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RESULTS OF THE UAV APPLICATION IN GEODETIC MEASUREMENTS PERFORMED IN THE TESTING SITE

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Key words: UAV, tachometric survey, GPS-survey, Delta Digitals software, double unequal observations, systematic error.

Purpose: to perform a comparison of the classical methods of creation of site plans with the method of constructing a situational plan based on the use of DJI drone technology.

Formulation of the problem

Modern scientific research in the field of engineering sciences is aimed at developing new effective methods of aerial photography using new digital technologies. The rapid development and improvement of unmanned aerial vehicles (UAVs) in recent years has allowed expanding the scope of their application to solve traditional problems in the field of applied geodesy, photogrammetry and cartography. Typically, solving such problems requires the development of appropriate technologies for the execution of works, as well as increasing the requirements for quality and accuracy of photography.

Therefore, an alternative solution in the present time, when the cost of using airplanes and helicopters has become way much higher, is the introduction of technology of using the UAV in aerial photography of small area sites [1].

Analysis of recent researches and publications that address solution of this problem

Using the UAV for aerial photography is an essential trend in the development of methods for collecting geospatial data and a cost-effective solution to most issues in the field of geodesy, cartography and surveying. By flying according to preset routes in automatic or semi-automatic mode it is possible to obtain accurate and reliable materials on the terrain, where either construction works, or ground-based laser scanning, or conditional monitoring of roads, railways or airports etc. are to be carried out [2]. The obtained digital aerial photographic materials are the basis for creation of digital and electronic maps, making of topographic and cadastral plans of the area.

Note that the use of UAVs has been earlier considered for agriculture [3] and civil aviation [4], to create large-scale plans for rural settlements [5], to make cadastral and topographic plans [6], for military purposes [7], for the mapping of road traffic events [8].

Unresolved parts of the general problem

Part of the overall problem is to set the parameters of the accuracy of building a plan based on the use of DJI drone technology.

Statement of problem task

The set task is to analyze and explore the possibilities of using unmanned aerial vehicles for geodetic measurements in the testing site, taking into account the formulated purpose of work.

General information

It is known that unlike tacheometric survey and measurement with the help of GPS-receivers, unmanned aerial vehicles allow performing aerial survey of a small area quickly, qualitatively and economically for the purpose of making topographic plans and orthophotomaps [9]. However, in order to assess the feasibility of using this technology among the existing methods of surveying, it is necessary to compare its results with the obtained materials of the proposed surveys of the test site - a small area in the territory of Kryviy Rih National University (Fig. 1).

Fig. 1. Experimental test site on Yandex map

Marks were placed along the contour and in the middle of the lawn (Fig. 2).

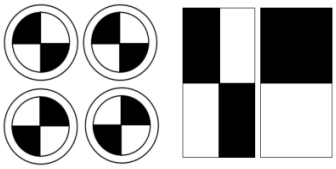

Fig. 2. Marks for experimental test site

The coordinates of the marks were determined using tacheometric survey, GPS survey and UAV. For this study the Sokkia SET 530 R tacheometer, the TOPCON Hiper + GPS receiver, the DJI Phantom 3 Professional quadrocopter and the metal tape were used. The geodesic devices were brought into working position in accordance with the individual operating instructions for the devices [10, 11, 13].

Table 1 shows the number of marks that were used for different shooting methods.

Table 1

Number of processed marks

Shooting method		
UAV	Tachometric shooting	GPS-survey
55	80	65

As we can see, the number of marks processed with UAV is the smallest, so it should be investigated whether the accuracy of determining the coordinates of marks is affected by their number.

Delta Digitals software was used for processing the received materials, the powerful cartographic core of which allows using thousands of raster images and hundreds of thousands of vector objects in conventional signs in one card, maintaining a complete technological chain from processing geodetic measurements to printing technical documentation, cross-linking and scaling of images, writing and reading files in popular GIS formats [12].

After loading of the tacheometric survey file into the Geodesy module, the coordinates were calculated and equalized. As a result of the corresponding actions with the computed coordinates of the tacheometric survey and the coordinates of the GPS survey, a generalized scheme for the location of marks at the test site at a scale of 1: 500 was constructed (Fig. 3).

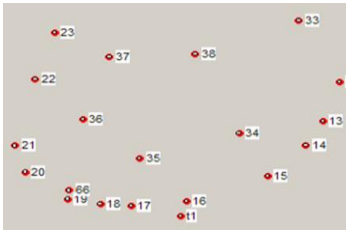

Fig. 3. Fragment of the generalized scheme of the location of marks on the test site

Below is the order of constructing the contour of the test site, which consists of the following. On the toolbar click the Collection (Figure 4) button, after which the program goes into the appropriate mode and the cursor of the manipulator takes the form of a cross .

