AERIAL SURVEY TEST PROJECT WITH DJI PHANTOM 3 QUADROCOPTER DRONE

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***Abstract**: The paper deals with the optimization of the aerial triangulation based on UAS images. The images were taken with a DJI Phantom 3 quadrocopter and they were measured in Photomod Lite ver. 4.4. The bundle adjustment was carried out twice, first in Photomod Solver and later in BINGO ver. 6.8. During the adjustment 14 ground control points were used and 31 points were calculated as new points. Using these new points we could compare the coordinates to the coordinates received from the high-precision field surveying measurements. From the coordinate differences the calculated RMS errors of horizontal coordinates are around one pixel size on the ground and to 2.5 pixels vertically. The final results showed us that a non-metric camera at low flight height with a quadrocopter can be used effectively and accurately at aerial surveys of relatively small areas.*

***Keywords:** UAS, aerial triangulation, bundle adjustment, error assessment*

1. Introduction

1.1. Short summary of completed tasks

For testing, some large scale aerial photos were used taken at a relative height of 100 m. The test field was marked with 49 signs distributed by a grid. The images were taken with a DJI Phantom 3 quadrocopter having a 12 Mpixel camera and they were measured in Photomod Lite ver. 4.4 and the bundle block adjustment of 11 images was done also in Photomod. After checking the residuals and RMS values a second bundle adjustment was carried out in BINGO ver. 6.8. During the final block adjustment the camera calibration and the systematic image distortion compensation was calculated as well. During the adjustment 14 ground control points were used and 31 points were calculated as new points. Using these new points we could compare the coordinates to the coordinates received from the high-precision field surveying measurements. From the coordinate differences the calculated RMS errors of horizontal coordinates are around 4 centimeters and the RMS error of vertical coordinates is 9 centimeters. The pixel size on the ground was about 3.5 cm, which means the RMS errors corresponds to 1.1 pixel in X, Y and to 2.5 pixels vertically.

1.2. Drone or UAS

In the last few years many producers developed and commercialized various types of unmanned aerial systems. These vehicles are commonly known as drones but this name was formally used only for military purposes. Professional platforms apply UAS (Unmanned

Aerial System), UAV (Unmanned Aerial Vehicle), or in Hungarian special language PNR. These devices are grouped as followed:

- according to the manner of usage: military or civic,
- according to the construction: fixed winged, copters, flapping winged, balloons,
- according to the controlling system: terrestrial, GPS controlled, mixed,
- according to the engine type: electrical, internal combustion or gas turbine,
- according to the range: close, small, medium, remote,
- according to the significant flying parameters: flying height, term, velocity,
- according to the on board sensors: photo camera, video camera, laser scanner, radar, olfactometer.

There are many available literature on this topic and there are factories and users, amateurs and professionals in both cases. It may be expected from real professionals to use more valuable and of course more expensive equipment which bears service background and complete controlling and processing software.

2. Test Area

The first step for getting to know the ability of an UAV system is the determination of the available accuracy. The given detailed parameters are well known but it is advisable to try it out in real life. For keeping the prestige of our profession, the photogrammetry it is important to signify our devices by credible accuracy data. For this reason our Faculty wish to ensure possibility for users to test their devices on a fixed test field.

The test area is located not far from our hometown Székesfehérvár, near Csór and Iszkaszentgyörgy. This area is also the test area for the annual topographic and geodetic networks field practice for students. The area is easily accessible and covered with meadows, topographically fractured but with no huge level difference. The test area was chosen considering that there should not be trees and shrubs and huge altitude differences. Big difference in altitude may cause big scale difference because the relative flying altitude was planned for 50 and 100 meters.

For first step three possible areas were selected but finally for practical reasons a 200x200 meters area was picked as shown on the Fig. 1.

