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EFFICIENCY OF APPLICATION OF SATELLITE TECHNOLOGY WHEN PERFORMING LAND AND CADASTRAL WORKS IN SETTLEMENTS

Purpose. The purpose of this work is to study the effectiveness of using satellite technology in real-time kinematics mode for work performed to determine the areas of land of different size within a settlement. **Methodology.** To realize this purpose we have conducted experimental research on satellite observation points and triangulation of polygonometry in Chernihiv and the region. During the research it was assumed to get the control coordinates on the basic points from static observation. For basic triangulation points around Chernihiv were selected – Kyiinka (KIIN) Yatsevo (JATS) Glushets (GLUS), where three teams spend the first day of observation in "static" mode for over 4 hours. During this time, the other three teams conducted observations at points of the city polygonometry, each time starting with the hour mode "Fast-Static" and then in RTK-mode. Then rover receivers were set to receive amendments of the network System.NET. For this in the controllers there were created six projects that had a different configuration. The research resulted in modeling of objects of different shapes and sizes. For this, we used a network of urban polihonometry, and triangulation points around Chernihiv, where satellite observations were performed. Nine models of landfills were planned, the areas of which were calculated based on coordinates issued from the catalog coordinates and measured using RTK mode by satellite receivers. The program-methodical complex, developed by scientists of the Scientific and Research Institute of Geodesy and Cartography, were used for transformation and recreation of coordinates. **Results**. Coordinates transformation from MSC into SC-63 were completed by the key and formulas, and then transformation of the coordinates x, y in Gauss-Kruger coordinates into geodetic coordinates B, L via formulas was performed. For theoretical defining of area of the ellipsoid site we used method of numerical integration per a contour that is specified by geodetic latitude B and longitude L. In order to reduce errors in cartographic projections in the cities we used the local coordinate system, the mathematical basis of which is Gauss – Kruger projection with a displaced axial meridian. Considering the fact that the distortion in this case will be minimal, calculation of areas of intended object models was carried via the coordinates in the local system. In accordance with our program of satellites observations at the points of polygonometry and triangulation, the measurements were carried out in real time in six different configurations. Based on the analysis of these studies, we analyzed the dependence of the measured areas on modeled land plots by defining coordinates using settelite observations and evaluated the accuracy of such definitions, as well made a conclusion on the possible permissible values of distortions of land areas within the boundaries of a settlement. **Scientific novelty**. The data of the research again confirm the efficacy of using RTK observations and re-course to a new geodetic framework created on the base of modern measuring GNSS-technology. The feasibility of using the local coordinate system to determine the areas, takes place under certain circumstances, in particular, it is known that the former geodetic networks and networks of thickening were developed with appropriate accuracy for that time base. Clearly, the quality of former networks cannot fully ensure the accuracy of the current work. However, the results of our research of using of points of the network at the local level, such as at the city traverse network of a settlement, when determining the areas of objects with the size up to 800 hectares causes no doubts and meets the requirements of accuracy. **The practical significance**. Improving the accuracy of coordinate definitions is connected with the introduction of modern, uncontested satellite technology. Analysis of the study confirms the feasibility of using a local coordinate system while performing work at the local level with the area of up to 1000 hectares object. If it is necessary to define areas of objects larger than 1000 hectares with the accuracy of 50 m^2, the satellite methods of measurements should be used, that ensure error of coordinates within 0.005–0.020 m.

Key words: GPS; GNSS; reference station; SGN; networks of thickening; RTK-technology, VRS.

Formulation of the problem

Cartographic information as a digital description of objects of a map and their spatial location in a defined coordinate system is a major factor at solving tasks of land management and cadastre.

It is known that with the help of satellite technology the spatial position of points on the Earth's surface is determined [Dawidowicz, 2014; Lamparski, 2007; Seeber, 2003], and plans of land plots and land use, index cadastral maps, maps of territorial zones, etc. are made in the national system of plane rectangular coordinates. During the satellite observations on the definition of coordinates of points (boundary markers) and designing onto the plane in the selected projection and coordinate system of areas of land plots can be distorted.

Accordingly, the calculated area will differ from the actual that may negatively influence the accuracy of land cadastre information. Considering also the rapid development of land relations in Ukraine and the emergence of a land market, the increase in land prices is obvious. Therefore, the research aimed at finding new and improving existing methods of increasing accuracy of areas definition during the cadastre works are relevant and up to the time.

Analysis of recent research and publications devoted to solving this issue

Today more and more wide application in geodesic support of land cadastral works acquire highly accurate satellite technology of detecting the location of natural origin objects of a physical surface within the adopted implementations of E arth's reference coordinate system. Implementation of practical realization is their transformation into a flat rectangular coordinates based on a selected projection, say, of Gauss-Kruger.

Modern literature pays a lot of attention to the research of these questions. For example, [НДІГК, 2009] for the first time classification of lands by the size of their areas, based on their accurate model was proposed. The classification of methods for determining areas by instrumental means and by the type of reduction of lands on the surface of relativity was developped. Strict high precision mathematical methods were grounded and proposed to identify and evaluate the accuracy of land area by coordinates of the vertices of the contours as of the orthogonal projections on a horizontal plane, the projections on the surface of an ellipsoid and on a plane of map projections. The properties of geographic information systems regarding the definition of land areas are studied and guidelines for their use are proposed.

