REGISTRATION OF BUILDING WALL GEOMETRY AS CARRIED OUT BY SPATIAL FORWARD INTERSECTION AND 3D POLAR METHODS

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1. INTRODUCTION

While taking inventory measurements of constructional elements of a building, such as a wall, it is deviations of the chosen checkpoints from the vertical reference plane (Pawłowski, Przewłocki 1997) which are most commonly determined. The wall together with its deviation values is then presented by axonometric projection. Modern measuring technologies including the use of motorized devices, such as a laser scanner and a motorized total station, allow a surveyor to determine the position of not only characteristic points on the building wall, but also its whole surface. Thanks to these devices we can acquire quite a number of spatial data and thus create three-dimensional models of the researched civil structure.

2. THE DESCRIPTION OF THE RESEARCHED BUILDING

The researched object was the northern side wall of six-storey section C of the building of Technical University of Koszalin, located on 2 Śniadeckich Street (fig. 1). The building was opened for public use in September 2001. The surface layer of its façade was made from thin-coat plaster, which is also used for insulating building in "light-wet" technology - textured plaster with etched - "woodworm" - finish (this information is vital for the exact measurement carried out in one of the applied methods).

So as to determine the deviations of the building wall from the vertical plane two measuring methods were employed:

- **spatial forward intersection,**
- **3D polar method.**

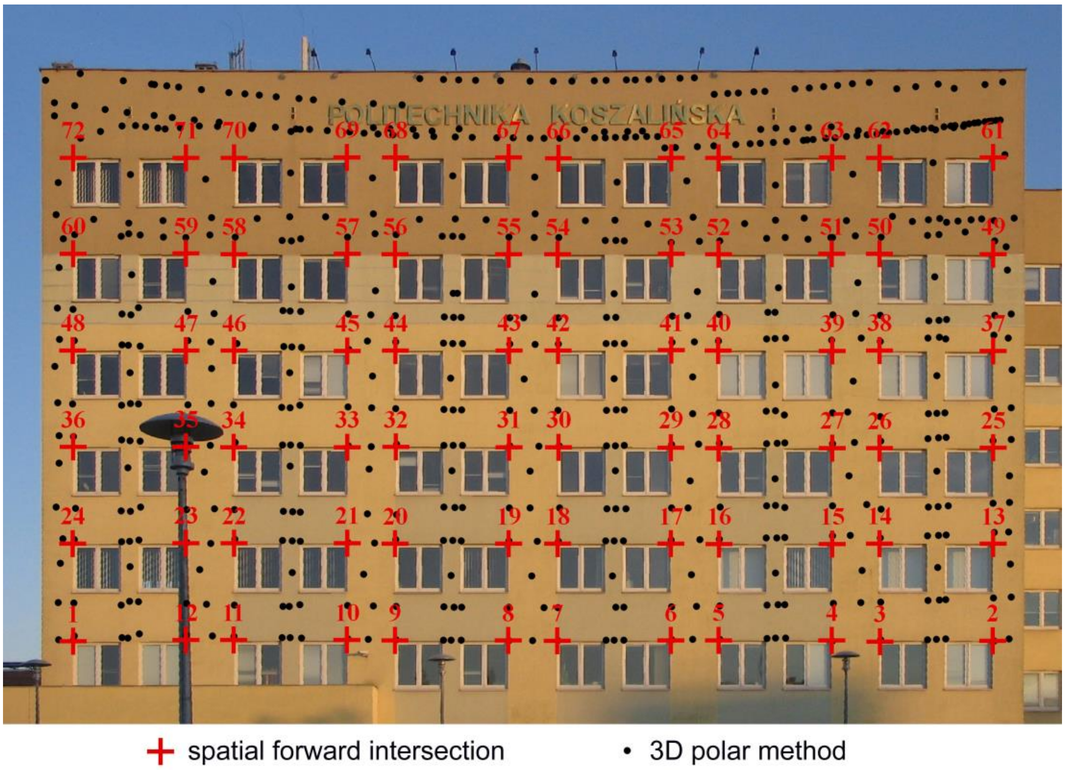

Fig. 1. Location of points which were observed on the researched building.