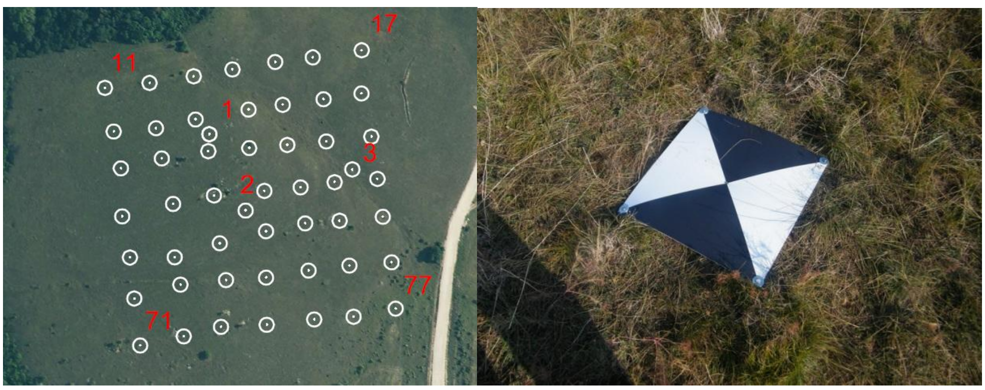


Fig. 1. Point locations and a mark on the test area

The following task was to choose the point marks. Special literature tells about different sign marks but their common attribution is the white black colour and high contrast. In our research light grey colour was selected instead of white because the experience of our former field work showed us that the white colour is not well recognisable in full sunshine. Although the point marks containing concentric circles are more widespread, point marks containing opposing triangles were chosen instead (Fig. 1.).

The size of the point marks are 50x50 centimetres in order to be visible in case of higher or lower flying altitude. They are made of waterproof plastic and cardboard (see Fig. 1.).

On the field, the corners and midpoints were set out first using the Real Time Kinematic (RTK) measuring method on the bases of previously calculated coordinates. All the other point marks were installed among these points of an average 33 meters distance. The distances between the points are approximate. Some points were shifted some meters away due to topographic difficulties. The point were fixed by nails and were numbered from 11 to 17, 21 to 27… 71 to 77 matched to rows and columns. On Fig. 2. the ground control points are marked with red circles for the aerial triangulation.

