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# Accuracy of the photogrametric measuring system for large size elements

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## Abstract

The aim of this paper is to present methods of estimating and guidelines for verifying the accuracy of optical photogrammetric measuring systems, using for measurement of large size elements. Measuring systems applied to measure workpieces of a large size which often reach more than 10000mm require use of appropriate standards. Those standards provided by the manufacturer of photogrammetric systems are certified and are inspected annually. To make sure that these systems work properly there was developed a special standard VDI / VDE 2634, "Optical 3D measuring systems. Imaging systems with point - by - point probing. " According to recommendations described in this standard research on accuracy of photogrametric measuring system was conducted using K class gauge blocks dedicated to calibrate and test accuracy of classic CMMs. The paper presents results of research of estimation the actual error of indication for size measurement $MPE_E$ for photogrammetric coordinate measuring system TRITOP.

**Keywords:** Photogrammetry, coordinate measuring technique, maximum permissible error of indication for size measurement, accuracy, optical coordinate measuring system

## 1. Introduction

Photogrammetry is a field of science and technology dedicated to the reproduction of shapes, sizes and relative positions of objects on the ground on the basis of photogrammetric images (photograms). Photogrammetry derives from three Greek words: photos - light, grama - a record, metreo - measure. This area has been developed gradually, in the 20's, there had been analog photogrammetry, where the basic instrument had been an analog autograph. Obtained data had had the analog form. From 1961, in use had been the analytical autograph. The basic form of data had been the raster. However, since 1991 in use has been a digital autograph which is a digital photogrammetric station.
Photogrammetry bases on the standard photographs and is especially useful for the digitization of large objects. It consists in making multiple images of the test object, and then automatically or manually indication of common points on each photograph. The photogrammetry is often used together with other 3D scanning techniques to ensure the entire measuring surface is detected properly and to maintain a tight tolerance on large surface of measured area.
In order to determine the location of individual elements point it should be set a coordinate system associated with the camera. It consists of three axes perpendicular to each other (the camera optical axis OO ', and axes that are on the background of the film plane). On the basis of a photographic image is obtained a beam of rays directed from the stand position to removable object points what allows to specify horizontal and vertical angles of these points. Nevertheless, it is not sufficient to clearly identify their location (Fig. 1). Therefore, it need to be taken another picture from another direction (measurement of photogrammetric stereo), on which it will be determined horizontal and vertical angles of the various points from the second camera. Thus, unequivocal position of points in terms of direction and distance is determined.

The three-dimensional model in photogrammetry technique is created using specialized software that reads in reference points. These points represent characteristic of objects, and therefore the tested object must be firstly prepare to photogrammetric images. Reference points can be painted, sticked (cerebral material) or illuminated with LEDs.
In the past, photogrammetric measurements were used only in geodesy to create topographic maps. Now, thanks to a simple system configuration and rapid image acquisition independent from measurement volume and as a result of low cost it is used in architecture, aerospace, shipbuilding and automotive [2, 4, 5, 6, 7].
The accuracy of photogrammetry methods mainly depends on: the resolution, stability and class of cameras, the number of made photos, degree of photos coverage, type of markers used on the tested object surface, the calibration procedure, applied software.

## 2. Photogrammetric system TRITOP

TRITOP is the optical measuring system for noncontact and accurate registration of objects coordinates dedicated for industrial use. This mobile technology enables anywhere to optimal due to the time quality control and analysis of deformation.
All characteristic points of the object are identified while the object is photographed from different angles with the photogrammetric camera. Based on digital photo TRITOP`s software automatically calculates 3D coordinates of glued markers and elements of the object. Using this system object can be measured from a distance up to 10 m. The software smoothly manage a few thousand of points.
The main idea of the photogrammetry is observation of reference points from different directions and gathering all that view in one image and calculating into 3D coordinates of points. Reference points that are visible in the snap, have a permanent position. Based on photographs taken at different angle it is possible to determine the camera position in respect of points.
The purpose of drawing up a series of photos is the determination of reference points from different directions, and arranged to each other at the greatest possible angle.

