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Measurement strategy as a determinant of the measurement uncertainty of an optical scanner

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ABSTRACT

The subject of the article is an attempt to determine the impact of the applied measurement strategy on the accuracy of the measurement result. This problem is particularly crucial when measuring large objects. In these cases, it is not always possible to provide ideal conditions for the submission of particular scans. It is necessary to adjust the strategy to specific imposed conditions defined by the geometry of the object and to the time frame of the measurement itself.
With regard to the above, an attempt was made to carry out a series of accuracy studies testing the structural light scanner while measuring elements of overall dimensions greater than the measuring capacity of the scanner. At the same time, various potential measuring strategies were simulated in practical applications. Our studies were conducted using a pre-designed test template with a defined distribution pattern of reference points and geometrical elements. Moreover, in order to make an in-depth investigation of the issue, some trials were undertaken with the use of limiting parameters. That means the scanner had both an excess and shortage of information required for a correct assembly of scans. Those scopes were taken into consideration in the study in order to use the acquired knowledge in practical measuring applications. Furthermore, conclusions from the conducted studies indicate peaks and troughs of respective measuring strategies with special care for determining relationships among the used strategies and the measuring accuracy parameters.

1. INTRODUCTION

In recent years, optical scanners are gaining more and more popularity in the area of product geometry inspection. They have proven themselves perfectly in analytical areas, today they are entering into production areas [1, 2] and usage in various areas of life [3].This article is a part of the work aimed at showing what the use of different measurement strategies means for the accuracy parameters of the measurement. The choice of these strategies and the proper preparation of the object to be measured determines the timing measurement, so it is also an important economic factor [4]. By examining the accuracy of the measurement system in different work modes, it is possible to determine the maximum measurement deviation obtained with it and consciously decide on specific strategies and - which is closely related to this - to the appropriate preparation of the object being measured.
Therefore, the issue of defining the metrological properties of optical scanners is up-to-date and willingly discussed by a

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number of scientists. The first studies on the issue, published by Keller P. [5], among others, were focused on the analysis of origin of errors, derived from using an optical measuring method during the control of flat elements, and reducing them to an absolute minimum. In their paper, Palousek D. et al. [6] discussed a study on the measuring accuracy depending on type and thickness of the used flatting agent's layer. A paramount conclusion from their studies is supported by the fact that the use of a titanium-based protective coating instead of traditional chalk makes it possible to diminish 10-fold the thickness of coating, with the maintenance of a high measuring accuracy. Detailed findings on the calibration of 3D optical scanners were published in the works of Barbero B. [7] at al. & Acko B. et al. [8]. In order to determine the uncertainties of measurements taken with optical scanners, various calibration elements were used: spheres, cylinders, tetrahedrons, among other things. In that instance, determined measurement uncertainties for Atos systems did not exceed 25 µm. Dury M. [9] published a paper on a specially elaborated device for the calibration of scanners, which took into consideration changeable conditions of lighting and temperature. Apart from that, there is plenty of works, e.g. by Harding [10], researching the sensitivity of scanners to colour and surface roughness. Most recent studies on the accuracy of 3D scanners touched the problem of comparing the possibilities and versions of software for data analysis, and focused on methods for the digitization of complexly shaped-objects [11, 12].
Hence, studies on measuring strategies are relevant means of broadening our knowledge regarding the effect of multiple factors on the measuring accuracy of optical scanners. It is of utmost importance when attempts to gather information on the geometry of products characterized by complex shapes and big overall dimensions are made. Additionally, the ISO 10360-8 standard presents the way of the scanner calibration as a coordinate machine equipped with an optical head. However, it neither contains any specific guidelines concerning the distribution of reference points, nor a means of connecting individual measuring spots in one entity. This parameter is associated with a so-called measuring strategy. Importantly, it plays a pivotal role in the final result of a measurement. Besides, in practice it is not always possible to provide the scanner with a good deal of reference points. This leads to situations, in which the scanner has no choice but to assembly single acquisitions by using numerous strategies during one measurement.