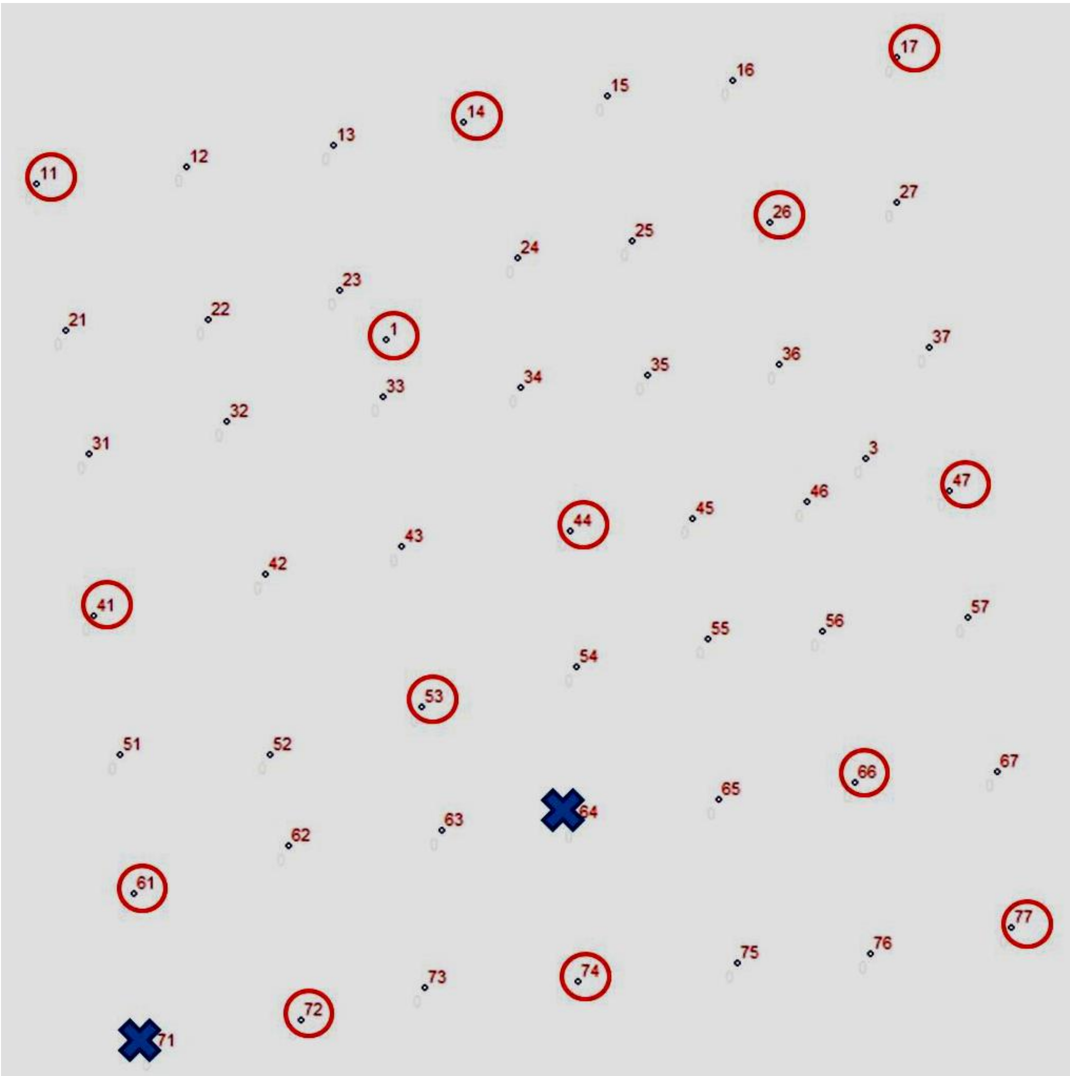


Fig. 2. Location and numbering of point marks

Unfortunately, the points 64 and 71 were disappeared for unknown reasons although they are not visible from the road. The geodetic coordinates of the points were measured with total station from a previously fixed base point. The aim was to reach the centimetre accuracy, and at the same time, the positions were defined using GPS measurements as well.

3. Phantom DJI 3

3.1. Technical data

Our Faculty has a DJI Phantom 3 Advanced aircraft (Fig. 3.). This UAV is available from the middle of 2015 and has more new features e.g. safer indoor use. The whole equipment is 1280 grams and its maximum ascend speed is 5 km/h and maximum horizontal speed is around 45 km/h. The UAV is equipped with GPS/Glonass receiver and has a precise 3 axis gimbal for good performance. The maximum operating range is more than 2 kilometres and the 4480 mAh LiPo battery operates for 22 minutes per charges.

Autopilot and ‘GO HOME’ function is available at any time or at less than 20 percent battery operation time. During flight an almost real time video (latency is 220 ms) is available thanks to DJI’s Lightbridge technology.

The on board camera is a Sony EXMOR 1/2.3” camera which has 12.4 million effective pixels (the total pixels are 12.76 millions). The lens has a FOV of 94° with 20 mm focal length (35 mm format equivalent) and with f/2.8. The ISO range is 100-3200 for video recording and 100-1600 for photos. The shutter speed varies between 8 and 1/8000 seconds.

A new technology helps to fly safe indoor as the UAV is equipped with ultrasound sensors. The still photography modes contains single shot, burst shooting (3/5/7 shots), auto exposure and time lapse. The video mode contains 2.7K, FHD and HD.

The DJI GO application is available for IOS and Android. We use this device with Samsung Galaxy3 8” tablet.

Fig. 3. DJI Phantom 3 Advanced UAS (source: DJI.com)

3.2. Taking Photos

The images were taken on November 20 and 23, 2015. At first time it was a cloudy day and the images had no shadows at all. At second time the weather was sunny and the images were full of shadows and it was really surprising to see how the terrain details were visible and expressive. We managed to get 11 images organized in 4 strips with relative flight height of

100 m and with the approximate projection centres above the following marked points: strip1: 22, 24, 26; strip2: 34, 36; strip3: 42, 44, 46; strip4: 62, 64, 66 (see also Fig. 4.).

4. Aerial triangulation

4.1. Orientation and Measurement in Photomod

After pre-processing and improving the bright and contrast on images we started the orientation process of 11 images in Photomod Lite v4.4. [2]. The interior orientation meant simply to key in the camera parameters.

The next step was to measure the ground control points (GCPs). Each GCP should be measured only on one image at this stage. Later the occurrences of a GCP are measured in parallel with the measurement of tie points. Altogether we measured 14 GCPs covering the whole test field.

The next phase was to measure at least two tie points between the models and strips. This task was not always obvious, because the images were taken with different rotation angles in kappa and therefore the measurement of tie points was not an easy task at some places.
After the measurement of tie points we had to measure Gruber points for the relative orientation of models. During this procedure we measured also the missed GCPs. For the relative orientation the software needs at least 6 points. At some places we measured more.
Finishing the measurement we could build the block scheme and we could start the block adjustment procedure in Photomod Solver [3], (Fig. 4.).

