Analysis of the Present Acquisition Methods of Spatial Information about the Objects with Spatial Composition

Štefan SOKOL [1), Marek BAJTALA [2), Miroslav LIPTÁK [3)

[1) Prof. Ing., Ph.D.; Department of Surveying, Faculty of Civil Engineering, STU – Slovak University of Technology in Bratislava, Radlinského 11, 813 68 Bratislava, Slovak Republic; e-mail: stefan.sokol@stuba.sk, tel.: +421 2 59 274 689

[2) Ing.; Department of Surveying, Faculty of Civil Engineering, STU – Slovak University of Technology in Bratislava, Radlinského 11, 813 68 Bratislava, Slovak Republic; e-mail: marek.bajtala@stuba.sk, tel.: +421 2 59 274 392

[3) Ing.; Department of Surveying, Faculty of Civil Engineering, STU – Slovak University of Technology in Bratislava, Radlinského 11, 813 68 Bratislava, Slovak Republic; e-mail: miroslav.liptak@stuba.sk, tel.: +421 2 59 274 396

Summary

The contribution deals with the analysis of the present acquisition methods of spatial information about the objects with spatial composition. Although the field of acquisition of spatial information is quite extensive, attention is focused on the present most commonly used methods as spatial polar method, close-range photogrammetry and terrestrial laser scanning. Each of these methods has its specific characteristics resulting to advantages and disadvantages. The core of analysis is to test the accuracy of the achieved results obtained by measurement on the experimental point field. The contribution aim is to bring to reader the answers to the questions, which of these methods is suitable or unsuitable for the particular case of the spatial information acquisition in terms of statistical testing its accuracy.

Keywords: analysis of methods, spatial polar method, close-range photogrammetry, terrestrial laser scanning, statistical analysis

Introduction

Actual UMS (Universal measuring stations) using various software products offer in surveying new perspective possibilities for obtaining and processing information about objects with spatial structure. The use of terrestrial methods, photogrammetric methods and laser scanning technology is at present an effective tool for obtaining 3D data in different areas of the economy and sectors of the industry. The spatial polar method by using of UMS belongs in practice to certified and commonly used surveying methods. Determining of the spatial position of a point is based on the measurement of oblique length, horizontal direction and of zenithal angle and the calculation using well-known relationships. Photogrammetric methods are non-contact methods of measuring objects. In addition to saving fieldwork, high geometric and temporal resolution, their effectiveness is currently increasing by processing images with photogrammetric software, which offer varying degrees of automation of the processing (automatic measurement of signalized points, automatically finding identical points in different images, creating point clouds on the principles of the image correlation). Laser scanning technology allows the contactless measurement of object's surface. It is characterized by a high degree of automation of the measuring and collecting large amounts of data in short time. Nevertheless, that these current technologies speed up the work of surveyors and make it effective, in their selection it is important to have verified the accuracy of the used method. To verify the accuracy of each method, there was an experimentally geodetic measurement implemented on the campus atrium of the Faculty of Civil Engineering in Bratislava. The objective of the presented article is to assess the accuracy of determining the spatial coordinates of points by photogrammetry and by the laser scanning due to the results achieved by spatial polar method.

Experimental measurement

Experimental measurements were carried out in the atrium of the Faculty of Civil Engineering. Due to the availability and possibility of installation of detailed points, as well as the feasibility of specific measurements, we build the experimentally point field (EPF) on two perpendicular walls of the atrium in the Faculty of Civil Engineering in Bratislava (Fig. 1). EPF consists of 48 detailed points signaled by targets (indication F1 – F48). Used targets are formed by a black square substrate with dimensions of 50×50 mm, on which a reflecting white foil is centrically glued with a diameter of 40 mm (Fig. 2). In the middle of reflective foil is centrically located a ring with diameter of 2 mm. Size of the reflecting foil was calculated on the assumption of object distances between the device and the observed points with a maximum of 30 m and the smallest resolution of image element in the processing of the captured target of observed point in a digital image. For the needs of transformation of the laser scanner coordinate system to the reference coordinate system, EPF was supplemented by four points (L10 – L13) signaled by using a Leica HDS planar targets (Fig. 3) allowing automatically evaluation of target's centers determined by scanning directly in Cyclone software environment.

