DOI: 10.22616/j.balticsurveying.2019.016

DIFFERENTIATION OF REQUIREMENTS FOR THE ACCURACY OF CADASTRAL SURVEYS: THE VALUE OF REAL ESTATE AS A DETERMINING FACTOR

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Abstract
For millennia, the geodesic industry has improved methods and technologies for obtaining information on the location of objects on the Earth's surface, whose key task has been to improve the accuracy and reliability of measurements. At the same time, in recent decades, the rapid development of positioning technologies based on satellite radio navigation systems has created prerequisites for a situation where the acceptable accuracy of determining the geodetic characteristics of real estate becomes quite affordable even when using non-specialized geodetic equipment, including personal mobile devices. The article shows that the error in determining the area of land for registration of rights to real estate has its own "cost", which depends on the value of real estate in the area of survey. By the example of model sites, it is shown that further improvement of the accuracy of engineering surveying to determine the spatial characteristics of real estate objects would be economically feasible only if the cost of geodetic surveys (including the cost of purchasing new geodetic equipment, payment for labor of specially trained engineers, additional technical services and etc.) will not exceed the "cost of error" to determine the area of the site. Using the example of Ukraine, it is shown that the most accurate geodetic surveys (determining turning points of land borders with an accuracy of more than 0.02 m) are economically feasible only when the market value of a land plot exceeds USD 208 per square meter.
Key words: accuracy, geodetic surveys, value of land, cadastral registration.

Introduction

At the current pace of development of satellite and network technologies, the role of man in performing topographic and geodetic surveys in the field of land management is decreasing. In particular, today the use of GNSS-technologies has practically replaced the basic methods of creating geodetic networks for various geodetic works (triangulation, trilateration, polygonometry), including the determination of the coordinates of the turning points of the land plot during cadastral surveys and land inventories, the establishment of boundaries of the land plot on the ground.
Existing differentiation of accuracy and cost of topographic and geodetic surveys, in particular, for the purpose of inventory of land, creates preconditions for further research in the field of engineering economics, namely:

- definition of the dependence of the cost of topographic and geodetic works in the field of land management on the accuracy of these works;
- estimation of the efficiency of using modern satellite technologies for the purpose of the real estate cadastre (especially when installing (fixing) the turning points of the land plot within the permissible error of 0.5 meters), and determining the prospects for using these mobile gadgets (smartphones, tablets, etc.) for these purposes;
- the establishment of acceptable accuracy of topographic and geodetic surveys in the real estate cadastre depending on the market value of the land plot.

Problems of establishing the requirements for the accuracy of land cadastral papers were undertaken by various scientists, in particular, Zhilinsky (2013) tried to investigate the influence of economic factors on the accuracy of geodetic measurements during cadastral works, and established, in the conditions of the city of Lviv, the size of the error of determining the area of land in cash equivalent (Жилінський, 2013).
Petrov and Tserklevich (2011), found that the change in the mean square error (MSE) of determining the coordinates of the points of land plots boundary proportionally affects the change in the MSE of their area.
Kristin M. Stock (1998) carried out a sociological study, in which she insisted on the accuracy of establishing the boundaries of the land in the countryside. It is determined that the overwhelming majority of surveyed landowners, including local authorities and relevant municipal organizations in the study area, require the maximum accuracy of establishing the boundaries of the land plot in the range of +/- 0.2 and +/- 0.5 m.

An analysis of the historical stages of the development of technologies in geodesy and their impact on the accuracy of land cadastral surveys is presented in the scientific publication Belle A. Craig and Jerry L. Wahl (2003).
At the same time Tim Burch (2017) in his article draws attention to the fact that the development of modern GNSS technologies reduces the relevance of the classical study of geodetic surveying methods and minimizes the role of a certified geodesist specialist in the implementation of various types of land cadastral work (Tim Burch, 2017).

Methodology of research and materials

The current state of the development of GNSS technologies allows you to get the coordinates of the points with the maximum possible accuracy of 1 meter (raw data by satellite observations) even under favorable observation conditions (PDOP, GDOP, etc.).
It is clear that for the purpose of land management, the accuracy of positioning in 1 m is not permissible, such circumstances directly influenced the development of appropriate positioning methods for achieving higher accuracy in determining the planned height position of the reference points: the static method; fast static; RTK – Real Time Kinematics.
However, the use of RTK mode involves receiving amendments from the base station, that is, from the receiver which is set at a point with a known (true) coordinate, points of the state geodetic network. To date, such base stations have permanent stations.
In Ukraine, the main organizations that hold national networks of GNSS permanent stations are private companies, as described in table 1.

