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# ACCURACY OF COORDINATE DETERMINATIONS OF THE NETWORK OF PROTECTED ZONE POINTS ACCORDING TO THE RESULTS OF GNSS OBSERVATIONS

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**Abstract.** The article examines errors of the planned position of the points of the educational and research site "Fortuna" of the Chernihiv Polytechnic National University (Ukraine), located in a forested area. Kinematic positioning has been performed using a GNSS receiver GeoMax Zenith 10/20 in real time mode. The network of permanent satellite GNSS stations System NET has been used as a coordinate basis. RTK Master Auxiliary Corrections (MAX) technology has been used to form the corrective amendments. The calculation of RTK corrections has been performed using the software package Leica GNSS Spider v4.3. The Transverse Mercator cartographic projection has been used to determine the flat rectangular coordinates in the USK-2000 system. The values of the coordinates determined in the RTK mode have been compared with the coordinates obtained by the method of electronic polygonometry, which are estimated to be 3 times more accurate. Coordinate differences have formed error vectors. As a result of analysis of the vector field, a stable tendency has been established: the deviation of the planned coordinates of the site points, determined by the method of GNSS-observations in real time mode and located in the forest park zone, in the direction of the base station.

**Keywords:** GNSS-observations, Real Time Kinematic, base station, points of polygonometry, error research, USC 2000.

## Introduction

Fast and reliable resolution of ambiguities is a particularly important task in RTK real-time kinematics, as the effect of atmospheric errors depends on increasing the length of the base rover, which reduces the accuracy of the coordinates calculation. External adjustments in the atmosphere are needed to increase the speed and reliability of resolving ambiguities. The article (Grejner-Brzezinska et al., 2007) uses four different methods of ionosphere modeling as a source of external information, discusses their impact on the speed, reliability and accuracy of rover positioning. Each method demonstrates a different level of accuracy, and thus determines the optimality of its application when ionospheric conditions change (Grejner-Brzezinska et al., 2007).

It is known that the estimation of ionospheric delays in GNSS measurements requires considerable time to eliminate ambiguities, especially in the case of long baselines. The paper (Kheloufi & Niati, 2020) considers the influence of spatial correlation of errors in the study of GPS, Galileo and BDS characteristics, while double-difference ionospheric delays are considered as stochastic quantities. The authors propose a model of spatial correlation, which approximately gives the covariance between the individual errors belonging to the two stations. The results obtained as a result of the simulation show that taking into account the spatial correlation provides a shorter time for eliminating ambiguities compared to when the spatial correlation is not taken into account in the stochastic model. For all studied dual-frequency combinations, when the baseline length of 500 km is processed with an interval of 5 s, the time required to successfully eliminate ambiguities was 5–9 minutes, and for all three-frequency combinations – 2.5–3 minutes.

Improving accuracy and reliability of user coordinates is possible if GNSS data is processed using the RTK network. In the article (Lim & Rizos, 2008) a distributed server network system RTK has been proposed and tested, which allows to calculate the coordinates of the rover in the required frame of reference. The described server network architecture is independent of the receiver, and

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hence of network scaling and user experience. The test results show that the proposed RTK server network system provides centimeter-level coordinates for regional GPS networks with an average base distance (20–35 km) and a long base distance (50–100 km) (Lim & Rizos, 2008).

There are different variations and additions to the RTK method. For example, the paper (Pepe, 2018) considers the technology of Network Real Time Kinematic shooting, which features the use of measurements obtained and stored in a network of Continuously Operating Reference Stations – CORS. This allows to obtain more robust error models that can reduce distance-dependent errors within the area covered by CORS. The article considers the use of an low-cost GNSS receiver, which, receiving differential corrections from the CORS network, allowed to obtain high accuracy at a distance from the base rover (permanent station) of a few kilometers after performing appropriate statistical processing of the obtained data. The disadvantage of this work is the lack of research with more accurate GNNN receivers operating in the CORS network.