As it is known, to determine the areas of geospatial objects on the surface of the reference ellipsoid, it is necessary in the value of the area, calculated by the coordinates x, y in Gauss-Kruger projection, to introduce an amendment δ_P:

$$\delta_P = -\frac{y_m^2}{R_m^2} P, \qquad (1)$$

where: R_m – the average radius of curvature of the ellipsoid of Krasovsky, that for the territory of Ukraine is 6378 kilometers; P – calculated area of land on the plane of Gauss-Kruger.

According to the results of determining areas of ellipsoid surface space by flat rectangular coordinates of their peaks in Gauss-Kruger projection, it is found [Radov, 2011], that within a single coordinate zone of the area any land can be calculated with accuracy up to 1 m^2. In large areas, which are located in several coordinate areas the error in determining the area does not exceed 5–10 m^2. The work [Vynohradov, 2009] is devoted to issues of determining areas of physical surface land for cadastre. Since the relief of any land is very diverse, there is always some generalization in calculations. Therefore, the definition of this area is subjective. Three options for calculating areas are considered – by the program GIS "Map 2005", by the horizontal lengths and by length of segments of the rectangular grid. With the resulting matrix of heights there are horizontals constructed with cross section of 0.25 m and their length on the plot is calculated. Physical area is calculated by the horizontals with cross sections 0.25, 0.5, 1.0, 2.0 and 4.0 m. The next method of calculating the area is in marking and dividing into similar intervals of mutually perpendicular profiles. Errors of calculation of areas are 16 m^2, 15 m^2 and 9 m^2, confirming the expediency of application of the method of iterations.

Research of calculating areas of land on the surface of the ellipsoid and their distortion when projecting on a plane are given [Baranovskyi, 2005; Baranovskyi, 2009]. Numerical integration by the exact contour by geodetic coordinates and discrete computing of areas in rectangular coordinate system of equal area conic projection is recognised as the most effective method.

The methods of calculation of areas of considerable territories, the boundaries of which are set by coordinates of points, are studied, and the dependence of error of calculation on the space distance between adjacent points of polygons is shown. The need to calculate the coordinates of intermediate points depends on the excess of allowable values of distances between adjacent points [Baranovskyi, 2013].

In the practice of land planning activity, the areas of land on the plane, which are in the same zone of Gauss-Kruger projection, are defined by piecewise-linear polynomials, which are set by flat rectangular coordinates of the beginning and end of linear segments. Then, the area of land consisting of n-points of turning can be calculated according to the known formula

$$P=\frac{1}{2}\times\sum_{i=1}^{n}x_i\times\left(y_{i+1}-y_{i-1}\right), \quad (2)$$

And the accuracy of calculating areas of objects on a plane [Baranovskyi,2013] can be written as

$$m_P=\frac{1}{2}\left[\sum_{i=1}^{n}\left(y_{i+1}-y_{i-1}\right)^2 m_{x_i}{}^2+\sum_{i=1}^{n}\left(x_{i-1}-x_{i+1}\right)^2 m_{y_i}{}^2\right]^{\frac{1}{2}}. \quad (3)$$

Usually mark $m_s=\sqrt{m_x{}^2+m_y{}^2}$ and $m_T=\sqrt{m_{S_{i-1}}^2+m_{S_i}^2}$ and accept $m_x=m_y=m$ and $m_{S_{i-1}}=m_{S_i}$, $m_{T_i}=m_{T_{i-1}}$, then the formular (3) is written the following way:

$$m_P=\frac{m}{2}\sqrt{\sum_{i=1}^{n}D_{i-1,i+1}^2}=\frac{m_{T_i}}{4}\sqrt{\sum_{i=1}^{n}D_{i-1,i+1}^2}, \quad (4)$$

where i – number of current peak of the landfill, $D_{i-1,i+1}$ – the length of the lines between the peaks, the previous and next. For example let's calculate with which accuracy will be defined the area, if the side of the square is 1000 m and the mean square error of the position of the vertices of the square is $m_{T_i}=5$ mm, we will get $m_P=2.5$ m^2, or 0.0025 %.

In the work [Kubakh, 2010] the relationship of local coordinate systems with the state geodetic system of coordinates USC-2000 is examined and it is proposed to coordinate the transfer between systems SC-63 and USC-2000, using the transformational field of coordinate transformation if it is economically justified and appropriate. Calculation of the corrections in the measured line in the coordinate system SC-42 / SC-63 is presented in the Table 1.

As can be seen from Table 1, amendments may be small and reach significant quantities. If we talk about the coordinate system SC-63, then with the maximum distance of 125 km to the edge of the zone, apparently amendments for reduction of measured lines will be minor.

Further improvement of planned coordinates and measurements on the physical surface can be achieved only on condition of creation and functioning of local geodetic systems of coordinates [Cherniaha, 2010]. Requirements for conditions of creation and use of geodetic projections for administrative entities are also defined.