Determining of spatial coordinates using the polar method

To determine the spatial coordinates of the detailed points of EPF was used the UMS Leica TS30, which with its characteristics of precision of measuring directions and lengths belongs among the most precise instruments used in geodetic practice. ($\sigma_\alpha = 1.5^{cc}$, $\sigma_d = 0.6\,mm + 1.5\,ppm$ on reflective prism, resp. $\sigma_d = 2.0\,mm + 2.0\,ppm$ on arbitrary surface). Measurement of detailed points was realized from six positions of the device. From the positions 5001 and 5002 were determined the points of reference network (9001–9007) placed on the surrounding walls of the atrium (Fig. 4) measuring the horizontal directions in three groups with simultaneous measurement of lengths. The network reference points served to determine other points (5003–5006), by the method of transitional stand. Configuration of reference points and position of the newly specified points is shown in fig. 4.

Fig. 1. Experimental point field

Rys. 1. Pole punktów doświadczalnych

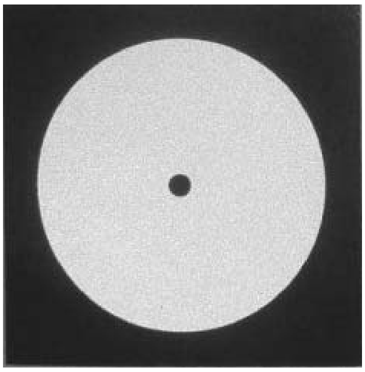

Fig. 2. Reflective foil (points F1 – F48)

Rys. 2. Folia odblaskowa (punkty F1-F48)

Fig. 3. Leica HDS planar target (points L10 – L13)

Rys. 3. Leica HDS planowanie płaskie (punkty L10-L13)

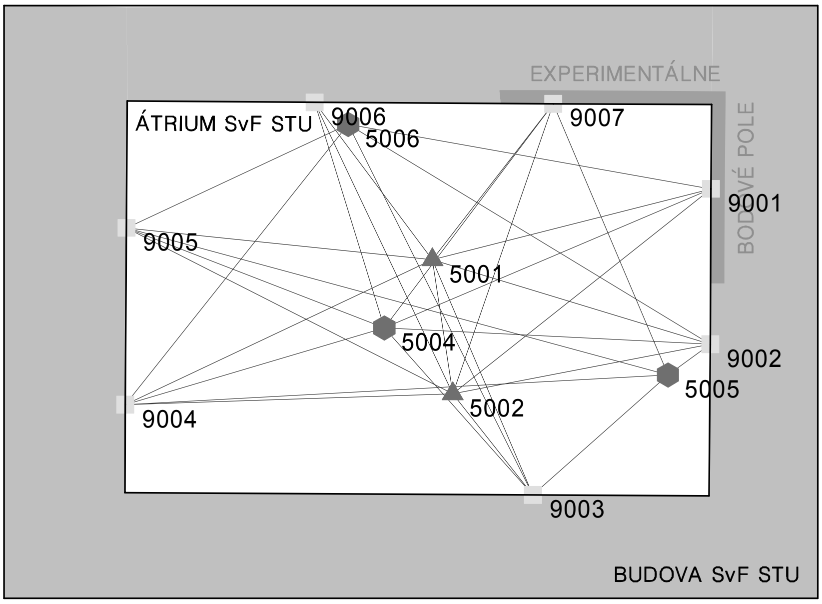

Fig. 4. Control network

Rys. 4. Sieć kontrolna

The measurement of detailed points was made in two groups with simultaneous measurement of lengths. The measured data were processed in Leica Geo Office environment and the estimation of the resulting coordinates was carried out by the method of least squares, using the second linear model [1], [2].

