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METHODS OF REVALUATION OF FORMER GEODETIC MEASUREMENT NETWORKS

Marek Ślusarski

Summary

Geodetic field measurements carried out in the past when establishing and updating the land registers were based directly on geodetic measurement networks. The accuracy parameters of these networks are lower compared to modern geodetic measurement networks. Currently, archival materials of the National Geodetic and Cartographic Resources are used in surveying works on real estate. The following paper presents and evaluates three methods of improving the accuracy parameters of former registry and measurement networks. The first method (I) involves transforming the coordinates of former network points into a current coordinate system based on the coordinates of the adjustment points. The second method (II) is based on a strict alignment of a geodetic network together with additional measurement of selected points to strengthen the network. The third method (III) consists of an inventory and measurement of all existing points of former geodetic networks and a strict alignment of the network to determine the coordinates of destroyed points. The effectiveness of the revaluation methods of former networks was assessed on the basis of experimental studies using data from test objects. Satisfactory results of the improvement of accuracy parameters of the network were achieved by the method (I) in those cases in which the ratio of the number of adjustment points to the total number of tested points was approx. 1/3. Similarly, for the method (III), satisfactory results can be achieved if approx. 30% of network points are used as additional control points. However, in the method (II), good results can be achieved if the percentage of searched-out points used as control points is only about 10% of all network points. Examining the complex surveying works (fieldwork and inhouse studies) has shown that both the method (I) and the method (II) of revaluation of geodetic networks have similar efficiency.

Keywords

modernisation of land and building registry • cadastre • spatial data quality

1. Introduction

The Land and Building Register (EGiB) – according to the Geodetic and Cartographic Law Act [2021] – is understood as an official register that guarantees a uniform national system of collection, updating, and sharing information on land, buildings, and premises, their owners and other entities owning or managing these land, buildings or premises. Subsequent changes in legal regulations are aimed at creating the EGIB as a full-value system for recording real estate data.

The accuracy of the location of spatial objects in databases is described using two attributes: data source and position error [Zandbergen 2008, ISO 2013]. The main attribute characterising an evidential parcel is the numerical description of boundaries along with the data on boundary points. The data on boundary points are described, among others, by the identifier, rectangular coordinates, the method of obtaining data on a point, and information on meeting the accuracy standards. The position of boundary points should be determined in relation to the points of the horizontal geodetic or measurement control network with an accuracy of not less than 0.10 m [Regulation on the land and building registration, Rozporządzenie w sprawie ewidencji gruntów i budynków 2021]. This provision excludes the possibility of using techniques other than geodetic measurements to create a numerical description of the boundaries of cadastral parcels – meeting the accuracy standards in force. However, the modernisation of the EGiB and standard surveying works on real estate (divisions, delimitations) require using archival materials of the National Geodetic and Cartographic Resources.

Geodetic field measurements carried out when establishing and updating land registries were based directly on registry and measurement networks [Technical instruction B-III 1965, Instrukcja techniczna B-III 1965, Surowiec 1987]. Geodetic networks were established in the form of multi-row polygon lines and multi-row measuring lines. These networks are characterised by low accuracy parameters caused by [Ślusarski and Justyniak 2017]:

- disproportionately lower precision of angular and linear measurements in relation to modern measurement techniques,
- low accuracy and low number of control points,
- multi-row nature of the network as a result of the limitations of computational techniques of the time and different periods in which the surveying work was carried out,
- approximate methods of network alignment.

Measurement networks established in the 1980s and 1990s of the 20th century were characterised by higher accuracy in relation to registry networks. By the provisions set out in the Technical Instruction G-4 [1983], the points of the geodetic measurement network should have been determined with a position error of not more than 0.20 m, and for agricultural and forest areas – not more than 0.50 m. However, the accuracy parameters of these networks are lower compared to modern geodetic measurement networks. The main reasons for this are [Ślusarski and Justyniak 2017]:

- disproportionately lower precision of linear measurements in relation to modern measurement techniques,
- the duality of the network resulting from the limitations of computational techniques of the time,
- approximate network alignment techniques.