Aim of the work

Aim of the work is to study the efficiency of usage of satellite technology in real-time kinematics mode for work performed to determine the areas of land plots of different sizes within a settlement.

Table 1

Amendments to the measured line (D = 1000 m) in the system of coordinates SC-42/SC-63

Height, m	Y_m, km						
	0	50	100	125	150	200	250
0	0.000	0.031	0.123	0.192	0.276	0.491	0.768
250	-0.039	-0.008	0.084	0.153	0.237	0.452	0.729
500	-0.078	-0.048	0.044	0.114	0.198	0.413	0.689
750	-0.118	-0.087	0.005	0.074	0.159	0.374	0.650
1000	-0.157	-0.126	-0.034	0.035	0.120	0.335	0.611

Methodology

For the realization of this goal of experimental studies we performed satellite surveillance on points of polygonometry and triangulation of Chernihiv and the region. We shall briefly describe the course of research, as its detailed description and characteristics of dual-frequency GNSS-receivers are given in [Tereshchuk, 2014].

To obtain control values of coordinates at points we started from static observation (at least 1 hour). As basic triangulation points were selected the ones around Chernihiv – Kyiinka (KIIN) Yatsevo (JATS) Glushets (GLUS), on which surveillance on the first day was conducted by three teams in "static" mode over 4 hours. During this time, the other three teams conducted surveillance at points of city polygonometry, each time starting with hour mode "Fast-Static" and then in RTK-mode. Next rover receivers were set on reception of amendments of the network System.NET. For this purpose in the controllers were created six projects that had a different configuration, such as, for example:

3.a – automax (hereinafter the figure means the number of a brigade);

3.v – vrs (virtual reference station);

3.n – nearest;

3.ki – the mount point (kvda); 3.ni – the mount point (nizh); 3.ch – the mount point (cniv).

Figure 1 shows a schematic arrangement of placed polygonometry and triangulation points on the territory of Chernihiv and the region.

When connecting to RTK-server we indicated its name, for example, a – for the configuration automax, v – for VRS etc. IP-address – for all configurations, port – 2114 – for configuration: automax, vrs, nearest, port – 8085 – for mount points: kvda, nizh, cniv. Access to the network server System.NET was held by protocol NTRIP, and amendments were passed in the format RTCMv3.

Before the observations we agreed to install in the menu of the controller the approximate number of measurements at each configuration on the point – 30, while in the static mode 3600.

As a result of the research we have done modeling of objects of different shapes and sizes. For this, we used a network of urban polygonometry and triangulation points around Chernihiv, where satellite observations were performed. Nine models of landfills were marked, areas of which were calculated based on the coordinates issued from the catalog of coordinates and measured using RTK mode by satellite receivers.

Next, to perform a number of coordinate transformations, we use software and methodical complex, developed by scientists of Scientific Research Institute of Geodesy and Cartography and may implement methods for transformation and conversion of coordinates of points. The scheme of model transformations is given in Figure 2.

At the beginning coordinate transformation from one Cartesian coordinate system to another is performed, ie from the MSC into the SK63 by the key and formulas:

$$\begin{pmatrix} X_{CK63} \\ Y_{CK63} \end{pmatrix} = \begin{pmatrix} \cos\alpha - \sin\alpha \\ \sin\alpha + \cos\alpha \end{pmatrix} \begin{pmatrix} X_{MCK} \\ Y_{MCK} \end{pmatrix} + \begin{pmatrix} C_{X_{MCK}} \\ C_{Y_{MCK}} \end{pmatrix} \quad (5)$$

where, X_{CK63}, Y_{CK63} – input coordinates, X_{MCK}, Y_{MCK} – output coordinates, k – zoom ratio, α – angle of rotation, $C_{X_{MCK}}, C_{Y_{MCK}}$ – parallel transfer on X_{MCK} and Y_{MCK}.

The next phase includes converting coordinates *x, y* in Gauss-Kruger projection into geodetic coordinates *B, L* by the known formulas:

$$l'' = \frac{y}{N_1 \cos B_1}\rho''\left\{1 - \frac{y^2}{6N_1^2}\left(1 + 2t_1^2 + \eta_1^2\right) + \right.$$
$$\left. + \frac{y^4}{120N_1^4}\left(5 + 28t_1^2 + 24t_1^4 + 6\eta_1^2 + 8\eta_1^2 t_1^2\right)\right\},$$

$$B = B_1 - \frac{y^2}{2M_1N_1}t_1\rho''\left\{1 - \frac{y^2}{12N_1^2}\left(5 + 3t_1^2 + \eta_1^2 - 9\eta_1^2 t_1^2\right) + \right.$$
$$\left. + \frac{y^4}{360N_1^4}\left(61 + 90t_1^2 + 45t_1^4\right)\right\}, \quad (6)$$

$$t = tgB, \qquad \eta = e'^2 \cos B, \qquad N = \frac{a}{\sqrt{1 - e^2 \sin^2 B}},$$

where, B_1 – width of the image base of ordinate plane on the surface of the ellipsoid; y – ordinate of the point; N – the radius of curvature of the first vertical at this point; M – the radius of curvature of the meridian at this point; e^2 – meridian ellipse eccentricity; e'^2 – second meridian ellipse eccentricity; $\rho'' = 206264.8062$; t, η – auxiliary values.