In order to locate the points, measured by the above mentioned methods, a picture of the wall was taken by using non-metric camera – Canon A85. The photo was then calibrated through the 3rd order polynomial (affine) transformation, with 12 adjustment points, by applying ArcGIS software.

3. MEASUREMENTS TAKEN BY SPATIAL FORWARD INTERSECTION AND 3D POLAR METHODS

The main objective of the spatial forward intersection and 3D polar methods was to determine spatial coordinates of the points observed on the building wall, so as to get the information about its geometry. Observation was conducted by the measurement base placed parallel to the building wall, at a distance of 56 metres (fig. 2). The measurement base consisted of three, stabilized points A, B, C, lying on the straight line, the distances between which were repeatedly measured by Topcon GTS 226 total station. Over-heights between the base points were established by direct levelling with the use of Topcon AT-G7N level. The measuring system was defined by taking the coordinates of point A (10.000; 10.000; 10.000) and OY-axis parallel to the straight line crossing points A, B, C.

The measurement, using the spatial forward intersection, was being taken from point A and C simultaneously, by use of two Topcon GTS-226 total stations. For this measurement two characteristic points were chosen, that is, the ones in the upper corners of the window openings, which formed uniformly laid out grid consisting of 72 nodes. The observation was made at two telescope positions and then averaged values of horizontal and vertical angles were calculated.