Registry and measurement networks were the basis for the reference for measurements of boundary points carried out mainly by the orthogonal method. Therefore, it is possible to determine the average location error of a boundary point, which is affected by the average errors of measurement techniques and control networks. For orthogonal measurements, controlled by the geodetic network – following the principles set out in the Technical Instruction G-4 [1983] – it can be assumed that the average location error of a boundary point in relation to a detailed geodetic control network will not be greater than ±0.31 m, by the equation [Adamczewski 2005]:

$$m_{P\max} = \sqrt{m_1^2 + m_2^2 + m_3^2 + m_4^2} = 0.31 \text{ m} \tag{1}$$

where:

$m_1 = 0.10$ m – average error of measurement by the orthogonal method,
$m_2 = 0.15$ m – average error of the second-order measurement line,
$m_3 = 0.15$ m – average error of the first-order measurement line,
$m_4 = 0.20$ m – average error of the geodetic measurement network.

Based on the model of the composition of errors occurring during measurements by the orthogonal method (1), it can be estimated that for a certain group of boundary points the acceptable average error value will be exceeded. For this reason, it will be possible to use archival technical reports containing data on geodetic measurements of the boundaries of cadastral parcels to a limited extent. For geodetic works, where archival materials are used, the methodology of improving the accuracy parameters of the former measurement networks is of key importance.

2. Proposed methods of revaluation of the former networks

The former registry and measurement networks are characterised by low accuracy, and they lack homogeneity. Restoring the former value to these geodetic networks requires the use of several methods, in the implementation of which new measurements should be made for some points and the realignment of the network and transformation of coordinates should be performed. Based on the author's own experience and research work on the assessment of the data quality of official spatial databases, a set of three methods of improving the accuracy parameters of the former networks was defined [Ślusarski and Jurkiewicz 2017].

The first method (I) includes the transformation of the coordinates of the points of the former networks into the current coordinate system. The second method (II) is based on a strict alignment of the geodetic network along with additional measurement of selected points to strengthen the network. The third method (III) consists of the inventory and measurement of all existing points of the former geodetic networks and strict alignment of the network to determine the coordinates of destroyed points.

The implementation of the intended goal – improvement of the accuracy parameters of the former geodetic network – will be achieved as a result of surveying measurement and calculation works, defined in detail in the scope of each method.

For the method (I) entitled 'Transformation of the coordinates of the points of the former networks into the current coordinate system', four stages of the procedure were specified:

1) measurement of (selected) existing points in the field that belong to the former network, using the RTN GNSS technique and the polar method;
2) calculation of coordinates of the measured points;
3) calculation of transformation parameters from the original system to the '2000' system, using the existing network points in the field as adjustment points;
4) transformation of coordinates of surveyed object points from the original system to the '2000' system, taking into account the Hausbrandt corrections.

For method (II) entitled 'Strict alignment of the network with the additional measurements for its strengthening', eight steps of the procedure were defined:

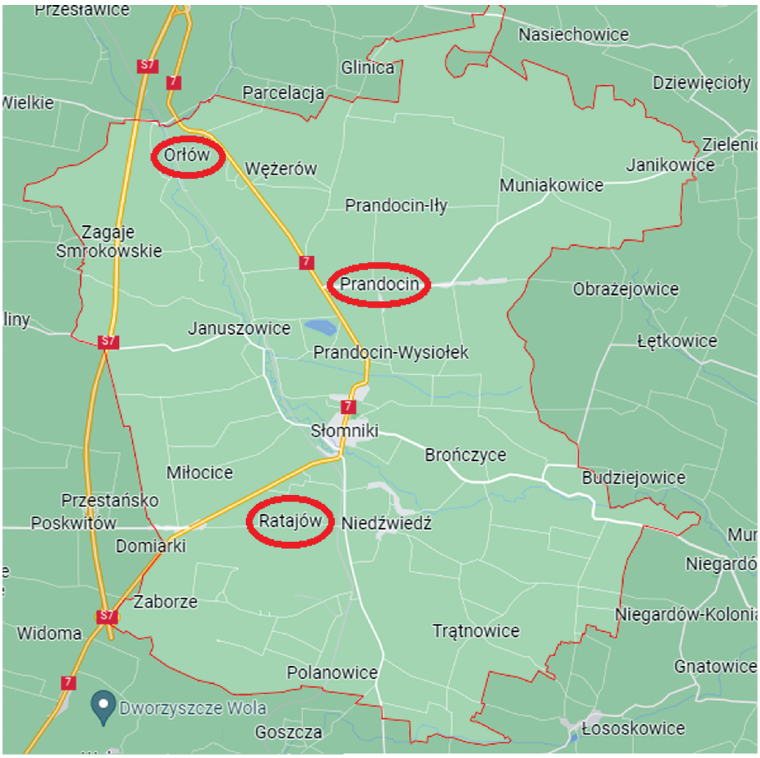
1) creating, based on source (archive) reports, sets of angular and linear observations;
2) aligning parts of the geodetic network in the '2000' system in reference to the current geodetic network using the intermediary method;
3) analysis of alignment results; selection of points and observations that do not meet the accuracy requirements, based on position error and corrections to angles and distances;
4) selection of network points that do not meet the accuracy requirements to find them in the field and perform additional measurements;
5) measurement of existing network points in the field using the RTN GNSS technique and the polar method;
6) calculation of coordinates of the measured points;
7) re-aligning the former network with the error assumption of the measured reference points, based on the average errors of their coordinates (X and Y);
8) analysis of alignment results; for points that do not meet the accuracy requirements in the network – additional measurements; finally, exclusion of polygon sequences that do not meet the accuracy parameters from the network.

For the method (III) 'Inventory and measurement of all existing points of the former network', five stages were defined:

1) searching in the field for all existing points of the geodetic network based on source measures (angles and distances) and coordinates of these points from the geodetic resource,
2) measurement of the existing in the field points of former networks by the RTN GNSS technique and the polar method,
3) calculation of searched out coordinates and measured points,
4) list of points that were not searched out,
5) creation of sets of angular and linear observations for destroyed points on the basis of source (archive) reports,

6) alignment of the network of destroyed points (in the ‘2000’ system) by the intermediary method with reference to the geodetic control network and the measured points, with the error assumption of reference points based on their average errors for coordinates X and Y.

The revaluation of the accuracy parameters of the former control network can be carried out as a result of additional surveying, measurement, and calculation work. The size and scope of these works will vary depending on the quality of the archival materials used and the applied method of conduct. Experimental tests were run to assess the efficiency of improving the accuracy parameters of the former registry and measurement networks by the three proposed methods. Three test objects located in the Słomniki municipality (Małopolskie voivodeship) were analysed (Fig. 1).



Source: Municipal Office in Słomniki., https://slomniki.pl/

Fig. 1. Location of test objects

The tested geodetic networks come from three different cadastral districts. These networks were established in the 1960s and 1970s for surveying work performed when establishing and updating both the base map and the cadastral map. The District

Centre for Geodetic and Cartographic Documentation has lists of coordinates of the network points in the '1965' and '2000' systems. In the Geodetic Resource, there are also archival technical reports containing measurement data, allowing to calculate the coordinates of measurement network points.

The three analysed objects were located in the Słomniki municipality. For the test object 'A', 151 points were tested, for the object 'B' – 183 points, and for the object 'C' – 237 points. As a result of the measurement works, 59 points on the premises of 'A', 49 on 'B' and 73 on 'C' were inventoried, which constitutes 39%, 27%, and 31% of all points respectively (Table 1). The position of the searched out points was determined on the basis of the results of measurements using the tachymetric method and the technique of precise GNSS positioning. The position of these points was determined in relation to the geodetic network with an accuracy not exceeding ±0.03 m. The estimated accuracy of the position of the points of the tested networks was determined on the basis of displacement vectors of the test sample points (searched out network points) in relation to their position considered to be error-free (determined coordinate values). The preliminary assessment of the accuracy of the tested measurement networks shows that the geometric accuracy of the points of these geodetic networks ranges from ±0.29 m to ±0.38 m (Table 1). The required accuracy for the measurement network points ($\mu \le$ 0.20 m), which were in force until 2011, is met only by 18% to 35% of the tested points.

