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THE ANALYSIS OF THE RESULTS OF AERIAL PHOTOGRAPHY EXPERIMENTS ON THE BASIS OF A DEVELOPED UAV MODEL

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Summary

Modern techniques related to the creation of topographic and cadastral plans of land areas are based on the use of digital data received as a result of aerial photography. This article discusses three core technological issues in the application of UAVs in topographic aerial photography connected to the stabilization of the UAV during the flight: maintenance of a constant speed, maintenance of a straight line of flight and the reduction of tilt. This article presents the results of a study of the aerial photography errors and describes the ways in which the latter can be addressed.

Keywords: aerial photography, UAVs, image mosaicking, orthophotomaps, digital camera, camera calibration

INTRODUCTION

UAVs can be used in many ways: in the geomorphological (Tonkin *et al.*, 2014) and geological studies (Vasuki *et al.,* 2014), soil erosion (d'Oleire-Oltmanns *et al*., 2012), archaeological searches (Chiabrando *et al.,* 2011), mapping of pipelines (Siebert, Teizer, 2014), in the study of rivers and road pavement (Room, Ahmad, 2014, Zhang, 2008), in the study of the ice cover in Antarctica (Lucieer *et al*., 2014), etc. The most significant advantages of using UAVs compared to manned aerial photography certainly are the low cost and the possibility

to receive imagery of land areas in real time for further processing (Everaerts, 2008). Notwithstanding the fact that there are some issues in the use of UAVs related to the legal regulation concerning the flight permissions and certification (Federal Aviation Administration, 2013), their use is becoming more frequent.

Aerial photography with the use of UAVs is not fundamentally different from a similar process with the use of larger aircrafts but is characterized by some special features which will be considered further in the article. The UAV flight to capture digital images used in the creation of large-scale plans is usually done at a flight speed between 70 km and 110 kilometers per hour (20-30 m /sec) and at the altitudes between 100m and 500 m (Colomina, Molina, 2014, Dale, 2009, Niethammer *et. al.*, 2012).

Non-metric digital cameras (NMDC) with a 10-20 megapixels sensor are commonly used for aerial photography (Colomina, Molina, 2014). The range of the cameras' focal lengths ranges from 15 to 50 mm, which corresponds to the pixel size on the ground (GSD) from 5 to 20 cm. The use of these cameras involves their full calibration. This primarily concerns the definition of the elements of image orientation, lens distortion and reproduction of color (Shang *et al*., 2013, Habed, Boufama, 2008, Douterloigne, 2013). In addition, new cameras and laser scanners are developed for UAVs (Droeschel, *et al.*, 2013, Grenzdörffer *et al.*, 2012, Mäkeläinen *et al*., 2013). For example, one publication (Mäkeläinen *et al*., 2013) presents a new 2D hyperspectral frame camera system developed by VTT (the Technical Research Centre of Finland) and Rikola Ltd. Mosaic Mill can convert camera data in the desired format for photogrammetric processing and ensures the necessary accuracy for further use. It is even proposed to use smartphones (Kim *et al.*, 2013).

Many studies have been conducted to develop and optimize technological processes for large-scale plans creation (Mancini at al., 2009, Remondino *et al*., 2011). One of the studies (Gini *et al*., 2012) produced a large number of multispectral high resolution images. For the purpose of this study, two compact digital cameras were used: Pentax Optio A40 for RGB images and Sigma DP1 to obtain a NIR group. Another study (Junqing *et al.*, 2012) provides information about the use of unmanned systems in the Shanxi province (China) to obtain data to produce plans at a scale 1: 1000 as well as about the main stages and systems in the use of UAV. It is emphasized that UAV allows taking high precision aerial images for large-scale DLG (Digital Line Graphic) photography and has great prospects.

Another research direction on digital aerial photography with the use of UAV concerns the assessment of qualitative and quantitative characteristics of the obtained data. Here we would like to note that most authors prefer the classic method in the creation of plans which envisions the necessity of control points for the process of photo triangulation and subsequently for the creation of

orthophotomaps (Nex, Remondino 2014, Turner *et al.*, 2012, Vallet *et al*., 2011, Zhang, 2008). There are many publications devoted to the improvement and automation of UAV systems. They primarily refer to various types of sensors that allow location and stabilize UAVs during aerial photography (Coppa *et al*., 2008, Witayangkurn *et al*., 2011). There are many publications concerning the prospects of UAV systems. In particular, publication (Remondino *et al.*, 2011) emphasizes the relevance of the use of UAVs in the fields of science, technology and military affairs.