The paper (Grejner-Brzezinska et al., 2005) shows that relative positioning, taking into account real-time network ionospheric corrections, allows to achieve position accuracy at the centimeter level even for distant baselines.

There are works on comparing GNSS receivers for positioning accuracy. For example, Catania et al. (2020) compared the positioning accuracy of four GNSS receivers, differing in technical characteristics and operating modes. The article also considered the determination of the influence of the external antenna and RTK differential correction technique on the positioning accuracy achieved with the help of these satellite receivers. It has been shown that the method of differential correction of RTK is fundamental to obtain more accurate location data.

The accuracy of determining the position of points by GNSS observations is also affected by obstacles present in the field and limited visibility of the horizon. This is investigated, in particular, in the work (Yanchuk & Shulgan, 2020), where a practical check of the regression equation was performed to calculate the prognostic root mean square error (RMSE) of the spatial, planned and altitude position of the baseline endpoint relative to the initial one. The compiled equations allow to perform a prognostic assessment of the accuracy of satellite calculations based on data on existing obstacles. The existing formulas for forecast estimation of accuracy of observations in the conditions of limited visibility of horizon have been checked.

A number of works are also devoted to the processing of the obtained results of GNSS observations. For example, the paper (Tereshchuk et al., 2019) considers the processing of the results of field satellite GNSS measurements at the points of the State Geodetic Network of the Northern Region of Ukraine using OCTAVA and GrafNav/GrafNat software packages. Based on the results of the study, a method has been developed for estimating the accuracy of processing the results of GNSS observations by software packages based on the method of double nonequilibrium measurements.

## Methods

According to the results of field and in-house geodetic works performed in the period from March to April 2016, the planned coordinates of the geodetic points of the educational and scientific site "Fortuna" were determined (Tereshchuk, 2017). They consisted in determining the coordinates of geodetic points as a result of GNSS observations in the kinematic mode and control observations by electronic polygonometry (Figure 1). Kinematic positioning was performed using a GNSS receiver GeoMax Zenith 10/20 in real time mode. The network of permanent satellite GNSS stations System NET was used as a coordinate basis.

The basic ones have strong connections with the points of the Ukrainian permanent GNSS network. The technology of observation provided access to the network server via mobile Internet – communication according to the GSM/GPSRS standard. Amendments from the network were transmitted in the standardized format RTCM v3.x. through the mobile services operator MTS.

RTK Master Auxiliary Corrections (MAX) technology was used to form the corrective amendments. It uses an open algorithm and is accepted by the RTCM 104 committee as a standard for GNSS networks. This technology involves the formation of corrections in real time mode simultaneously from several base stations, one of which – the main (Master), and the others – auxiliary (Auxiliary). The main and auxiliary stations were determined automatically, depending on the position of the receiver. The CNYV station was identified as the main station.

The calculation of RTK corrections was performed using the Leica GNSS Spider v4.3 software package installed on the network server.

Transverse Mercator cartographic projection was used to determine flat rectangular coordinates.

As a result, the coordinates of the network points in the coordinate system USK-2000 Z6 were determined. Coordinate calculations were performed in GeoMax X-PAD software (Tereshchuk, 2017).

USC-2000 is the Ukrainian coordinate system, introduced in accordance with the resolution (Kabinet Ministriv Ukrainy, 2004). USC-2000 as the State Geodetic Reference System is clearly consistent with the International Land Reference Coordinate System ITRS/ITRF2000 for the era of 2005. Moreover: the scale of the reference system is equal to the scale of the ITRS/ITRF2000 system, the coordinate axes of the reference system are parallel to the coordinate axes of the ITRS/ITRF2000 system, the center of the reference coordinate system provides optimal deviation of the reference ellipsoid surface from the real Earth above the surface of the reference ellipsoid and the deviations of the temporal lines are minimal. Krasovsky's reference ellipsoid with a large half-axis of 6378245 m and a compression of 1: 298.3 (Baranovskyi et al., 2009) is taken as the reference surface. The location of the points of polygonometry on the territory of the site is shown in Figure 1.

