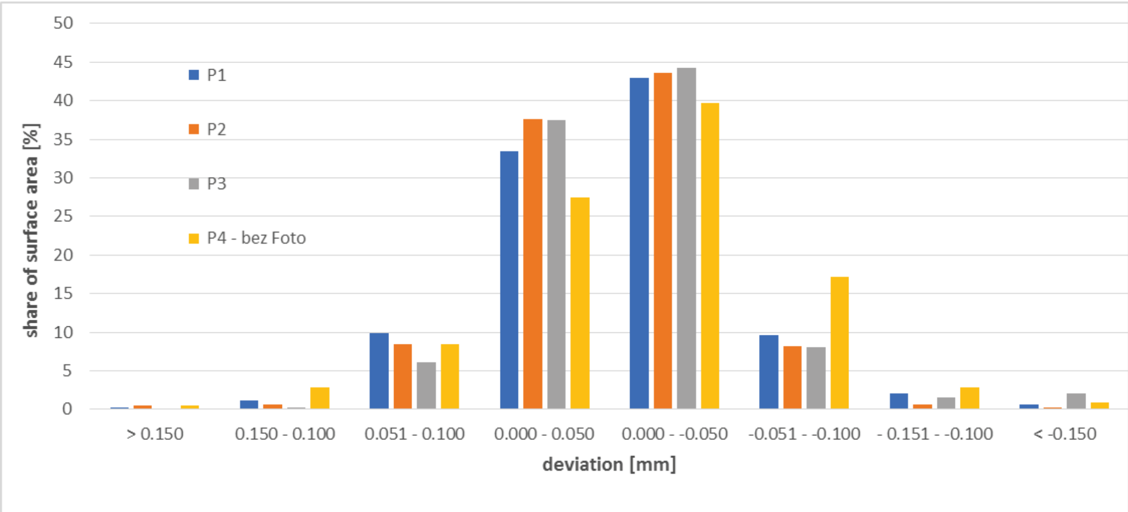


Fig. 4. Scanning of 500 mm base field repeatability, comparison of results with the baseline model – percentage participation of the area in the deviation range for individual scans performed to assess the repeatability of the measurements

To evaluate the influence of the measurement field size on the reproducibility of the examined element, the measurement results made by measuring fields were compared: 250 x 250 x 200 mm, 1000 x 800 x 800 mm. Baseline measurements were used to measure the measurement area 500 x 400 x 400 mm (first measurement as reference measurement). In addition, the photogrammetric technique was used to eliminate the errors associated with the individual scans. In all cases, scanning was performed using the same reference points.