For theoretical determination of the area of the site of the ellipsoid we use the method of numerical integration on the contour that is specified by geodetic latitude B and longitude L :

$$P_{elips.} = a^2\left(1-e^2\right)\iint\left(1-e\ \sin^2 B\right)^{-2}\cos B dl dB\,, \quad (7)$$

where a, e^2 – parameters of the ellipsoid.To reduce the error of map projections in cities usually local coordinate systems are used, the mathematical basis of which is Gauss-Kruger projection with a displaced axial meridian. Considering the fact that distortion in this case will be minimal, the calculation of areas of the marked object models we carried out by the coordinates in the local coordinate system.

In accordance with our program of satellite observations on polygonometry and triangulation points, the measurements were carried out in real time by six different configurations. Based on the analysis of these studies we can conclude about the possible allowable distortion of values of land areas within the boundaries of a settlement. Let us analyze dependences of calculated areas at simulated space by defining coordinates using satellite observations, and estimate the accuracy of such definitions.

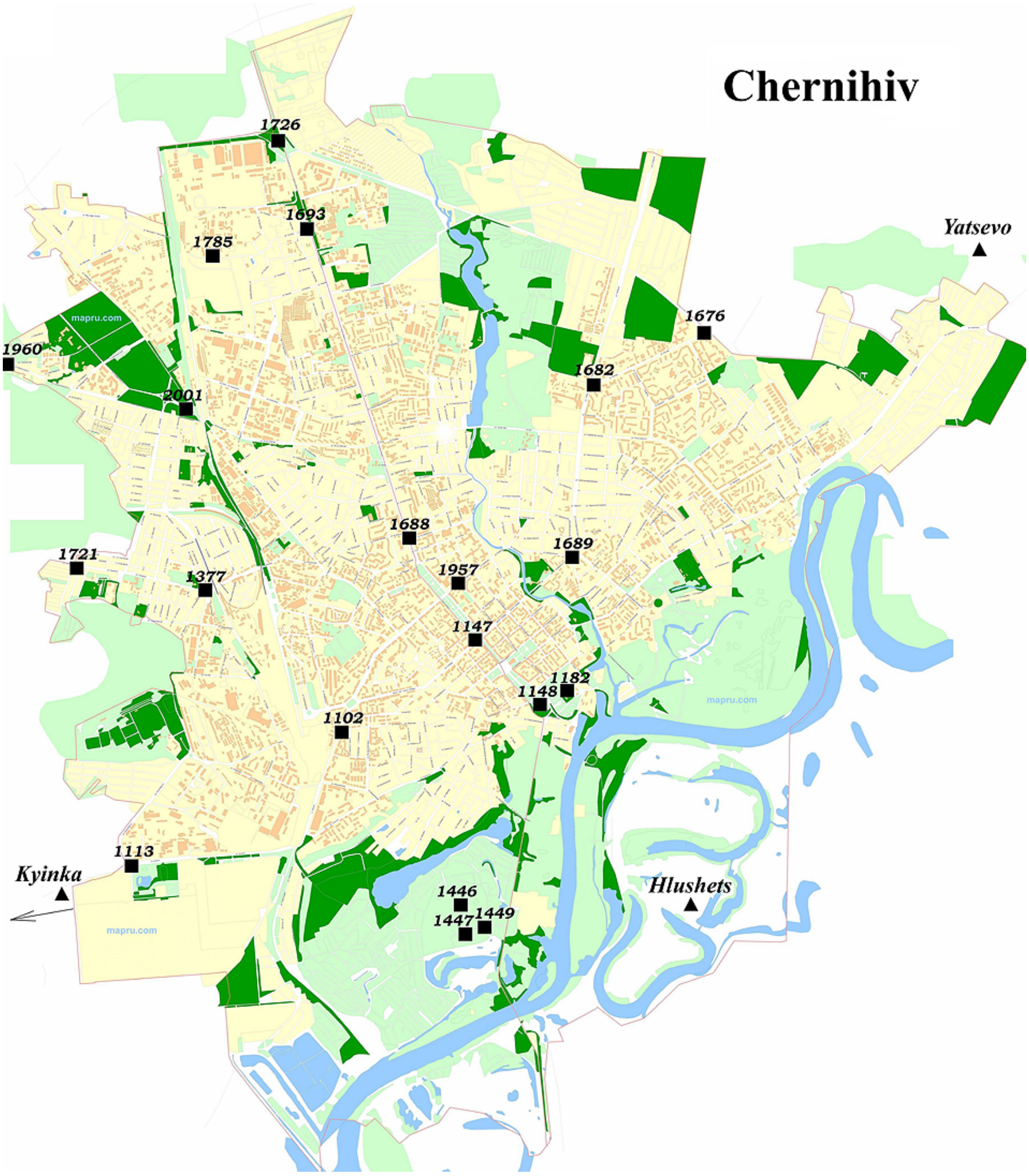

Fig. 1. Location of triangulation points and polygonometry in Chernihiv area

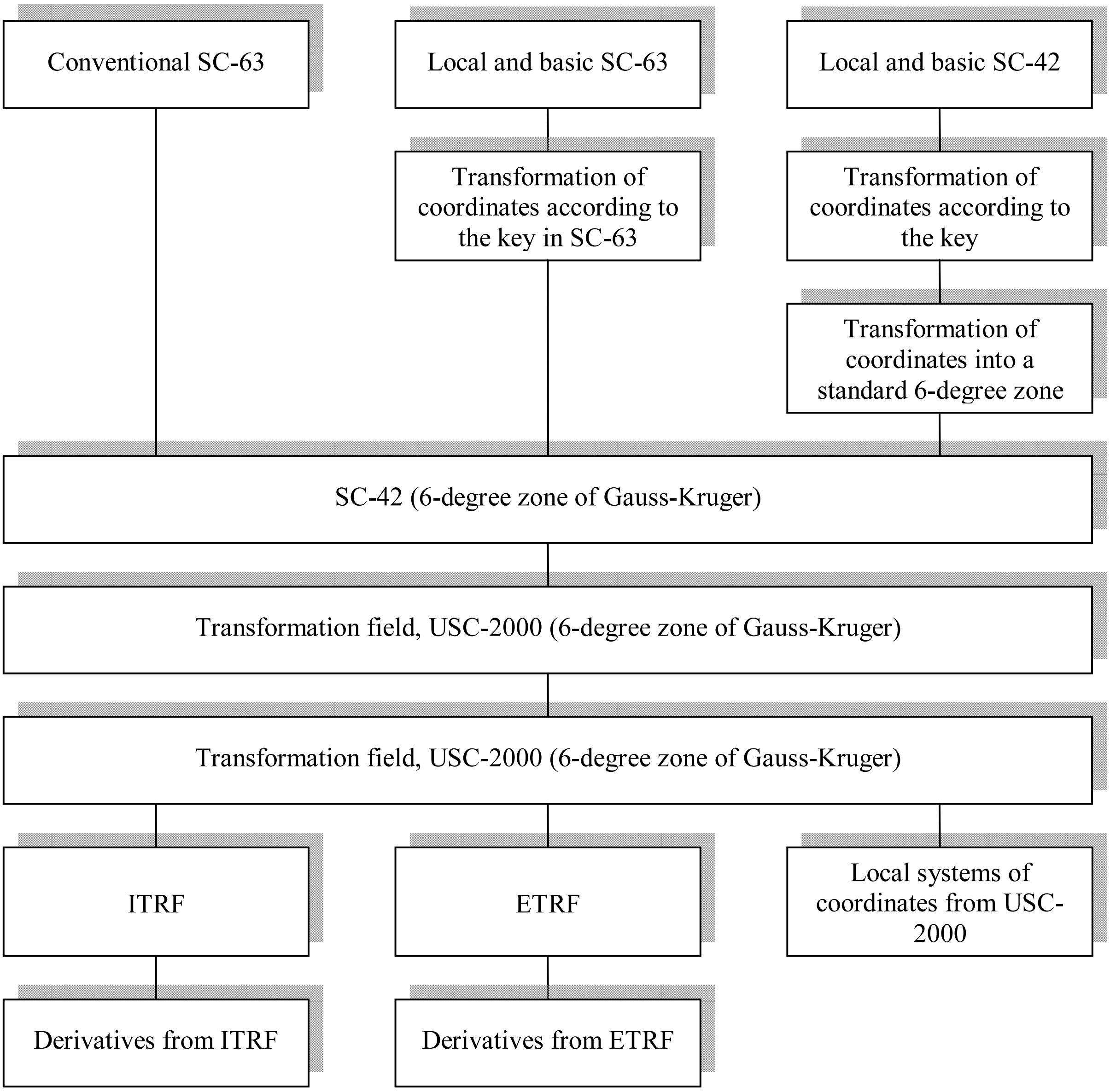

Fig. 2. Scheme of typical coordinate transformations

The results of research of areas calculation are given as a deviation between the calculated areas by the coordinates obtained from satellite observations and areas calculated by the coordinates in the local system, and the variances are compare with the results obtained by the formula (4).

