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Azizjon Ruziev, PhD on Geographical Sciences,
Senior Lecturer at the Department of Geodesy and Geoinformatics, National University of Uzbekistan
Otabek Yusupjonov, PhD student at the Department of Geodesy and Geoinformatics, National University of Uzbekistan

EXPERIMENTAL RESEARCH OF THE ACCURACY OF THE ENGINEERING AND TOPOGRAPHIC SURVEY PLAN PERFORMED WITH A TOTAL STATION

Abstract: The purpose of the research is to study the methodology and accuracy of large-scale topographic survey based on experimental tests. For this purpose, a typical plot of land was selected for the test. Topographic survey on a scale of 1:500 was carried out using total station, processed the results and created a digital terrain model. Control measurements were carried out on the plan and on the ground to assess the accuracy of the planned position of the points of the solid contours of the terrain depicted on the plans, and the accuracy of the relief image. processing of control geodetic measurements was carried out based on the theory of mathematical processing and accuracy assessment. In order to confirm the reliability of the obtained accuracy indicators of the plans, the normal distribution of the series of measurement errors was checked. the obtained value confirms that the error series obeys the normal distribution law.

Keywords: topographic survey, plan total station, geodetic networks, error, accuracy.

Introduction. With the continuous growth of the world population, the need for the construction of residential buildings, cultural, domestic, industrial and transport facilities is increasing. To address these issues, the United Nations 2030 Sustainable Development Agenda defines the objectives of "Ensuring openness, safety and environmental sustainability of cities and towns" [1]. For the implementation of these facilities, it is of great importance to obtain science-based, accurate and reliable geodetic data and cartographic materials to support facility design, construction and reconstruction.

The world pays particular attention to research in this direction, including improving the accuracy of topographic surveys performed during pre-project topographic and geodetic surveys for the construction of hydraulic, industrial, transport and other engineering structures and cities. Also important are the use of modern electronic measuring instruments and satellite technologies in large-scale topographic surveys, the use of GIS software for processing the results, and research aimed at improving the methods of topographic surveys.

Analysis of scientific and technical literature and publications on this topic shows that the following scientists from different countries Y.Jalloh, A.Ahmad, Z.M.Amin, K.Sasaki [2], U.Kizil, L.Tisor [3], K.Amirthavarshini, V.Vasanthakumar, M.Kannan, M.Nandhini Chella Kavitha conducted research on large-scale topographic surveys. Among the CIS (Commonwealth of Independent States) countries, the following Russian scientists such as V.D. Bolshakov, N.G. Viduev, G.P. Levchuk, N.N. Lebedev, V.V. Bakanova, Y.K. Mikhelev conducted theoretical and experimental studies of the accuracy of surveying terrain contours and relief images in large-scale topographic surveys.

The study and analysis of the work performed in the practice of Uzbekistan shows that in recent years, despite the fact that all engineering and topographic surveys are carried out using modern instruments and technologies, research on the methodology and accuracy of the work were not carried out. However, especially in design and construction work such aspects are of great scientific and practical importance, and support effective planning and implementation of topographic and geodetic work.

With the growing demand for large-scale topographic plans in the construction industry of Uzbekistan, the task of providing high-quality topographic plans using modern geodetic instruments and technologies arises.

This multifaceted and complex task requires the solution of many scientific and technical issues. One of them is the science-based improvement of the methodology for the production of large-scale topographic surveys using modern instruments and technologies.

Until 2000, large-scale topographic surveys for construction in Uzbekistan were carried out using traditional methods and land surveying instruments. In recent years, due to the increasing spread of modern electronic measuring devices and new satellite technologies, all large-scale engineering and topographic surveys are carried out exclusively with using them.

The purpose of the research is to study the methodology and accuracy of large-scale topographic survey based on experimental tests. For this purpose, a typical plot of land was selected for the test, on which the following works was carried out: (i) topographic surveys at a scale of 1:500 using total station, (ii) processing the results, and (iii) creating a digital terrain model; (iv) carrying out control measurements on the plan and on the ground to assess the accuracy of the planned position of the points of solid contours of the terrain depicted on the plans, and the accuracy of the relief image; (v) processing of control geodetic measurements based on the theory of mathematical processing, accuracy assessment.

