



EXPERIMENTAL EVALUATION OF THE ACCURACY PARAMETERS OF FORMER SURVEYING NETWORKS

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Abstract

Surveying field measurements performed during the development and updating of land registry were based directly on measuring networks. Accuracy parameters of these networks are lower in comparison with modern measurement networks. The main reasons for the lower accuracy relate mainly to the lower precision of measurements, two orders of network and approximate techniques for determining the coordinates of the points of these networks. Currently, archival materials of the State Geodetic and Cartographic Resource are used during surveying of real estate (division, separation, modernization of land registry). The paper presents the results of experimental evaluation of the accuracy parameters of former networks. The purpose of the performed evaluation was to analyze the possibilities of use archival materials of the State Geodetic and Cartographic Resource during surveying works related to real estate. The study was carried out on the basis of three test objects located in the Małopolskie voivodship. Points of the analyzed networks found on the ground were measured (approx. 34% of all points), and then their coordinates were determined. The representative research sample was constituted by sets of deviations Z – the length of the displacement vector of the point in the research sample in relation to its position considered as error free.

The basic estimator of the accuracy of analyzed networks was the root mean square error RMSE. This estimator was determined on the basis of a vector Z^* originating from the set, from which the outlying observations were removed. Values of calculated RMSE show, that for the analyz-

ed objects the required accuracy is met by no more than 16% of the points of the networks ($RMSE \leq 0.20$ m). Therefore, it may be concluded, that for more than 80% of the border points the average position errors exceed the threshold size: 0.30 m relative to the 1st class geodetic network. Hence the conclusion that during surveying real estate, archival materials of the State Geodetic and Cartographic Resource should be used in a limited scope.

Keywords: modernization of land and building registry, cadastre, spatial data quality

INTRODUCTION

According to the Geodetic and Cartographic Law (2015) land and buildings registry (EGiB) is understood as an information system that ensures the collection, updating and sharing, in a uniform manner for the whole country, information on land, buildings and premises, their owners and the other entities maintaining or managing the land, buildings or premises. Subsequent changes to the legislation are moving towards the creation of EGiB as a fully-fledged system of recording data on real estate (Regulation 2001). Implemented in the whole country modernization of land and buildings registry databases substantially affect the gradual improvement of the quality of the data collected there.

The main features that describe the quality of the EGiB database are: location accuracy and completeness and actuality of sets (Felcenloben 2011). The accuracy of the location of objects is characterized by two attributes: the data source and the position error. For plots, the numerical description of their borders should be implemented by means of border points, which position in relation to the geodetic control network of the 1st class has been determined on the basis of surveying situational measurements with an error not exceeding an average of 0.30 m. This provision excludes the possibility of using other techniques than the surveying measurements, to create a numerical description of the boundaries of the plots. However, during the performance of typical surveying works related to real estate (division, separation) and during the modernization of EGiB, the archival materials of the State Geodetic and Cartographic Resource can be used. The purpose of the performed evaluation of the accuracy parameters of the old measuring networks was to analyze the possibilities of use archival materials of the State Geodetic and Cartographic Resource during surveying works related to real estate.

Surveying field measurements performed during the creation and updating of the land registry were based directly on registry and measurement networks. The registry networks were created in the form of multi-order traverses and

multi-order measuring lines. These networks are characterized by low accuracy parameters, the sources of which were:

- disproportionately lower precision of angular and linear measurements in relation to the modern measurement techniques,
- low accuracy and a small number of control points,
- multi-order networks what was the result of the limitations of former computational techniques and from different time periods in which the surveying works were carried out,
- approximate methods of networks adjustment.

Measuring networks created in the 80s and 90s of the twentieth century were characterized by higher accuracy in comparison to the registration networks. According to the provisions set out in the Technical Manual G-4 (1983), points of measurement network are determined with the average position error not greater than 0.20 m, and for agricultural land and forests with error not greater than 0.50 m. However, the precision parameters of these networks are lower than in contemporary measuring networks. The main causes of lower accuracy are:

- lower precision of linear measurements in relation to the modern measurement techniques,
- two-orders of networks, what was the result of the limitations of former computational techniques,
- approximate methods of networks adjustment.