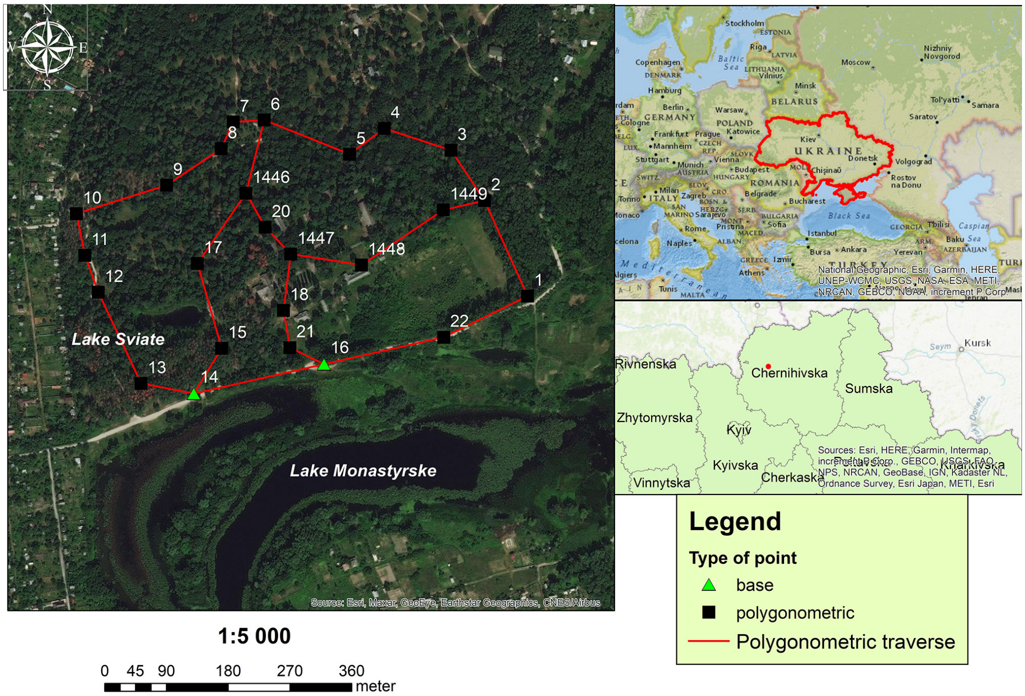


Figure 1. Location of polygonometry points on the territory of the site

The evaluation of the polygonometric network project was performed using CREDO DAT 3.10 software. Table 1 shows the values of the planned coordinates of geodetic points as a result of GNSS-observations in real time $(X_i)_{RTK}$, $(Y_i)_{RTK}$ and control observations by electronic polygonometry method $(X_i)_{TACH}$, $(Y_i)_{TACH}$.

Table 1. Values of planned coordinates of points and center of gravity of the system of points

