КАРТОГРАФІЯ І АЕРОФОТОЗНІМАННЯ
CARTOGRAPHY AND AERIAL PHOTOGRAPHY

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DEVELOPMENT AND INVESTIGATION OF UAV FOR AERIAL SURVEYING

Aim. To develop an UAV for topographical aerial surveying goals, to explore its features, and comply with assigned tasks. **Methodology.** Scientists of the Institute of Geodesy in National University Lviv Polytechnic and manufacturers of Abris Design Group consistently designed and studied several models of UAVs, in order to create a perfect model, to make it possible to organize aerial surveying for topographical purposes. As a result of previous experimental work, technical requirements for the creation of UAVs were defined. It is for these requirements the latest model UAV Arrow was constructed. To test the model of the aircraft, a technological scheme of testing has been developed in order to identify design deficiencies and obtain appropriate certified aerial photos and further to create large-scale topographical plans and orthophotomaps. **Results.** As a result of pilot works with the use of UAV Arrow, possible problems related to the UAV launch were identified and means to eliminate them were given. As a result of the testing aerial surveying from the Arrow UAV, 132 images from 7 routes were obtained. In order to assess the accuracy of determining the coordinates of points of the locality, 57 points were marked. The coordinates of control points were determined during the execution of the horizontal and vertical tie-in by GPS-receivers Trimble R7 in RTK mode. After the creation of orthophotomaps, in the Digitals software package, using these materials the coordinates of the above-mentioned control points were measured and the MSE were founded. MSE for planned coordinates were: $m_x = 0.19$ m, $m_y = 0.11$ m, which confirms the ability to create plans at a scale of 1:2000. **Scientific novelty.** The UAV Arrow was designed and investigated, which application allowed performing aerial surveying and processing of large-scale orthophotomaps with the required accuracy. **Practical significance.** The possibility of using materials obtained from the results of aerial surveying with UAV Arrow to process orthophotomaps at a scale of 1:2000 was proven.

Key words: unmanned aerial vehicle (UAV); aerial surveying; digital camera; orthophotomap.

Introduction

The possibility of using unmanned aerial vehicles (UAVs) as a new way of obtaining photogrammetric information is generated by the disadvantages of two traditional methods of obtaining data: with the help of space satellites or air manned vehicles, namely, the possibility of surveying from low altitudes and directly in the vicinity of objects, getting high resolution images, application in emergency zones without risk to the life and health of pilots, profitability [Glotov V., 2016].

It should be noted that the technology of aerial surveying from UAVs has been largely worked out today, but there are still numerous problems that need to be addressed for consideration [Galetsky V., 2012; Glotov V., 2010, 2013, 2014].

Research on the possibility of large-scale aerial surveying of rural settlements in order to create orthophotomaps has been engaged for more than eight years by native experts [Galetsky V., 2012; Glotov V., 2014]. Let's briefly recall how the experimental works on the creation and research of aerial surveying UAV began. The study was started by testing the UAV "Bird", with a two-cylinder engine of internal combustion, which carried out multi-route aerial surveying. After analysis of the obtained results, significant deficiencies of the proposed design of the UAV and aerial surveying technology were identified, in particular: insufficiently precise observance of speed and altitude of the flight due to the absence of operative telemetric information for the pilot; in most cases, the image's multidimensional was unsatisfactory (> 16 %), especially between routes; overlapping as

longitudinal as transverse were unsatisfactory (<56 %); the absence of triple overlap on some images, instability of the remote control system of the aircraft at a distance of more than 700 meters; straightness of routes was unsatisfactory – as evident by the presence of discontinuities (> 3 %); the drift angle and angle of image inclination exceeded tolerances > 3–5°; the low stability of the system to electromagnetic interference; insufficient protection of the digital camera (DC) when moving on the ground; inconvenient access to the camera, which made it difficult to change the settings; the high vibration level that caused the image to smear; the relatively high flight speed on the route.