Registry and measurement networks constituted a reference to the coordinate system for measurements carried out for border points using orthogonal or polar methods. Therefore, the mean error of the position of the border point can be determined. The size of the error depends on the mean errors of measuring techniques and reference networks. For polar measurements referred to geodetic networks – in accordance with the provisions set out in the Technical Manual G-4 (1983) – it can be assumed that the average error of the position of the border point in relation to the geodetic control network of the 1st class is not greater than 0.25 m, according to the formula:

$$m_{P1max} = \sqrt{m_1^2 + m_2^2 + m_3^2 + m_4^2} = 0.25 \text{ m} \quad (1)$$

where: $m_1 = 0.10 \text{ m}$ – mean square error of the measure by polar or orthogonal method,
 $m_2 = 0.20 \text{ m}$ – mean square error of the measurement network,
 $m_3 = 0.10 \text{ m}$ – mean square error of the III class network,
 $m_4 = 0.05 \text{ m}$ – mean square error of the II class network.

In the case of orthogonal measurements dialed to the geodetic network in accordance with conditions as in the case of the polar method it can be assumed that the mean square error of the position of the border point in relation to the geodesic network class 1 is not greater than 0.33 m, according to the formula:

$$m_{P2max} = \sqrt{m_1^2 + m_5^2 + m_6^2 + m_2^2 + m_3^2 + m_4^2} = 0.33 \text{ m} \quad (2)$$

where: $m_5 = 0.15 \text{ m}$ – mean square error of the measuring line of the II order,
 $m_6 = 0.15 \text{ m}$ – mean square error of the measuring line of the I order.

On the basis of the errors composition model by the polar measurements (1), it can be estimated that the mean square error of the border points position determined by this measurement technique will not exceed the limit value (0.30 m) specified in the current provisions. In the case of orthogonal measurements (2) for a certain group of border points acceptable value of mean square error will be exceeded. For this reason, the archival documentation containing technical data on the surveying measurements of the plots borders can be used to a limited extent. Therefore it is essential for the works related to the EGiB modernization, where the archival materials are used the evaluation of former accuracy parameters of the measurement networks.

MATERIAL AND RESEARCH

The positional accuracy is a key element of the spatial data quality, which directly affects the value of performed geospatial analysis. The positional accuracy is assessed by the accuracy of the geometrical objects, which relates mainly to the proximity of coordinate values in relation to the values considered to be error-free. The dominant approach in the analysis of the accuracy of the spatial databases objects positions is the method based on a representative set of control points coordinates, used to determine the values characterizing errors factors. This method is the basis of the analyses presented in the research works (Zandbergen 2008, Liao *et al.* 2010, Doskocz 2013). It is also used in national and international technical standards.

For the purposes of this study, the research of measurement network accuracy was carried out using three test objects located in the Małopolskie voivodship. The analyzed data are derived from the National Geodetic and Cartographic Resource and include areas of three registry precincts in Olkusz commune in the Olkusz district. The examined networks were created in the 60s and 70s of the twentieth century for the surveying works performed for creation and updating the basic map and the registry map. In the Geodetic Resource there are archival

technical documentations including measurement data allowing calculation of the coordinates of the measuring networks points.

On the basis of archival documentation a number of measurement networks points were determined, which were calculated using geodetic measurements, and their results are included in the technical documentation. For the object marked "A" it is 230 points, for the object "B" 207 points, and the object "C" 185 points. As a result of the measuring works done by the authors 75 points in the area of the object "A" were surveyed, 83 for „B" and 56 on „C", which equals respectively 33%, 40% and 30% of all points. Existing in the field, points of analyzed networks may constitute research attempt, provided that the requirements of representativeness are maintained.

The requirement of the representativeness of a sample of data is described with two conditions: the randomness of the sample and the appropriate sample size. The randomness of the sample means, that each element of the general population has an equal probability to enter the sample population. Uniform distribution of the points, found in the field around the test area, fulfills the condition of the data sample randomness (fig. 1).