| No. of a point | $(X_i)_{RTK}$ | $(Y_i)_{RTK}$ | $(X_i)_{TACH}$ | $(Y_i)_{TACH}$ |
|---|---|---|---|---|
| 1 | 5 705 239.515 | 6 381 731.300 | 5 705 239.523 | 6 381 731.221 |
| 2 | 5 705 378.77 | 6 381 668.733 | 5 705 378.746 | 6 381 668.661 |
| 3 | 5 705 452.181 | 6 381 619.698 | 5 705 452.168 | 6 381 619.65 |
| 4 | 5 705 484.189 | 6 381 522.49 | 5 705 484.15 | 6 381 522.42 |
| 5 | 5 705 446.369 | 6 381 472.04 | 5 705 446.305 | 6 381 471.995 |
| 6 | 5 705 496.343 | 6 381 347.49 | 5 705 496.303 | 6 381 347.433 |
| 7 | 5 705 493.443 | 6 381 302.423 | 5 705 493.36 | 6 381 302.394 |
| 8 | 5 705 454.551 | 6 381 284.908 | 5 705 454.469 | 6 381 284.886 |
| 9 | 5 705 401.403 | 6 381 205.237 | 5 705 401.313 | 6 381 205.238 |
| 10 | 5 705 359.733 | 6 381 073.826 | 5 705 359.639 | 6 381 073.839 |
| 11 | 5 705 299.045 | 6 381 086.186 | 5705 298.956 | 6 381 086.211 |
| 12 | 5 705 245.200 | 6 381 105.561 | 5 705 245.136 | 6 381 105.58 |
| 13 | 5 705 112.353 | 6 381 168.099 | 5 705 112.318 | 6 381 168.124 |
| 14 | 5 705 097.265 | 6 381 244.734 | 5 705 097.265 | 6 381 244.734 |
| 16 | 5 705 140.204 | 6 381 434.647 | 5 705 140.204 | 6 381 434.647 |
| 22 | 5 705 179.637 | 6 381 609.143 | 5 705 179.65 | 6 381 609.114 |
| 1446 | 5 705 389.626 | 6 381 320.971 | 5 705 389.534 | 6 381 320.924 |
| 1447 | 5 705 300.898 | 6 381 386.266 | 5 705 300.841 | 6 381 386.242 |
| 1448 | 5 705 284.769 | 6 381 489.266 | 5 705 284.765 | 6 381 489.243 |
| 1449 | 5 705 365.209 | 6 381 608.669 | 5 705 365.193 | 6 381 608.606 |
| 15 | 5 705 163.579 | 6 381 285.399 | 5 705 163.535 | 6 381 285.399 |
| 17 | 5 705 287.233 | 6 381 250.028 | 5 705 287.175 | 6 381 250.03 |
| 18 | 5 705 218.722 | 6 381 375.656 | 5 705 218.705 | 6 381 375.672 |
| 20 | 5 705 339.964 | 6 381 349.065 | 5 705 339.909 | 6 381 349.027 |
| 21 | 5 705 164.458 | 6 381 384.949 | 5 705 164.446 | 6 381 384.972 |
| Σ | 142 632 794.7 | 159 534 326.8 | 142 632 793.6 | 159 534 326.3 |
| $X_O$; $Y_O$ | 5 705 311.786 | 6 381 373.071 | 5 705 311.744 | 6 381 373.05 |
| $\Delta X_O$; $\Delta Y_O$ | 0.042 | | 0.021 | |

The coordinates of the center of gravity $O$ of the system of geodetic points of the number $n = 25$ according to coordinates $X_i$, $Y_i$, determined from both methods, by formulas:

$$X_O = \frac{\sum_1^n X_i}{n};$$
$$Y_O = \frac{\sum_1^n Y_i}{n}, \quad (1)$$

and the difference of the coordinates of the same name, which are determined from both methods

$$\Delta X_O = (X_O)_{RTK} - (X_O)_{TACH},$$
$$\Delta Y_O = (Y_O)_{RTK} - (Y_O)_{TACH}. \quad (2)$$

The values of the coordinates of the centers of gravity of the system of points and their differences are given in Table 1.

Based on the research (Tereshchuk, 2017) it was found that the relative error of the position of the network points is $\left(\frac{m_S}{S}\right)_{RTK} \approx \frac{1}{10000}$. After processing the moves of the electronic polygonometry, the relative error of the planned position of the points was obtained $\left(\frac{m_S}{S}\right)_{mean} = \frac{1}{28500}$ (Tereshchuk, 2017).