Based on the results of the processing of the received materials, the conclusion was made about the need to improve the design and technological scheme. For this purpose, a specialized small UAV "Pegasus" with an electric motor was developed. Particular attention in design of the aircraft was focused on providing protection for on-board equipment and a DC during a nose up glide path. The aircraft was equipped with a new remote control system with a large radius of action, and a modern integrated system for determining, recording, and remote monitoring of flight parameters. The main objective of the experiment was to study the accuracy of piloting while passing parallel routes of 1000 meters length at a flight altitude of 300 meters relative to the launching point. The routes were built on landmarks, and the operator monitored the UAV visually.

After analyzing the quality of the obtained routes, it should be noted that the straightness, the yaw, and the longitudinal overlap of the photos are fixed within the tolerances. It was also satisfactorily in compliance with the altitude and speed of the flight. The protection of aircraft systems and the DC was provided at the appropriate level and allowed reliable operation from unprepared sites in the real conditions of rural settlements. Remote control of the Pegasus aircraft in accordance with the proposed technology allowed to maintain with an accuracy acceptable for aerial surveying, routes up to 1000 m in length at a flight altitude of 200–500 m. However, the unresolved problem remained – rather large pitch angles and roll angles, probably, due to insufficient stabilization of the UAV.

To resolve the above-mentioned disadvantages a new modification of the UAV Sky Bow-G, equipped with a radio beacon and parachute, was been created. The aircraft also has the appropriate navigation equipment, which allows undertaking aerial photography automatically. The results of the UAV Sky Bow-G survey showed that it meets the basic requirements for classical aerial surveying: maximum flight stability with the help of the corresponding gyro stabilizing equipment provided; runway restrictions were developed, namely catapulting and landing with a parachute system. The repeated tests confirmed the fidelity of most design decisions, but at the same time, the values of the leeways remained unsatisfactory, which exceeded the permissible values. In our case, the quality of the materials received was influenced by the incorrect assessment of the speed and direction of the wind at the flight altitude, which led to an incorrect assessment of the yaw and, subsequently, improper orientation of the camera relative to the axis of the plane. In addition, the design of the aircraft in relation to the configuration of the fuselage and the flight planes did not correspond to modern developments.

The authors [Altena, 2014, Hadjimitsis, 2004; Mahiny, 2007; Smith, 1999] had similar problems and concluded that the initial image data depend and change under the influence of atmospheric conditions. The effect of wind to tens and thermal effects can easily cause the appearance of rather large angular elements of external orientation - up of degrees, which is a problem for traditional analytical photogrammetric processing in software.

Therefore, to eliminate the final disadvantage of the previous models, the authors remaining task was to develop an optimal model of the aircraft in which all the above-mentioned defects would be absent.

Aim

To develop UAV for topographical aerial surveying goals, to explore its features, and function in compliance with assigned tasks.

Methodology

Based on the above, the requirements for the establishment of UAV for aerial survey were formulated:

1) Ensuring maximum flight stability utilizing appropriate gyro stabilizing equipment;

2) The presence of a geodetic GPS receiver on board, to determine linear elements of external orientation of the images in the kinematic mode with sufficient accuracy (10–20 cm);

3) Installation of navigation equipment, to implement semi-automatic and automatic control of the device;

4) The presence of an aerodevice, to compensate for yaw;

5) Important means of safety in relation to the UAV itself and on-board equipment (parachute system, radio beacon.);

6) The presence of a sufficiently powerful DC, resolution (20–60 Mp);

7) It is important to ensure the possibility of transporting the UAV without the availability of special means;

8) It is desirable to limit the runway (implementation of the regime "take off from the hand" and glide at the point).