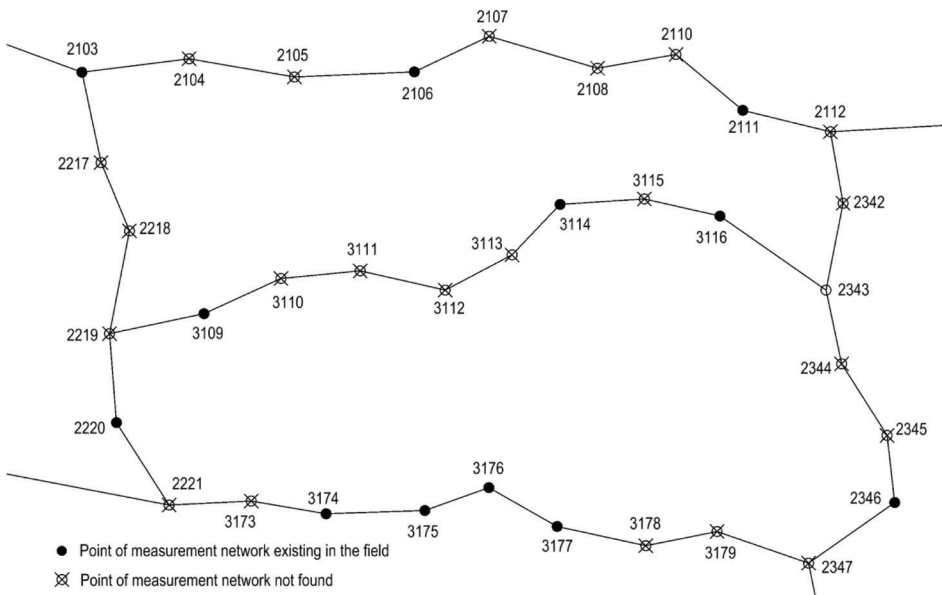


Figure 1. Fragment of the measuring network sketch with the results of the inventory

Sample size needed to estimate the accuracy of the position with assumed in advance probability level can be determined by the confidence interval for the standard deviation. The formula for the minimum sample size is given by (Volk 1965):

$$n = \frac{x^2 \sigma^2}{2e^2} \quad (3)$$

where: n – the minimum size of the statistical sample,
 x – value of the random variable X with the standardized normal distribution $N(0, 1)$,
 σ – standard deviation,
 e – confidence interval.

Assuming, that the positional accuracy of spatial data will be determined with the probability $P = 0.99$, for which $x = 2.58$ and nominal accuracy of $\sigma = 0.20$ m, with the confidence interval, $e = 0.05$ m. then the minimum sample size calculated with the formula (3) would be $n = 54$. The number of points found in the terrain, respectively, for objects 75, 83 and 56 fulfill the condition of minimum size of the research sample.

In the next part of the work analyses of the positional accuracy of the points of measurement networks are shown in relation to the geodesic network. The research sample was constituted by the sets of the deviations Z – the length of the shift vector of the point in the research sample in relation to its position considered error-free. The elements of the research sample were correctly identified and clearly traced in the area surveyed points of the studied networks. The location of the points in the research sample, which can be considered error-free, were determined on the basis of results of tachometric measurements method and precision GNSS positioning technique. The position of these points was determined in relation to the geodetic network with the accuracy not exceeding ± 0.03 m.

Elements of the research sample can contain outliers. In the case of the experimental data, including the field of geodesy and cartography, data samples contain individual information about randomly selected objects, for which it is assumed that all of them have the same accuracy characteristics. Apart from obvious mistakes, every measurement observation provides information on the accuracy of the data set; therefore determination of outliers should be based on precisely defined rules. For the determination of outliers the method for assessing the significance of differences between two means can be used. In testing of outliers the significance of difference: $|X_{outlier} - X_{average}|$ should be evaluated. Statistics t (Greń 1987, Ney 1976) is determined according to the formula:

$$t = \frac{|X_{outlier} - X_{average}|}{\sigma \sqrt{\frac{1+n}{n}}} \quad (4)$$

where: σ – standard deviation,
 n – size of the sample.

For determination of outliers for three objects, in terms of investigating measuring networks accuracy, variable Z was adopted for the analysis. Table 1 shows the size of the vector Z , the values of which is the boundary of outliers sets, calculated using the t -statistic (4) and for identifying the so-called cut sets. The determined cut sets formed the basis of made by the authors of the paper analyzes of the accuracy. The percentage of elements considered outlying for each of the three objects is not greater than 5% (tab. 1).