2. *Production systems and dimensional control*

Due to the globalization of sales markets, we are increasingly dealing with mass production methods. They guarantee, thanks to the use of modern assembly methods and the automation of manufacturing processes, the maintenance of a competitive unit price while maintaining high repeatability and quality of the product.

The use of modern automated assembly lines entails the need to manufacture components of a product with high repeatability and dimensional accuracy. In order to be able to control such processes, it is necessary to quickly provide information about the current geometry of the product at various stages of manufacture. This allows reducing the number of shortages, thus ensuring low production costs, timely deliveries and maintaining a high level of customer satisfaction. For the dimensional inspection process of the product, this results in the following requirements:

- shortened inspection time
- better accuracy parameters of control and measurement resources
- increasing the amount of provided information about the controlled item

The most popular control and measurement means used are:

- dimensional gauges and simple devices based on sensors such as dial gauge
- measuring stations, e.g. optical ones placed in production lines
- measuring machines and devices working in coordinate technology (fig. 1a)

3. *Optical scanners*

In recent years optical scanners have been used more and more widely [13, 14]. They largely replace coordinate measuring machines, and at the same time provide much more information about the geometry of the product. Optical scanners can be characterized briefly as machines recording the image of the object being examined, which is digitally processed (digitized).

a)

b)

Fig. 1. Control and measurement resources: a) Zeiss PRO [15]-boom machine; b) automated measuring station with an optical scanner [16]

As a result of the scanner measurement we get a three-dimensional digital image of the object, which can easily be compared with the CAD model (fig. 2). A large number of measurement points collected during the scan (tens of thousands of measurement points during the registration of one image) allows a good assessment of the curved surface, which increases the interest in scanners in the plastics processing industry and plastic forming. The possibility of supporting reverse engineering, which is of great use in the phase of building prototypes, is also significant. An additional advantage is the ability to automate the measurement process (Figure 1.b), through the use of manipulators and robots [17].

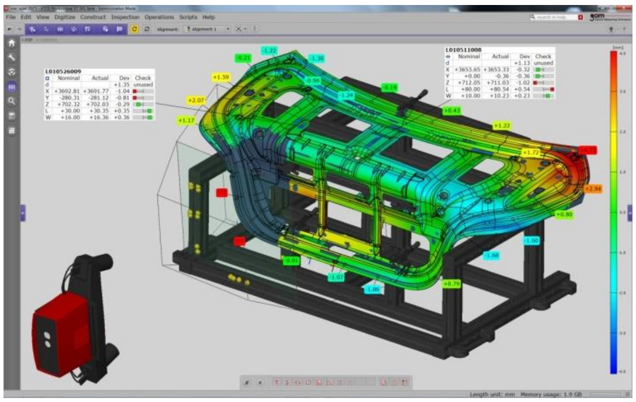

Fig.2. Image of deviations of the scanned stamped part with reference to the CAD model (software window) [16]

In practice, we encounter two basic types of scanners, namely based on:

- laser beam
- structural light

In the further part of the article the second case will be described, i.e. scanners based on structural light [18, 19, 20]. In a situation where the measured object is larger than the size of the measurement field, it is necessary to place multiple individual scans together. Different measuring strategies are used for this purpose.

4. Measurement strategies

We distinguish four basic measurement strategies [21]. Their selection depends on the ratio of the measuring volume to the size of the part.

Measurement strategies:

- strategy A - possible to use for objects smaller than the measuring volume of the scanner. It relies on gluing the detail and its immediate vicinity with reference points. It is important that the object does not change its position in relation to the reference points during the measurement (fig. 3).

Fig. 3. Example of measuring strategy A: object smaller than the measuring volume of the scanner

- strategy B - used in cases when the size of the measured object is at least twice as large as the measuring volume of the scanner. It relies on the preliminary determination of the location of reference points in place using photogrammetry, and then the combination of individual scans on the basis of these reference points (fig. 4). In this way we obtain a spatial model of the measured object.