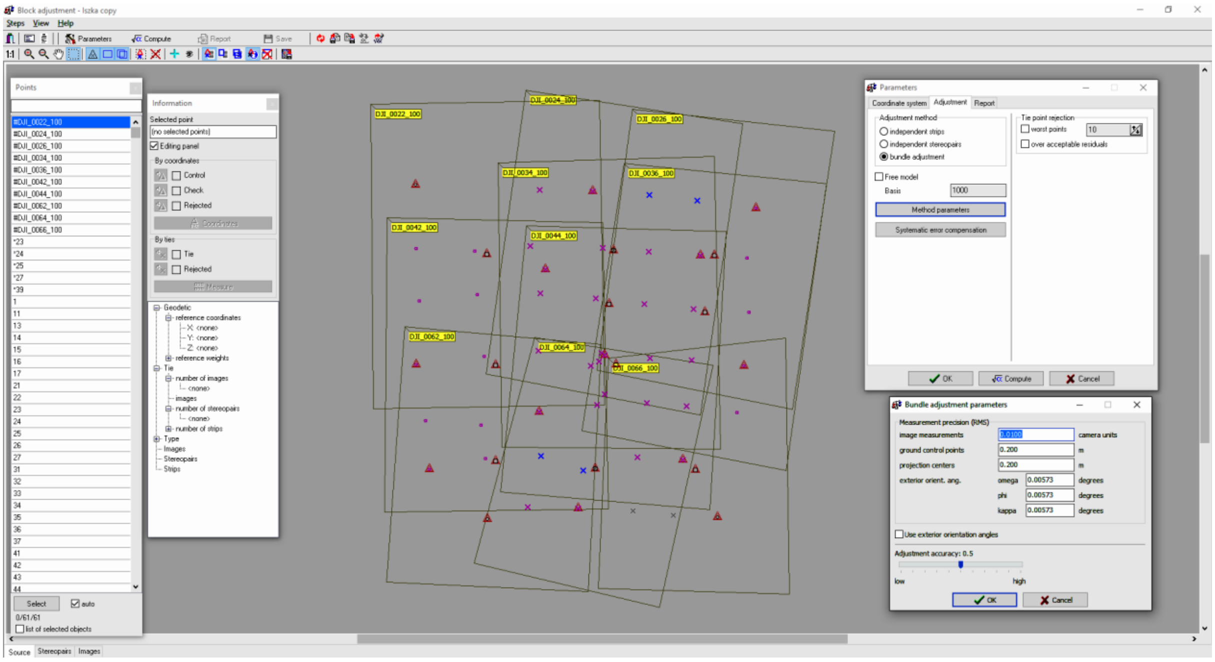
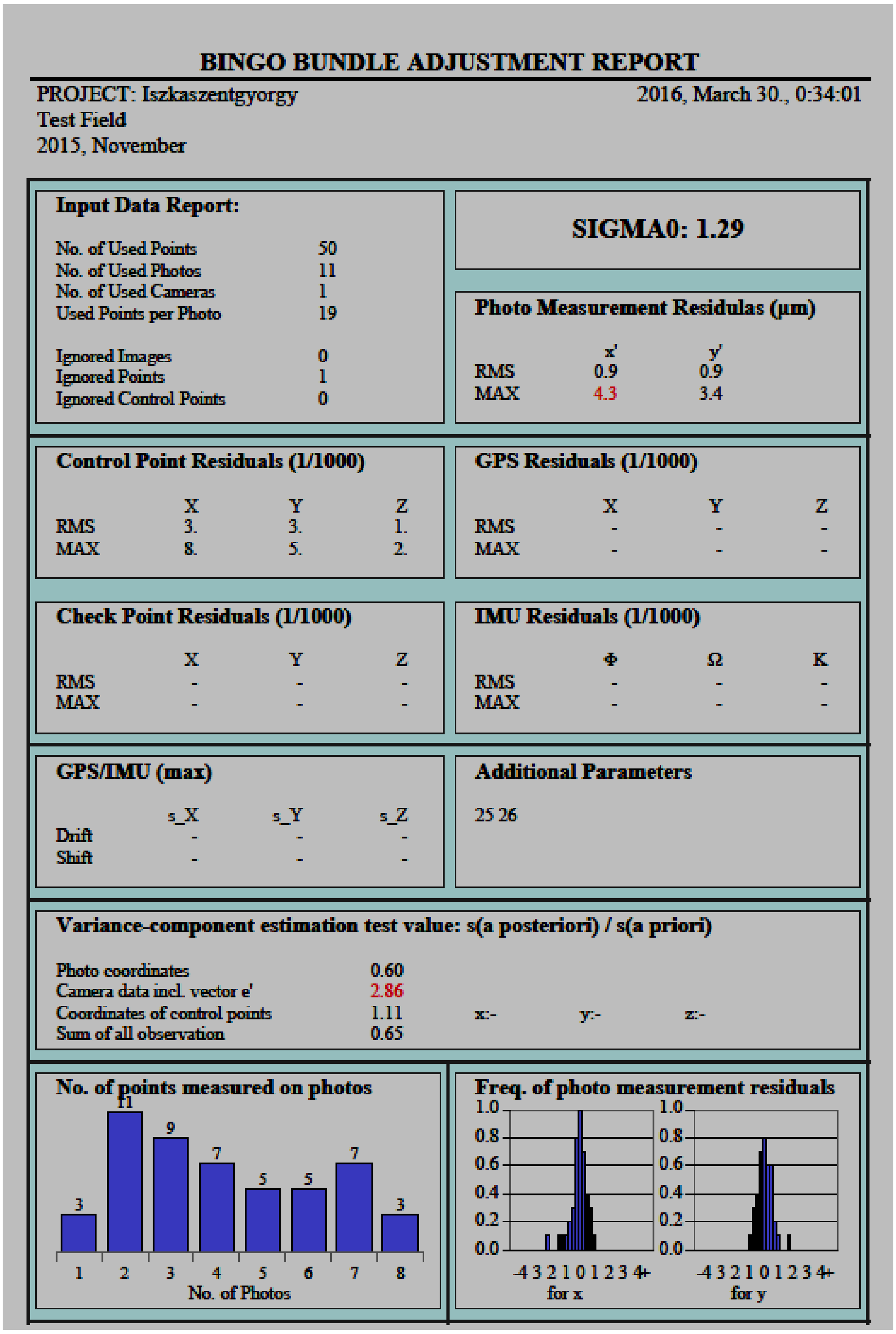