Table 1. Determination of outliers in research samples

Symbol of the object		
„A”	„B”	„C”
The threshold value of the vector Z on the basis of the statistics t		
0.70	0.81	0.60
The threshold value of the vector Z used to create the cut sets Z^*		
0.65	0.75	0.60
The number and percentage of outlying elements		
9 / 4%	10 / 5%	5 / 3%

RESULTS AND DISCUSSION

The basic features of the studied random variable distribution are determined using central tendency (position) and concentration measure (Adamczewski 2005; Wiśniewski 2005). In the process of testing the accuracy of measurement networks variables Z^* were analysed which are elements of the sampling cut sets. In the three analyzed sets, for the variable Z^* indices of dispersion and concentration of the distribution of the studied feature (position accuracy) were determined. The average value μ , median M , standard deviation σ , minimum and maximum values, quartile range, skewness S and kurtosis Ku were calculated (tab. 2).

All tested sets are asymmetric ($S \neq 0$) to a varying degree; what confirms the influence of a systematic factor. Negative values of kurtosis (according to the definition used now – for the normal distribution $Ku = 0$) indicate the presence of large number of medium deviations in the sets, and fewer number of large and small deviations in relation to the size from the normal distribution. This is a typical situation for the cut sets originating from empirical measurements, which are subjected to the rigors of the limit errors (Ney 1976). The difference between the median M and the average value μ is not significant; what means that there are no outliers in data sets.

Table 2. Descriptive statistics of the measuring networks accuracy

Statistic	„A”	„B”	„C”
	Z*	Z*	Z*
The quantity of set (<i>n</i>)	66	73	51
Average value (μ)	0.41	0.46	0.34
Median (<i>Med</i>)	0.41	0.45	0.32
Standard deviation (σ)	0.15	0.16	0.12
Minimum value	0.15	0.18	0.15
Maximum value	0.65	0.74	0.60
Quartile range	0.27	0.29	0.23
Skewness (<i>S</i>), error (<i>S</i>) = 0.15	-0.05	0.15	0.47
Kurtosis (<i>Ku</i>), error (<i>Ku</i>) = 0.27	-1.28	-1.21	-0.64

Preliminary assessment of the accuracy of tested measurement networks shows, that the geometrical accuracy of the networks points is in the range from ± 0.34 m to ± 0.46 m. (tab. 2). The basic estimator of accuracy of the analyzed networks will be the mean square error RMSE, determined on the basis of vectors Z^* , originating from the set, from which the outliers were deleted. Coefficient $RMSE_Z$ is given by the formula:

$$RMSE_Z = \sqrt{\frac{1}{N_R} \sum_{i=1}^N Z_i^{*2}} \tag{5}$$

In the case of the assumption that the coordinates of the reference points are characterized by the values accepted as error-free, then $RMSE_Z$ the estimator of the true errors of geometric position of the network points. Determination of the mean square error according to (5) will be correct in the case of the assumption that the errors are normally distributed, and the deviations in relative to the *X* and *Y* coordinates are independent. In addition, for the variable *Z* (with probability $P = 0.95$) Circular Error (CE) was determined using the formula (Czaja 1996; ISO 19157 2013):

$$CE_{95}_Z = 1,7308 \cdot RMSE_Z \tag{6}$$

For test sets also percentiles (90., 95. and 99.) and root mean square error RMSE (90%, 95% and 100%) were calculated. The values of calculated estimators are shown in Table 3. The values of calculated percentiles 90 and 95 are approx. 1.5 times higher than the corresponding estimates of RMSE (90 and 95). These differences are related to the skewness of the distribution of the variable

Z, which affects the relationship between the standard deviation and percentiles. Value of the CE95 statistics should be comparable to the 95th percentile. In the present case for the data from all three objects, CE95 overestimates the 95th percentile of 11% to 20%.

Table 3. Estimators of measurement networks accuracy

Estimator	Symbol of the object		
	„A”	„B”	„C”
90. percentile [m]	0.61	0.70	0.54
95. percentile [m]	0.62	0.71	0.56
99. percentile [m]	0.64	0.73	0.59
90% RMSE [m]	0.41	0.46	0.33
95% RMSE [m]	0.42	0.47	0.35
100% RMSE [m]	0.43	0.48	0.36
CE95 [m]	0.74	0.85	0.62

Determinate accuracy of the networks measurement points (estimated using the RMSE coefficient) and the numerical range, where with the probability of $P = 0.99$ is the index, shown in table 4. The determined values of estimators μ and RMSE are comparable to each other, the differences do not exceed 5%.