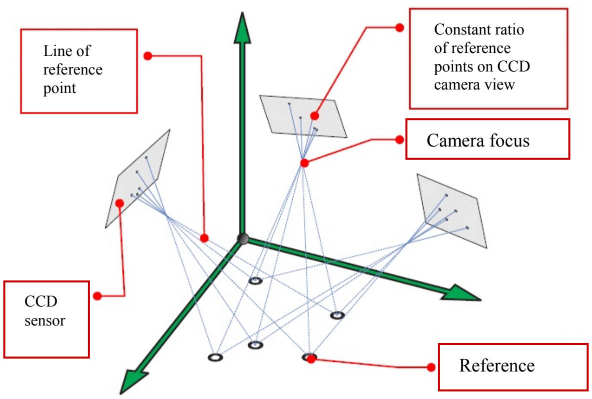


Fig. 1 Lines of reference points projection

The main task of the TRITOP`s software is precise search of ellipses (reference points seen in perspective) in a series of images and their spatial fit.TRITOP software enables the identification of measurement points based on measurement images in the coordinate system. Measurement data can be evaluated using the system e.g. control, comparison with CAD model etc. and also send obtained cloud of points to other coordinate systems e.g. ATOS.


Fig 2. Photogrammetric system TRITOP

**End guage**

End guages are selected according to the object size. Pattern should be placed in a space that will not affect on the reference points and on tested element. There are coded and uncoded patterns of length. The length of coded patterns is determined as the distance between the upper and the lower coded point. The length of uncoded patterns is determined as the distance between the upper and lower uncoded point. For unique identification of uncoded reference points, end guages are equipped with additional coded reference points at specified distance. On the basis of identified and numbered reference points the software automatically identify patterns in length.

**Coded reference points**

Coded reference points provide the TRITOP system opportunity to connect series of measurement snapshots as well as allow to automatically determination of the camera location. It is recommended to use many coded reference points in order to obtain the highest possible accuracy.

**Uncoded reference points**

Automatic determination of the element coordinates is feasible with use of uncoded reference points. Those points are automatically recognized by TRITOP software. Their layout depends on the measurement task. TRITOP can also recognize 3D points, patterns and lines that are drafted on the object in a halfautomatic mode. Snapshots from three different camera position need to be taken to determine the point position.

## 3. VDI\VDE 2634 standard

Instructions in VDI \ VDE 2634 standard [1, 8, 10] applies to flexible optical 3D measuring systems such as cameras, whose function relies on triangulation (such as photogrammetry systems). It presents methods for testing these systems. In order to evaluate the accuracy of measurement systems and to compare different ones, all quality parameters must be defined. The permissible limits for these parameters are defined by the manufacturer for the acceptance test, while in the case of reverification by the user. Due to the impact of operating mode and operating conditions on quality parameters, it is recommended to adopt the same operating modes and conditions to ensure comparable results. Exceeding of maximum values is acceptable when defined limitations are not meetment. The term operating modes means adapting of configuration options such as:

- type and intensity of illumination,
- measuring volume,
- type, number and arrangement of optical sensors used,
- type and duration of image acquisition, and evaluation processing,
- type, number and form of features to be analyzed .

The term operating conditons denotes external influences on the optical measuring system. These include e.g.:

- the temperature and its gradient,
- humidity,
- mechanical vibrations,
- electromagnetic interference,
- environmental lighting conditions,
- dust.

**Acceptance test**

Acceptance tests serve to verify the specified accuracy, is performed at the manufacturer`s or at the user`s following installation. There should be provided both optimal environmental conditions for the test and tested patterns appropriate preparation. When the temperature of the environment or any element of optical measuring system is far from the reference temperature, appropriate corrections shall be applied. When the acceptance test is completed report should be drafted summarizing its results. It is recommended that report includes all measured values. Both acceptance test and reverification of optical measuring systems base on the measurement of objects with known parameters, which could be a gauge block with circular reference points set in the formation in specified distances. The test is performed to verify that the measurement errors are within the limits specified by the manufacturer or user. In order to determine the length measurement error artefact is measured and the result is compared with the calibrated value[11]:

$$\Delta l = l_m - l_k \tag{1}$$

where:

$\Delta l$ – length measurement error,
$l_m$ – measured value of length,
$l_k$ – calibrated value of length;

The maximum value of permissible length measurement error ($MPE_E$) is defined by the manufacturer and depends on length [9]:

$$MPE_E = \pm\left(A + \frac{L}{K}\right) \leq B \tag{2}$$

where:
*A* – constant describing the contribution of random errors [um]
*L* - measured length [mm]
*K* - coefficient describing the nature of the changes in systematic errors
*B* - maximum value of measurement error.