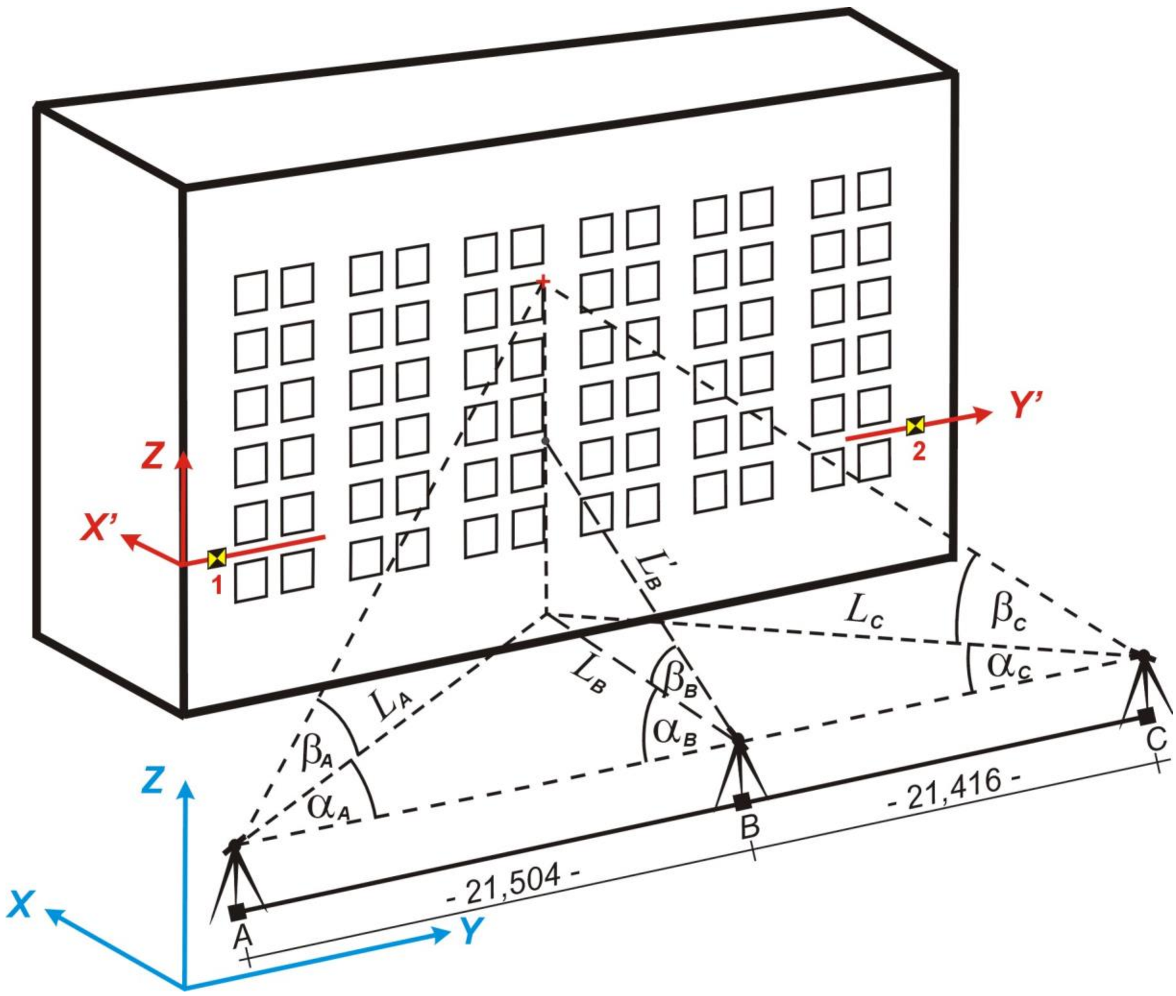

Fig. 2. Diagram of a survey.

The measurement, by applying the 3D polar method, was taken from B measuring position, referring to A and C points, by use of Topcon GPT-3007 reflectorless total station. For this total station is not motorized, the target axis was being manually directed to subsequently observed points. The examined wall was characterised by 586 points, evenly located on the whole surface. All the operations were recorded in the internal store of the measuring device.

4. ACCURACY ASSESSMENT

While measuring deviations of the building wall from the vertical plane, coordinate X of the points observed on the wall, plays the most vital role, whereas coordinates Y and Z indicate only the position of points in the local coordinate system.

In order to estimate the accuracy of X coordinate the least conveniently located point was chosen and measured by spatial forward intersection and 3D polar methods. Measuring position and reference points were claimed to be error-free. To calculate the mean error of X coordinate, set by spatial intersection method, the formula (1), presented in (Pękalski et al., 2003), was applied, together with the following data:

– $\alpha_A = 95.4600^g$, $\alpha_C = 61.7950^g$,

- $L_A = 56.936\ \text{m}$, $L_C = 68.815\ \text{m}$ (as derived from the sin theorem),
- $m_\alpha = \pm 0.0025^g$.

$$m_X = \frac{m_\alpha}{\sin(\alpha_A + \alpha_C)} \cdot \sqrt{L_A^2 \sin^2 \alpha_C + L_C^2 \sin^2 \alpha_A} \qquad (1)$$

$$m_X = \pm 0.005\ \text{m}$$

The mean error of X coordinate, set by the 3D polar method, was determined by applying the formula presented in (Jagielski 2003), when taking the following data:

- $\alpha_B = 99.8480^g$,
- $A_{BA} = 300.0000^g$,
- $L_B = 58.553\ \text{m}$,
- $m_\alpha = \pm 0.0025^g$,
- $m_{L_B} = \pm 0.010\ \text{m}$.

To estimate the accuracy of the polar method, mean error of ±0.010 m was taken under the circumstances that the total station's producer guarantees the accuracy of the measurement taken by the reflectorless total station's as ±0.005 m for the distance of over 25 m. This value was accepted as based on the research carried out in the Laboratory of Geodesy and Cartography of Technical University of Koszalin (Pawłowski, Deska 2006), which concerned the accuracy estimation of the distance measured by GPT-3007 reflectorless total station's, as depending on the angle at which the incidence laser beam upon the object, as well on the surface structure.

$$m_X = \sqrt{\cos^2(A_{BA} + \alpha_B) \cdot m_{L_B}^2 + L_B^2 \cdot \sin^2(A_{BA} + \alpha_B) \cdot m_\alpha^2} \qquad (2)$$

$$m_X = \pm 0.010\ \text{m}$$

From the above results it may be concluded that, for the taken assumptions, the spatial intersection method is more accurate than the 3D polar one which justifies accepting the points determined by this method as the reference points for the further assessment of the 3D polar method.