Thus, the ratio of the accuracy of determining the coordinates of the points of the site by electronic polygonometry and as a result of GNSS-observations in real time is 2.8 : 1, or with an accuracy of integer values of 3 : 1. In this case, according to (Sergeev & Krovin, 2000) coordinates of points $\Delta X_i$ and $\Delta Y_i$ can be considered as conditionally true errors, because conditionally true values of the planned coordinates $(X_i)_{TACH}$, $(Y_i)_{TACH}$, are determined via the method three times more accurate than $(X_i)_{RTK}$, $(Y_i)_{RTK}$.

$$\Delta X_i = (X_i)_{RTK} - (X_i)_{TACH},$$
$$\Delta Y_i = (Y_i)_{RTK} - (Y_i)_{TACH}. \quad (3)$$

To analyze the results of observations, the errors of the planned position of points are used – displacement of points in the plan, the coordinates of which are determined by GNSS-observations in real time mode, relative to the same points, the coordinates of which are determined by electronic polygonometry, in the form of vectors. The modules of the error vectors were determined by a known formula:

$$|r_i| = \sqrt{(\Delta X_i)^2 + (\Delta Y_i)^2}, \quad (4)$$

directional angles of error vectors

$$\alpha_i = arctg\frac{\Delta Y_i}{\Delta X_i}. \quad (5)$$

The average values of the projections of the error vectors on the coordinate axis were calculated:

$$\Delta X_M = \frac{\sum_1^n \Delta X_i}{n};$$
$$\Delta Y_M = \frac{\sum_1^n \Delta Y_i}{n}, \quad (6)$$

the modulus of the vector formed by the average values of the projections of the error vectors on the coordinate axis:

$$|\bar{r}| = \sqrt{(\Delta X_M)^2 + (\Delta Y_M)^2}, \quad (7)$$

and the directional angle of this vector:

$$\alpha_{\bar{r}} = arctg\frac{\Delta Y_M}{\Delta X_M}. \quad (8)$$

The results of calculations by formulas – are given in Table 2.

The control of calculations is the convergence of values:

$$\Delta X_O = \Delta X_M,$$
$$\Delta Y_O = \Delta Y_M. \quad (9)$$

Indeed (see Table 1 and Table 2): $\Delta X_0 = \Delta X_M = 0.042$, $\Delta Y_0 = \Delta Y_M = 0.021$.

Table 2. Results of calculation of modules and directional angles of error vectors

| No. of a point | $\Delta X_i$, m | $\Delta Y_i$, m | $\lvert r_i \rvert$, m | $(\alpha_i)°$ |
|---|---|---|---|---|
| 1 | –0.008 | 0.079 | 0.0794 | 264.22 |
| 2 | 0.024 | 0.072 | 0.0759 | 71.57 |
| 3 | 0.013 | 0.048 | 0.0497 | 74.85 |
| 4 | 0.039 | 0.070 | 0.0801 | 60.88 |
| 5 | 0.064 | 0.045 | 0.0782 | 35.11 |
| 6 | 0.040 | 0.057 | 0.0696 | 54.94 |
| 7 | 0.083 | 0.029 | 0.0879 | 19.26 |
| 8 | 0.082 | 0.022 | 0.0849 | 15.02 |
| 9 | 0.090 | –0.001 | 0.0900 | 359.36 |
| 10 | 0.094 | –0.013 | 0.0949 | 352.13 |
| 11 | 0.089 | –0.025 | 0.0924 | 344.31 |
| 12 | 0.064 | –0.019 | 0.0668 | 343.47 |
| 13 | 0.035 | –0.025 | 0.0430 | 324.46 |
| 14 | 0.000 | 0.000 | 0.0000 | – |
| 16 | 0.000 | 0.000 | 0.0000 | – |
| 22 | –0.013 | 0.029 | 0.0318 | 114.15 |
| 1446 | 0.092 | 0.047 | 0.1033 | 27.06 |
| 1447 | 0.057 | 0.024 | 0.0618 | 22.83 |
| 1448 | 0.004 | 0.023 | 0.0233 | 80.13 |
| 1449 | 0.016 | 0.063 | 0.0650 | 75.75 |
| 15 | 0.044 | 0.000 | 0.0440 | 0.00 |
| 17 | 0.058 | –0.002 | 0.0580 | 358.03 |