The size of measurement error parameter E, should be within acceptable limits independently from the position of the measuring object. The test is conducted correctly, when, apart from the measurement result which should be within acceptable limits, accompanied by the description of particular operating modes and conditions. It is recommended that the acceptance tests standard size were 2000x2000x1500 (length, width, height). At least five test length shall be tested on each measuring line(Fig. 3) The longest test on each measuring line should be at least as long as the shortest dimension of the measuring object. The maximum tested length should be at least two-thirds of the body diagonal of the element. If there are no artefacts with adequate dimensions, two overlapped pattern can be applied.
The longest segments should be located in the position that enables one end to be in the corner of the measurement object. In addition, for each plane should be at least one parallel line. Distribution of measurement errors can be represented graphically (Fig. 3).
The system meets the quality requirements, if the length measurement error value is within acceptable limits. In case of exceeding the limit on no more than one measuring line all measurements on that line should be repeated once. If the outcome exceed the limits once again the system can not be accepted.

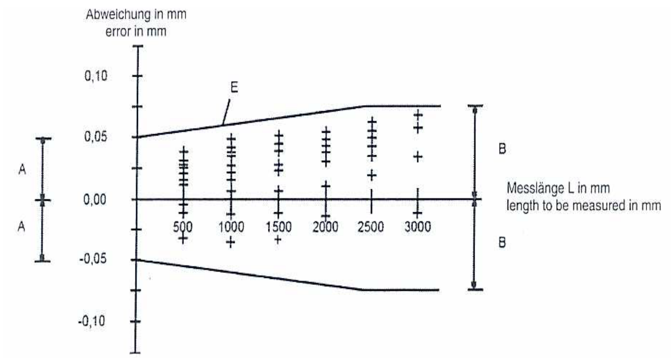



Fig. 3. Example of length measurement error diagram [10]

**Reverification**

Reverification of optical measuring system serves to ensure long – term compliance with limits for both the length measurement error and accurate measurement. Limits of the maximum permissible value are defined by the user. Comparing the results of following reverification measurement, it is possible to analyse trends in respect to change with instrument characteristics. Operating modes and operating conditions must be exactly the same for trend analysis.

This allows to draw conclusions regarding both the prevention and maintenance of the optical system. Before the reverification, measurement system should be prepared in accordance with the instructions described in the manual. Requirements for environmental conditions, temperature and measurement object preparation are the same as in the acceptance test. However, there are parameters like permissible deviation, the number of measuring lines, as well as the number of test sections, which could be defined by the user himself. The recommended procedure for reverification 3D measuring systems is analogue to that described for their acceptance. Differences can be found in systems admission for further work. When permissible value of the parameter is exceeded measuring system should be identified as only limited suitable for operation and it should be take appropriate corrective action.

Acceptable deviations should be determined individually by the user. If tests are performed in different locations, it is necessary to take into account environmental conditions. Reverification shall be performed according to specified testing schedule. A report shall be drafted upon completion of the test summarizing. On the basis of the report the user decide about forward proceedings.