5. STUDY OF THE MEASUREMENT RESULTS

The results of the measurements taken by spatial intersection and 3D polar methods underwent thorough analysis, which helped to determine spatial coordinates of all observed points on the wall in the measuring system, leading to establishing two independent sets of data. The X and Y coordinates of both sets were then independently transformed into the local coordinate wall system, with the help of Helmert's transformation formula. Two adjustment points, i.e. 1 and 2 (fig. 2) were taken,

sygnallised by reflective plates while the observation. The diagram used for the transformation included the following (Pawłowski, Przewłocki 1997):

- **transformation coefficients:**

$$(u,v) = \begin{vmatrix} \Delta X & \Delta Y \\ \Delta X' & \Delta Y' \end{vmatrix}^{[1,2]} \tag{3}$$

where:

$\Delta X, \Delta Y$ **- increments of coordinates between the adjustment points in the measuring system,**

$\Delta X', \Delta Y'$ **- increments of coordinates between the adjustment points in the local wall system.**

$$u = \frac{\Delta X \cdot \Delta Y' - \Delta X' \cdot \Delta Y}{\Delta X^2 + \Delta Y^2} \tag{4}$$

$$v = \frac{\Delta X \cdot \Delta X' + \Delta Y \cdot \Delta Y'}{\Delta X^2 + \Delta Y^2} \tag{5}$$

- **increments of coordinates in the local coordinate wall system:**

$$(\Delta X', \Delta Y') = \begin{vmatrix} \Delta X & \Delta Y \\ u & v \end{vmatrix}_{1,2} \tag{6}$$

$$\Delta X' = \Delta X \cdot v - \Delta Y \cdot u \tag{7}$$

$$\Delta Y' = \Delta X \cdot u + \Delta Y \cdot v \tag{8}$$

The set of data acquired from the measurement by the 3D polar method was then used to build a model of the wall surface, with the employment of GRID and ArcGIS software. Relying on the bibliography (Gościewski 2005), (Stateczny, Łubczonek 2004), kriging was chosen as the interpolation method with the following parameters:

- **semivariogram model – spherical,**
- **searching radius type – variable,**
- **output cell size – 0.10 × 0.10 m,**
- **number of points in the searching radius – 10.**

Further on, distances of points, marked out by the spatial intersection method, from GRID surface, along OX'-axis were measured, to be interpreted as the measure of compatibility of the surface model with the reference points. The obtained results (fig.3) let to conclude that maximum values of the above distances do not exceed 0.014 m, following the standard deviation of 0.006 m.

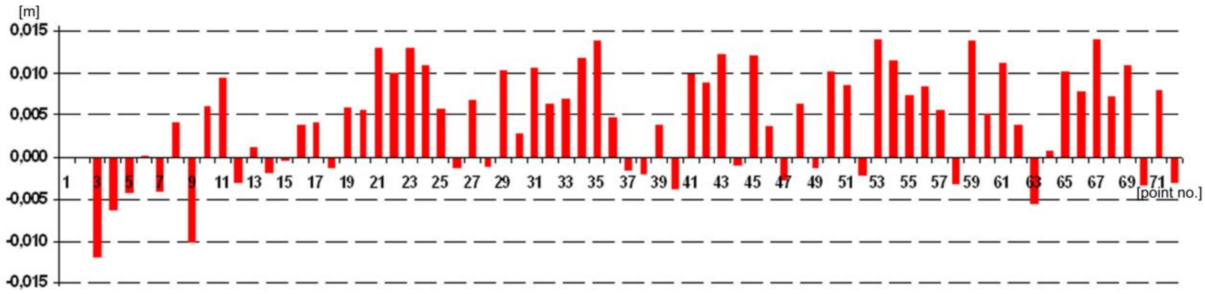

Fig. 3. Distances of points marked out by the spatial intersection method from GRID surface.

