USE OF UNMANNED AERIAL VEHICLES ON EXAMPLE OF PHANTOM 4 (STANDARD) FOR CREATING DIGITAL TERRAIN MODELS

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Abstract. Nowadays, more and more unmanned aerial vehicles (UAVs) are used to solve various problems. The use of specialized unmanned aerial vehicles causes some difficulties. The UAVs are quite expensive, and you need to have the necessary qualifications in order to effectively operate them. At the same time, there are a lot of non-specialized UAV models, which are much cheaper and easier to use. But the question remains about their capabilities. For example, how to generate a digital terrain model (DTM) of the required quality in order to use it in land use planning? The report is tasked with the scientific (theoretical) substantiation of the need for preliminary calculation of the parameters of aerial survey from the UAV to ensure a required accuracy of the DTM. The calculation involves taking into account the pixel size of the sensor, overlap, image base and the required RMSE of the heights. The report presents a comparison of two methods for DTM generation. Namely, the DTM generation as a result of photogrammetric processing of images obtained during aerial surveying with UAVs and a more traditional method of ground surveying using a modern total station. Obviously, the main criterion for the quality of the generated DTM is the accuracy of the spatial coordinates of its points. This paper presents the qualitative comparison of DTM that were generated using different engineering equipment and using various processing methods. The analysis of the results is based on the least squares method. The study concluded that the use of the photos from the UAVs is effective for the DTM generation.

Keywords: digital terrain model (DTM), unmanned aerial vehicle (UAV), aerial surveying, topographic surveying, RMSE (root mean square error).

Introduction

The object of the study: an open area in the landscape reserve Teply Stan was chosen for the experiment. The area of 2150 m^2 is a small slope with a vertical distance of 9 m and is shown in Fig. 1.

Considering that the area of the object is relatively small, and there are no objects interfering with the line of sight, it was decided to use the ends of the baseline 1000-2000 as control points (Fig. 1).

Fig. 1. **Scheme plot:** 1 – baseline; 2 – border area

The basis measurements were made with a Leica TS 09 Plus total station, the characteristics of which are presented in Table 1.

Table 1

Technical characteristics of the total station

Measuring method	Accuracy
Angular accuracy	3” (1 mgon)
Distance measurement with reflector	Precise + : 1.5 mm + 2.0 ppm Precise Fast: 2.0 mm + 2.0 ppm Tracking: 3.0 mm + 2.0 ppm

Measurements of the length of the basis and the vertical distance between its ends were carried out in the forward and reverse direction with the subsequent equalization based on the least squares method in the software Credo DAT 4.0. The coordinates of the ends of the basis were specified in the assumed coordinate system, while the grid azimuth of the line 1000-2000 was taken as the magnetic azimuth of this direction.

Materials and methods

It was decided to assess the accuracy of the generated DTM in two ways.

In the first method the accuracy was estimated using the differences in the coordinates of points of two independent models generated by the photogrammetric method from images taken from a UAV [1;2].

In the second method the accuracy was estimated by the differences in the coordinates of the points of the two models, one of which was generated by the photogrammetric method, and the second by the geodesic method.

Before aerial surveying, artificial targeting wascarried out.

Target is a black cross, printed on a white sheet of A4 paper. Later, the ground targets were used as reference and control points. The thickness of the shoulders of the crosses of the targets was calculated based on the resolution on the ground with the determined image geometry. A total of 40 points were marked. The flying height was pre-calculated based on the unspecified characteristics of the camera and in order to guarantee DTM accuracy [3;4].

The solution of such tasks of land use planning as

- development of projects for the anti-erosion organization of the territory;
- designing rice checks;
- reclamation of disturbed lands;
- terracing of slopes;
- determination of the boundaries of the water edge in the design of hydraulic structures;
- counting the volume of earthworks

requires the use of topographic plans with a height of the relief section not exceeding 0.5 m. Thus, the accuracy of the DTM should be no rougher than 0.12 m.

Based on these considerations, the flying height was pre-calculated by the formula 1 in order to guarantee DTM accuracy of 0.10 m [5-13].

$$H = \frac{m_h \times b}{m_{x:y}} \tag{1}$$

where m_h – RMSE of the of the heights, m (0.10 m);
b – image base, pix (800 pix);
$m_{x:y}$ – RMSE of image measurement, pix (3 pix).

So, the flying height was 26 m, aerial photo scale was 1: 7200.