After analysing the use of UAVs for aerial photography, we conclude that it is necessary to develop an aircraft model that would meet the requirements of classic aerial photography. This will provide high-precision surveying data which can be used in the production of large-scale topographic maps, cadastral maps and orthophotomaps. To achieve this, first of all errors that occur during aerial photography need to be explored, their influence need to be minimized through structural and technological improvements and the accuracy of the data needs to be analysed. Conclusions will be drawn on the basis of the analysis of the ability of this model to produce high-quality aerial photography.

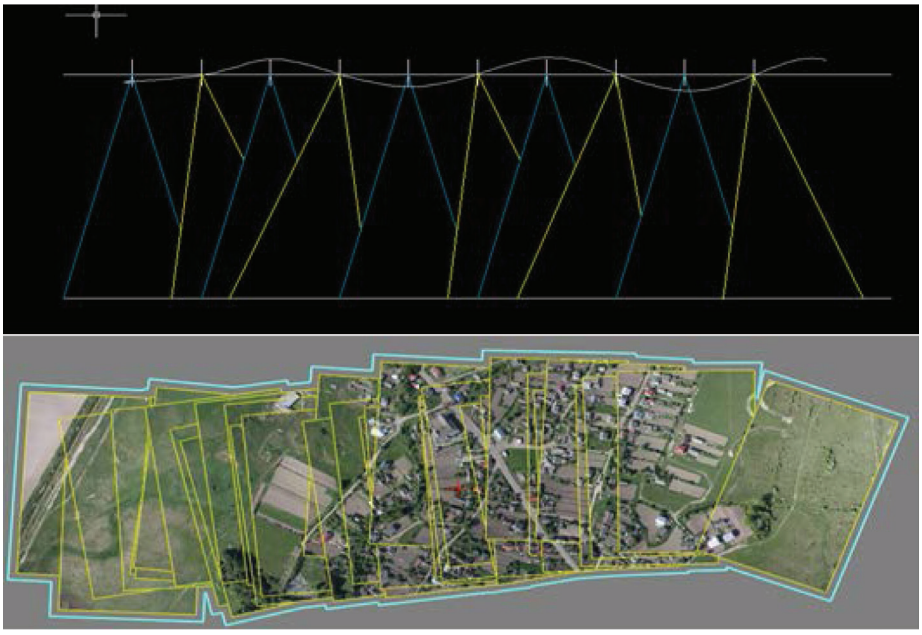

Figure 1. The effect of the pitch angle on the longitudinal overlapping of aerial photographs. The fluctuations of the pitch angle in accordance with the harmonic law (the frequency of oscillation is relatively low compared with the frequency of shooting) leads to a rhythmic instability of the longitudinal overlap.

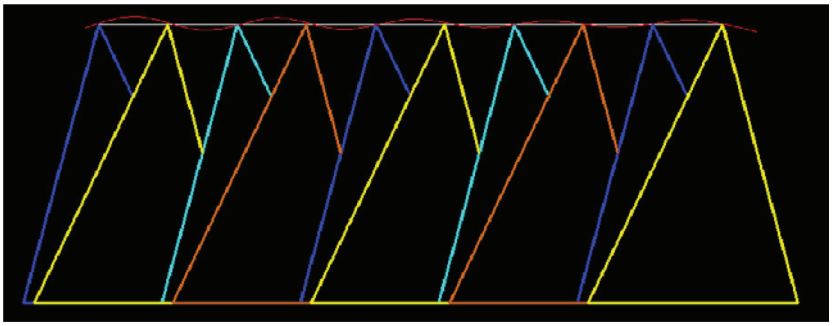

Figure 2. The effect of the pitch angle on the longitudinal overlapping of aerial photographs. The frequency of oscillation is relatively high compared with the frequency of shooting; the rhythmic instability of the overlap is different.