Comparability of close points (up to 10 cm) of X' coordinate, obtained from the measurement by spatial intersection and 3D polar methods, was then drawn. It was 14 pairs of points to have been selected, so as to calculate the differences of X' coordinates, the result of which are presented in table 1.

Table 1. Differences of X′ coordinates of the chosen pairs of points.

No	$X'_{\text{spatial intersection}} - X'_{\text{3D polar method}}$ (m)	No	$X'_{\text{spatial intersection}} - X'_{\text{3D polar method}}$ (m)
1	0.013	*8*	-0.006
2	0.006	*9*	-0.012
3	0.013	*10*	0.011
4	-0.010	*11*	0.003
5	0.004	*12*	0.011
6	0.000	*13*	0.007
7	-0.004	*14*	0.012

The above table shows that in only four out of fourteen cases, the determined value of difference ΔX′ slightly exceeds the interval defined by the mean error $m_{\Delta X'} = \sqrt{0.005^2 + 0.010^2} = \pm 0.011\ m$ (accepting that $m_{\Delta X'} = m_{\Delta X}$). This result may justify the moderately positive evaluation of the 3D polar method against the spatial intersection method, within measuring scope, which involves establishing X' coordinate for the purpose of evaluating the vertical plane of the building wall.

6. VISUALIZATION OF BUILDING WALL GEOMETRY

The geometry of the researched wall was presented in a graphic form by axonometric projection, calibrated projection and DTM. The deviation values of 72 points from the vertical surface, measured by the spatial forward intersection, are presented in fig. 4. The calculations of the 3D polar measurement are presented in three-dimensional form and the map with isolines (fig. 5), which were made with the help of the Surfer software. For better readability of the figure, size of the GRID cell was changed into 0.5 × 0.5 m.