A large overlap (80 %) is chosen to reduce the effect of distortion, since in this way the central parts of the images will be included in the processing. The direction of the flight strip is aligned with the long side of the image, which is 4000 pixels long [4;14].

The coordinates of the centers of the ground targets were obtained as a result of the total station survey and processing of the results in the software Credo DAT 4.0. The error in determining the coordinates of the ground targets is 0.004 m and is calculated by the formula 2. In this case, under the ordinary conditions, the error of the coordinates of the DTM points, generated using the total station survey, is 0.05-0.10 m.

$$m_P^2 = m_A^2 + \left(\frac{m_\beta}{\rho}\right)^2 S^2 + m_S^2 \tag{2}$$

where m_p – RMSE of the coordinates of the ground targets, m;
m_A – RMSE of the coordinates of the ends of the basis, m;
S – distance from the ground target to the end of the basis, m;
ρ – quality of arc-seconds in the radian;
m_β – angular accuracy of the total station, sec;
m_S – distance measurement precision of the total station, m.

After the total station survey was performed, aerial surveying of the object was performed using a Phantom 4 (standard) UAV, the characteristics of which are listed in Table 2.

Table 2

Technical characteristics of UAV

Position	Description
Sensor	1/2.3” Effective pixels: 12 M
Lens	FOV (Field Of View) 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞
ISO Range	100-3200(video) 100-1600(photo)
Electronic Shutter Speed	8 s to 1/8000 s
Max Image Size	4000 x 3000 (pix)
Still Photography Modes	Single shot Burst shooting: 3/5/7 frames Auto Exposure Bracketing (AEB): 3/5 Bracketed frames at 0.7EV Bias Time-lapse HDR UHD: 4096x2160 (4K) 24 / 25p 3840x2160 (4K) 24 / 25 / 30p
Video Recording Modes	2704x1520 (2.7K) 24/25/30p
	FHD: 1920x1080 24 / 25 / 30 / 48 / 50 / 60 / 120p HD: 1280x720 24 / 25 / 30 / 48 / 50 / 60p
Max. Bitrate Of Video Storage	60 Mbps
Sensor	1/2.3” Effective pixels: 12 M

As a result of aerial surveying, more than two hundred photos were taken, and after rejection forty photos were included in the photogrammetric processing. Image processing was carried out in the software “AgisoftPhotoscan”. Before processing, all telemetry data from the photos were deleted [14]. Photogrammetric processing in AgisoftPhotoscan included several steps:

1. import of control point coordinates,
2. measurement of the coordinates of the reference points in each image,
3. selection and measurement of the coordinates of tie points and block adjustment,
4. generation of a dense point cloud of a digital terrain model,
5. orthophoto production,
6. export coordinates of control points in the txt file.

To generate two independent DTMs two processing options were performed, which differed in a set of reference points. The reference points were located at the edges of the contour of the object. The measurement of the coordinates of the reference points on the images occurs in manual mode, all other processing steps are automated.

As a result, 3 DTMs were created, one - as a result of a total station survey and two independent models were obtained as a result of aerial survey using UAVs.

In the first case, the accuracy was estimated by the differences of double measurements, namely by the differences of coordinates of the points of the two models generated with the help of the photos from the UAV [15-17]. The calculation of the differences of coordinates is presented in Table 3. The RMSE of the plane coordinates was calculated by formula 3, and the RMSE of the height - by formula 4.TheRMSEoftheplanecoordinateswas 0,021m, and the RMSE of the heights was 0,046m.

$$m_{X:Y} = \sqrt{\frac{[dX^2]+[dY^2]}{2n}} \tag{3}$$

$$m_H = \sqrt{\frac{[dH^2]}{2n}} \tag{4}$$

where $m_{x:y}$ – RMSE of the plane coordinates, m;
dX; dY – differences of the plane coordinates, m;
m_H – RMSE of the heights, m;
dH – differences of the heights, m;
n – number of the points.