Determining the coordinates using the method of close-range photogrammetry

The method of convergent photogrammetry was used for imaging the EBP. Shots were taken from seven positions, 4 positions were located in bottom of the object and 3 positions on the roof of Faculty of Civil Engineering (Fig. 5). For capturing images was used the digital camera PhasOne 645D with focal length of 45 mm, aperture of f = 2.8 and digital back APTUS II-7 with resolution of 33 Mpix.

The image processing was carried out in PhotoModeler Scanner software. Identification of signalized points in the processing of images was performed using automated sub-pixel measurement of targets. This way the points were determined as a free network in model coordinate system of the PhotoModeler Scanner. After that the points were transformed using the spatial

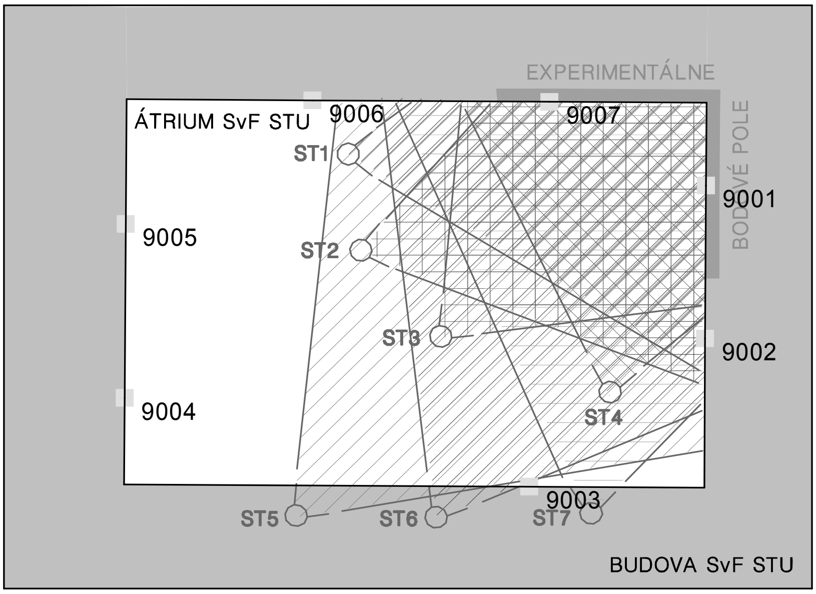

Fig. 5. Geometry of camera stations

Rys. 5. Geometria stacji kontrolnej

Table. 1. Residuals from transformation of points

Tabela 1. Pozostałości po transformacji punktów

Bod	X_{rez} [mm]	Y_{rez} [mm]	Z_{rez} [mm]
F28	0.000	0.001	-0.001
L10	-0.000	-0.000	0.001
L11	-0.000	0.000	-0.001
L12	-0.000	-0.001	0.001
L13	0.000	-0.000	-0.000

similarity transformation to the reference coordinate system obtained by the spatial polar method. For the transformation five ground control points were used (L1 – L13 and F28) [3]. Resulting residual values for ground control points are shown in tab. 1.

Determining the coordinates using the terrestrial laser scanning method

To determine the spatial coordinates of points in EBP using the method of terrestrial laser scanning was used Leica ScanStation2 scanner. The device is equipped with pulse rangefinder with declared accuracy of 4 mm for range of lengths of – 50 m. Scanner range is 300 m and at the maximum speed it is possible to scan 50000 points per second (www.geotech.sk). Measurement of laser scanner was carried out only for one stand (Fig. 6). Scanning density was set to 2 mm raster over a distance of 30 m. Given that the farthest point was 24 m away, we can assume that the density of scanning in horizontal and vertical direction was less than 2 mm and in average was around 1.5 mm. Scanning took about 4 hours and for the control were initially scanned the HDS 4 targets that have been rescanned also at the end of the scanning. Comparing the coordinates of the targets showed maximal differences of 1 mm.