Table 1

Analysis of Private Permanent Networks to Provide GNSS Surveillance Data Adjustment in Ukraine

Name	System Solutions	TNT TPI GNSS Network	Zak Pos
1	2	3	4
GNSS brand equipment offered by the company	Leica Geosystems	TOPCON	Trimble
The cost of services:			
Real-time positioning (RTK)			
1 hour	-	12 UAH	-
1 minute	4 UAH RINEX & Virtual RINEX – 1.20 UAH	0.70 UAH	1.75 UAH
1 month subscription	-	600 UAH	1 160 UAH
Subscription 3 months	5820 UAH	1600 UAH	-
Annual subscription	16080 UAH	5700 UAH	11 600 UAH
Post processing raw file in RINEX format	50 UAH	-	-
Equipment rental	1 day – 1000 UAH / day; 2-6 days – 800 UAH / day; 7-13 – days 760 UAH / day; 2 weeks – 8745 UAH; month – 17000 UAH	Do not provide such services (only the sale of equipment)	Do not provide such services
Precision farming	from 7000 UAH	from 900 UAH	-

The above information was taken into account when further development of the estimate of the cost of geodetic works in establishing the boundaries of the land plot (table 2).

Table 2

Calculation of the cost of geodetic works in relation to fixing the boundaries of the land plot

The level of acceptable accuracy for the purpose of inventory of land			GNSS technology		Estimate of the cost of geodetic works in relation to the establishment of the boundaries of the land plot ***				Number of employees	Cost of determining the boundaries of the land plot
			The type of the most effective method for achieving the correct accuracy	Geodetic binding	Cost of data on the coordinates of the item of the state geodetic network (reference points) *	Rent for the required geodetic equipment **	Cost of receiving RTK corrections **	Total		
I	a	up to 2 cm	Static	State geodetic network (reference points)	3×150 UAH = 450 UAH	Base + Rover (GNSS Leica GS08Plus (GS12) + CS10) – 2000 UAH/day; Tacheometer (Leica TS09plus R500 (5″)) – 1000 UAH/day;	-	3450 UAH	2	300 UAH / point (at the same time the minimum cost of departure of a surveyor is 1500 UAH)
	b	2-10 cm	Real Time Kinematic (RTK)	Permanent stations + SGN point for calibration	150 UAH	Rover (GNSS Leica GS08Plus (GS12) + CS10) – 1000 UAH/day;	5820 UAH/3 month →1 day=65 UAH	1215 UAH	1	300 UAH / point (at the same time the minimum cost of departure of a surveyor is 1500 UAH)
II		10-20 cm	RTK	Permanent stations + SGN point for calibration	150 UAH	Ровер (GNSS Leica GS08Plus (GS12) + CS10) – 1000 UAH/day;	65 UAH/day	1215 UAH	1	300 UAH / point (at the same time the minimum cost of departure of a surveyor is 1500 UAH)
III		20-50 cm	RTK	Permanent stations	-	Ровер (GNSS Leica GS08Plus (GS12) + CS10) – 1000 UAH/day;	65 UAH/day	1065 UAH	1	300 UAH / point (at the same time the minimum cost of departure of a surveyor is 1500 UAH)

*- according to the Research Institute of Geodesy and Cartography [2];
**- according to System Solutions (Table 1);
***- in the indicated estimate there are no calculations for logistics costs, since these data are individual for each object.

In Ukraine, in accordance with the Resolution of the Cabinet of Ministers of Ukraine dated May 23, 2012, No. 513 "On Approval of the Procedure for Land Inventory Management", the error of determining the turning points of land plots relative to the nearest points of the state geodetic network should not exceed (Resolution of the Cabinet …, 2012):

- in Kyiv, Sevastopol and cities of regional subordination – 0.1 meters;
- in other cities and towns – 0.2 meters;
- in villages – 0.3 meters;
- outside of settlements – 0.5 meters.