## 4. Research

The accuracy of photogrammetric coordinate system TRITOP was carried out using a set of seven steel gauge blocks of K-class for calibration of coordinate measuring machines (Fig. 4). On the guage blocks were carried out three measurement tests. Each trial included five measurements of the length of each guage block (seven patterns), which gives thirty-five measurements in each sample, and a total of three attempts, one hundred and five measurements. The results of measurements - deviations from the nominals - are presented in Table 1

The tested guage blocks are marked with coded and uncoded reference points (Fig. 5) and with crosses, which enable the software to determine point`s coordinates in 3D. Lines represent the position of patterns (scalars) of 500 mm length (Fig. 6). Gauge blocks are marked with four reference points. Three of them on one guage block`s measuring surface and one on the opposite side. On the basis of three measured points it was created one plane for each guage block (Fig. 7). On Figures 8, 9 and 10 it is shown a graphical analysis of test results and determined formula for the permissible error of the TRITOP system.

Fig. 4. Set of guage blocks

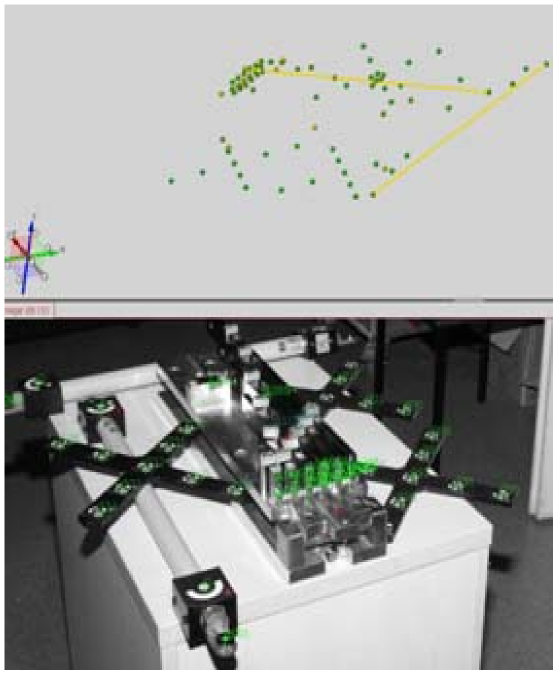


Fig. 5. Test stand – guage blocks marked with coded and uncoded points

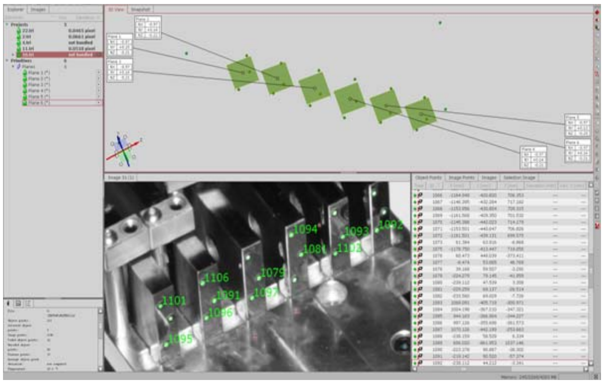


Fig. 6. Identified uncoded points and on the basis of them planes

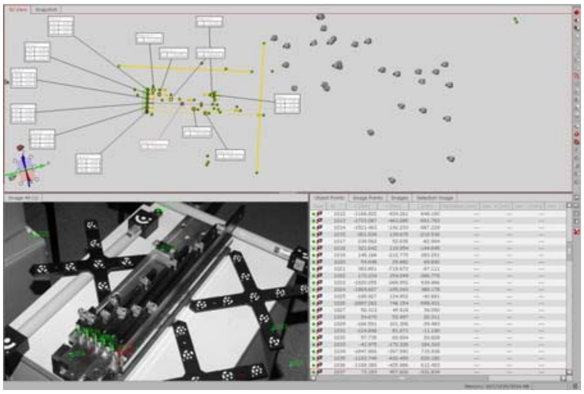
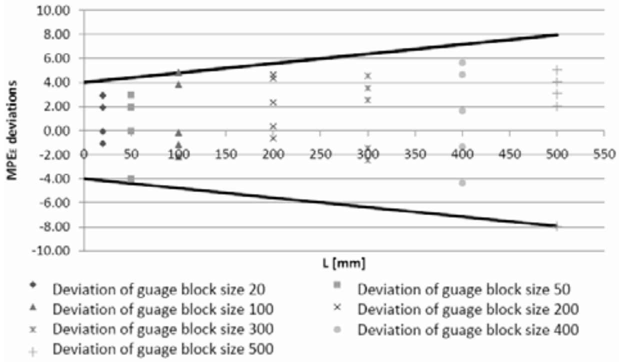