First, we write the system of equations (8):

$$\begin{array}{lll} \omega_1 = P^{a} - P_{Stat} & \upsilon_1 = P^{a} - P_{MCK} & \sigma_1 = \omega_1 - \vartheta_1 \\ \omega_2 = P^{n} - P_{Stat} & \upsilon_2 = P^{n} - P_{MCK} & \sigma_2 = \omega_2 - \vartheta_2 \\ \omega_3 = P^{vrs} - P_{Stat} & \vartheta_3 = P^{vrs} - P_{MCK} & \sigma_3 = \omega_3 - \vartheta_3 \\ \omega_4 = P^{ch} - P_{Stat} & \vartheta_4 = P^{ch} - P_{MCK} & \sigma_4 = \omega_4 - \vartheta_4 \\ \omega_5 = P^{nz} - P_{Stat} & \vartheta_5 = P^{nz} - P_{MCK} & \sigma_5 = \omega_5 - \vartheta_5 \\ \omega_6 = P^{kv} - P_{Stat} & \vartheta_6 = P^{kv} - P_{MCK} & \sigma_6 = \omega_6 - \vartheta_5 \end{array}, \quad (8)$$

where P_i^* – areas of the simulated plots calculated by the coordinates obtained from observation in the RTK mode; P_{Stat} – areas received by the results of observations in the “static” mode; P_{MCK} – land areas calculated by comparable coordinates in the local system; ω_i – deviation of areas of the studied plots, which coordinates of points of turning are determined from satellite observations in RTK and “static” modes; ϑ_i – deviation of areas of the studied plots, which coordinates of points of turning are determined from satellite observations in RTK mode and calculated by comparable coordinates of points in the local system.

We write the equations in general form

$$w_i = P_i - P_{Stat}, \quad (9)$$

$$J_i = P_i - P_{MCK}, \quad (10)$$

and create a difference $s_i = w_i - J_i$

$$s_i = w_i - J_i = P_i - P_{Stat} - P_i + P_{MCK} = P_{MCK} - P_{Stat} \quad (11)$$

$$s_i = P_{MCK} - P_{Stat} \quad (12)$$

In view of the equation (12), we can conclude that in order to assess the accuracy of calculation of areas of the studied sites, it is possible to have areas that are calculated by the coordinates obtained from satellite observations in the "static" mode, as well as areas that are predefined by comparable coordinates in the local system of coordinates.

The obtained results and their analysis

Now, as to the accuracy of calculation of areas in the local system of coordinates.

At the beginning, let us consider the accuracy with which coordinates of points of city polygonometry are obtained. As an example, take the plot B-2 for calculation. Number of lines on this site is n = 7 with the average length of the line $S_{cep.}$ =1760 m and the length of the course L =14080 m. According to the requirements of Instruction [Instruction on topographic marking, 1999], we accept a relative measurement error of sides in polygonometry of Class 4 $\frac{m_S}{S} = \frac{1}{25000}$.

General error M in the location of the final point of the course $M^2 = t^2 + u^2$, where *t, u* – longitudinal and transverse error of the course.

Let us write down

$$u = \frac{m_b''}{r''} L \sqrt{\frac{n+3}{12}}, \quad (13)$$

where m_b'' – mean-square error of measurement of angles, which we accept m_b'' =3'', r'' =206265''. Hence we get:

$$u = \frac{m_b''}{r''} L \sqrt{\frac{n+3}{12}} = \frac{3''}{206265''} 14080 \sqrt{\frac{10}{12}} = 0.1869 \text{ m.}$$

Taking into account the principle of equal influence, we accept $t = u$. Then $M^2 = 2t^2 = 2u^2$, or $M = t\sqrt{2}$, $M = u\sqrt{2}$ = 0,2643m. If to take into account that the number of points of the course is 8, the unknown error in the planned position of the point is calculated by the formula:

$$m_{XY} = \frac{M}{\sqrt{8}} = 0{,}093 \text{ m} \quad (14)$$

Let us write a relative error of the course

$$\frac{M}{L} = \frac{1}{T} \text{ or } \frac{t\sqrt{2}}{L} = \frac{u\sqrt{2}}{L} = \frac{1}{T}, \quad (15)$$

From where $\frac{M}{L} = \frac{1}{53200}$, which is consistent with accuracy of polygonometry of class 4. Thus, the area calculated analytically by known formulas will contain the error, the value of which mainly depend on the error of the planned position of points of polygonometry.

The results are given in Table 3, which includes names of the simulated plots (polygons) with a corresponding number of points, areas calculated in the local coordinate system and USC-2000, and presents the results of comparison of the measured *dP* (m^2) = $P_{MCK} - P_{УСК-2000}$, and calculated by the formular (4) values m_P (m^2).

To the measured or "practical" we refer comparison of results of calculation of areas by the coordinates in the local system with areas defined by coordinates of satellite observations in RTK-mode. To the calculated we assign accuracy of areas defined by the formula (4), taking into account values of received error of planned position of point of city polygonometry.

In fact, this is the comparison of instrumental methods of classical geodesy with satellite. It is advisable in this case to ask questions if the use of points of traditional geodetic framework and networks of thickening, such as urban traverse networks, can provide the necessary accuracy during the cadastral measuring and how it will affect the differences in the values of areas.

In our example, we can state that areas of figures defined by coordinates in the local system (MSC) obtained as a result of the classic geodetic works mainly correlate with areas obtained from the results of satellite observations in RTK mode.

Analyzing the data of the table, we notice that the value *dP*(m^2) in the vast majority are positive, except for the figures B i G. As we can see, the value of differences of areas *dP %* are relatively small in percentage, from 0.0002 to 0.0028 % and practically do not depend on the size of the area.