BASIC PARAMETERS OF UAV AERIAL PHOTOGRAPHY

It is known that the high accuracy of orthophotomaps can be achieved on the condition of the use of high-quality photographic and photogrammetric aerial photographs. First of all, it is essential to have proper conditions ensuring the straight line of flight, stable altitude and flight speed, the fixed longitudinal and transverse overlap of images and minimum tilt (Figure 1, 2).

Modern technologies used in the processing of aerial photographs allow correcting inaccuracies in navigation and stabilization during aerial photography within certain error limits (more than 12 – 15 degrees). This still leads to a significant decrease in accuracy of the coordinates of contour points.

Complexity of the analysis is due to the cross-influence of various parameters of navigation and stabilization of the aircraft on various aspects of quality of photogrammetric aerial photographs. For example, overlapping longitudinal instability can be caused by:

- unstable air flight speed,
- changes in the strength and direction of the wind;
- instability of the pitch angle.

A transverse overlap of images is considerably influenced by the deviation from the trajectory, the deviation from the line of flight and heel angles (Figure 3).

Removal of the images is caused by a deviation from the line of flight and the angle of heel. The situation is complicated by the fact that in order to return to the line of flight the aircraft must tilt which further increases the take-away.

As a result of such errors, the user receives an image mosaicking that besides the low photogrammetry estimates may have ruptures of contours between adjacent images.

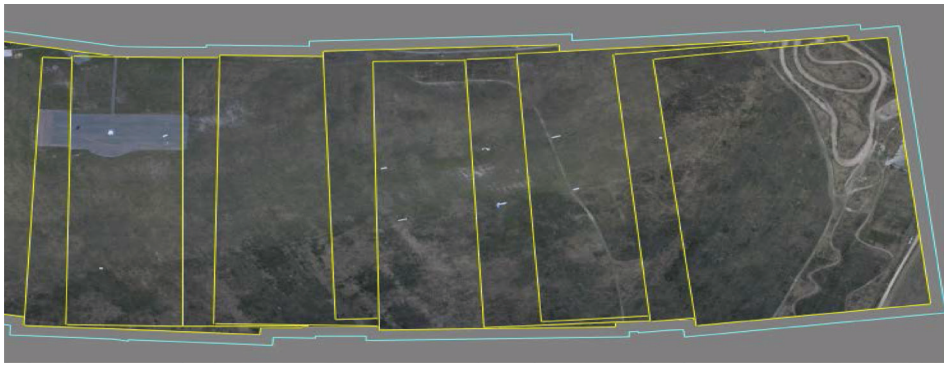

Figure 3. The effect of deviation from the line of flight and the angle of heel on traverse overlap and image orientation.

For further photogrammetric processing of aerial photography and for getting the most accurate results, it is necessary that the images taken in a flight have a triple overlap, and the overlap between images taken with block shooting during adjacent trajectories of flights should be at least 20%. In practice, during aerial photography with the use of UAV, these conditions are not always kept. The UAV flight is not always stable, it is influenced by wind gusts, turbulence and other disturbing factors. If aerial photography with the use of manned systems is planned with the overlap along the line of flight of 60% – 70% and between the lines of 30-40%, the aerial photography with the use of UAV must overlap along the line of flight by 80% and between the lines of up to 80% to allow for breaks in the photo triangulation block. However, these conditions lead to a large increase in both the number of flights and images, and thus to a reduction of the accuracy of the coordinates of contour points.

Another problem related to the aerial imagery's accuracy is connected to the camera. The main problem in the aerial photography is the use of non-calibrated everyday cameras without information about their exact focal length, the coordinates of the center of projection and the lens distortion. Thus, the nonlinear distortion of optics, acceptable in non-professional aerial photography, may be up to a few tens of pixels, which may significantly reduce the accuracy of the processing of aerial imagery. However, as mentioned above, these cameras can be calibrated in the laboratory, which would allow accurate image processing of digital images, almost the same as for professional small-format photogrammetric cameras. In addition, it is better to install lenses with fixed focal distance on these cameras. For the flight it is necessary to set the focus to infinity and disable the „AF" function as in flight the auto focus may not always work due to a small interval of shooting.

The second drawback of a camera mounted on a UAV concerns in particular the cameras with a focal latch (Canon, Sony, etc.) They, unlike professional photogrammetric cameras, use a focal latch which results in the exposure of different parts of the image is made at different times and from different positions of the devise. Thus, if even the shutter speed at shooting is 1/500 c, then with the UAV speed of 20 meters per second, the displacement of the camera during the shooting of a frame is 8 cm, which causes image blur (Figure 4, 5) (the altitude – 120 m, done with camera Sony Nex 5R).