*End of Table 2*

| No. of a point | $\Delta X_i$, m | $\Delta Y_i$, m | $\lvert r_i \rvert$, m | $(\alpha_i)°$ |
|---|---|---|---|---|
| 18 | 0.017 | −0.016 | 0.0233 | 316.74 |
| 20 | 0.055 | 0.038 | 0.0669 | 34.64 |
| 21 | 0.012 | −0.023 | 0.0259 | 297.55 |
| Σ | 1.051 | 0.522 | 1.1735 | |
| $\Delta X_M$, $Y_M$, $\overline{r}$, $\alpha_{\overline{r}}$ | 0.042 | 0.021 | 0.0469 | 26.41 |

The vector $\overline{r}$, formed by the sum of error vectors $\sum_{i=1}^{n} r_i$, which is divided by the scalar $n$:

$$\overline{r} = \frac{\sum_{i=1}^{n} r_i}{n}. \quad (10)$$

It is clear that when the vector field is homogeneous in moduli of the component vectors, but chaotic in their directions, the sum of the vectors $\sum_{i=}^{n} r_i$ forms the resulting vector, the direction of which can be any. If a vector field has a group of vectors whose directions form a certain sector and these vectors also have significant moduli, then the resulting vector can be within or close to this sector. In the case when a significant part of the vectors is located in directions in a certain sector, and their moduli are close in magnitude, the resulting vector of the vector field may also be within this sector, or close to it. That is, in the last two cases, the resulting vector $\sum_{i=1}^{n} r_i$ indicates the tendency direction, which is present in the vector field. If the resulting vector $\sum_{i=1}^{n} r_i$ to divide by the scalar $n$, the resulting vector will not change its previous direction. Therefore, the average value of the error vectors $\overline{r}$ may indicate the tendency direction present in the field of error vectors. In addition, the projections of the vector $\overline{r}$ on the coordinate axes allow you to perform control calculations by formula . The vector $\overline{r}$ is applied to the center of gravity of the system of geodetic points of this polygon, calculated by their coordinates, which is confirmed by the expression . The plan of the vector field of errors is given in Figure 2.

Error vectors are shown by dashed lines. From the center of gravity of the system of geodetic points – point $O$ a vector is drawn $\overline{r}$, depicted by a solid line. From Figure 2 it is seen, that a significant part of the error vectors located in the central part of the northern and north-eastern regions of the site have a north-easterly direction and significant values of their modules. The direction of the vector $\overline{r}$ is also directed to the northeast. Therefore, there is a tendency for a possible predominant orientation of the field of error vectors in the northeast direction. The CNIV base station is located in this direction. The scale of the vector field, i.e. the ratio of the length of the error vector in Figure 1 to its module is 1:5.

The directional angle of the direction to the CNIV base station was determined, the coordinates of which are $X_{CNIV}$ = 5711277.038 m and $Y_{CNIV}$ = 6383062.038 m (System Solutions official site, n.d.), from the center of gravity of the stroke with coordinates $X_O$ = 5705311.786 m and $Y_O$ = 6381373.071 m and the horizontal distance, which were respectively $\alpha_{CNIV} = 15.81°$ and $D_{CNIV}$ = 6199.893 m. In Figure 2 direction from the center of gravity $O$ to the base station CNIV is shown by a dashed line.

In Figure 2 it is seen, that direction of the vector $\overline{r}$ – the average of the error vectors of the planned position of the points and the direction to the base station CNIV are close to each other, and the differences between these directions is $\Delta\alpha = 26.41° - 15.81° = 10.6°$ (see Table 2). This indicates a tendency of the values of the planned coordinates of the points determined by the method of GNSS-observations in real time modes shifting towards the base CNIV station.