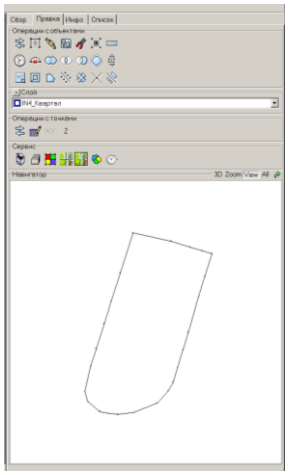

Fig. 4. Working window of the "Collection" mode

From the **Active Layer** list, select **IN4_Quarter**, from Collection template - **line**. Direct the cursor of manipulator to each mark until the cursor appears and register the points by clicking the left button of manipulator. Due to the fact that we have a closed test site, click the right button of manipulator on the last registered mark and select the function "Close object", after which the last registered mark closes with the registered initial mark.

As a result of processing of materials, two contour schemes of the test site (tachometric survey and GPS survey) were obtained. After comparing the obtained coordinates of the contour marks, it was concluded that the deviation between the corresponding coordinates does not exceed ± 0.002 m, therefore the test site scheme was generalized (Fig. 5).

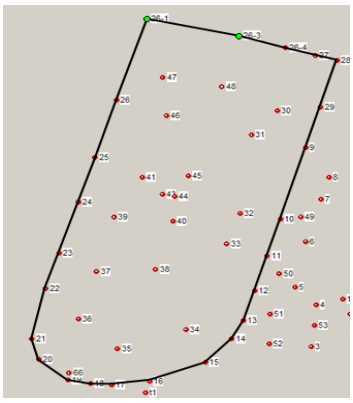

Fig. 5. The contour of test site after processing in the Delta Digitals program

Aerial survey of the test site was carried out in parallel with the above-mentioned surveys. The process of shooting was carried out in several stages: preparatory work, which consisted of adjusting the quadrocopter to the working position [13], marking the points on the test site, performing aerial survey and cameral processing of the obtained materials.

Photographic materials obtained as a result of aerial photography using UAVs were also studied in the Delta Digitals software package that we selected. Aerial photos were incorporated, and the video was scaled to 1: 500 (Figure 6). Based on the known coordinates of the three starting points, the coordinates of the marks were determined - the manipulator cursor was moved to the center of each mark on the photograph (Fig. 7).

Fig. 6. Incorporating of aerial photographs taken by UAV

Fig. 7. Arrangement of marks on the photo taken by UAV

The abovementioned actions made it possible to show the contour of the test site on a photograph obtained as a result of shooting with UAV (Fig. 8).

Fig. 8. The contour of the test site on photograph taken by UAV

The processing of the obtained materials made it possible to compare the calculated areas of the test site (Table 2).

Table 2

Area of the test site

Shooting method	UAV	Tachometric survey	GPS-survey
Defined area of land plot, ha	0,1098	0,1097	0,1098

As can be seen from Table 2, the values of the areas of the test site are almost the same, and the deviation of the area determined from the photograph taken by UAV and photograph from tacheometric survey is + 1.0 m^2.

After the surveys were completed, the distance between the marks was measured at the test site (Fig. 9).

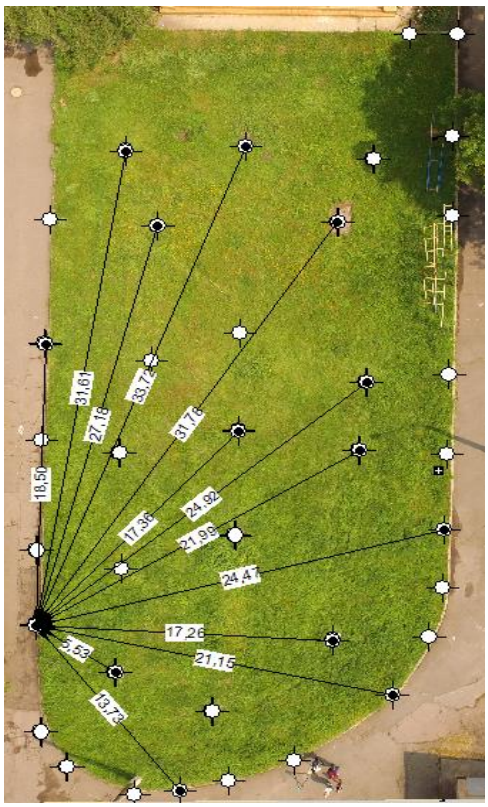

Fig. 9. Measured distances between brands on aerial photograph

In [14 - 16] cases of processing of double unequal observations are given. The analysis showed that sometimes double measurements are equivalent, and in each pair they are unequal, that is if the same values are obtained by different instruments [17]. For example, in our case the coordinates of the marks of the test site and the distance between the marks was measured four times, but with different instruments.