Figure 4. The image on the left side of the picture.

Figure 5. The same image on the right end of the picture.

Such errors can accumulate during the process of photogrammetric thickening while photographing elongated objects. In order to reduce the impact of this effect and to eliminate „blur" in the images, it is necessary to carry out aerial photography with the use of UAV at the lowest possible shutter speed (no longer than 1/500 c, the maximum shutter speed depends on the height and light). The problem of the curtain latch could be resolved by cameras with a central latch.

The images taken by digital cameras, both amateur and professional ones, have a rectangular form. It is more advantageous to place the camera so that a long side of the image is across the direction of the flight which allows to photograph a greater area during the flight. Aerial photography should be done with the maximal quality, with the least JPEG compression or in a RAW format if possible.

The modern level of development of navigation devices allows determining the elements of external orientation of images (EOI) directly in the process of aerial photography. A typical accuracy of such measuring achieves the measures in centimeters in accordance with spatial co-ordinates X, Y and Z and a 0.005 degree on the angles of roll, yaw and pitch for the most accurate systems Applanix POS AV mounted on large airplanes. It is often enough to carry out processing without using principle points. In any case, the availability of such data considerably simplifies processing and allows to execute some stages of processing fully in an automatic mode. Modern achievements in microelectronics allow to assemble a mechanical (more precisely a MEMS – electro-mechanical) gyroscope in a container sized a few millimeters at a cost as of 250 $. Such gyroscopes do not ensure exact stabilization as professional devices and are characterized by considerable deviation (about one degree in an hour) during their exploitation, but substantially simplify the subsequent processing of data. Small inertial systems such as IMU and high-precision two frequency GPS-receiver (TOPCON euro 160) can be mounted on UAVs. The passport accuracy of these GPS devices constitutes 10 mm + 1,5 mm x B (B is the distance to the base station in kilometers) in a plan and with a height of 20 mm + 1,5 mm x B. Unfortunately, as a rule, cheaper GPS receivers and not IMU sensors are mounted on UAVs. The data about the centers of projection of images in telemetric measuring is taken through NMEA protocols. It has in such case the accuracy of up to 20-30 meters. The roll, yaw and pitch angles are calculated through the speed vector of GPS measuring. The accuracy of the pitch angle in such telemetric measuring is low and can exceed 10 degrees, and the values can contain systematic errors that complicate the subsequent processing of data. If a two frequency GPS-receiver was used during aerial photography in a differential mode, the minimum number of principle points is needed to obtain the most accurate results of processing; usually 1-2 points are necessary for 100 images. In a number of cases processing can be conducted without principle points. In the case when the centers of

projection are known approximately, the standard requirements to the planned height are as follows: one planned height point for 6-10 bases of shooting.

The carried out experiments gave the possibility to formulate final requirements to aerial photography with the use of UAV.

1. It is necessary to ensure a maximum stability of flight with the adequate hydro-stabilizing equipment.
2. It is desirable to have aboard a geodetic GPS-receiver, with which linear elements of exterior orientation of images will be determined in a kinematic mode with a sufficient accuracy (10-20cm).
3. It is important to mount a navigation equipment which ensures a hand, semi-automatic and automatic control of the vehicle.
4. It is desirable to have an aero device equipped by miniature incremental rotor-optical sensors which determine the angular elements of external orientation in a few seconds.
5. It is important to ensure safety measures in relation to the UAV and onboard equipment (a parachute system, a radio beacon, etc.).
6. It is advisable to have a powerful digital camera in terms of resolution with a telephoto lens (not less than 20-60 Mp).
7. It is necessary to carry out metrology examination of digital cameras for the purpose of determining distortion and elements of internal orientation.
8. It is necessary to ensure that the UAV flight lasts for not less than 20-60 minutes.
9. It is desirable to limit the take-off and landing runaway (in the modes «start of the hand» and glissade to a point).
10. It is important to ensure the determination of the takeoff angle during the flight and its automatic establishment by an aero device.
11. It is desirable to provide the possibility of transporting the UAV without special equipment.