Even precision of computing of areas of objects on the plane by the formula (4) coincides mostly with the "practical" one, that is obtained from measurements using RTK satellite technologies. Thus, in the sector of F11, whose area is 26 561 083.826 m^2 and the number of rotation angles – 11, the difference is 466.952 m^2, that is 0.0018 %. Calculated data by a formula are almost twice smaller and generally depend on the size of the area. If to abstract from the size of land plots and to average the results of calculations, we note the convergence of the accuracy of the areas, such as 0.0013 and 0.0012.

For additional analysis of these statements, we consider the results of "static" observations at three points of the triangulation around Chernihiv. These are points Kyiinka, Yatsevo and Glushets of second and third classes respectively. The time of observations in the "static" mode in these points, as stated above, was more than 4 hours each. Processing of the results of this year observations was made by experts of the Scientific Research Institute of of Geodesy and Cartography, which also gave us the catalog coordinate values of these points. By the way, we also used our data of experimental GPS-observations on two of these points in October 2011 (288 GPS-day, 1657 a week), the program and preliminary results are described in [Tereshchuk, 2013]. Processing of measurement results at that time performed experts of Main Astronomical Observatory of NAS of Ukraine and Kharkiv National University of Radio Electronics.

Data observations in the "static" mode were taken by us for the measured, and the catalog ones – for the output. In fact, these repeated measurements of the same values is feature of quality of GPS measurements, such as traceability and repeatability because the first and second were performed in the "static" mode in different time intervals. Traceability – a commonly-accepted term of quality control system. This means that all measurements, as required by normative documents, must be made regarding physically existing points, andthere must be the opportunity to repeat them, that is, to make these measurements again.

Let us compare these measurements. The results of satellite measurements of coordinates of points of triangulation in the system USC-2000 are presented in Table 4.

The data indicates the convergence of results determining the coordinates within 0–2 cm. When comparing the areas calculated by the catalog and measured coordinates, the difference is only 0.0001 %. So high accuracy is caused by the reliability of satellite observations in repeated measurements. Analyzing the data, it can be argued that the use of satellite technology while performing cadastral measurement is very effective. Thus, if we take into account from our observations in formular (4) the average of errors in determining the coordinates of 0,015 m, the error in the value of the area $P(m^2)$ = 47 493406,402 m^2 will be $dP(m^2)$=51,687 m^2 with $dP(\ \%)$=0,0001 %.

Table 3

Accuracy of calculation of areas received from satellite observations

No.	Names of plots/ Number of points	Areas **(LSC)**	Areas **(USC-2000)**	dP (m^2)	dP (%)	m_P (m^2)	m_P (%)
1	A/5	4 027 505.103	4 027 414.476	90.627	0.0022	93.319	0.0023
2	B/8	9 466 693.078	9 466 742.007	-48.929	0.0005	143.071	0.0015
3	C/6	10 481 682.762	10 481 647.760	35.002	0.0003	150.546	0.0014
4	D/5	13 460 881.805	13 460 514.964	366.841	0.0027	170.603	0.0013
5	I/6	15 603 789.435	15 603 348.098	441.337	0.0028	183.681	0.0012
6	F/11	26 561 550.778	26 561 083.826	466.952	0.0018	239.650	0.0009
7	G/10	27 820 174.789	27 820 380.794	-206.005	0.0007	245.264	0.0009
8	H/13	50 747 749.672	50 747 637.765	111.907	0.0002	331.254	0.0006
9	J/11	77 309 300.450	77 308 721.591	578.859	0.0007	408.850	0.0005
			Medium	**204.066**	**0.0013**	**218.471**	**0.0012**

Table 4

Results and the accuracy of calculation of areas measured by the coordinates in the "static" mode

Marking	USC-2000 CATALOG		USC-2000 MEASURED		*dx*	*dy*
	X	Y	X	Y		
Kyiinka	5703236.538	6372788.541	5703236.538	6372788.563	0.000	0.022
Yatsevo	5714363.152	6385962.313	5714363.167	6385962.309	0.015	-0.004
Glushets	5705514.730	6384022.785	5705514.729	6384022.794	-0.001	0.009
Area, P, m^2	47493357.295		47493406.402			
Accuracy	dP (m^2)= 49.107	m_P (m^2)= 51.687				
dP(%)	0.0001	0.0001				

Scientific novelty and practical importance

These values once again confirm effectiveness of RTK observations and transition to the new geodetic framework created on the basis of modern measuring GNSS-technologies. Now about the usefulness of local coordinate system for determining areas. It is known that the former geodetic networks and networks of thickening were developed with some accuracy using former instrumental base. Clearly, quality of that time networks can not fully ensure the accuracy of the current works. However, the results of our research of using points of the network at the local level, such as at the level of the city traverse network of a settlement, in determining the areas of objects up to 800 hectares, is beyond doubt and meets the requirements of accuracy.

According to the results of the research, we can claim that modern measuring GNSS technology considering the efficiency and accuracy of execu-tion is now uncontested. Coordinate definitions, and, correspondingly, the definition of areas of objects with the application of advanced satellite receivers significantly increase the productivity and quality of cadastral works, contributing at the same time to the increasing accuracy of position of points.