Below is one of the examples of processing the results of unequal double observations in terms of the significance of systematic error, which is presented in Table 3.

If the difference of double measurements $d_i = x_i - x_i^{'}\ (i = 1, 2, \dots, n)$ obtained from unequal observations, x_i, a but in pairs, that is $(p_{x_i} = p_{x_i}^{'})$, т then we have the weight of differences, which we find using the formula

$$\frac{1}{p_{d_i}} = \frac{1}{p_{x_i}} + \frac{1}{p_{x_i}^{'}} = \frac{2}{p_{x_i}} \text{ i } p_{d_i} = \frac{p_{x_i}}{2} = \frac{p_i}{2}. \qquad (1)$$

The criterion for the presence of the constant systematic error is the fulfilment of the inequality:

$$|[p_d d]| \le 2{,}5\,\frac{[|p_d d|]}{\sqrt{[p_d]}}. \qquad (2)$$

Let us present the results of calculating the criterion (2) from the data in Table 1

$$727{,}287 > 2{,}5\,\frac{727{,}287}{\sqrt{76}}.$$

It can be seen from the calculation results that the inequality is not fulfilled, hence, further calculations should be carried out in the following order. The difference contains systematic error, which is calculated by the following formula

$$\theta = \frac{[pd]}{[p]} = \frac{727{,}287}{76} = \pm 9{,}570 \text{ мм.} \quad (3)$$

Error of unit weight is calculated using the formula

$$\mu = \sqrt{\frac{[d'^2 p]}{2(n-1)}} = \sqrt{\frac{15668{,}62}{2 \cdot (38-1)}} = \pm 14{,}551 \text{ мм.} \quad (4)$$

The RMS errors of the mean values $x_{i\,ср} = \frac{x_i + x_i'}{2}$ are found from the formula

$$m_{(x_i)_{ср}} = \frac{\mu}{\sqrt{2p_i}}. \quad (5)$$

Table 3

The results of estimating the accuracy of determining the distances calculated from the coordinates by GPS survey and UAV aerial photography