Table 4. Estimated accuracy of measurement networks

Estimator	Object symbol		
	„A”	„B”	„C”
Determined value			
Average value ()	0.41 ± 0.04	0.46 ± 0.05	0.34 ± 0.03
RMSE	0.43 ± 0.05	0.48 ± 0.06	0.36 ± 0.03

The values of estimators μ and RMSE (tab. 4) show, that the average values of the position errors of measurement networks points for the three test items are in the range from 0.34 m to 0.46 m. For all the analyzed cases the average values of positional errors do not meet the required accuracy ($RMSE \leq 0.20$ m). Analyzing intervals of RMSE values (tab. 5) it was stated, that for the analyzed objects only 12% to 16% of the points of measurement networks meet the required accuracy. In the next interval of values (0.21m–0.50 m) there are more

than half of the punkts (approx. 63%). About 24% of examined measurement networks points is characterized by RMSE ratio > 0.51 m.

Table 5. The RMSE size in accordance with the value intervals

Value interval	Object symbol		
	„A”	„B”	„C”
	Number and percentage of network points		
RMSE ≤ 0.20 m	8 / 12%	7 / 10%	8 / 16%
0.21 m \leq RMSE ≤ 0.50 m	43 / 65%	47 / 64%	31 / 61%
RMSE > 0.51 m	15 / 23%	19 / 26%	12 / 23%

CONCLUSIONS

On the basis of the results of the study it can be concluded that during surveying works related to real estate (division, separation, modernization of land records) archival materials of the State Geodetic and Cartographic Resource can be used to a limited extent. One of the reasons for these restrictions is insufficient precision of the part measurements network points. In the case of the analyzed objects no more than 16% of the points of the networks (RMSE ≤ 0.20 m) meet the required accuracy. Therefore it may be concluded that over 80% of the border points, the average position errors exceed the threshold value: 0.30 m in comparison to the geodesic network of the first class.

Global improvement of the precision parameters can be achieved through the strict alignment of measurement networks on the basis of the source measurement (angles and lengths). This network will be connected to the points of geodetic network and measured (existing in the field) points of the renewed measurement network.

REFERENCES

- Adamczewski A. (2005). *Teoria błędów dla geodetów*. Oficyna Wyd. PW w Warszawie.
- Czaja J. (1996). *Modele statystyczne w informacji o terenie*. Wyd. AGH w Krakowie.
- Doskocz A. (2013). *Metodyka oceny dokładności wielkoskalowych map cyfrowych*. Wyd. UWM w Olsztynie.
- Felcenloben D. (2011). *Geoinformacja. Wprowadzenie do systemów organizacji danych i wiedzy*. Wyd. Gall w Katowicach.
- Gręń J. (1987). *Statystyka stosowana*. PWN Warszawa.

Instrukcja technicznej G-4. *Pomiary sytuacyjne i wysokościowe*. (1983). GUGiK Warszawa.

ISO. (2013). *ISO 19157: Geographic information – Data quality*.

Liao S.B., Bai Y., (2010). *A new grid-cell-based method for error evaluation of vector-to-raster conversion*. *Computational Geosciences*, 14, 539–549.

Ney B. (1976). *Metody statystyczne w geodezji*. Uczelniane Wyd. Naukowo-Dydaktyczne AGH w Krakowie.

Rozporządzenie Ministra Rozwoju Regionalnego i Budownictwa z dnia 29 marca 2001 r. w sprawie ewidencji gruntów i budynków (Dz.U. Nr 38, poz. 454, z późn. zm.).

Ustawa Prawo geodezyjne i kartograficzne z dnia 17 maja 1989 r. (Dz. U. z 2015 r., poz. 520 z późn. zm.).

Wiśniewski Z. (2005). *Rachunek wyrównawczy w geodezji*. Wyd. UWM w Olsztynie.

Volk V. (1965). *Statystyka stosowana dla inżynierów*. WNT Warszawa.

Zandbergen P.A. (2008). *Positional Accuracy of Spatial Data: Non-Normal Distributions and a Critique of the National Standard for Spatial Data Accuracy*. *Transactions in GIS*, 12(1), 103–130.

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