Table 3

Calculation of the differences of the coordinates of the model points (method 1)

Point	Model 1			Model 2			dX, m	dY, m	dH,m
	X, m	Y, m	H, m	X, m	Y, m	H, m			
3	998.404	1008.655	100.205	998.433	1008.692	100.103	-0.029	-0.037	0.102
6	1002.208	1012.971	100.546	1002.207	1012.984	100.603	0.001	-0.013	-0.057
7	1010.937	1014.237	100.675	1010.944	1014.264	100.613	-0.007	-0.027	0.062
8	1005.892	1015.394	100.761	1005.923	1015.383	100.878	-0.031	0.011	-0.117
9	1000.873	1017.056	100.820	1000.846	1017.043	100.917	0.027	0.013	-0.097
10	995.374	1017.752	100.779	995.351	1017.769	100.789	0.023	-0.017	-0.010
11	990.671	1018.398	100.613	990.679	1018.427	100.579	-0.008	-0.029	0.034
12	991.219	1024.880	101.375	991.222	1024.912	101.449	-0.003	-0.032	-0.074
13	996.156	1024.162	101.527	996.175	1024.156	101.508	-0.019	0.006	0.019
14	1002.556	1023.533	101.797	1002.574	1023.520	101.773	-0.018	0.013	0.024
15	1008.374	1022.269	101.637	1008.377	1022.277	101.654	-0.003	-0.008	-0.017
16	1013.310	1021.309	101.387	1013.328	1021.287	101.436	-0.018	0.022	-0.049
17	1014.786	1027.010	102.197	1014.809	1027.004	102.307	-0.023	0.006	-0.110
18	1010.709	1029.315	102.607	1010.745	1029.289	102.646	-0.036	0.026	-0.039
19	1004.306	1029.975	102.632	1004.333	1029.963	102.648	-0.027	0.012	-0.016
20	997.297	1032.271	102.677	997.263	1032.248	102.757	0.034	0.023	-0.080
21	991.453	1032.240	102.563	991.410	1032.212	102.518	0.043	0.028	0.045
22	991.564	1039.020	104.069	991.555	1039.005	104.012	0.009	0.015	0.057
23	998.130	1038.404	104.001	998.161	1038.403	104.098	-0.031	0.001	-0.097
24	1005.783	1036.192	103.927	1005.769	1036.191	103.861	0.014	0.001	0.066
25	1012.719	1035.540	103.727	1012.732	1035.518	103.660	-0.013	0.022	0.067
26	1017.289	1034.189	103.538	1017.245	1034.200	103.419	0.044	-0.011	0.119
27	1019.199	1039.320	104.530	1019.190	1039.290	104.450	0.009	0.030	0.080
28	1014.900	1043.359	105.274	1014.855	1043.337	105.186	0.045	0.022	0.088
29	1007.566	1043.671	105.290	1007.584	1043.697	105.381	-0.018	-0.026	-0.091
30	998.942	1045.279	105.715	998.977	1045.289	105.776	-0.035	-0.010	-0.061
31	991.596	1046.482	105.546	991.591	1046.507	105.629	0.005	-0.025	-0.083
32	999.327	1051.838	107.152	999.363	1051.822	107.197	-0.036	0.016	-0.045
33	1009.495	1052.107	107.327	1009.491	1052.107	107.286	0.004	0.000	0.041
34	1021.220	1045.054	105.754	1021.238	1045.073	105.741	-0.018	-0.019	0.013
35	1023.665	1051.641	107.298	1023.641	1051.665	107.327	0.024	-0.024	-0.029
36	1017.724	1051.776	107.050	1017.728	1051.772	107.003	-0.004	0.004	0.047

In the second case the accuracy was estimated based on the true errors of the coordinates of the points of the first model and the model generated using the data of the total station surveying [15-17]. The coordinates of the points received by the total station were taken as true values. The calculation of the differences of coordinates is presented in Table 4. The calculation of the RMSE of the plane coordinates and the heights was made according to the formulas 5; 6. The RMSE of the plane coordinates was 0.036m, and the RMSE of the heights was 0.071m

$$m_{X:Y} = \sqrt{\frac{[X^2]+[Y^2]}{n}} \tag{5}$$

$$m_H = \sqrt{\frac{[H^2]}{n}} \tag{6}$$

where $m_{x:y}$ – RMSE of the plane coordinates, m;
ΔX, ΔY – differences of the plane coordinates, m;
m_H – RMSE of the heights, m;
ΔH – differences of the heights, m;
n – number of the points.