The previous analysis of the factors influencing the results of aerial photography persuaded us of the fallaciousness of another stereotype idea that in order to receive high-quality data of aerial photography it would be enough to stabilize the photo devices on the UAV. If this allows diminishing the angles of external orientation of images, it does not resolve the problem of non-linear trajectories of flight and scale difference of images as a result of unstable height. In subsequent work, the priority task would be the stabilization of the airplane.

In order to define the quantitative estimation of the influence of the parameters of navigation and airplane stabilization on photogrammetric quality of images on a test airplane, it was decided to synchronize the work of the automatic control system of the airplane and photo camera as well as to record the parameters of these systems with the frequency of discretization of 10hz (Figure 6). The analysis of the received results allowed carrying out the design of the

airplane flight during the surveying, to define and optimize the algorithms of the airplane flight and aerial photo device control and to develop principles of the development of routes. As a result of works certain requirements to aerodynamic and flight characteristics of UAV were established. In accordance with these requirements a specialized airplane SkyBow-G with an electric engine was created (Figure7). The airplane is equipped with an autopilot with a complete pilotage-navigation system and an aerial photo device control system. A combination of image mosaicking, trajectory diagrams and synchronous diagrams of the work of control systems allowed building exact mathematical models of processes.

The following processes of aerial photography are considered necessary:

- flight and landing is in an automatic or a pilot-controlled mode,
- flight routes of aerial photography are executed in an automatic mode,
- the surveying routes are determined and programed in advance or directly before the flight against the wind and executed only in a given direction.

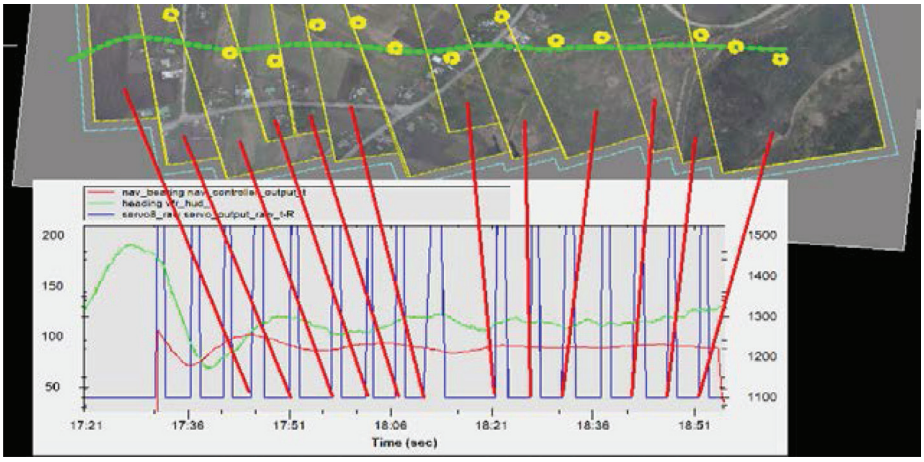

Figure 6. A synchronous diagram of the work of the trajectory system and of the aerial photo device.

The following functions are carried out under the control of the autopilot:

- ensuring the accuracy of UAV navigation along the surveying routes,
- ensuring the stabilization of flight, the pitch and roll angles, altitude and air speed,
- ensuring the opening and closing of the protective shutter of the camera in extreme points of aerial photography,
- formation of the strobe to trigger the camera at regular distance intervals (with a corresponding interval of aerial photography),

- ensuring the orientation of the camera in a predetermined direction in order to minimize the influence of the drift angle.

Figure 7. A general view of the UAV «SkyBow-G».

TECHNICAL SPECIFICATIONS OF THE AERIAL PHOTOGRAPHY UAV «SKYBOW-G»

- the weight of the airplane is 5.5 kg,
- the maximum take-off weight is 9.5 kg,
- the type of the engine is an electric commutatorless one with a low level of vibration and noise,
- the flight time is up to 30 minutes,
- the flight speed is 70-90 km/hour,
- the maximal deviation from the trajectory is no more than 10 m for 1000m,
- the maximal deviation from the set height of flight is +/ – 5 m,
- the maximal possible strength of wind is 8 m/s,
- the maximum lateral wind is 6 m/s,
- the time for the flight preparation is up to 30 min,
- the necessary size of flight runaway is 50 m,
- the volume for transportation is 1.0x0.5x0.5 m.