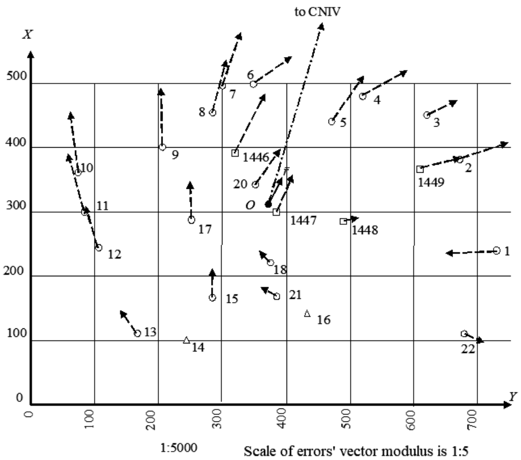


Figure 2. Plan of mutual location of geodetic points of the educational and scientific site "Fortuna" and vectors of errors of points

This tendency needs to be explored in more detail. For this purpose, it is possible to determine the increments of coordinates $\Delta X_i'$ and $\Delta Y_i'$ directions from geodetic points to CNIV station and directional angles of these directions $\alpha_i'$ by formulas:

$$\Delta X_i' = X_{CNIV} - X_i;$$
$$\Delta Y_i' = Y_{CNIV} - Y_i; \quad (11)$$

$$\alpha_i' = arctg \frac{\Delta Y_i'}{\Delta X_i'}. \quad (12)$$

There are calculations of deviations of grid directions $\alpha_i$ of vectors of errors from grid directions $\alpha_i'$ from these points to the CNIV station:

$$\Delta\alpha_i = \alpha_i - \alpha_i'. \quad (13)$$

Table 3 shows the results of calculations by formulas (11)–(13).

To construct a histogram of the distribution of the deviations of the directions of the error vectors relative to the direction to the base station CNIV, it is necessary to calculate the deviations of the error vectors to the east and west, relative to the direction to the base station. Moreover, deviations to the east will be considered positive and equal to:

$$\beta_i = \Delta\alpha_i, \quad (14)$$

and deviations to the west are negative and equal to:

$$\beta_i = 360° - \Delta\alpha_i. \quad (15)$$

The results of the calculation of these deviations are given in the last column of Table 3.

Table 3. The value of the directional angles from the points to the CNIV station

| No. of a point | $\Delta X_i'$, m | $\Delta Y_i'$, m | $(\alpha_i')°$ | $(\Delta\alpha_i)°$ | $(\beta_i)°$ |
|---|---|---|---|---|---|
| 1 | 6037.515 | 1331.192 | 12.43 | 251.78 | –108 |
| 2 | 5898.292 | 1393.752 | 13.29 | 58.27 | 58 |
| 3 | 5824.87 | 1442.763 | 13.91 | 60.93 | 61 |
| 4 | 5792.888 | 1539.993 | 14.89 | 45.99 | 46 |
| 5 | 5830.733 | 1590.418 | 15.26 | 19.85 | 20 |
| 6 | 5780.735 | 1714.98 | 16.52 | 38.42 | 38 |
| 7 | 5783.678 | 1760.019 | 16.93 | 2.33 | 2 |
| 8 | 5822.569 | 1777.527 | 16.98 | –1.96 | –2 |
| 9 | 5875.725 | 1857.175 | 17.54 | 341.82 | –18 |
| 10 | 5917.399 | 1988.574 | 18.58 | 333.55 | –26 |
| 11 | 5978.082 | 1976.202 | 18.29 | 326.02 | –34 |
| 12 | 6031.902 | 1956.833 | 17.97 | 325.49 | –35 |
| 13 | 6164.72 | 1894.289 | 17.08 | 307.38 | –53 |
| 14 | 6179.773 | 1817.679 | 16.39 | – | – |
| 16 | 6136.834 | 1627.766 | 14.86 | – | – |
| 22 | 6097.388 | 1453.299 | 13.41 | 100.74 | 101 |
| 1446 | 5887.504 | 1741.489 | 16.48 | 10.58 | 11 |
| 1447 | 5976.197 | 1676.171 | 15.67 | 7.17 | 7 |
| 1448 | 5992.273 | 1573.17 | 14.71 | 65.42 | 65 |
| 1449 | 5911.845 | 1453.807 | 13.82 | 61.93 | 62 |
| 15 | 6113.503 | 1777.014 | 16.21 | –16.21 | –16 |
| 17 | 5989.863 | 1812.383 | 16.83 | 341.19 | –19 |
| 18 | 6058.333 | 1686.741 | 15.56 | 301.18 | –59 |
| 20 | 5937.129 | 1713.386 | 16.10 | 18.54 | 19 |
| 21 | 6112.592 | 1677.441 | 15.35 | 282.21 | –78 |