Methods. The research used methods such as field measurements, and evaluation of the quality of measurement results applying probability theory, methods of mathematical statistics and mathematical processing using suitable GIS programs.

Measurements. With the aim of establishing a geodetic network on the campus of the National University of Uzbekistan (NUUz), 7 test points has been fixed. 6 among them form a closed polygon (Figure 1). The shortest side of the network is 124.4 m and the longest side is 230.7 m [4]. This network in the form of a traverse line was built (fixed) in accordance with the requirements of the current Instruction [5, 6] of the Republic of Uzbekistan regulating geodetic works.

Figure 1. The sketch of the test network on an aerial photo (left) and without a background (right)

The above points of the survey base also served as the base for the survey with the total station. At each point of the survey base a topographic survey was carried out by the method of electronic tacheometry using a total station Focus 8. Field coding and sketching were performed during the survey. Field coding allows to automate the use of topographic survey data.

Field coding and sketching were carried out during the surveying process. Field coding allows you to automate the use of topographic survey data.

Field measurement data were exported to a personal computer and processed using the CREDO_DAT program. The digital model of the test site was created in the AutoCAD Civil 3D program.

For the purpose of assessing the accuracy of engineering-topographic plans, solid contour points were marked on the topographic plan of the tacheometric survey and the length of the segments between them was determined by scale and the lengths of the same lines were measured on the ground. The differences between the lengths of these segments ΔS_i were calculated using the following formula [9]

$$\Delta S_i = S_{p,i} - S_{g,i}, \quad (1)$$

where $S_{p,i}$ and $S_{g,i}$ are, respectively, the horizontal distances between the contour points measured on the plan and on the ground.

The measurement results and their differences are presented in table 1.

Table 1.

Distances between contour points measured on the plan and on the ground and their difference

No.	Measured distance S, m		Differences ΔS_i, cm	ΔS_i^2	No.	Measured distance S, m		Differences ΔS_i, cm	ΔS_i^2
	on the plan	on the ground				on the plan	on the ground		
1	7.44	7.438	0.2	0.04	21	35.632	35.608	2.4	5.76
2	6.474	6.481	-0.7	0.49	22	33.775	33.767	0.8	0.64
3	29.783	29.823	-4	16	23	33.407	33.369	3.8	14.44
4	21.596	21.624	-2.8	7.84	24	52.431	52.421	1	1
5	23.156	23.179	-2.3	5.29	25	46.122	46.104	1.8	3.24
6	26.598	26.644	-4.6	21.16	26	47.235	47.213	2.2	4.84
7	23.47	23.473	-0.3	0.09	27	27.498	27.47	2.8	7.84
8	21.901	21.891	1	1	28	20.583	20.569	1.4	1.96
9	3.01	3.014	-0.4	0.16	29	43.79	43.783	0.7	0.49
10	47.235	47.213	2.2	4.84	30	30.501	30.525	-2.4	5.76
11	8.905	8.906	-0.1	0.01	31	55.207	55.219	-1.2	1.44
12	32.127	32.129	-0.2	0.04	32	58.641	58.653	-1.2	1.44
13	33.786	33.839	-5.3	28.09	33	53.39	53.421	-3.1	9.61
14	45.208	45.224	-1.6	2.56	34	58.959	58.956	0.3	0.09
15	56.71	56.66	5	25	35	50.563	50.502	6.1	37.21
16	51.525	51.521	0.4	0.16	36	23.306	23.281	2.5	6.25
17	46.044	46.042	0.2	0.04	37	36.044	36.062	-1.8	3.24
18	18.954	18.96	-0.6	0.36	38	28.859	28.906	-4.7	22.09
19	78.68	78.727	-4.7	22.09	39	32.104	32.119	-1.5	2.25
20	39.13	39.122	0.8	0.64	40	59.218	59.239	-2.1	4.41
Σ			**-17.8**	**135.9**				**7.8**	**134**

Using the data in Table 1, the root-mean-square error of the differences (true error) and a single measurement was found from the following formula

$$m_{\Delta S}=\sqrt{\frac{[\Delta S^2]}{n}}, \qquad (2)$$

where n is the number of lines measured on the plan and on the ground.