Fig. 7. Sample results of a single check

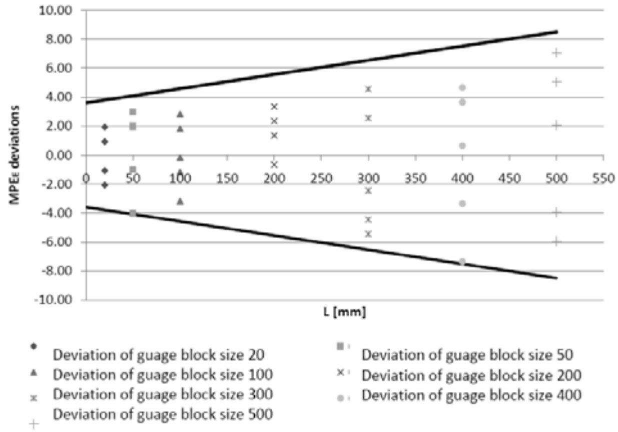
Table 1. Summary of test results.
The value of calculated deviations [µm]

| Lp. | Determined deviation [µm] | | | | | | |
|---|---|---|---|---|---|---|---|
| Gauge block | Gauge block dimension [mm] | | | | | | |
| | 20 | 50 | 100 | 200 | 300 | 400 | 500 |
| 1 | 1,93 | 1,98 | -1,17 | 0,35 | 3,55 | 4,65 | 3,05 |
| 2 | 2,93 | -4,02 | -0,17 | 4,65 | -2,45 | -4,35 | -7,95 |
| 3 | -1,07 | 2,98 | 3,83 | 2,35 | 4,55 | -1,35 | 2,05 |
| 4 | 2,93 | 1,98 | -2,17 | 4,35 | 2,55 | 5,65 | 4,05 |
| 5 | -0,07 | -0,02 | 4,83 | -0,65 | -1,45 | 1,65 | 5,05 |
| 6 | -2,07 | -1,02 | -3,17 | 1,35 | -4,45 | -3,35 | 2,05 |
| 7 | -1,07 | -4,02 | 1,83 | 3,35 | 4,55 | -7,35 | -3,95 |
| 8 | 0,93 | 2,98 | 2,83 | 2,35 | -2,45 | 4,67 | -5,95 |
| 9 | 1,93 | 2,98 | -1,17 | -0,65 | 2,55 | 3,65 | 5,05 |
| 10 | -1,07 | 1,98 | -0,17 | 3,35 | -5,45 | 0,65 | 7,05 |
| 11 | -2,07 | 0,98 | -4,17 | -1,65 | 2,55 | -5,35 | 1,05 |
| 12 | -0,07 | 1,98 | 2,83 | 2,35 | 3,55 | 3,65 | 4,05 |
| 13 | 1,93 | -1,02 | 1,83 | 4,35 | -1,45 | 5,65 | -2,95 |
| 14 | 0,93 | -0,02 | -1,17 | 3,35 | 1,55 | -6,35 | 4,05 |
| 15 | 2,93 | -2,02 | -0,17 | 1,35 | -3,45 | 2,65 | 9,05 |



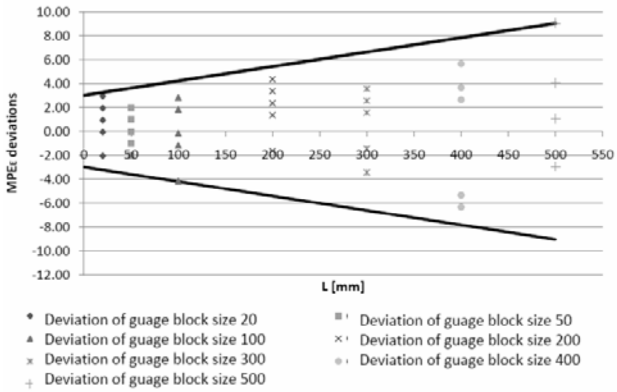

$$MPE_{E_{TRITOP\,I}} = \pm\left(4 + \frac{L}{100}\right)$$

Fig. 8. Graphic summary of test results for measurements from1 to 5 and the calculated formula for the maximum permissible error