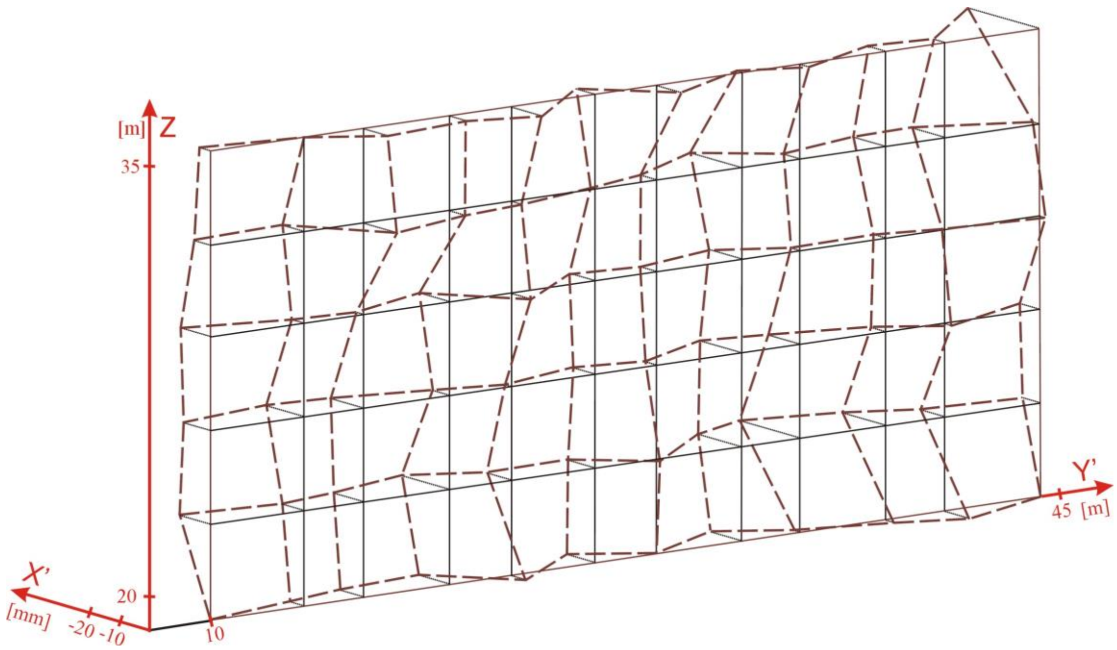

Fig. 4. Deviations from the vertical reference plane obtained from the spatial forward intersection measurement.

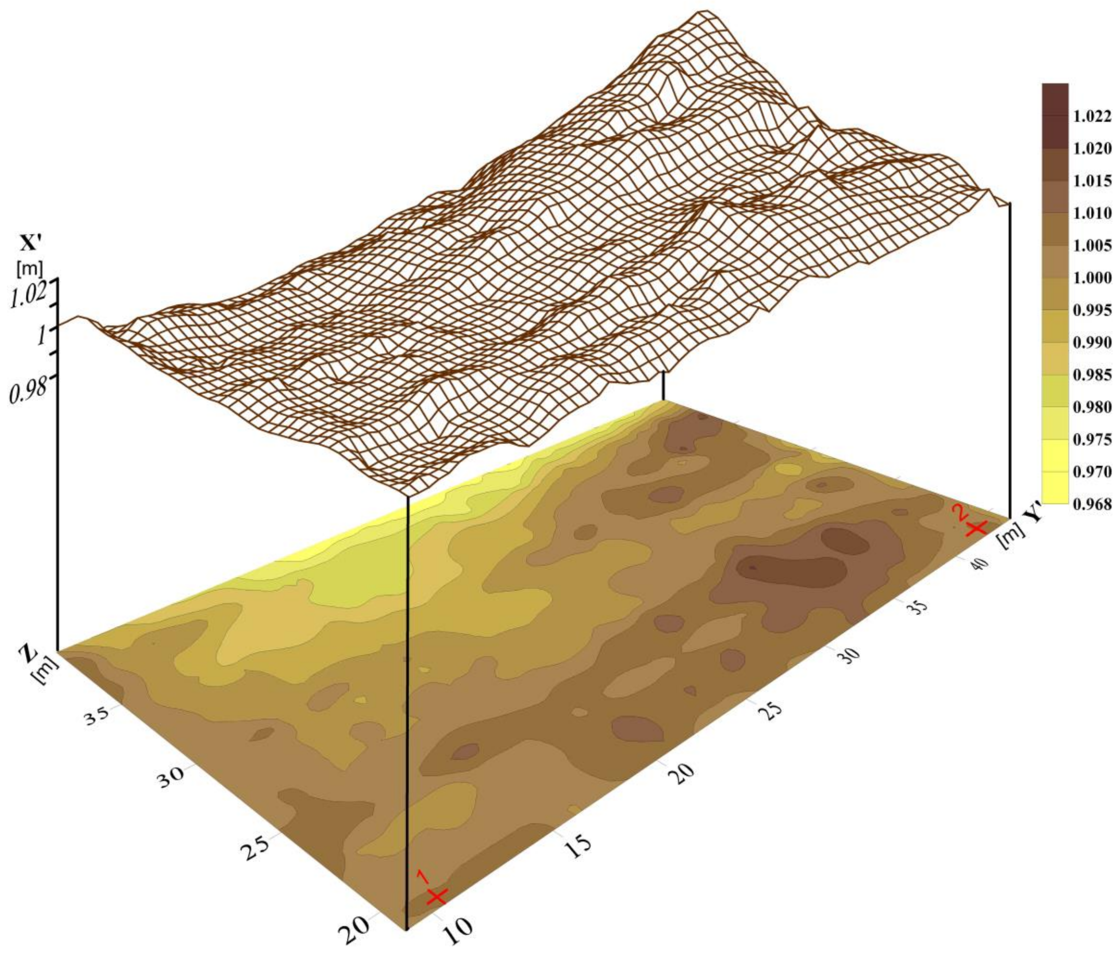

Fig. 5. Model of the building wall and its projection onto a horizontal plane as a form of the graphical-analytical presentation of the results of the 3D polar method.