Results. According to the table 1, $m_{\Delta S}=\pm 2{,}60\,cm$ were determined using formula (2). It can be seen that the root mean square error of the image of contour points on the topographic plan of the electronic tacheometric survey is ±2,60 cm, which is 4 times less than the value set for the scale 1:500 in the instruction ±10 (0,2 mm on the scale of the plan).

To confirm the reliability of this conclusion, the normal distribution of the series of differences found as a result of double measurements was checked using the laws of mathematical statistics. The normal distribution law is characterized by the distribution density of the random variable Δ

$$\varphi(\Delta)=\frac{1}{\sigma\sqrt{2\pi}}e^{\frac{-(\Delta-a)^2}{2\sigma^2}}. \qquad (3)$$

The main parameters of a normally distributed random variable Δ in expression (3) $a=M(\Delta)$ and $\sigma^2=D(\Delta)$ are found by the following formulas

$$a=M(\Delta)=\frac{[\Delta]}{n}, \qquad (4)$$

$$\sigma(\Delta)=\sqrt{D(\Delta)}\approx m=\sqrt{\frac{[\Delta^2]}{n}}. \qquad (5)$$

Empirical values for constructing a normal distribution curve $\varphi(\Delta)$ were calculated using formulas (4) and (5): $a=-0{,}25$ cm; $m=+2{,}60$ cm.

The absence or small magnitude of a systematic error in the difference (errors) given in Table 1 is confirmed by the small magnitude of the obtained mathematical expectation $M(\Delta S)=-0{,}25$ cm, that is, it is close to zero.

The study of the distribution of a statistical series begins with the construction of a histogram. To construct a statistical grouped series, the errors were distributed in twelve intervals (the length of the interval equal to half the mean square error, $0.5m=1.3\,cm$). The number of errors corresponding to each interval m_i was calculated. Then the frequency is calculated from the formula

$Q_i = \frac{m_i}{n}$. Based on the obtained data, an empirical distribution graph (histogram) was created (Fig. 2). The theoretical curve that smooths the histogram was built using the values calculated from the formula (3) (Fig. 2).

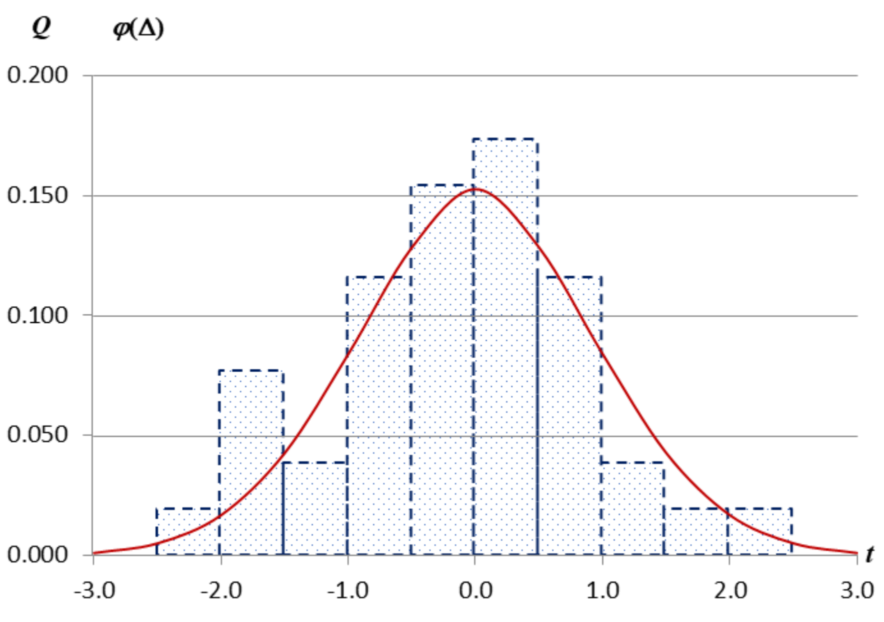

Figure 2. Histogram and theoretical curve

To assess the degree of approximation of the statistical distribution (histogram) to the theoretical normal distribution law (distribution curve), K.Pearson's χ^2 value was used as a measure of their difference (Table 1).