Processing and evaluation of the coordinates of the reflective foil centers was made in Cyclone 6.0 software. Unlike the automated processing of HDS targets, the evaluation of centers of the reflecting foils was done manually using the functions provided by the software. The shape of the scanned reflective foil seems like a spatial unit, where the scanned surface reflections and reflective foil stands out on constant of 34 mm (Fig. 7). herefore, they were first removed protruding points of reflecting surface (blue points fig. 7). From the remaining points was after that generated a regression plane in which was a circle inserted with radius of 20 mm. By exporting the center coordinates of the circle were obtained the resulting model coordinates of the observed point (Fig. 8).

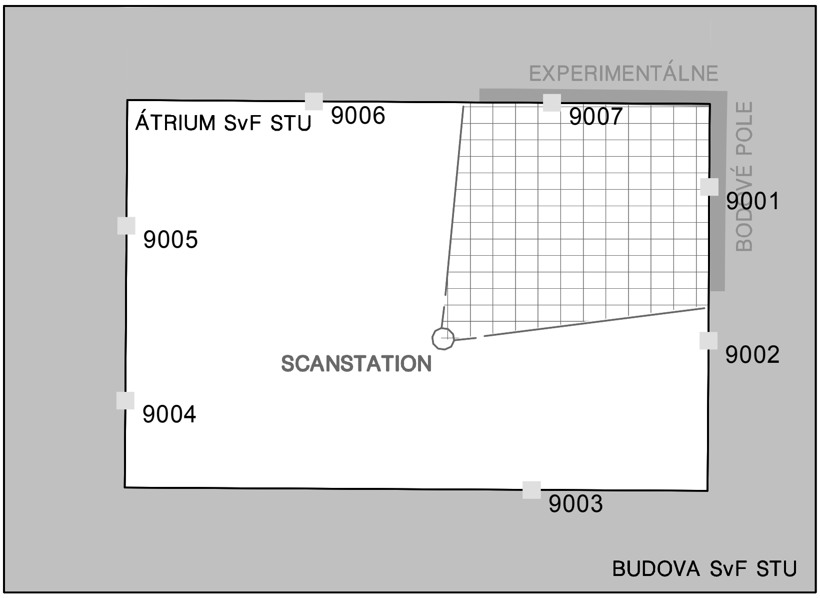

Fig. 6. Scanner station

Rys. 6. Stacja skanera

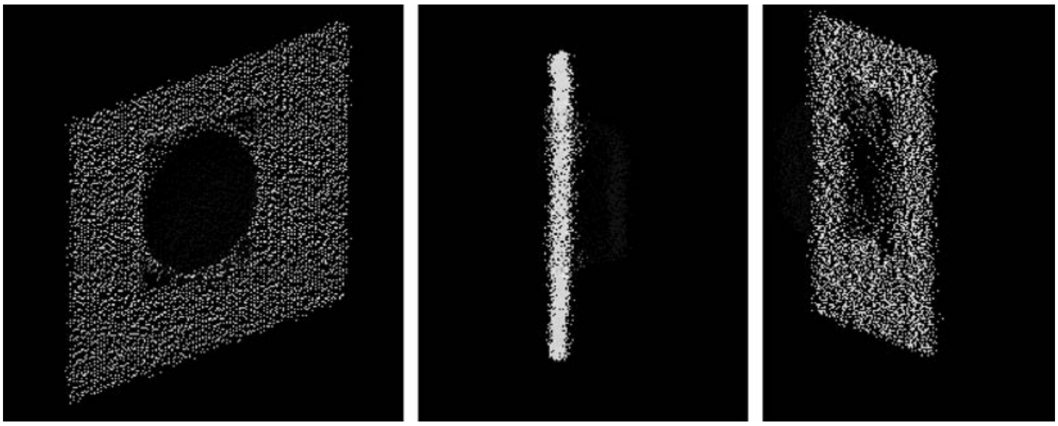

Fig. 7. Shape of a scanned relfective foil

Rys. 7. Kształt po skanowaniu folii odblaskowej

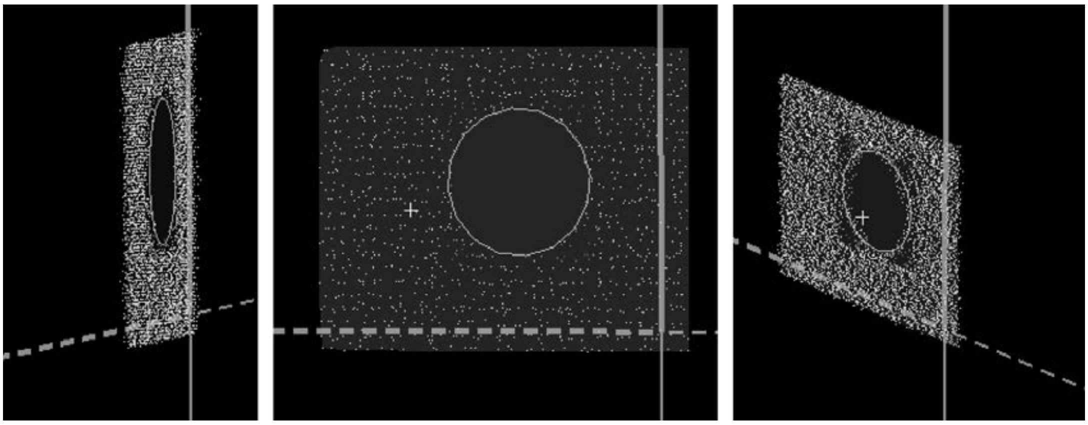

Fig. 8. Determination of a center of a reflective foil

Rys. 8. Określenie środka folii odblaskowej

The model coordinates of the EPF was transformed to the reference coordinate system by spatial similarity transformation. For the transformation were once again used five control points with residual values shown in table 2.

The analysis of used methods