There is a statistical table of distribution of deviations of directions $\beta_i$ of error vectors relative to the base direction (Table 4).

Table 4. Statistical table of distribution of deviations of directions

| No. of intervals | $(l)°$ | $k$ | $\tilde{p}$ |
|---|---|---|---|
| 1 | –105 –75 | 2 | 0.09 |
| 2 | –75 –45 | 2 | 0.09 |
| 3 | –45 –15 | 6 | 0.25 |
| 4 | –15 15 | 3 | 0.13 |
| 5 | 15 45 | 3 | 0.13 |
| 6 | 45 75 | 5 | 0.22 |
| 7 | 75 105 | 2 | 0.09 |
| Σ | – | 23 | 1.00 |

In this table: $(l)°$ – limits of intervals of distribution of values $\beta_i$, $k$ – frequency of occurrence of values $\beta_i$ within the intervals, $\tilde{p}$ – selective probability of occurrence of values $\beta_i$ within this interval, which is calculated by the formula:

$$\tilde{p} = \frac{k}{n}. \quad (16)$$

It should be noted, that value $\beta_1 = -108°$ is attributed to the first interval due to the proximity of this value to –105° (see Table 3 and Table 4). What is more, the number of error vectors is taken $n = 23$, since geodetic points 14 and 16 are the starting points.

According to the data in Table 4 a histogram of the sample distribution of the deviation of the directions of the error vectors relative to the direction to the base station CNIV has been constructed (Figure 3).

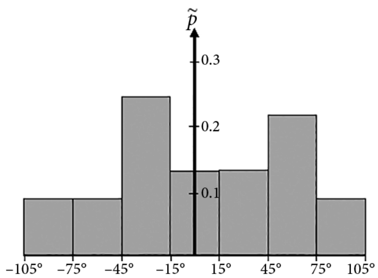


Figure 3. Histogram of the selective distribution of the deviation of the directions of the error vectors relative to the direction to the base station CNIV

The histogram (Figure 3) shows that most often deviate the error vectors relative to the direction to the CNIV base station in the sectors (–45° –15°) and (45° 75°), respectively 25% and 22% (see Table 4). Deviations in the central sector (–15° 15°) are 13%, deviations in the wider central sector (–45° 45°) already have 51% of error vectors, deviations in the wider central sector (–75° 75°) have 82% of error vectors. There are no deviations in the opposite direction.

Thus, there is a steady tendency to deviate among the planned coordinates of the points located in the forest park area of the educational and research site "Fortuna" of Chernihiv Polytechnic National University and determined by GNSS-observations in real time mode, towards the base station CNIV.

## Conclusions

A method for determining the prevailing direction of deviation of the planned coordinates of geodetic points, based on the comparison of coordinate values determined by the method of GNSS-observations with the coordinates of the same points determined by the method of electronic polygonometry has been developed. For this purpose, the interpretation of directions and values of deviations in the form of a vector field and statistical processing of the number of deviations from a certain prevailing direction have been used. There is a steady tendency to deviate among the planned coordinates of the points located in the forest park area and determined by GNSS-observations in real time mode, in the direction of the base station.

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