7. CONCLUSIONS

While researching the geometry of a building wall, deviations from its vertical plane at characteristic points of the façade are usually determined with millimetre accuracy. When the centimetre accuracy is viewed as adequate for marking out the points of the researched wall, the polar 3D method can be successfully applied by use of any measuring device as accurate as GPT-3007 total station.

Measuring the accuracy of determining the location of point by the polar 3D method is mostly influenced by distance measuring error, which depends on the precision of a total station, as well as on the surface structure of the building and the incidence angle of laser beam glancing on the surface. The researched surface is properly determined if the above parameters are favourable. To make the measurement quicker and more effective, observations are advised to be taken with the help of a motorized device, which may also provide more data.

Data obtained from the measurement taken by the polar 3D method can prepare for creating DTM and observing it on the computer screen in three-dimensional system. It should be emphasized that the term of numerical terrain model is frequently associated with any research carried out in 3D system (Bojarowski 2005). This way of visualization is favourable for its user, and in case of cyclic observations at definite intervals, it helps to make comparisons, as well as statistical and spatial analyses. The results may then be presented as cross-sections or by creating differential surfaces.

REFERENCES

Bojarowski K. 2005. Analizy przestrzenne i statystyczne w projektowaniu i ocenie stanu obiektów z wykorzystaniem NMT. Materiały VII Konferencji Naukowo-Technicznej nt.: Aktualne problemy Geodezji Inżynieryjnej. Warszawa/Białobrzegi. (Spatial and statistical analyses in designing and assessing buildings with the use of DTM. The materials of the 7th Science and Technology Conference on: Current problems of Engineering Geodesy. Warsaw/Białobrzegi).

Pękalski M. 2003. Ćwiczenia terenowe z geodezji inżynieryjnej i miejskiej. Oficyna Wydawnicza Politechniki Warszawskiej. Warszawa. (Field practice on Engineering and urban geodesy. Publishing house of the Technical University of Warsaw).

Gościewski D. 2005. Tworzenie numerycznego modelu terenu typu GRID z wykorzystaniem kombinacji algorytmów interpolacyjnych. Materiały XIX Jesiennej Szkoły Geodezji. Wrocław. (Development of numeric GRID-type land model using combinations of interpolar algorithms. The materials of the 19th Autumn School of Geodesy. Wrocław).

Jagielski A. 2003. Geodezja II. P.W. Stabil, Kraków. [Geodesy II. Published in Kraków].

Pawłowski W., Przewłocki S. 1997. Pomiary inżynierskie metodami geodezyjnymi. Wydawnictwo Politechniki Łódzkiej. Łódź. (Engineering measurements by geodetic methods. Publishing house of Technical University of Łódź).

Pawłowski W., Deska K. 2006. Koncepcja metodyki testowania tachimetrów z laserowym dalmierzem impulsowym w kontekście pomiarów struktury geometrycznej przekryć wiszących Zeszyty Naukowe Politechniki Łódzkiej. (The concept of testing methods of total stations with a pulsed laser rangefinder in the context of measurement of the geometrical structure of suspended roofs. Academic booklets of Technical University of Łódź).

Stateczny A., Łubczonek J. 2004. Modele powierzchni terenu. Metody nawigacji porównawczej. Gdynia. (Models of land surface. Comparable navigation. Gdynia).

Wasilewski A., Mroczkowski K. 1999. Próby ustalenia zależności między obserwowanymi przemieszczeniami a stanem naprężeń. Biuletyn Naukowy ART Olsztyn. (Study on the relation between dislocations and stresses. Academic booklet of Olsztyn).