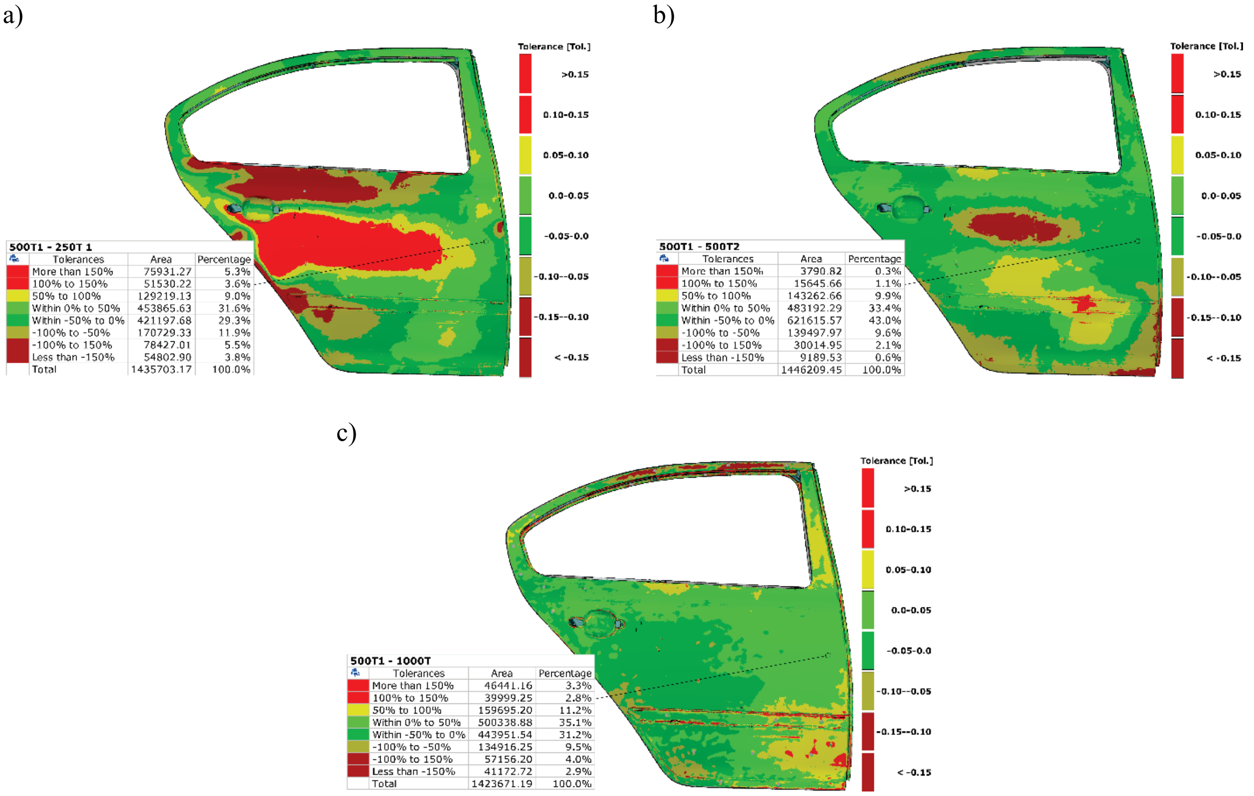
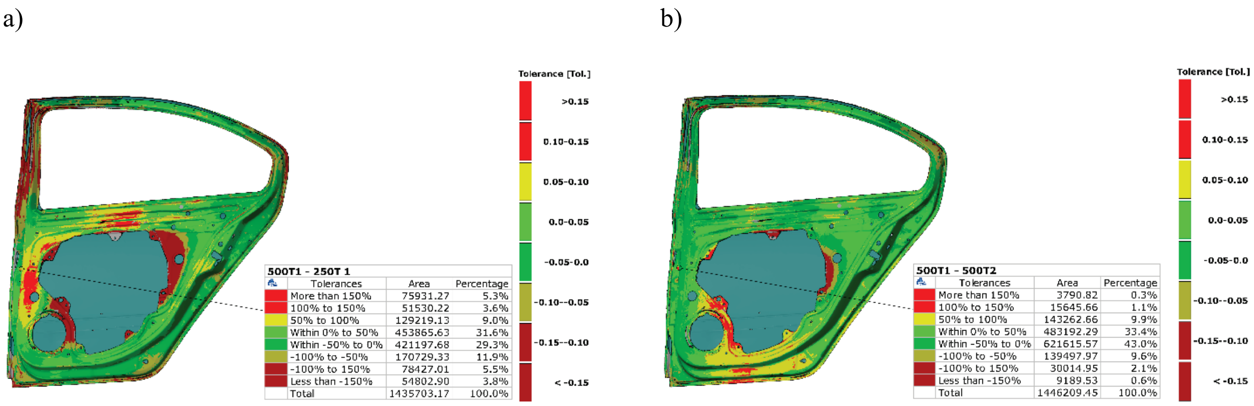


Fig. 5. Evaluation of the influence of measurement field sizes relative to the base field 500 mm, external door side a) measurement with 250 mm field; b) measurement 500 mm field; c) measurement 1000 mm field

Based on the results analysis, it can be seen that the change of the measurement field relative to the base field results in an increase in absolute deviation in the range above 0.100 mm (Fig. 7.). Use of smaller measurement field (250 mm) caused significant differences across the entire surface of the measured element (Fig. 5a, 6a). This is due to an increased resolution and accuracy of the scanner, which with the same camera parameters measures the area four times smaller than the base field – 500 mm.