Conclusions

Improving accuracy of coordinate definitions is connected with the introduction of modern satellite RTK technologies in the implementation of reference coordinate system of basic points. Regarding the feasibility of using a local coordinate system when calculating areas of objects of a settlement, in particular, during works at the local level, with the object's area 1,000 hectares, while maintaining satisfying precision, the use of the coordinates of points of urban traverse networks is seen as possible. When calculating areas of more than 1,000 hectares with accuracy 50 m^2, satellite methods of removal, ensuring error in determining the the coordinates within 0.005–0.020 m should be used.

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ЕФЕКТИВНІСТЬ ЗАСТОСУВАННЯ СУПУТНИКОВИХ ТЕХНОЛОГІЙ ПІД ЧАС ВИКОНАННЯ ЗЕМЕЛЬНО-КАДАСТРОВИХ РОБІТ У НАСЕЛЕНИХ ПУНКТАХ

Мета. Мета цієї роботи полягає у дослідженні ефективності застосування супутникових технологій у режимі кінематики реального часу під час виконання робіт з визначення площ земельних ділянок різних розмірів у межах населеного пункту. **Методика.** Для реалізації цієї мети експериментальних досліджень ми провели супутникові спостереження на пунктах полігонометрії та тріангуляції м. Чернігова та області. Під час проведення досліджень передбачено отримати контрольні значення координат на базових пунктах, починаючи зі статичних спостережень. За базові вибрано пункти тріангуляції навколо напрямку Чернігова–Киїнка (KIIN), Яцево (JATS), Глушець (GLUS), на яких спостереження першого дня проводили три бригади в режимі "статика" більше ніж 4 годин. За цей час інші три бригади проводили спостереження на пунктах міської полігонометрії, щоразу починаючи з годинного режиму "Fast-Static" і потім у RTK-режимі. Далі роверні приймачі налаштовувалися на прийом поправок від мережі System.NET. Для цього у контролерах створювали шість проектів, які мали різну конфігурацію. У результаті проведених досліджень ми виконали моделювання об'єктів різної форми та розмірів. Для цього використано мережу міської полігонометрії, а також пункти тріангуляції навколо м. Чернігова, на яких виконували супутникові спостереження. Визначено дев'ять моделей полігонів, площі яких обчислювалися на основі координат, виписаних з Каталога координат і виміряних за допомогою RTK-режиму супутниковими приймачами. Для трансформації та перетворення координат точок застосовано програмно-методичний комплекс, який розробили науковці

Науково-дослідного інституту геодезії та картографії. **Результати.** Виконані перетворення координат з МСК у СК63 за ключем і формулами, а потім перетворення координат *x, y* на проекції Гаусса–Крюгера в геодезичні координати *B, L* за формулами. Для теоретичного визначення площі ділянки еліпсоїда ми скористалися методом числового інтегрування за контуром, що задається геодезичними широтами *B* та довготами *L.* З метою зменшення похибок картографічних проекцій у містах ми застосували місцеву систему координат, математичною основою якої є проекція Гаусса–Крюгера зі зміщеним осьовим меридіаном. Зважаючи на те, що спотворення у цьому випадку будуть мінімальними, обчислення площ визначених моделей об’єктів ми виконували за координатами у місцевій системі. Відповідно до нашої програми супутникових спостережень на пунктах полігонометрії та тріангуляції вимірювання проводилося в режимі реального часу за шістьма різними конфігураціями. На основі проведеного аналізу таких досліджень проаналізовані залежності виміряних площ на змодельованих ділянках через визначення координат за допомогою супутникових спостережень, а також проведено оцінку точності таких визначень та зроблений висновок про можливі допустимі величини спотворення площ ділянок у межах границі населеного пункту. **Наукова новизна.** Дані проведених досліджень вкотре підтверджують ефективність застосування RTK-спостережень та перехід на нову геодезичну основу, створену на базі сучасних вимірювальних GNSS-технологій. Доцільність застосування місцевої системи координат для визначення площ наявне за певних обставин, а саме відомо, що колишні геодезичні мережі та мережі згущення розвивалися з відповідною на той час точністю інструментальної бази. Зрозуміло, що якість тодішніх мереж не може сповна забезпечити точності сьогоднішніх робіт. Проте, за результатами наших досліджень використання пунктів мережі на локальному рівні, як на рівні міської полігонометричної мережі населеного пункту, під час визначення площ об’єктів до 800 га, не викликає сумнівів і задовольняє вимоги точності. **Практична значущість**. Підвищення точності координатних визначень пов’язане із впровадженням сучасних, поки що, безальтернативних супутникових технологій. Аналіз досліджень підтверджує доцільність застосування місцевої системи координат під час виконання робіт на локальному рівні при площі об’єкта до 1000 га. За необхідності визначення площ об’єктів більших за 1000 га з точністю 50 м^2, слід використовувати супутникові методи знімання, які забезпечують похибку визначення координат у межах 0,005–0,020 м.

*Ключові слова***:** GPS; GNSS; референцні станції; ДГМ; мережі згущення; RTK-технологія, VRS.

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