The stated allowable accuracy of determining the position of the turning points of the land plot on the ground, we have been based on the analysis of the cost of topographic and geodetic works, namely:

- when choosing effective methods of creating a reference geodetic network – the most accurate differential method in the application of GNSS technologies is the "Static" method, which allows to determine the position of points (sampling ground) to 1 mm, and then, with the help of the geometry, fix the boundaries of the land plot to within 10-20 mm; At the same time, the application of the polygonometric method, in modern technologies, is inappropriate, except for the presence of dense building, densely planted areas – forest arrays, etc.
- in determining the required geodetic equipment and the number of performers. According to the above methods, for the purpose of achieving the appropriate precision, we have identified the kits of the required equipment and presented their market lease payment (System Solutions. Rental…),

determined on the basis of (Table 2) the amount of payment for receiving RTK corrections, and the cost of coordinates of the outgoing points of the State Geodetic Network (Official website. State…).

It is important to note that at the time of drafting the estimate of the cost of land cadastral works for fixing the boundaries of the land, the rate of USD – 28.12 UAH / $ (official data of the National Bank of Ukraine as of 18.09.2018), and the average wage in Ukraine – 7621 UAH / month ($ 271) (Official website. Pension …).

Thus, from the above calculations in Table 3, we have the cost of geodetic works for fixing the boundaries of the land plot with an accuracy of I-a of 45.27% of the average monthly salary in Ukraine and requires two executors, and II – 15.94% (one performer), III – 13.97% (one performer).

In fact, we have established a direct correlation between the accuracy and cost of topographic and geodetic works in relation to fixing the boundaries of the land plot on the ground, that is, what is "higher precision" so "higher price".

Discussions and results

According to the results of our analysis, we can further speak about the dubious necessity of conducting high-precision geodetic surveys (in view of their high cost) for the purpose of land cadastre, in particular, inventory of land and the establishment of boundaries of land in the area. We believe that achieving high accuracy in conducting geodetic works in the field of land cadastre is an indirect necessity, which should be determined based on the market value of the surveyed land plot.

Subsequently, our studies concerned the definition of acceptable accuracy of land cadastral work, which in our opinion, should be determined on the basis of economic factors. That is, in order to find out the expediency of implementing high-precision topographic and geodetic works in the field of land cadastre, it is necessary to compare the error of the definition of the area and market value of the corresponding land with the cost of geodetic works.

Conditionally, if a plot of land has the shape of a rectangle whose sides a and b are defined with average square errors m_a and m_b accordingly, then the error of determining the area of the land S, according to the theory of errors, will be determined by the formula:

$$m_s^2 = (\frac{\partial s}{\partial a})^2 \times m_a^2 + (\frac{\partial s}{\partial b})^2 \times m_b^2 \quad (1)$$

We find partial derivatives:

$$\frac{\partial s}{\partial a} = b; \frac{\partial s}{\partial b} = a \quad (2)$$

Having defined partial derivatives we have the general formula for determining the error of the area of the land plot of a rectangular shape, with certain errors in measuring the length (m_a) and width (m_b):

$$m_s^2 = b^2 \times m_a^2 + a^2 \times m_b^2 \quad (3)$$

Thus, mathematically proved and quite understandable is the fact that the error in the area of the land will be directly affected by the error of determining the linear elements (boundaries) of the land.

Consequently, in general, if the value of f is expressed in terms of independently measured values x_i (i = $\overline{1, n}$) – the coefficients, then the mean square error m_f of the value of f will be

$$m_f = \pm\sqrt{\sum_{i=1}^{n} a_i^2 \times m_i^2} = \pm\sqrt{[a^2 \times m^2]} \quad (4)$$

If the measurements x_i (i = $\overline{1, n}$) are equivalent and $m_1 = m_2 = \ ... \ = m_n = m$, then:

$$m_f = \pm m\sqrt{[a^2]} \quad (5)$$

The resulting formula for the mean square error is obtained from the relation::

$$m_F^2 = (F_x')_0^2 \times m_x^2 + (F_y')_0^2 \times m_y^2 + \ ... + (F_u')_0^2 \times m_u^2, \quad (6)$$

and expressions for partial derivatives of f for arguments x_i:

$$\frac{\partial f}{\partial x_i} = a_i, \left(i = \overline{1, n}\right). \quad (7)$$