Taking into account these requirements scientists of the Institute of Geodesy at the National University Lviv Polytechnic and manufacturers of ABRIS Design Group, designed aerial surveying UAV of FLIRT family (Flying Intelligent Robotic Tool) named Arrow (Fig. 1), which was many times cheaper than similar models represented on the world market, Fig. 2.
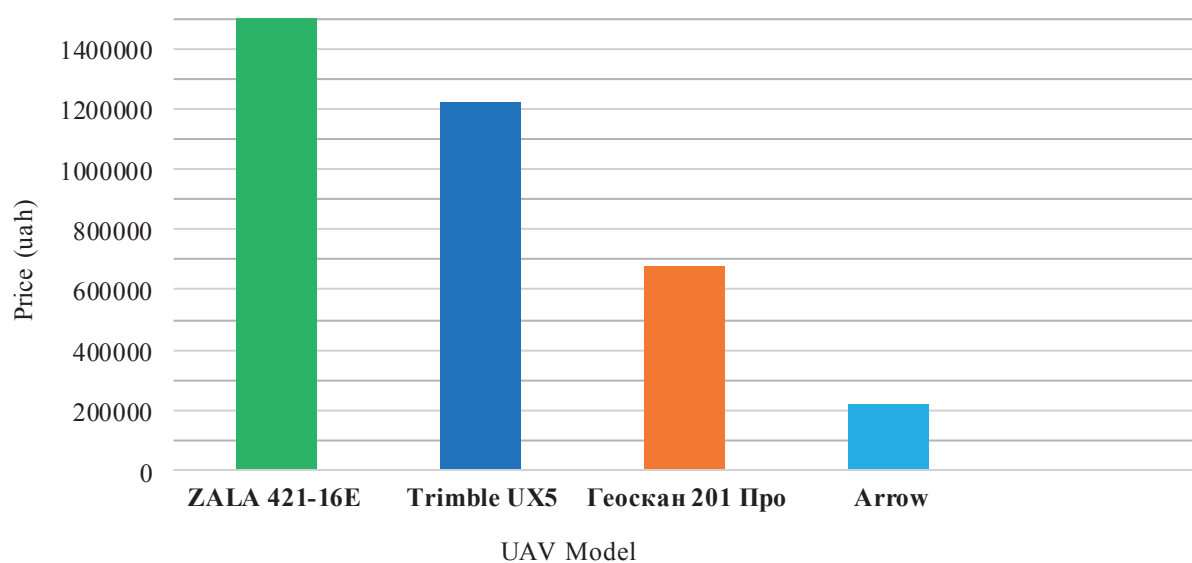

Fig. 1. UAV Arrow before the start

Fig. 2. Advantages of the obtained result in comparison with existing analogues

The technical characteristics of the UAV Arrow

Characteristics	Parameters
Takeoff weight, kg	4.8
Battery capacity, Ah	16
Minimum flight speed, km/h	50
Cruising flight speed, km/h	60–80
Maximum flight time, min	100
Maximum flight range, km	100
Maximum controlled distance from the base, km	15
Maximum flight altitude, m	5000
Minimum operational altitude, m	75
The maximum image resolution, cm/pix	2
Dimensions in transportation configuration, sm	120×25×25
Limiting wind speed, m/s	12

The technical characteristics of the UAV Arrow are given in Table 1.

The body of the aircraft is made of durable fiberglass and carbon fiber, resistant to external influences, but it is not waterproof. To reduce the impact loads when landing it is equipped with a parachute system, as well as applied rubber dampers. The UAV is intended for operation in simple meteorological conditions in the range of temperatures -25 – +40 degrees Celsius. In the aircraft, a determination is made of the flight yaw and is automatically compensated by turning the aircraft to the angle of deviation from the route.

The airplane is easy to handle for transportation in a compact transport case. The low working height and flight speed allow high-quality photos with a resolution of 2 cm/pixel. Creating an aerial survey project and managing the UAV takes place using a computer with installed software. To simplify and ease the preparation of the UAV Arrow before the start, there is a manual control panel that connects to the computer from which the project is launched. DC Sony QX1 is used to take the photos of the earth's surface. The technical characteristics of the DC Sony QX1 are shown in Table 2.