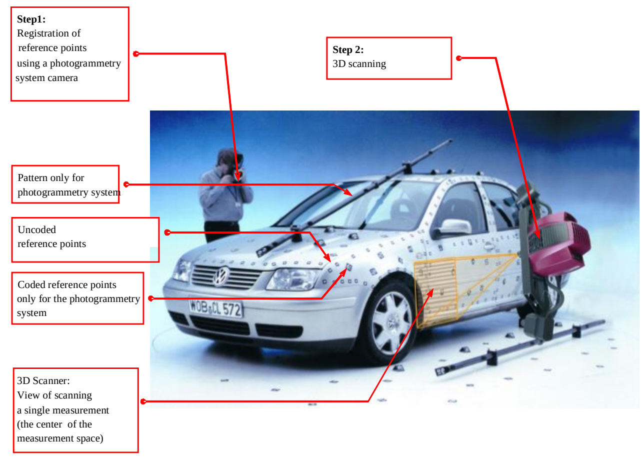

Fig. 4. Example of measuring strategy B using a camera (photogrammetry) and a structural light scanner

- Strategy C - used also for objects larger than the measuring volume of the scanner. It is based only on reference points, it is not supported by photogrammetry. It relies on assembling individual scans based on common reference points for neighboring scans (fig. 5). An important parameter is the selection of the appropriate starting position and providing a minimum of 30-40% coverage of individual scans. It is recommended that particular scans contain a minimum of 3, and preferably 4-5 common reference points.

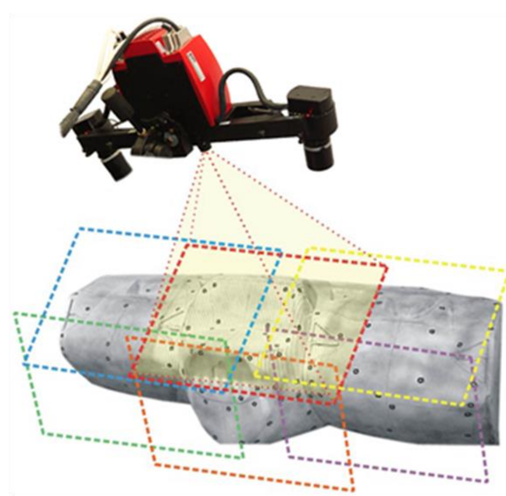

Fig.5. Diagram of measuring an object larger than the measuring volume of the measurement scanner

- Strategy D - measurement takes place without reference points. The particular scans are combined based on the "best fit" match of the geometry elements of the object, which are common to neighboring scans. A strategy that can be used for objects with different geometries and surfaces characteristic of all coordinate axes.

5. *Research object*

Technical data about the accuracy parameters of scanners is determined for individual measurement volumes. But what happens in cases where we have to submit individual scans in larger areas? How does this affect the uncertainty of measurement? This issue was decided on to explore the research work. In order to ensure a repeatable environment for research, it was decided to build a pattern with known geometry that would enable testing of particular measuring strategies (fig. 6).

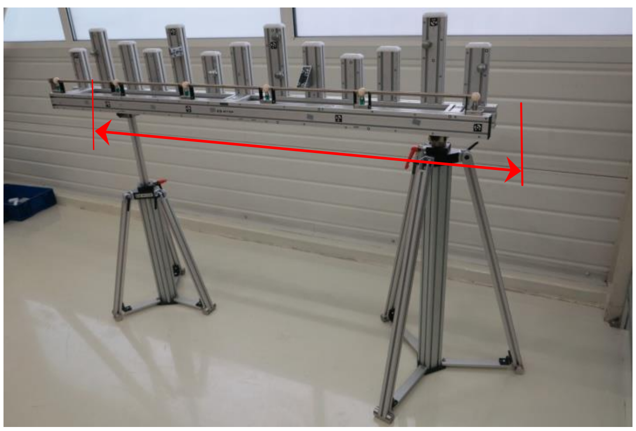

Fig.6. View of the test pattern

The research pattern was based on the rod-ball template from the company Retter. The pattern between the six outermost balls has a distance of 2m. The pattern itself, after being integrated with the research element, has been checked by a coordinate measuring machine with a maximum permissible error of MPEE 1 + L / 350 μm in order to determine its length. As a result of the measurements, this value was estimated at 2000.101 +/- 0.008 mm.