At the same time, the function to determine the area of the land plot with known coordinates of the turning points, will have the following form:

$$S = \frac{1}{2}\sum_i^n X_i(Y_{i+1} - Y_{i-1}) \quad (8)$$

In this case, the margin of error in determining the area of the land will be determined by the following formula:

$$m_s = \sqrt{1/4\sum_{i=1}^n\{(X_{i+1} - X_{i-1})^2 \times m_y^2 + (Y_{i+1} - Y_{i-1})^2 \times m_x^2\}} \quad (9)$$

where m_x, m_y – mean square error of the coordinates of the turning points of the land plot.
In the course of our study, we determined the margin of permissible error in determining the area of land. To do this, simulation of the size of the land plot, which in shape corresponded to the figure of the rectangle, with different perimeters (lengths) of the parties in the range from 0.01 ha to 5 hectares. The average quadratic error in determining the position of turning points was determined in accordance with the Resolution of the Cabinet of Ministers of Ukraine dated May 23, 2012 No. 513 (Resolution of the Cabinet …, 2012) (Table 3).

Table 3

Calculation of the error of the area of land

№	**Placement of land [1]**	**The average square error of determining the position of the turning points of the land (m) [1]**	**Calculation of the error of the area of land, m²**					
			Land area, ha					
			5	**1**	**0.5**	**0.25**	**0.10**	**0.01**
			Perimeter, m					
			895	**400**	**283**	**200**	**128**	**40**
1	Kiev, Sevastopol city and cities of regional subordination	to 0.02 (high precision)	17.9	8	5.66	4	2.56	0.8
		0.1	89.5	40	28.3	20	12.8	4
2	in other cities and towns	0.2	179	80	56.6	40	25.6	8
3	in villages	0.3	268.5	120	84.9	60	38.4	12
4	outside of the settlement	0.5	447.5	200	141.5	100	64	20

Thus, we have calculated the errors in determining the area of land ($S_1 = 0.01\ ha$; $S_2 = 0.10\ ha$; $S_3 = 0.25\ ha$; $S_4 = 0.50\ ha$; $S_5 = 1.00\ ha$; $S_6 = 5.00\ ha$), taking into account the errors of the position of the turning points ($m_1 = 0.02\ m$; $m_2 = 0.1\ m$; $m_3 = 0.2$ м; $m_4 = 0.3\ m$; $m_5 = 0.5\ m$) (table 3).
The next stage of our study was to determine the acceptable accuracy of establishing the boundaries of the land due to its market value. Taking into account the data of Table 2 (cost of topographic and geodetic works) and table 3 (size of errors in land parcels) and taking into account the norms of the current legislation (Resolution of the Cabinet …, 2012), we determined the minimum size of land values to achieve cost-effective implementation of high-precision geodetic measurements in the field of inventory of land (table 4).
That is, we justified the marginal market value of the land plot, in which the implementation of topographic and geodetic works of appropriate accuracy will be economically feasible in the field of land cadastre.
From the data obtained (Table 4), it is safe to say that precise geodetic work (determination of the position of the turning points of the land plot to 0.02 m), in view of their high cost, in comparison with other, it is expedient to carry out in cases where the market value of 1 m² the land plot reaches 207.59 m² / $ when establishing boundaries of a land plot with a total area of 0.01 hectares; 64.87 m² / $ –

land area of 0,10 hectares; 41.52 m² / $ – land area of 0.25 hectares; 29.34 m² / $ – land area of 0.50 hectares; 20.76 m² / $ – land area of 1.00 hectares; 9.28 m² / $ – land area of 5.00 hectares.