The technical characteristics of the DC Sony QX1

Weight	216 g
Dimensions	74×70×53 mm
Matrix type	CMOS
Focal length	25 cm
Effective resolution	20.1
Matrix format	APS-C
Matrix size	357.28 mm^2 (23.20×15.40 mm)
Pixel size of the matrix	4.25 microns
Matrix aspect ratio	3:2
File format of images	JPEG, RAW (12-bit ARW 2.3)
Serial capture, frames / sec	3.5
Settings ISO	Auto, 100, 200, 400, 800, 1600, 3200, 6400, 12800, 16000
Range of shutter speed	30 - 1/4000

To calculate aerial surveying routes, the **Flirt planner** program is used, to design the aerial survey site, to include, the place of start and landing, the box by which the aircraft will gain altitude, the routes of aerial surveying, the glide path zone, and the opening location of the parachute, Fig. 3.

When designing routes, it is necessary to load the data from the nearest weather station, to account for the speed and direction of the wind, the appropriate weather conditions, to specify the focal length of the camera, the resolution of photos, the value of the longitudinal and transverse overlays, the type of relief, the voltage on the battery, the method of

landing, direction landing, and the scanning area. Other parameters are set automatically: the height of the aerial surveying, the distance between the routes, the length of all routes, the aerial surveying time, the maximum yaw on the routes, the battery voltage that will be used (maximum 12 A), and the survey area.

Fig. 3. Construction of the aerial surveying route where: 1 – starting point, 2 – height dial box,
3 – circle of decline, 4 – place parachute opening, 5 – landing point

Results

As a result of experimental works, problems related to the UAV launch, DC, glide path were identified and were eliminated during the research.

1. If the ailerons and elevator do not respond to roll and pitch, inspect the levers of the ailerons, elevator, and, if it is necessary, replace them.

2. If the camera does not take a test shot – inspect the power connection of the camera and take a test shot using Mission Planner to avoid its falling asleep.

3. If Flirt Planner does not open or respond – check the availability of the internet and restart the program.

4. If the Mission Planner does not open a saved WP file – it is corrupted, so try to open another saved copy of this file or create a new WP file.

5. In the event that the aircraft's altitude is sharply reduced and substantially lower than the given altitude in the corresponding flight area, and the spatial position is clearly unstable for a considerable time, there are other obvious signs of an abnormal flight, – disable the UAV engine, and open the parachute.

6. If the battery voltage is stable below 13.8V and starts to fall rapidly, it is necessary to return the UAV to the starting point, where it will fly in a circle at a safe altitude, then select a suitable landing sector, shut down the UAV engine, and open the parachute.

7. If implementation of the project goes clearly beyond the plan, the quality of navigation is unsatisfactory, then the UAV should be returned to the starting point acting according to the scheme described in the previous paragraph.

8. If the telemetry signal disappears, inspect the quality of the connection of the USB cable to the docking station and the quality of the antenna fixation on telemetry. Move the telemetry, and change the antenna position in space. Restart the Mission Planner and re-establish the connection.

9. To confirm the possibility of processing large-scale orthophotomaps based on materials obtained from the Arrow UAV, the authors carried out aerial surveying of the city Vynnyky territory from a height of 520 m at an aircraft speed of 80 km/h. The following settings were selected: focus infinity, aperture – F / 4.5, ISO auto-exposure, shutter speed – 1/1000 second. It is worth noting, that the piloting process was conducted in fully automatic mode. The result was 132 photos of 7 routes.