Results from the processing of data for all methods are the spatial coordinates of 47 points. The accuracy of determining the points using the close-range photogrammetry method and the laser scanning technology can be compared individually, in the direction of individual coordinate axes or together, for example with spatial length between pairs of points. For the purpose of analyzing are the coordinates of the points obtained by the spatial polar method considered as reference. Then for the coordinate differences, resp. differences of lengths simply apply equation (1).

Maximum differences of coordinates and lengths in positive and negative direction are shown in fig. 9.

In the case, where coordinate differences, resp. length differences are produces only by the treatment of coincidence errors, the mean value of set differences equals zero, resp. its difference from zero is

Table 2. Residuals from transformation of point

Tabela 2. Pozostałości po transformacji punktu

Bod	X_{rez} [mm]	Y_{rez} [mm]	Z_{rez} [mm]
F28	-0.003	0.000	0.001
L10	0.001	0.001	0.000
L11	0.001	-0.001	-0.000
L12	-0.000	0.001	-0.000
L13	0.001	-0.001	-0.000

$$
\begin{aligned}
\Delta X_i^F &= X_i^{PPL} - X_i^F & \Delta X_i^{LS} &= X_i^{PPL} - X_i^{LS}, \\
\Delta Y_i^F &= Y_i^{PPL} - Y_i^F & \Delta Y_i^{LS} &= Y_i^{PPL} - Y_i^{LS}, \\
\Delta Z_i^F &= Z_i^{PPL} - Z_i^F & \Delta Z_i^{LS} &= Z_i^{PPL} - Z_i^{LS}, \\
\Delta d_i^F &= d_i^{PPL} - d_i^F & \Delta d_i^{LS} &= d_i^{PPL} - d_i^{LS}.
\end{aligned} \tag{1}
$$

for:

$i = 1,\ 2,\ \dots,\ n$ – (in case of coordinates $n = 47$, in case of lengths $n = 1081$), where,

X^F, Y^F, Z^F – are photogrammetricaly obtained coordinates,

X^{LS}, Y^{LS}, Z^{LS} – coordinates obtained from laser scanning,

$X^{PPL}, Y^{PPL}, Z^{PPL}$ – coordinates determined by the spatial polar method,

d^F, d^{LS}, d^{PPL} – spatial lengths computed from the coordinates.

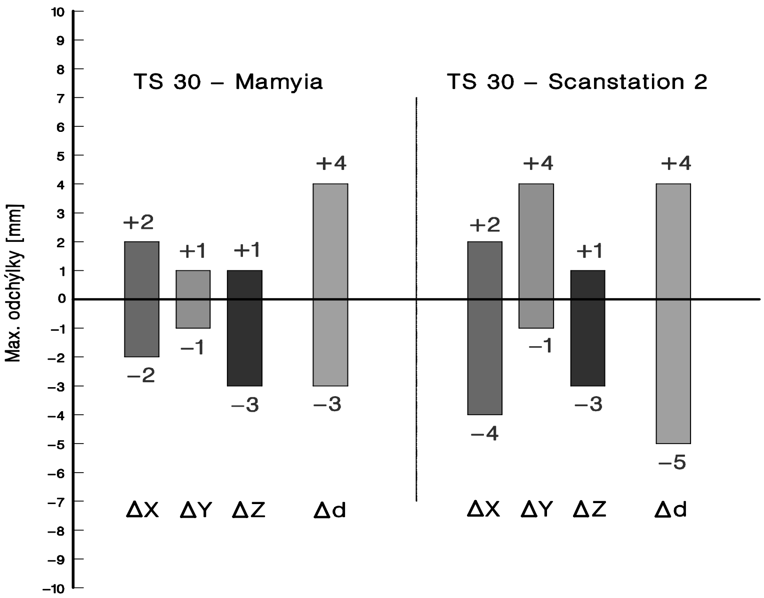

Fig. 9. Comparison of different methods of measurement

Rys. 9. Porównanie różnych metod pomiarowych

statistically insignificant. From the view of statistics it means to test the match of the mean value μ with the known constant μ_0 ($\mu_0 = 0$), i.e.:

$$H_0 : \mu = \mu_0 \text{ beside } H_1 : \mu \neq \mu_0 . \tag{2}$$

The null hypothesis is rejected on chosen significance level α ($\alpha = 5\%$), if the calculated value of tested statistics $\check{S}^1$ not aquire the values from the field H_0 of non-rejection [4], [5]. In that case the alternative hypothesis H_1 is accepted, which means, that besides the coincidence errors there is also an influence of systematic errors. The results of testing are shown in tab. 3.

Conclusion

Goal of this article was to compare the accuracy of various methods for determining the spatial coordinates of the measured object. When comparing and testing, we considered the spatial coordinates from the spatial polar method as reference, and the spatial coordinates determined by digital photogrammetry and terrestrial laser scanning as the test.

From graphical comparison of the maximum differences is seen that with the method of digital photogrammetry compared to the terrestrial laser scanning in X and Y-axis better results were achieved. In axis Z maximum differences are equal. In terms of maximum differences in spatial lengths, here are fully reflected variations in individual axes and logically, there occurred also the greatest maximum differences in both methods.