Use of a larger measuring field (1000 mm) caused significant differences in areas with small dimensions elements – the place of slat fixing on the door in which, after the dismantling the glue remains and the places where the extrusions of the individual fragments with small radius – the edges, the place of bonding (Fig. 5c, 6c). This is due to a reduction in the resolution and accuracy of the scanner, which, with the same parameters, measures the area four times larger than the base field – 500 mm.



c)

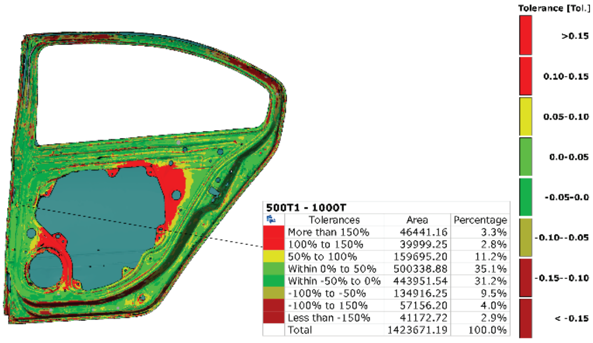


Fig. 6. Estimation of the impact of the measurement size relative to the base area of 500 mm, door inside a) measuring field 250 mm; b) measuring field 500 mm; c) measuring field 1000 mm

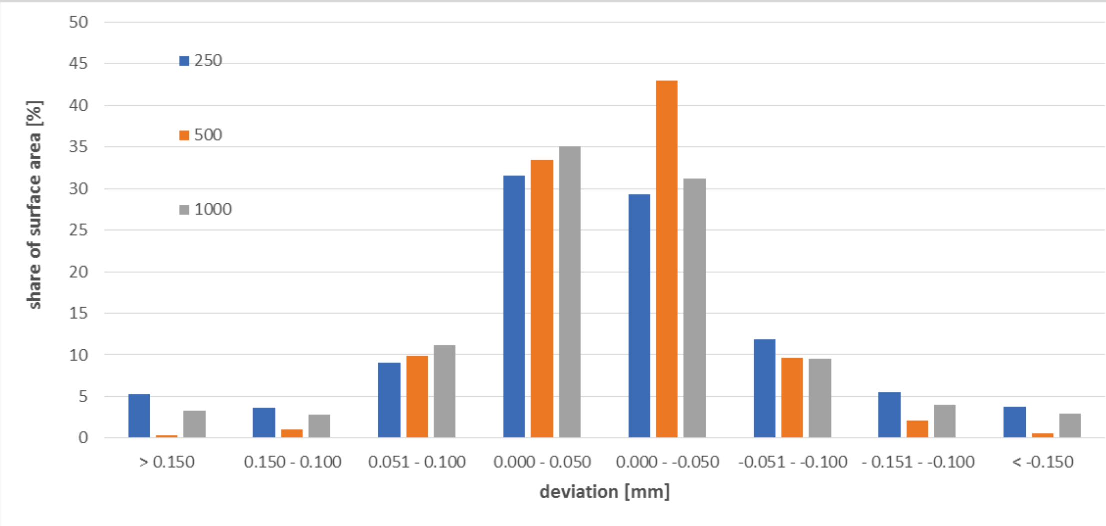


Fig. 7. Comparison of percentages of surface area in deviation ranges for individual scans performed to evaluate repeatability of measurements

4. Conclusions

- 3D scanners are a good alternative to standard measurement tools. They allow quick measurement and multi-faceted analysis, which makes them widely applicable in many areas of science and technology as well as in everyday life.
- The studies and results demonstrate the full suitability of the ATOS IIe scanner for the geometry of vehicle components. However, the accuracy of the mapping images depends of the object's scanning techniques and scanner performance.
- During choose of a scanning device, depending on the size of the object to be examined, it is important to choose a scanner that has a suitable measuring object for the object to be tested, a suitable measuring area for the required accuracy.
- For large objects, any available measuring area of the selected scanner can be used. The key issue is to determine the purpose of the measurement and to reach a compromise between the scanning time and the accuracy of the measurement.
- In case of small objects scan, the uses of large area measurement fields are associated with an increase in inaccuracy of scanned object. This may also cause difficulty in mapping the details of the test item.
- The use of photogrammetric techniques is reasonable in order to increase the accuracy of measurements. Photogrammetric techniques are useful in mapping elements whose dimensions exceed the maximum area used in measuring the field.

- An important consideration in measuring accuracy, especially in high accuracy measuring fields, is the proper preparation of the object and proper fitting during measurements.

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