№ лінії	Відстані, м		d, мм	d^2	p	pd	d'	d'^2	pd'^2	m, мм	Знаменник відносної похибки
	GPS	БПЛА									
22-25	18,569	18,577	8	64	2,67	21,35	-15,66	245,33	654,73	± 6,30	2300
22-47	31,569	31,582	13	169	1,57	20,41	-10,66	113,70	178,49	± 8,21	2400
22-46	27,255	27,266	11	121	2,30	25,34	-12,66	160,35	369,46	± 6,78	2500
22-48	34,230	34,238	8	64	2,89	23,15	-15,66	245,33	709,85	± 6,05	4300
22-31	31,879	31,892	13	169	2,69	35,03	-10,66	113,70	306,42	± 6,27	2500
22-40	17,630	17,638	8	64	1,49	11,92	-15,66	245,33	365,65	± 8,43	2200
22-32	25,132	25,142	10	100	2,12	21,25	-13,66	186,68	396,61	± 7,06	2500
22-33	22,211	22,221	10	100	1,88	18,78	-13,66	186,68	350,53	± 7,51	2200
22-12	24,560	24,568	8	64	2,08	16,61	-15,66	245,33	509,34	± 7,14	3100
22-34	17,392	17,398	6	36	1,47	8,82	-17,66	311,98	458,68	± 8,49	2900
22-15	21,271	21,279	8	64	1,80	14,39	-15,66	245,33	441,14	± 7,67	2700
22-18	13,765	13,770	5	28	1,16	6,17	-18,36	337,20	392,38	± 9,54	2600
22-30	36,351	36,363	12	144	3,07	36,87	-11,66	136,03	417,99	± 5,87	3000
22-9	36,115	36,126	11	112	3,05	32,36	-13,06	170,64	520,95	± 5,89	3400
22-10	29,231	29,245	14	196	2,47	34,60	-9,66	93,37	230,75	± 6,55	2100
22-11	26,512	26,524	12	144	2,24	26,90	-11,66	136,03	304,88	± 6,87	2200
22-13	23,711	23,721	10	100	2,00	20,04	-13,66	186,68	374,19	± 7,27	2400
22-14	22,949	22,959	10	100	1,94	19,40	-13,66	186,68	362,17	± 7,39	2300
22-16	17,444	17,452	8	64	1,47	11,80	-15,66	245,33	361,79	± 8,47	2200
22-29	40,643	40,657	14	196	3,44	48,10	-9,66	93,37	320,81	± 5,55	2900
22-20	9,488	9,492	4	14	0,80	3,02	-19,90	395,88	317,53	± 11,49	2500
22-24	12,345	12,350	5	29	1,04	5,64	-18,26	333,54	348,09	± 10,07	2200
22-26	26,749	26,758	9	81	2,26	20,35	-14,66	215,00	486,17	± 6,84	3000
22-39	12,525	12,529	4	16	1,06	4,24	-19,66	386,63	409,36	± 10,00	3100
22-(26-3)	41,011	41,024	13	161	3,47	44,03	-10,96	120,19	416,67	± 5,53	3200
22-(26-1)	38,351	38,363	12	132	3,24	37,28	-12,16	147,94	479,61	± 5,71	3300
22-17	15,078	15,085	7	46	1,27	8,67	-16,86	284,36	362,47	± 9,11	2200
11-33	29,892	29,900	8	58	2,53	19,20	-16,06	258,02	651,97	± 6,47	3900
11-32	34,988	34,997	9	72	2,96	25,14	-15,16	229,92	679,99	± 5,98	4100
11-30	19,605	19,613	8	64	1,66	13,26	-15,66	245,33	406,60	± 7,99	2500
11-31	16,403	16,410	7	50	1,39	9,85	-16,56	274,33	380,41	± 8,74	2300
11-48	23,397	23,407	10	100	1,98	19,78	-13,66	186,68	369,24	± 7,32	2300
11-34	13,765	13,771	6	37	1,16	7,10	-17,56	308,46	358,95	± 9,54	2300
11-10	21,118	21,123	5	25	1,79	8,93	-18,66	348,31	621,77	± 7,70	4200
11-38	13,276	13,282	6	36	1,12	6,73	-17,66	311,98	350,15	± 9,71	2200
11-40	12,084	12,089	5	28	1,02	5,41	-18,36	337,20	344,47	± 10,18	2300
11-47	26,983	26,996	13	169	2,28	29,66	-10,66	113,70	259,37	± 6,81	2100
11-44	13,551	13,556	5	25	1,15	5,73	-18,66	348,31	399,00	± 9,61	2700
∑	899,028	899,36	334	3244	76,00	727,29	-565,53		15668,62		

Note. Values in some cells of Table 1 are rounded to two decimal places, but the calculations used a greater number of decimal places.

Based on the results of the calculations, graphs of dependencies were obtained (Figures 10 - 12).

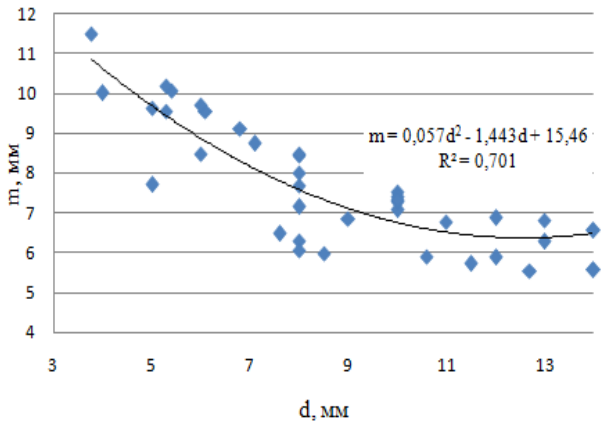

Fig. 10. The dependence of RMS errors () on the difference between the distances (mm)