In the testing of mean value of differences sets at the significance level $\alpha = 0.05$ is seen that the null hypothesis was not rejected by the positional coordinates of X and Y from the photogrammetry method and elevation coordinates from the method of terrestrial laser scanning, confirming the equivalence of polar spatial method. The results obtained suggest that

Table 3. Test of the equality of a mean with a known constant

Tabela 3. Test równości średnich o znanej stałej

	μ [mm]	σ [mm]	$\check{S}^1$	Field of non-rejection H_0
ΔX^F	0.2	1.0	1.371	-2.013 – 2.013
ΔX^{LS}	-0.7	1.2	-3.999	-2.013 – 2.013
ΔY^F	0.1	0.7	0.979	-2.013 – 2.013
ΔY^{LS}	0.8	1.5	3.656	-2.013 – 2.013
ΔZ^F	-0.6	0.8	-5.142	-2.,013 – 2.013
ΔZ^{LS}	0.0	0.9	0.000	-2.013 – 2.013
Δd^F	0.6	1.0	19.727	-1.962 – 1.962
Δd^{LS}	-0.2	1.4	-4.697	-1.962 – 1.962

by the method of terrestrial laser scanning operate systemic effects greater than by the method of digital photogrammetry. These experimental measurements were carried out to a distance of about 25 m, where it is seen that from comparing and testing of results from all methods it is not possible to determine which of the methods is more accurate. We expect that for larger lengths (50 to 100 m) are systemic effects more indicative and it will be also a more significant statistical confirmation of the differences between the methods possible.

Literatura – References

1. *Bajtala M. Sokol Š.: Odhad variančných komponentov z meraní v geodetickej sieti. In: Acta Montanistica Slovaca. ISSN 1335-1788, 2005. č. 10, s. 68-77*
2. *Gašinec J. Gašincová S.: Neštandardné postupy v spracovaní meraní v lokálnych geodetických sieťach (Substardand practices of adjustment measurements in local geodetic networks2005. In: Acta Montanistica Slovaca. Roč. 10, č. 2 (2005), s. 94-103. - ISSN 1335-1788*
3. *Fraštia M.: Tvorba presných priestorových modelov historických objektov metódou blízkej fotogrametrie. In: Acta Montanistica Slovaca. ISSN 1335-1788, 2009, vol. 14, special issue 1, s. 34-40*
4. *Gašincová S. Gašinec J. Staňková H. Černota P.: Porovnanie MNŠ a alternatívnych odhadovacích metód pri spracovaní výsledkov geodetických meraní. In: SDMG 2011: sborník referátů 18. konference : Praha, 5.-7. října 2011. - Ostrava : VŠB-TU, 2011 P. 40-50. - ISBN 978-80-248-2489-5*
5. *Staňková, H., Černota, P.: A Principle of Forming and Developing Geodetic Bases in the Czech Republic, Geodesy and Cartography, Vilnius: Technica, 2010, Vol. 36, No. 3 p. 103-112, ISSN 1392-1541 print/ISNN 1648-3502 online.*

Analiza aktualnych metod gromadzenia informacji przestrzennych na temat obiektów o kompozycji przestrzennej

Niniejszy artykuł dotyczy analizy obecnych metod pozyskiwania informacji przestrzennej o obiektach o kompozycji przestrzennej. Chociaż obszar pozyskiwania informacji przestrzennej jest dość obszerny, uwaga skupiona jest na aktualnie najczęściej używanych metodach takich jak przestrzenna metoda polarna, fotogrametria bliskiego zasięgu oraz naziemny skaning laserowy. Każda z tych metod ma swoje specyficzne cechy wynikające z wad i zalet. Rdzeniem analizy jest zbadanie dokładności wyników otrzymanych przez pomiar na obszarze eksperymentalnym. Celem artykułu jest przedstawienie czytelnikowi odpowiedzi na pytania, która z tych metod jest odpowiednia bądź nieodpowiednia do konkretnego przypadku pozyskiwania informacji przestrzennej w kategoriach testów statystycznych jej dokładności.

Słowa kluczowe: metody analizy, przestrzenna metoda polarna, fotogrametria bliskiego zasięgu, naziemny skaning laserowy, analiza statystyczna.