Table 4

Economic feasibility of the implementation of topographic and geodetic works

I – Economic feasibility of carrying out topographic and geodetic works with high accuracy						
1-a) mean square error of determination of the position of the turning points of the land plot to 0.02 m						
Land area, ha	5.00	1.00	0.50	0.25	0.10	0.01
Error in the area of the land, m²	17.90	8.00	5.66	4.00	2.56	0.80
Market value of land to achieve economic effect, 1m² / $	9.28	20.76	29.34	41.52	64.87	207.59
II – Economic feasibility of carrying out topographic and geodetic works with the correct accuracy						
1) mean square error of the definition of the position of the turning points of the land plot of 0.1 m						
Land area, ha	5.00	1.00	0.50	0.25	0.10	0.01
Error in the area of the land, m²	89.50	40.00	28.30	20.00	12.80	4.00
Market value of land to achieve economic effect, 1m² / $	0.96	2.16	3.05	4.31	6.74	21.56
2) mean square error of the definition of the position of the turning points of the land plot of 0.2 m						
Land area, ha	5.00	1.00	0.50	0.25	0.10	0.01
Error in the area of the land, m²	179.00	80.00	56.60	40.00	25.60	8.00
Market value of land to achieve economic effect, 1m² / $	0.48	1.08	1.52	2.16	3.37	10.78
3) mean square error of the definition of the position of the turning points of the land plot of 0.3 m						
Land area, ha	5.00	1.00	0.50	0.25	0.10	0.01
Error in the area of the land, m²	268.50	120.00	84.90	60.00	38.40	12.00
Market value of land to achieve economic effect, 1m² / $	0.32	0.72	1.02	1.44	2.25	7.19
4) mean square error of the definition of the position of the turning points of the land plot of 0.5 m						
Land area, ha	5.00	1.00	0.50	0.25	0.10	0.01
Error in the area of the land, m²	447.50	200.00	141.50	100.00	64.00	20.00
Market value of land to achieve economic effect, 1m² / $	0.19	0.43	0.61	0.86	1.35	4.31

At the same time, given the high cost of high-precision geodetic equipment and the rapid development of modern telecommunication technologies (smartphones, tablets) with the support of positioning technologies (GNSS-technology), it is extremely important to provide a scientific and practical evaluation of the use of these electronic gadgets in the implementation of land -capital works (surveying, inventory of land, establishing boundaries of the land plot on the ground), especially when the marginal error of the performance of these works must be achieved in range 20 – 50 cm, depending on the location of the land (in other cities and towns – 0.2 meters, in villages – 0.3 meters, outside the settlements – 0.5 meters (Resolution of the Cabinet …, 2012)).

For example, to date, Xiaomi has been developed and offered to users, the new flagship Xiaomi Mi 8, equipped with a dual-frequency GPS module L1 + L2. In fact, the Mi 8 is now the most accurate GPS-module on the market among smartphones, which can actually be used for land cadastral works, provided that there is adequate software (coftu) for receiving RTK corrections from GSM base stations (Groupe Special Mobile) – channel (GPS Worldwide Laboratory …).

The urgency of the use of modern electronic gadgets for geodetic measurements, is confirmed by studies conducted by NextNav (2018) (GPS World Staff, 2018). In the course of the study, vertical

position accuracy was determined, with the help of different models of phones and signals from the installed network of beacons NextNav. The services provided by NextNav's Metropolitan Beacon System (MBS) allow mobile phones and other devices to reliably determine their location in space, enclosed spaces, and urban environments where GPS signals can not be obtained.
With regard to special applications for smartphones, for the full use of GNSS technologies, an interesting development is the soft product "GNSS Compare" (Tracy Cozzens, 2018). This software displays general information about GNSS satellite systems, allows the user to choose, the best satellite constellation for precise positioning, compare the performance of signals between different satellite systems, and so on.

Conclusions and proposals

As a result of the calculation, we obtained the following results, in particular, with an average square error of the installation of turning points up to 2 cm, a land plot of 0.01 hectares (rectangular – 4 turning points), the error of the area will be 0.8 m², 0.10 hectares – 2.56 m², 0.25 ha – 4.00 m², 0.5 ha – 5.66 m², 1 ha – 8.00 m², 5 ha – 17.9 m².
Accurate surveying (determining the position of the turning points of land to 0.02 m), because of their high cost, compared with others, it is advisable to in cases where the market value of 1 m² of land reaching 207.59 m² / $ in determining the boundaries of the land plots with a total area of 0.01 ha; 64.87 m² / $ – land area of 0.10 hectares; 41.52 m² / $ – land area of 0.25 hectares; 29.34 m² / $ – land area of 0.50 hectares; 20.76 m² / $ – land area of 1.00 hectares; 9.28 m² / $ – land area of 5.00 hectares..
We are convinced that in the near future the development of technologies (software) in the field of telecommunications, satellite positioning techniques, GNSS-technologies will allow ordinary landowners to carry out land-cadastral surveys of their land plots (up to 0.5 m accuracy) with the help of modern smartphones. This is confirmed by the tendency to use gadgets (special software, in particular, Pix4D, DJI Go, etc.) and UAVs in cadastral surveys, which have changed the general pursuit of aerial photography, photogrammetry as a whole. As a result, existing technologies have allowed users to process the results of photographing automatically.

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