Table 4

Calculation of the differences of the coordinates of the model points (method 2)

Point	Model 3			Model 1			ΔX, m	ΔY, m	ΔH,m
	X, m	Y, m	H, m	X, m	Y, m	H, m			
3	998.395	1008.610	100.274	998.404	1008.655	100.205	0.009	0.045	-0.069
6	1002.202	1013.011	100.479	1002.208	1012.971	100.546	0.006	-0.040	0.067
7	1010.918	1014.220	100.563	1010.937	1014.237	100.675	0.019	0.017	0.112
8	1005.900	1015.378	100.855	1005.892	1015.394	100.761	-0.008	0.016	-0.094
9	1000.857	1017.072	100.744	1000.873	1017.056	100.820	0.016	-0.016	0.076
10	995.401	1017.731	100.870	995.374	1017.752	100.779	-0.027	0.021	-0.091
11	990.640	1018.395	100.542	990.671	1018.398	100.613	0.031	0.003	0.071
12	991.187	1024.846	101.302	991.219	1024.880	101.375	0.032	0.034	0.073
13	996.138	1024.153	101.444	996.156	1024.162	101.527	0.018	0.009	0.083
14	1002.546	1023.549	101.854	1002.556	1023.533	101.797	0.010	-0.016	-0.057
15	1008.418	1022.250	101.724	1008.374	1022.269	101.637	-0.044	0.019	-0.087
16	1013.325	1021.305	101.474	1013.310	1021.309	101.387	-0.015	0.004	-0.087
17	1014.819	1027.000	102.263	1014.786	1027.010	102.197	-0.033	0.010	-0.066
18	1010.750	1029.313	102.545	1010.709	1029.315	102.607	-0.041	0.002	0.062
19	1004.339	1029.976	102.674	1004.306	1029.975	102.632	-0.033	-0.001	-0.042
20	997.266	1032.242	102.754	997.297	1032.271	102.677	0.031	0.029	-0.077
21	991.431	1032.197	102.644	991.453	1032.240	102.563	0.022	0.043	-0.081
22	991.564	1039.059	104.001	991.564	1039.020	104.069	0.000	-0.039	0.068
23	998.101	1038.388	103.915	998.130	1038.404	104.001	0.029	0.016	0.086
24	1005.762	1036.184	103.851	1005.783	1036.192	103.927	0.021	0.008	0.076
25	1012.728	1035.563	103.827	1012.719	1035.540	103.727	-0.009	-0.023	-0.100
26	1017.301	1034.237	103.470	1017.289	1034.189	103.538	-0.012	-0.048	0.068
27	1019.207	1039.358	104.411	1019.199	1039.320	104.530	-0.008	-0.038	0.119
28	1014.854	1043.397	105.367	1014.900	1043.359	105.274	0.046	-0.038	-0.093
29	1007.527	1043.666	105.229	1007.566	1043.671	105.290	0.039	0.005	0.061
30	998.976	1045.319	105.748	998.942	1045.279	105.715	-0.034	-0.040	-0.033
31	991.629	1046.480	105.491	991.596	1046.482	105.546	-0.033	0.002	0.055
32	999.376	1051.793	107.211	999.327	1051.838	107.152	-0.049	0.045	-0.059
33	1009.517	1052.146	107.368	1009.495	1052.107	107.327	-0.022	-0.039	-0.041
34	1021.215	1045.043	105.673	1021.220	1045.054	105.754	0.005	0.011	0.081
35	1023.674	1051.635	107.356	1023.665	1051.641	107.298	-0.009	0.006	-0.058
36	1017.694	1051.790	107.093	1017.724	1051.776	107.050	0.030	-0.014	-0.043

Results and discussion

According to the results of the assessment of accuracy, we can say that the accuracy of the coordinates of the points of the models generated using the photos from the UAV is quite high and is comparable with the results of the ground-based measurements. It is quite possible to use such DTM for solving land management tasks.

At the same time, the density of points of such models is much higher than the density of points of the models generated using ground surveys, and this gives a more detailed view of the terrain in a particular area.

Conclusions

1. It is possible to use UAVs, equipped with semi-professional digital cameras, to generate a high-density DTM of a requiredaccuracy.The density of points of the DTM, generated using the photos from the UAVs, is much higherthan the density of points of the DTM, generated as a result of ground surveys.
2. It has been experimentally proven that images obtained during aerial surveyingwith UAVs with reasonable parameters (flight height, image base, overlap) allow DTM generation of arequired accuracy. So, according to the images obtained by a camera with a principal distance of 3.61 mm at a scale of1:7200 the DTM was generated with RMSE of heights of 0.07 m for a required RMSE of 0.10 m.
3. The accuracy of the DTM, generated by the photogrammetric method with a different set of reference points, was estimated from the difference in double measurements. RMSE, characterizing the accuracy of the heights of the DTM points, was 0.05 m.

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