THE EXPERIMENTAL RESULTS OF AERIAL PHOTOGRAPHY USING THE UAV «SKYBOW-G»

To test this model of aircraft various field tests, both design and operational, were conducted. We describe only one of them.

The purpose of the flights is a complex test of aerial photography technology for small towns using a UAV in an automatic mode. The aerial photography was carried out using the SkyBow-FR aircraft. First the NMDC Canon EOS 450D Rebel with an EF-S 18-55 lens and an optical image stabilizer was mounted on the UAV. The flights were carried out in the following way: the take-off and landing in a piloted mode and the aerial photography flight in an automatic mode. The flight routes were determined and loaded into the autopilot immediately before the flight. The following tasks were performed under the control of autopilot:

- ensuring navigation of the UAV along the flight routes in a full automatic control mode with the stabilization of altitude, air speed and roll, yaw and pitch angles,
- opening and closing of the camera protective blinds in the set points of the route,
- formation of the strobe to trigger the camera shutter at regular distance intervals,
- the orientation of the camera axis to a preset magnetic course to minimize the rotation angle in accordance with the flight line,
- telemetry operation of the flight parameters was transferred to the operator on the ground in real-time.

Results of the first experiment. Weather conditions in the area of operation were unfavorable for aerial photography: dense clouds with the lower edge of 450-500 m, the visibility of 4 km, the wind near the ground of 8 meters per second with gusts of up to 10 meters per second and sporadic drizzle. Two parallel routes with a course of 40 degrees, up to 2500 m long along the main street of the village were selected for surveying. The distance between the axes of the routes was 100 m. The height of surveying was 300 m. The base of aerial photography B_x was 60 m. The wind was head-lateral, with the lateral wind of 5 meters per second and the head wind of 9 meters per second. With the flight air speed of 70 kilometers per hour, the speed on the route was 7-8 meters per second (25-30 kilometers per hour) and the drift angle was up to 40 degrees. The route was carried out in two flights: the first flight along the route to the southeast, the second along the route to the northwest. Each flight time was about 14 minutes. During the second flight there was a strong wind, sometimes up to 12 meters per second. Fixed settings of frame exposure were set. During the first route they were set as follows: the ISO at 300, the shutter at 1/500, the aperture at 5.6, the autofocus off and the optical stabilizer on. During the second route they were set as follows: the ISO at 200, the shutter at 1/500, the aperture at 4, the autofocus off and the optical stabilizer on.

The analysis of telemetry data showed the following:

- the ground speed changed within 20-35 kilometers per hour due to the strong head wind,

- the distance between the centers of images was quite stable despite the gusty wind and variable ground speed due to connecting the shutter triggering to distance and not to the time interval,
- the altitude was stable within 5 meters, therefore it was within the permissible limits,
- the tilt angle was satisfactorily as a whole. Tilts were due to strong lateral wind gusts,
- the pitch was generally satisfactory resulting in an acceptable longitudinal overlapping of images,
- the camera orientation system in most cases compensated a large drift angle; during the second route, presumably in moments of strong lateral wind gusts the autopilot generated signals of magnetometer failure, images with large rotation angles were taken in these moments.

The analysis of image quality is as follows: during zooming appears the contours blurriness, which increases with the opening of the diaphragm. It can also be caused by the inaccuracy in determining the focus distance. Image blur due to airspeed is unlikely due to the low ground speed and very fast shutter speed. As a result, the following conclusion was made: imagery was satisfactorily under the unfavorable metrological conditions.

Results of the second experiment. Weather conditions in the area of operation were favorable: dense clouds with the lower edge of 300 m, the visibility was 4 km, the wind of 110 degrees at the ground was 5 meters per second, mainly steady and sporadic drizzle. Due to changes in the wind direction and in order to survey a larger area, routes were reoriented. 7 routes were planned with an MK of 90 degrees: 1-2 routes with a 1500 m length, 3 with a 1200 m length, and 4-7 with a 1000 m length. D_y was 150 m. The height of aerial photography was limited by the lower edge of clouds and thus was 270 m. B_x was 60 m, and B_y was 150 m. The wind was head-lateral with the lateral component of up to 2 meters per second and the head component of up to 4.5 meters per second. With the flight air speed of 70 kilometers per hour, the speed on the route was 12-14 meters per second (43-50 kilometers per hour) and the drift angle was up to 10 degrees. The route was carried out in two flights: the first flight along routes 1-3 and second one along routes 4-7. Each flight time was about 14-16 minutes.