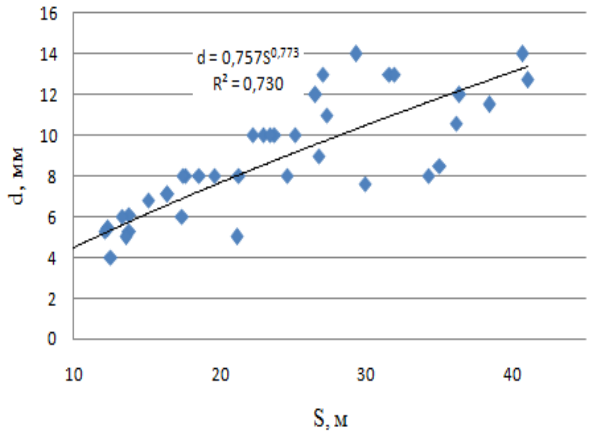

Fig. 11. Dependence of the difference between the distances (mm) from the measured distances (S, m)

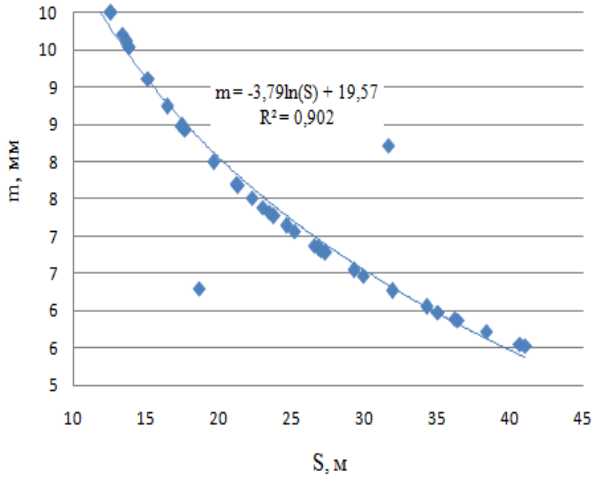

Fig. 12. Dependence of RMS errors (mm) on the measured distances (S, m)

Based on the plotted dependences of the obtained values we see that the correlation coefficient varies within the limits of + 0.701 - + 0.902, so that the relationship between the variables is strong, and the values obtained are reliable.

Software Statistica_10 allows building a variation series in the form of a histogram (Figure 13).

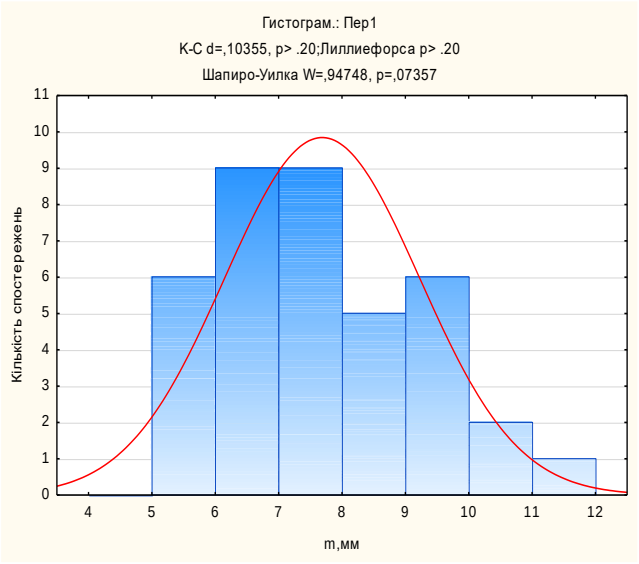

Fig. 13. Variation series in the form of a histogram

Using the description of statistics for the statistical series of the obtained mean square errors of average values, the following indicators were determined: ($\bar{X}$) – 7.687 mm; median (M_e) – 7.352 mm; asymmetry (A_S) – 0.543; standard asymmetry error m_A – 0.383; excess $(E)_\chi$ – - 0,558; standard excess error m_E – 0.750.

Based on the analysis of characteristics, we can establish the following:

1) the asymmetry is right-sided (positive), since $A_S = 0.543 > 0$;
2) the asymmetry is insignificant and has arisen due to accidental circumstances, since $\frac{|A_S|}{m_A} = 1{,}42 < 3$;
3) the distribution is plane-vertex ($E_\chi = -0{,}558 < 0$);
4) the deviation from the normal is insignificant, since $\frac{|E_\chi|}{m_E} = 0{,}744 < 3$.

Conclusions

Having investigated the obtained mean square errors of the average values of the measured distances, we can conclude that the distribution of the investigated variation series is plane-vertex (E_χ – - 0.558) with the extremely right-sided asymmetric distribution ($A_S: 0 < 0{,}5 <$ 0.543).

The results of estimating the accuracy of determining the distances computed from the coordinates of the surveys made showed that the distances are determined with relative errors less than 1:2000, hence, the use of the UAV is justified for the large-scale shooting of small areas and linear objects.