Table 1. Basic statistics of the tested networks

Statistics	Object symbol		
	'A'	'B'	'C'
Number of points of the former control network	151	183	237
Number and percentage of searched out control network points in the field	59/39%	49/27%	73/31%
Estimated accuracy – average value (μ) [m]	0.29	0.38	0.36
Percentage of points for which $\mu \le 0.20$ m	35%	18%	23%

Therefore, it can be concluded that the position errors for more than 65% of boundary points can exceed the limiting value of 0.10 m with respect to the measurement network. The global improvement of the accuracy parameters of boundary points can be achieved by the revaluation of those networks that were the basis for geodetic measurements.

3. Results and discussion

According to the current regulations, the average error of position of the points of the horizontal geodetic network may not be greater than 0.10 m in relation to the points of the horizontal geodetic network [Regulation on technical standards, Rozporządzenie w sprawie standardów technicznych 2020]. The location of boundary points should be determined in relation to the points of a horizontal geodetic or measurement control network with an accuracy of not less than 0.10 m [Regulation on the land and building registration, Rozporządzenie w sprawie ewidencji gruntów i budynków 2021]. However, the coordinates of boundary points shall be modified if the deviation expressed by the square root of the sum of the squares of the differences between the previous boundary point coordinates and the coordinates of that point obtained as a result of the new geodetic measurements is greater than 0.15 m [Rozporządzenie w sprawie standardów technicznych 2020].

Based on the above values, it was assumed that the boundary error of the measurement network point position ($m_{OSNOWAmax}$) cannot exceed 0.15m. Therefore, the results concerning the methods of revaluation of former networks were related to the value of the determined boundary error of the network point position.

The first method (I) involves transforming the coordinates of the former network points into a current coordinate system based on the coordinates of adjustment points. In the experimental research, the searched-out and measured points of the former networks were used (Table 2). The first-degree conformal transformation with Hausbrandt post-transformation corrections was applied [Wysocki 2011]. Local coordinate systems were realised by geodetic networks and measurements as conformal systems (no corrections to angles were introduced). Conformal transformation preserves the local shape of figures from the original system [Kadaj 2000].

Table 2. Estimated accuracy of networks in the process of coordinate transformation (Method I)

Statistics	Object symbol		
	‘A’	‘B’	‘C’
Number of tested network points	59	49	73
Total number and the ratio of adjustment points	6/10%	5/10%	8/11%
Estimated accuracy – average value (μ) [m]	0.26	0.35	0.34
Total number and the ratio of adjustment points	18/30%	15/31%	23/31%
Estimated accuracy – average value (μ) [m]	0.18	0.22	0.21
Total number and the ratio of adjustment points	30/51%	25/51%	37/51%
Estimated accuracy – average value (μ) [m]	0.13	0.16	0.15

In the process of coordinate transformation, appropriately selected sets of adjustment points were used. The percentage of these points in the total number of points investigated was about 10%, 30%, and 50%, respectively. Satisfactory results ($\mu \approx 0.20$ m) of the improvement of accuracy parameters of the networks in the process of coordinate transformation were achieved in cases in which the ratio of the number of adjustment points to the total number of surveyed points was about 1/3 (Table 2). The boundary-value of the average points' position ($\mu \leq 0.15$ m) of the tested networks will not be exceeded in cases where the ratio of adjustment points to the total number of surveyed points was about 50% (Table 2).

The second analysed method (II) is based on a strict alignment of the network with additional measurements aimed at strengthening the network. In the experimental studies – at the first stage – coordinates of points of the tested networks were determined on the basis of archival source materials. Results of the alignment (Table 3) show that the average accuracy (m_p) of the position of points of those networks is within the range from 0.25 m to 0.36 m (Tab. 3). Required accuracy ($m_p \leq 0.15$ m) was not fulfilled for any of the analysed objects.