Fixed settings of frame exposure were set. Due to very low light, the ISO was increased. During the first flight, the ISO was set at 500, the shutter at 1/500, the aperture at 6.1, the autofocus was off and the optical stabilizer was on. During the second flight the cloud edge decreased, it drizzled, and the light decreased. The exposure parameters were adjusted: the ISO was set at 600, the shutter at 1/500, the aperture at 5.6, autofocus was off and the optical stabilizer was on. A general image mosaicking of the flight area along routes 1-7 is presented in Figure 8.

The analysis of telemetry data and image mosaicking showed the following:

- the altitude, the tilt angle, the pitch and the distance between the centers of images as well as the longitudinal and transverse overlap were well maintained,
- the linear character of routes 1-3 was well maintained,
- in the first half of routes 4-7 appeared sinusoidal areas caused by lengthy stabilization before reaching the trajectory due to turbulence just beneath the cloud edge (and sometimes with entering in the clouds),
- the non-linear movement affected the drift angle of images (a side effect of the camera stabilization algorithm in accordance with a set magnetic course). Because of this some images are rotated by an angle of up to 15º.

Figure 8. Aerial image mosaicking of routes 1-7.

Contours are quite sharp on zoomed images, and the effect of grain (due to a high ISO) appears earlier than image blur (Figure 9).

Figure 9. Contours blurred due to ISO increase.

Figure 10. Aerial image mosaicking which combine three routes. The height of imagery is 300 m. The imagery is made by a digital camera Canon EOS 450 D (three routes, 10 photos each).

THE DETERMINATION OF THE QUANTITATIVE AND QUALITATIVE CHARACTERISTICS AND THE ACCURACY OF MEASUREMENT

The results of analysis of initial experiments were taken into account, and later on (about 1000 images were made in total using this airplane model) high-quality digital images were obtained with a different set of longitudinal and transverse overlaps and the set values of angular orientation (Figure 10). Also the altitude and the straight trajectory of routes are stable, which guarantees the maintenance of a set scale and of the inter-route overlap of the whole aerial photography area (the results of angular elements – Table 1).

Table 1. Values of angle elements of external orientation of digital images (the altitude – 300 m, 3 routes with 10 photos each).

Number of the route and photos	α °	ω °	æ °
1 1	-4.3	0.4	4
1 2	-3.4	1.7	1
1 3	-0.7	1.2	5
1 4	-0.1	1.8	2
1 5	-2.9	0.4	2
1 6	1.0	2.8	6
1 7	2.8	3.4	5
1 8	-2.3	1.9	0
1 9	-3.0	1.2	2
1 10	1.9	0.9	1
2 1	3.4	1.5	2
2 2	2.7	1.0	0
2 3	-3.5	2.2	1
2 4	1.6	1.5	2
2 5	1.8	1.2	2
2 6	-2.3	1.5	1
2 7	1.1	2.0	1
2 8	2.5	2.7	0
2 9	-2.8	1.6	1
2 10	0.5	2.8	1
3 1	3.5	2.9	2
3 2	2.3	2.2	3

Number of the route and photos	α °	ω °	æ °
3 3	-1.3	1.4	1
3 4	-0.9	1.7	1
3 5	1.1	1.7	1
3 6	-0.5	1.2	2
3 7	-1.0	3.5	3
3 8	0.2	2.3	0
3 9	0.3	0.2	1
3 10	-0.9	2.9	2

After analyzing the data presented in Table 1 one must emphasize that angles correspond to the planned imagery, and this in turn enables us to get more exact coordinates. Due to the low airspeed and low vibration even when a NDNC is used, high-quality images can be obtained (Figure 11).

In order to determine the quantitative characteristics, a reference area was established in a selected rural area where the coordinates of control points were measured using a GPS-receiver in the whole area (Figure 12).

Figure 11. A fragment of a digital image taken from the altitude of 300 m by a digital camera Canon 6D.