$$\chi^2 = \sum_{i=1}^{k} \frac{(m_i - n\,p_i)^2}{n\,p_i}. \qquad (6)$$

According to the number of degrees of freedom $r = k-1-s = 12-1-1 = 10$ (k is the number of interval, s is the number of parameters) and $\chi^2 = 5{,}655$ values obtained from the formula (6), the probability value $p(\chi^2) = 0{,}8416$ was obtained from [8]. Taking into account that this value is much larger than the accepted value of probability ($p = 0.1$), experimental measurements allow to confirm the hypothesis of normal distribution of errors.

To assess the accuracy of the relief image on the topographic plan, the difference (error) ΔH_i between the heights of the points $H_{p,i}$ determined from the topographic plan and the heights of points $H_{g,i}$ measured on the ground is found from the following formula

$$\Delta H_i = H_{p,i} - H_{g,i}. \qquad (7)$$

In Table 2 shows the marks of the points determined on the plan and on the ground and their differences according to the formula (12).

Table 2

Elevations of relief points measured on the plan and on the ground, and their differences

№	Measured elevation H, m		Differences ΔH_i, cm	ΔH_i^2	№	Measured elevation H, m		Differences ΔH_i, cm	ΔH_i^2
	on the plan	on the ground				on the plan	on the ground		
1	35.39	35.42	-3	9	19	35.88	35.859	2.1	4.41
2	35.39	35.366	2.4	5.76	20	35.84	35.84	0	0
3	35.34	35.333	0.7	0.49	21	35.82	35.854	-3.4	11.56
4	35.3	35.269	3.1	9.61	22	35.57	35.541	2.9	8.41
5	35.31	35.362	-5.2	27.04	23	35.3	35.29	1	1
6	35.35	35.379	-2.9	8.41	24	35.28	35.32	-4	16
7	35.27	35.307	-3.7	13.69	25	35.48	35.467	1.3	1.69
8	35.34	35.267	7.3	53.29	26	35.38	35.432	-5.2	27.04
9	35.7	35.633	6.7	44.89	27	35.95	35.951	-0.1	0.01
10	35.53	35.519	1.1	1.21	28	35.56	35.602	-4.2	17.64
11	35.67	35.649	2.1	4.41	29	35.53	35.519	1.1	1.21
12	35.04	35.028	1.2	1.44	30	35.66	35.678	-1.8	3.24
13	35.41	35.422	-1.2	1.44	31	35.73	35.727	0.3	0.09
14	35.4	35.404	-0.4	0.16	32	35.67	35.645	2.5	6.25
15	35.44	35.418	2.2	4.84	33	35.56	35.583	-2.3	5.29
16	35.71	35.718	-0.8	0.64	34	35.59	35.549	4.1	16.81
17	35.31	35.302	0.8	0.64	35	35.72	35.703	1.7	2.89
18	35.22	35.222	-0.2	0.04	36	35.69	35.715	-2.5	6.25
Σ			**-3**	**9**				**-3**	**17**

The mean square error of the relief image, calculated according to the Table 2 from the above formula (2), was $m_{\Delta H} = \pm 3{,}0$ cm. This value is twice as accurate as the allowed value of ±6.0 cm (¼ of the contour interval) which is set in the instruction for the flat area.

The parameters of the normal distribution of the difference (errors) in the heights of the points were calculated by formulas (4) and (5) $a=M(\Delta H)=0{,}10$ cm, $\sigma(\Delta H)=m_{\Delta H}=3{,}0$ cm.

The absence or small magnitude of the systematic error is confirmed by the proximity to zero of the obtained mathematical expectation $M(\Delta H)=0{,}10$ cm.