Fig. 4. Bundle adjustment in Photomod Solver

4.2. Bundle Adjustment with BINGO

In order to have better results we decided to repeat the bundle block adjustment using the BINGO v6.8 software. The initial values of the exterior orientation elements were taken from

Photomod Solver, so we expected only small corrections. Before running the BINGO we decided to add the camera calibration process to the adjustment and referring to the BINGO manual [1], we added two additional parameters to correct the systematic image errors. The final report of results is shown on Fig. 5. The sigma0 is 1.3 microns, which is acceptable. Since the adjustment procedure is optimised to the ground control points, the RMS errors of GCPs are extremely good, in X, Y it is only 3 mm and in Z it is 1 mm.



BINGO BUNDLE ADJUSTMENT REPORT

PROJECT: Iszkaszentgyorgy 2016, March 30., 0:34:01
Test Field
2015, November

Input Data Report:

No. of Used Points	50
No. of Used Photos	11
No. of Used Cameras	1
Used Points per Photo	19
Ignored Images	0
Ignored Points	1
Ignored Control Points	0

SIGMA0: 1.29

Photo Measurement Residulas (μm)

	x'	y'
RMS	0.9	0.9
MAX	4.3	3.4

Control Point Residuals (1/1000)

	X	Y	Z
RMS	3.	3.	1.
MAX	8.	5.	2.