After this, the area was photographed from the air with the following parameters: the altitude of aerial photography was 300 m with the camera Canon EOS 450D. A topographical plan was prepared on the basis of the obtained digital images. The coordinates of 24 control points and the assessment of the ac-

curacy of spatial coordinates were measured on the plan. The results are shown in table 2.

Figure 12. Image mosaicking of the area where the reference area is located.

Table 2. Evaluation of accuracy in accordance with control points.

No	ΔX [m]	ΔY *[m]*	ΔZ *[m]*
1	-0.089	0.019	0.091
2	0.086	-0.045	0.097
3	0.011	0.005	0.012
4	-0.074	-0.140	0.158
5	-0.067	-0.034	0.075
6	0.074	-0.015	0.075
7	-0.048	-0.014	0.049
8	-0.006	-0.012	0.013
9	0.054	0.037	0.025
10	0.124	0.014	0.125
11	0.054	0.071	0.089
12	-0.110	-0.128	0.169
13	0.091	-0.093	0.130
14	-0.016	0.129	0.130
15	-0.011	-0.025	0.028
16	-0.072	0.015	0.073

No	ΔX [m]	ΔY *[m]*	ΔZ *[m]*
17	-0.061	-0.061	0.086
18	-0.011	-0.051	0.052
19	0.130	-0.018	0.132
20	-0.015	0.040	0.042
21	-0.111	0.102	0.151
22	0.103	-0.006	0.103
23	-0.022	0.007	0.024
24	-0.082	0.039	0.091

Accordingly, the mean squared errors (MSEs) were as follows m, m, m. As shown in Table 2, MSEs do not exceed permissible values, which correspond to the requirements to a topographic plan at a scale 1: 1000. Thus, the presented data prove the possibility to apply the discussed UAV model in the creation of large-scale plans and orthophotographs of areas.

DISCUSSION AND CONCLUSIONS

As a result of our research on aerial photography with the use of UAV, the following conclusions can be drawn:

1. Without any doubt, the use of UAV for aerial photography is promising; a big interest in the production of these devices proves this.
2. The proposed and tested UAV model «SkyBow-G» meets the basic requirements for the classical aerial photography:
   - the maximum flight stability was ensured by using the appropriate hydro-stabilizing equipment; b) an appropriate navigation equipment allowing to control the device in a manual, semi-automatic and automatic ways was installed,
   - an aerial device equipped with tiny incremental rotary optical sensors allowing to define the angle elements of external orientation was used,
   - the safety features of the UAV installed onboard, a parachute system and a radio beacon are important,
   - a sufficiently powerful digital camera with a telephoto lens and a sensor resolution of 22 megapixel, Canon 6D, was used,
   - a technique to define the distortion and elements of internal orientation on digital cameras was developed and tested,
   - the UAV flight lasted at least one hour due to the use of an internal combustion engine,

- the possibility of UAV transportation without special equipment was ensured,
- the delimitation of the runway was developed: the take-off from a catapult and landing using a parachute system,
- the definition of an in-flight tilt angle and its automatic determination with the use of an aerial photography device was ensured.

3. In an automatic mode, with sufficient precision of navigation and stabilization, it is possible to survey of up to 5 kilometers of areas during 15 minutes of flight.

In the future it is planned to ensure:

- in order to increase the efficiency of aerial photography, it is necessary to consider the possibility of aerial photography during the "return" flights; this necessitates the ability to control the angle of camera orientation with a different angle of takeoff. Thus efficiency can be 10 km in 15 minutes of flight,
- the distance of reaching the trajectory for the flights against the wind should be increased by 150-200 m,
- the flights with wind speeds up to 8 meters per second are possible, but are hardly feasible. A good quality of navigation and stabilization is easily achieved with wind speeds of up to 6 meters per second,
- the algorithm of camera stabilization should be improved in order to avoid errors caused by the algorithm itself. An accurate regulation of the camera before the flight with the adjustment of magnetic and route trajectories to reduce the influence of magnetic changes and deviation is needed,
- in the future it is planned to install a geodetic GPS-receiver on board, which will determine with sufficient accuracy (10-20cm) linear elements of exterior orientation of images in a kinematic mode and to test a technological plan of aerial photography to create orthophotographs and topographical plans on the basis of obtained images,
- currently, the aircraft is being tested by carrying out aerial photography of given areas for the creation of large-scale plans and cadastral plans.

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