$$MPE_{E_{TRITOP\,II}} = \pm\left(4 + \frac{L}{100}\right)$$

Fig. 9. Graphic summary of test results for measurements from6 to 10 and the calculated formula for the maximum permissible error




$$MPE_{E_{TRITOP\,III}} = \pm\left(3 + \frac{L}{80}\right)$$

Fig. 10. Graphic summary of test results for measurements from11 to 15 and the calculated formula for the maximum permissible error

## 5. Conclusions

Research on accuracy of photogrammetric coordinate system TRITOP was performed on a base of standards VDI / VDE 2634 and ISO 10360. Compatibility of the two standards is maintained. Measured values of guage blocks length were analyzed and for each sample maximum permissible error $MPE_E$ of coordinate measuring system TRITOP were determined. For the first two samples maximum permissible error $MPE_E$ was $MPE_{E\ TRITOP\ I\ and\ II}$ = ± (4 + L/100) µm, where L is given in mm. And for the third tsample $MPE_{E\ TRITOP\ III}$ = ± (3 + L/80) um, where L is given in mm. Data presented in graphs shows that in the first two samples limit of the maximum permissible error of the measured value increases with increasing length of the guage block. For the third one the increase is more substantive.

Differences between obtained results are coused by accuracy of focus set, maintaining a constant distance from the photographed element and an improved image quality in terms of capturing more reference points and quantity of images on which the same reference point is detected.

In order to confirm the accuracy of photogrammetric coordinate system TRITOP in its full measurement volume there will be required further studies based on large patterns such as gauge blocks with a length of 1000 mm and 2000 mm. The maximum permissible error given by the TRITOP`s manufacturer – GOM company, is $MPE_E$ = ± (5 + L/50) um, where L is given in mm, according to the guidelines of VDI / VDE 2634.

## References

[1] R. Hartym, Dimensional accuracy of investment casting for the burned pattern process, Archives of Foundry, Volume 6, No18 (2/2), (2006) 231-236

[2] M. Wieczorowski, M. Ruciński, R. Koteras, Application of optical scanning for measurements of castings and cores, Archives of Foundry Engineering, 10 (2010), 265-268.

[3] B. Enquist, Use of optical measurement techniques in furniture design, Building Design Papers, 2 (2005), Chalmers University of Technology, Göteborg, Szwecja.

[4] W. Boehler, M. Bordas Vicent, K. Hanke, A. Marbs, Documentation of German Emperor Maximilian I's Tomb, Internal publication, GOM, Braunschweig, 2003

[5] G. Budzik, M. Oleksy, M. Grzelka, M. Wieczorowski, M. Magniszewski, J. Slota, The application of optical measurements for the determination of accuracy of gear wheels casts manufactured in the RT/RP process, Archives of Foundry Engineering, 10, 1/2010, s. 395-398.

[6] Grzelka M. Investigations and Implementation of Measurement Methods, Monogrfia, Poznan University of Technology, 2010, ISBN 978-83-61287-47-6,

[7] Grzelka M., Chajda J., Budzik G., Gessner A., Wieczorowski M., Staniek R., Gapiński B., Koteras R., Krasicki P., Marciniak L., Archiwum Odlewnictwa, Optical coordinate scanners applied for the inspection of large scale housings produced in foundry technology,

[8] Halim Setan. Mohd Ibrahim Sharuddin, Ma'arouf Ismail, Applications of Digital Photogrammetric Systems for Dimensional Measurement and 3D Modeling, 3th FIG Regional Conference, Jakarta, Indonesia, October 3-7, 2004

[9] Ratajczyk E., Współrzędnościowa technika pomiarowa, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2005

[10] VDI/VDE 2634, Optical 3D measuring systems imaging systems with point – by – point pro bing

[11] PN-EN ISO 10360-2:2001

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## Abstract
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