GPS Residuals (1/1000)

	X	Y	Z
RMS	-	-	-
MAX	-	-	-

Check Point Residuals (1/1000)

	X	Y	Z
RMS	-	-	-
MAX	-	-	-

IMU Residuals (1/1000)

	Φ	Ω	K
RMS	-	-	-
MAX	-	-	-

GPS/IMU (max)

	s_X	s_Y	s_Z
Drift	-	-	-
Shift	-	-	-

Additional Parameters

25 26

Variance-component estimation test value: s(a posteriori) / s(a priori)

Photo coordinates	0.60			
Camera data incl. vector e'	2.86			
Coordinates of control points	1.11	x:-	y:-	z:-
Sum of all observation	0.65			

Fig. 5. BINGO adjustment report page

4.3. Summary of Results and conclusions

The ground resolution of images were about 3.5 cm, and we gained almost this value in accuracy. We could check the residuals on new points and calculate the RMS errors using only the coordinates of the new ground points. We could do this calculation, because these points were measured with high precision total stations and GPS receivers. The Table 1. shows the residuals and the RMS errors.

Table 1. Residuals of ground points after the bundle adjustment

No.	Y (m)	X (m)	H (m)	dY (m)	dX (m)	dH (m)
13	590 976.696	209 128.530	245.683	0.020	0.110	-0.150
15	591 039.213	209 139.678	245.081	0.050	0.090	-0.160
16	591 068.267	209 143.279	244.126	0.010	0.060	-0.100
21	590 915.185	209 085.711	243.035	0.050	0.060	0.160
22	590 947.857	209 088.317	246.838	-0.030	0.020	0.090
23	590 978.066	209 095.173	248.572	0.010	0.040	-0.050
24	591 018.813	209 102.740	245.292	-0.030	0.030	-0.070
25	591 045.122	209 106.537	244.924	0.020	0.030	-0.030
27	591 105.680	209 115.265	243.955	-0.050	0.010	0.050
31	590 920.663	209 057.335	242.932	0.060	0.090	0.110
32	590 952.203	209 065.020	246.550	-0.040	-0.040	0.110
33	590 987.957	209 070.636	248.690	-0.020	0.000	0.000
34	591 019.411	209 073.002	245.838	-0.030	-0.020	0.010
35	591 048.580	209 075.481	243.145	0.000	0.010	-0.020
36	591 078.650	209 078.298	244.758	-0.060	-0.010	0.000
37	591 113.272	209 081.907	244.414	-0.040	-0.010	-0.020
42	590 960.934	209 029.727	243.404	-0.040	0.010	0.060
43	590 992.339	209 036.357	245.779	-0.010	-0.020	0.000
45	591 058.808	209 042.718	243.002	0.000	-0.010	0.010
46	591 085.014	209 046.670	242.243	-0.040	-0.020	0.000
51	590 927.720	208 988.394	235.802	0.030	-0.010	-0.040
52	590 962.085	208 988.560	238.448	-0.020	-0.020	0.010
54	591 032.259	209 008.635	242.192	-0.040	-0.030	0.060
55	591 062.374	209 014.878	241.908	0.000	-0.010	-0.010
56	591 088.832	209 016.827	240.689	-0.020	-0.020	0.020
62	590 966.545	208 967.388	235.346	-0.040	-0.030	-0.070
63	591 001.480	208 970.960	237.028	0.010	-0.020	-0.070
65	591 064.864	208 978.301	236.981	0.030	-0.020	-0.330
73	590 997.673	208 934.788	232.139	0.050	-0.090	-0.070
75	591 069.227	208 940.480	230.632	0.080	-0.040	-0.160
76	591 099.497	208 942.433	230.137	0.070	0.070	-0.040
			RMS (m)	0.038	0.044	0.094

The main task was to prove the capability of a DJI Phantom 3 quadrocopter in aerial surveying. The test field with 49 marks was ideal to carry out the investigation. Our goal was to reach one pixel accuracy after the aerial triangulation and practically this goal was achieved. The calibration of the applied camera was done in PhotoModeler software (http://www.photomodeler.com/index.html), but later on we decided not to use the calibration results, instead of it, we added the camera calibration process to the BINGO bundle adjustment and it was a good decision, since it had large improvement on final RMS errors presented in ground coordinates.

We measured only the marked points on photos and it had also beneficial effects on the final results.

5. References

1. *Kruck, E. – Bingo 6.6 Manual, Bundle Adjustment for Engineering Applications, A Program System for Close Range Photogrammetry and Aerial Triangulation Including Three-Dimensional Geodetic Network Adjustment, Aalen, , pp. 156, 2014;*
2. *Racurs – User's manual of Photomod Montage Desktop 4.4., pp. 159, Moscow, 2008;*
3. *Racurs – User's manual of Photomod Solver 4.4., pp. 75, Moscow, 2008.*