Table 3. Initial numerical and accuracy characteristics of networks (Method II)

Parameter		Object symbol		
		'A'	'B'	'C'
Number of tested network points		151	183	237
Number of reference points (geodetic network)		16	19	24
Number of observations	linear	165	203	262
	angular	180	219	285
The error of point position [m]	average (m_p)	0.25	0.36	0.32
	maximum ($m_{\max}$)	0.38	0.55	0.49

In the second stage of this method (II) the tested networks were reinforced with additional control points originating in those networks. The percentage of additional control points in the total number of tested points was about 10% (Table 4). The results of the re-alignment (Table 4) show that the average error (m_p) in the position of points of the tested networks ranges from 0.15 m to 0.18 m, and the maximum error ranges from 0.20 m to 0.26 m. For 90% of points of the tested networks, the position error would not exceed the boundary value $m_{\mathrm{OSNOWAmax}} = 0.15$

Table 4. Resulting numerical and accuracy characteristics of networks (Method II)

Parameter		Object symbol		
		'A'	'B'	'C'
Number of selected network points		136	164	213
Number of additional control points and percentage of tested points		17/11%	19/10%	24/10%
The error of point position [m]	average (m_p)	0.15	0.18	0.16
	maximum ($m_{\max}$)	0.21	0.26	0.23
Number and percentage of points for which $m_p \leq 0.15$ m		126/93%	147/90%	193/91%

The third analysed method (III) is based on inventory and measurement of all existing points of the former network. In the experimental research the points of former networks were used, the percentage of which in the total number of the surveyed points was about 30% (Table 5). The results of the accurate alignment show that the average error (m_p) of position for the points of the tested networks ranged from 0.13 m to 0.16 m, and the maximum error ranged from 0.19 m to 0.22 m (Table 5). For 92% of points of the tested networks, the position error would not exceed the boundary value $m_{\text{OSNOWAmax}} = 0.15$.

Table 5. Numerical and accuracy characteristics of networks (Method III)

Parameter		Object symbol		
		'A'	'B'	'C'
Number of tested network points		151	183	237
Number of control points (geodetic network)		16	19	24
Number of additional control points and percentage of tested points		50/33%	49/27%	72/30%
Number of selected network points		130	160	211
The error of point position [m]	average (m_p)	0.13	0.16	0.14
	maximum (m_{max})	0.19	0.22	0.19
Number and percentage of points for which $m_p \leq 0.15$ m		126/97%	147/92%	198/100%

Satisfactory results of the improvement of the accuracy parameters of the tested network were achieved for each of the three analysed methods. The realisation of the intended goal – the revaluation of the former network – was achieved as a result of additional surveying, measurement, and calculation work. The scope of these works will determine the effectiveness of the proposed methods of revaluation of the networks.

Measurable results of improvement of the accuracy parameters of the networks were achieved by the method (I) (coordinate transformation), in those cases where the ratio of the number of adjustment points to the total number of surveyed points was approx. 1/3. Similarly for the method (III) (inventory and measurement of all searched out points), satisfactory results can be achieved if approx. 30% of network points are used as additional control points. However, in the method (II) (strict alignment of the network with the additional measurement), good results can be achieved when the percentage of searched out points and used as reference points are only about 10% of all network points.

4. Conclusions

The archival materials of the National Geodetic and Cartographic Resource may be used only to a limited extent during the execution of surveying works on real estate (divisions, demarcation, modernisation of land records). A visible increase in the size of the used archival data can be achieved by the revaluation of the former registry and measurement networks. Improvement of the accuracy parameters of these networks will be achieved through the use of one of three approaches: the transformation of the coordinates of the points of the former network based on the coordinates of the adjustment points; strict alignment of the network with the additional measurement for strengthening the network; inventory and measurement of all existing points of the former networks.

Analysing the effectiveness of the proposed methods of revaluation of the networks, it was found that the method (II) requires the least effort in terms of inventory and measurement of additional network points used in the process of strict alignment as control points. However, in this method, it is necessary to additionally prepare sets of angular and linear observations on the basis of source technical reports. When examining the complex surveying works (field works and inhouse studies), it was concluded that both the method (I) and the method (II) of revaluation of the geodetic network are characterised by similar costs.

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Dr hab. inż. Marek Ślusarski
University of Agriculture in Krakow
Faculty of Environmental Engineering and Land Surveying
Department of Land Surveying
ul. Balicka 253 a, 30 198 Kraków
e-mail: marek.slusarski@urk.edu.pl
ORCID: 0000-0002-8573-936X