To construct a statistical grouped series, the errors were distributed in twelve intervals (the length of the interval equal to half the mean square error, $0.5m=1.48\,cm$). The number of errors corresponding to each interval m_i was calculated. Then the frequency is calculated. Based on the obtained data, an empirical distribution graph (histogram) was created (Fig. 3). The theoretical curve that smooths the histogram was built using the values calculated from the formula (3) (Fig. 3).

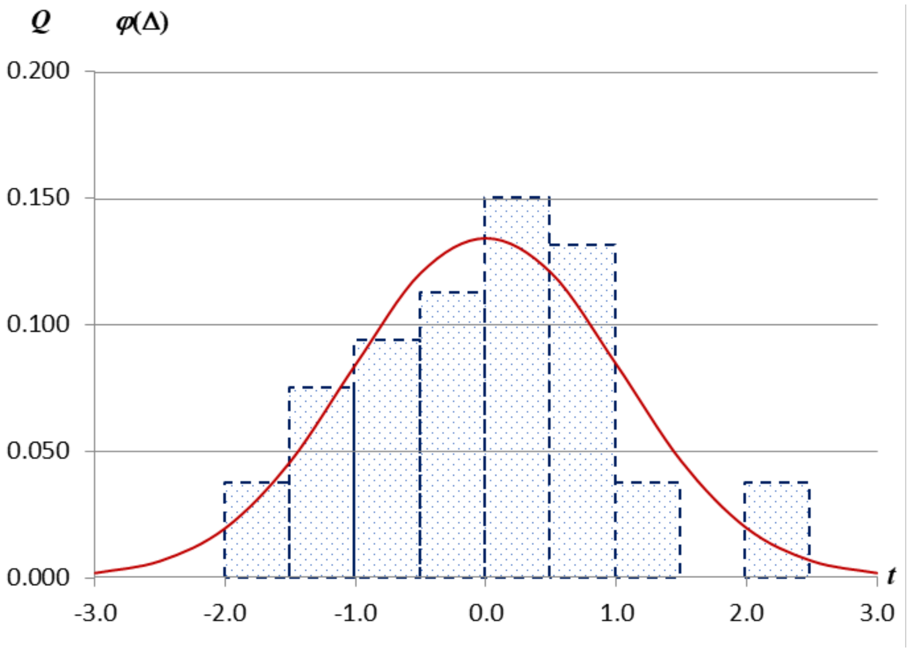

Figure 3. Histogram and theoretical curve

According to the number of degrees of freedom $r=10$ and $\chi^2=7{,}291$ values obtained from the formula (6), the probability value $p(\chi^2)=0{,}6973$ was obtained from [8]. Taking into account that this value is much larger than the accepted value of probability ($p=0.1$), experimental measurements allow to confirm the hypothesis of normal distribution of errors. The results of the experiment with the inequality $0{,}6973>0{,}1$ confirm the hypothesis about the normal distribution of measurement errors.

Discussions. The measurements performed to assess the accuracy o of the image of the situation of the terrain and relief of the topographic plan on a scale of 1:500 made from the results of the surveying of the test site with a total station were developed mathematically, and the following results were obtained: the root-mean-square error of the image on the plan of electronic tacheometry of the contours $m_s=\pm2{,}6$ cm, which is 4 times more accurate than the standard value of ±10 cm, set for a scale of 1:500; and the root-mean-square error of the image of the relief was $m_H=\pm3{,}0$ cm, which is twice as accurate as the allowed value of ±6.0 cm (¼ of the contour interval) specified in the instruction.

In order to confirm the reliability of the obtained accuracy indicators of the plans, the normal distribution of the series of measurement errors was checked and the following was determined: the arithmetic mean value in the range of errors was practically close to zero; no value greater than 3m was found in the range of errors; Based on Pearson's χ^2 criterion, the probability of proportionality of empirical and theoretical distributions was $p=0{,}842$. The fact that $0{,}842>0{,}1$ confirms that the series of errors obeys the law of normal distribution.

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