Using the pattern tripods, a structure with characteristic geometric elements was added to it from the SPN 4200N 40x80 profiles. Thanks to this, the construction has obtained the right stiffness. In order to be able to test different strategies, reference points were glued on the template and characteristic geometric elements were provided (fig. 7).

Currently, research is being carried out to examine the impact of different measurement strategies on the accuracy of measurement. Comparison of test results for different scanners and the strategies used will, however, be the subject of a separate article.

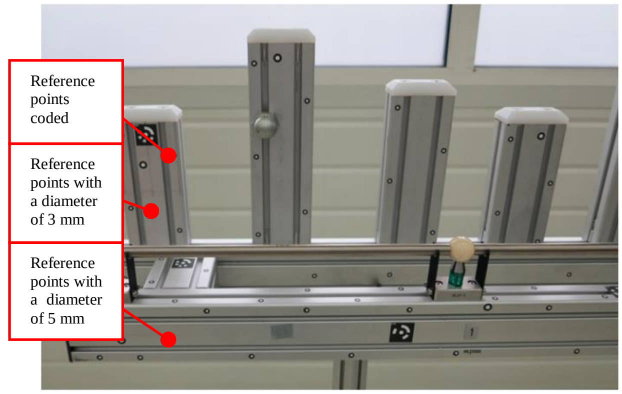

Fig.7. Diagram of the arrangement of reference points and geometric elements on the test pattern

6. *Test results*

Using a built-in template, a series of measurements were carried out for various measuring strategies. Each series consisted of 30 repetitions, which enabled statistical processing of the results obtained. The table below (table 1) presents measurement results for waveforms using strategy B, C and D.

Table 1. Measurement results

Strategy	Elements connecting scans	Ø	R	sigma
C	**3 common points**	2000,025	0,10	0,025
B	**Photogrammetry**	2000,115	0,04	0,011
D	**Detail geometry**	2000,138	0,09	0,024
	Denomination	2000,102		

As you can see the scatter of measurements using strategies that combine scans based on reference points (strategy C) and based on the geometry of the detail (strategy D) is twice as large as in the case of combining scans based on photogrammetry. This proves greater repeatability of measurements based on strategy B. In addition, the average value of the series of measurements based on photogrammetry lies closest to the actual value of the pattern. This is illustrated by the graph (fig. 8).

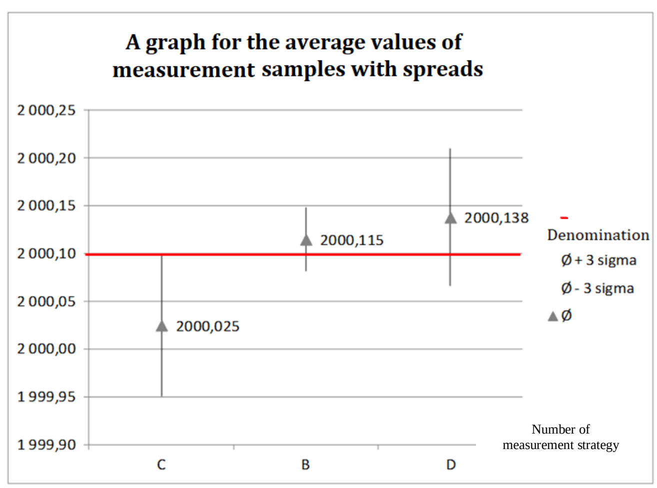

Fig.8. Statistics of results obtained in several series of measurements

All the series of measurements, having a theoretically sufficient number of common reference points, or even more, irrespective of whether they were object's geometry-assisted or not, demonstrate a constant error. It is based on a tendency for the shortening of the measured length from 0.03 up to 0.08 mm (fig. 10 &fig. 11). This phenomenon does not occur in the photogrammetry-assisted series (fig.9).