The prospect of further research will be: the substantiation of the requirements for the technology of aerial photography of traffic accidents and the process of processing the digital images taken by the UAV.

References

1. A.E. Altynov. Features of the aerial photography system based on a helicopter-type unmanned aerial vehicle/A.E. Altynov, V.K. Barbassov, M.S. Bataev, N.M. Gavryushin, D.O. Dryga//Engineering Surveys. ─ 2013. ─ No. 9. ─ P. 36 ─ 40.

2. V.K. Barbasov. Multi-rotor unmanned aerial vehicles and possibilities of their use for remote sensing of the Earth/V.K. Barbasov, M.N. Gavryushin, D.O. Dryga et al.//Engineering Surveys. ─ 2012. ─ No. 10. ─ P. 38 ─ 42.

3. Stankevych S.A. Application of modern technologies of aerospace photography in the agrarian sector / Stankevych S.A., Vasko A.V. // Scientific aspects of geodesy, land management and information technologies: materials of scientific and practical conference – 2011. – P. 44 – 50.

4. Matiichnyk M.P. Trends of using the unmanned aerial vehicles in civil aviation / Matiichnyk M.P., Kachalo I.A. // Materials of the XI International scientific and technical conference “AVIA 2013”. – 2013. – P. 97.

5. V. Galetskiy. Analysis of experimental works on the creation of large-scale plans for rural settlements using UAV/V. Galitsky, V. Glotov, V. Kolesnichenko, A. Prohorchuk, A. Zerklevich//Geodesy, cartography and aerial photography. - 2012. - No. 76. - P. 85 - 93.

6. UAV: use of aerial photography for mapping. [Electronic resource] - Access mode: http://www/uasresearch.com.

7. 7. Hlotov V. Analysis of the possibilities of using unmanned aerial vehicles for military purposes / V. Hlotov, A. Hunina, Yu. Teleshchuk // Modern achievements of geodetic science and production. – 2017 – Ed. 1 (38). – Pp. 139-146.

8. Y. Y. Atamanenko. Technical possibilities of application of unmanned mobile model for registering accidents/A.E. Kulikovskaya, Y.Y. Atamanenko//Modern achievements of geodesic science and production. - Lviv. - 2015. - Issue I (29). - P. 84 - 87.

9. V. Glotov. Analysis of the possibilities of using unmanned aerial vehicles for aerial survey processes/V. Glotov, A. Gunina//Modern achievements of geodetic science and production. ─ 2014 ─ Issue (28). ─ P. 65 ─ 70.

10. Manual. Electronic tacheometer GTS-230 series (GTS-233, GTS-35, GTS-236, GTS-239). - Moscow. - 2003. - 173 C.

11. Instruction manual. GPS-receiver TOPCON Hiper +. - Moscow. - 2006. - 162 C.

12. D. Fedorov. Digitals. Use in geodesy, cartography and land management/D. Fedorov//Publication of LLC "Analitika". - 2015. - 354 C.

13. Instruction manual for Phantom 3 Professional [Electronic resource]. - Access mode: http://quadrone.ru.

14. V. D. Bolshakov. Theory of errors of observations: Textbook. For universities/V.D. Bolshakov. - 2 nd ed., rev. and added - M.: Nedra, 1983. - 223 C.

15. V. D. Bolshakov. Equalization of geodesic constructions: reference book/V.D. Bolshakov, Y. I. Markuse, V.V. Golubev. - Moscow: Nedra, 1980. - 413 C.

16. S.P. Voytenko. Mathematical processing of geodetic measurements. Theory of measurement errors: Textbook. S.P. Voitenko. - M.: KNUBA. - 2003. - 216 C.

17. V.A. Ryabchy. Probable-mathematical analysis of a limited number of unevenly accurate measurements of a single value/V.A. Ryabchii, V.V. Ryabchii//Modern achievements in geodesic science and production: Sciences -UOGKG. - L.: Publishing house Lviv Polytechnic. - 2013. - Issue - P. 25 - 30.

Results of UAV application for geodetic measurements at the test site

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Tachometric survey, GPS survey and aerial photography with the DJI Phantom 3 Professional UAV was carried out at the test site. As a result of the processing of survey materials, the coordinates of the test site contour and the distance between the marks were obtained in Delta Digitals software. Mathematical processing of the results of unequal double observations on the importance of a systematic error was performed, and the average square errors of the average measured distances were investigated and calculated in the Statistica_10 software. On the basis of the obtained variation series a histogram was constructed.