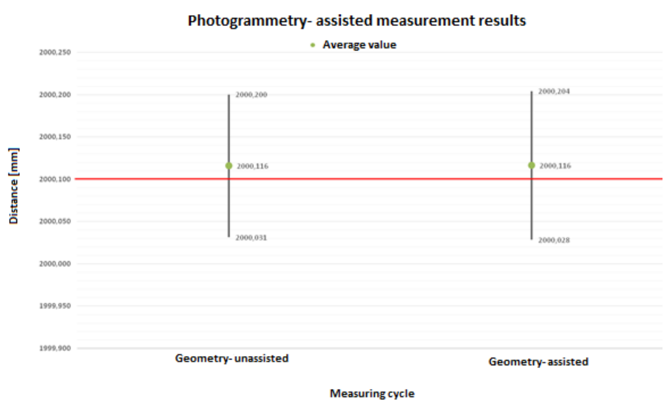

Fig.9. Photogrammetry-assisted measurement results

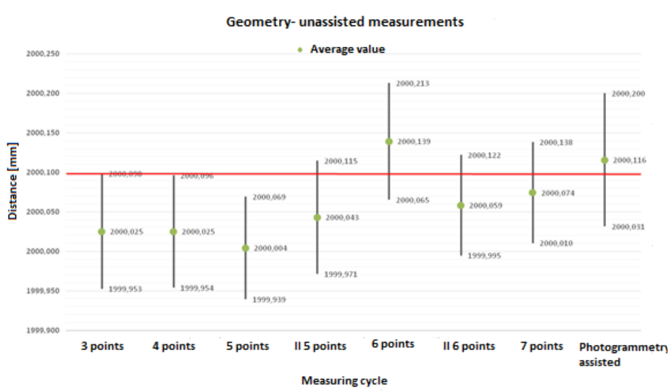

Fig.10. Values of standard deviation and differences of arithmetic mean for measurements and the template length nominal value for the object's geometry-unassisted measurements

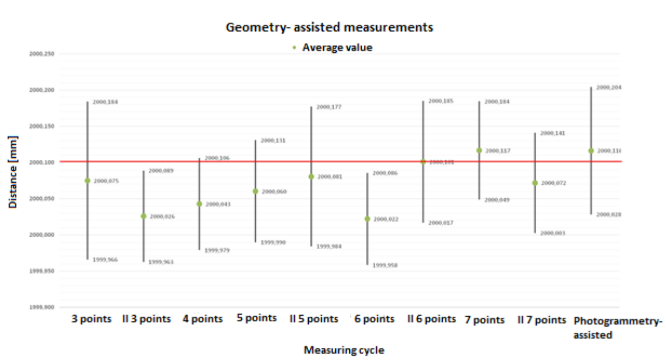

Fig.11.Values of standard deviation and differences of arithmetic mean for measurements and the template length nominal value for the object's geometry-assisted measurements

Even the phenomenon of dimension elongation appears there, although at the level of only up to 0.02 mm. Trials conducted with the use of parameters below the manufacturer's recommendations, i.e. with too few reference points available in the neighbouring scans, have revealed – in accordance with our presumptions – that the measurements were burdened with a very big error. The spreads of results reached 130 mm.

7. *Conclusions*

Based on the conducted tests, it can be said that the accuracy of measurements of large objects using a scanner depends on the strategy used. It is best to put together several scans based on photogrammetry. In cases where this is not possible, we must take into account the deterioration of the accuracy parameters of the measurement. Concrete measuring strategies should therefore be used with full awareness of not only their advantages but also their disadvantages.

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