To determine the operation of the aerostructure of the Arrow aircraft, an aerial survey was carried out from the Trimble UX5 UAV of the same site in Vynnyky. Comparative analysis of the angles of yaw, and the roll and pitch of the Arrow and Trimble UX5 UAVs on each route was made. Graphs for three routes are presented on Fig. 4–6.
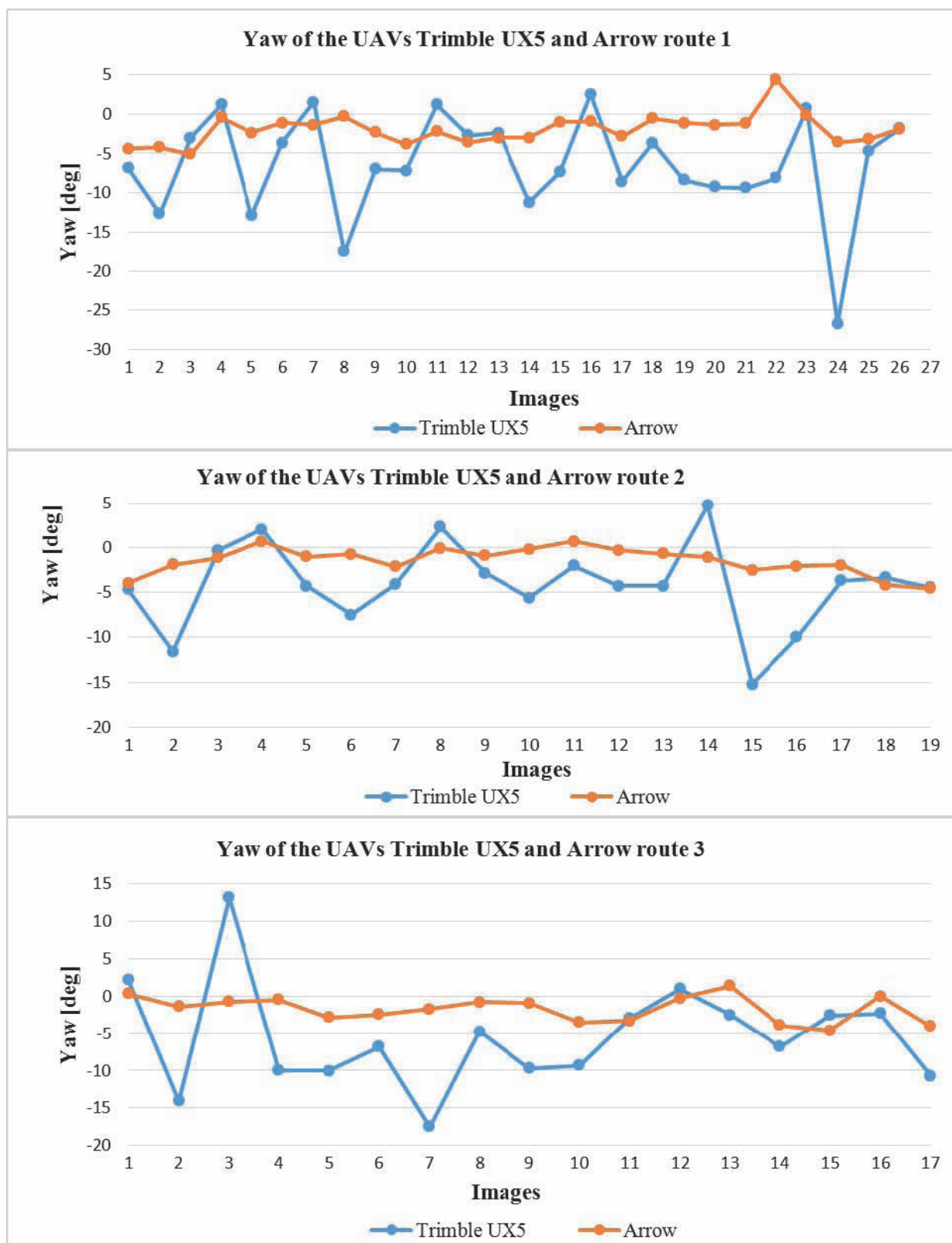

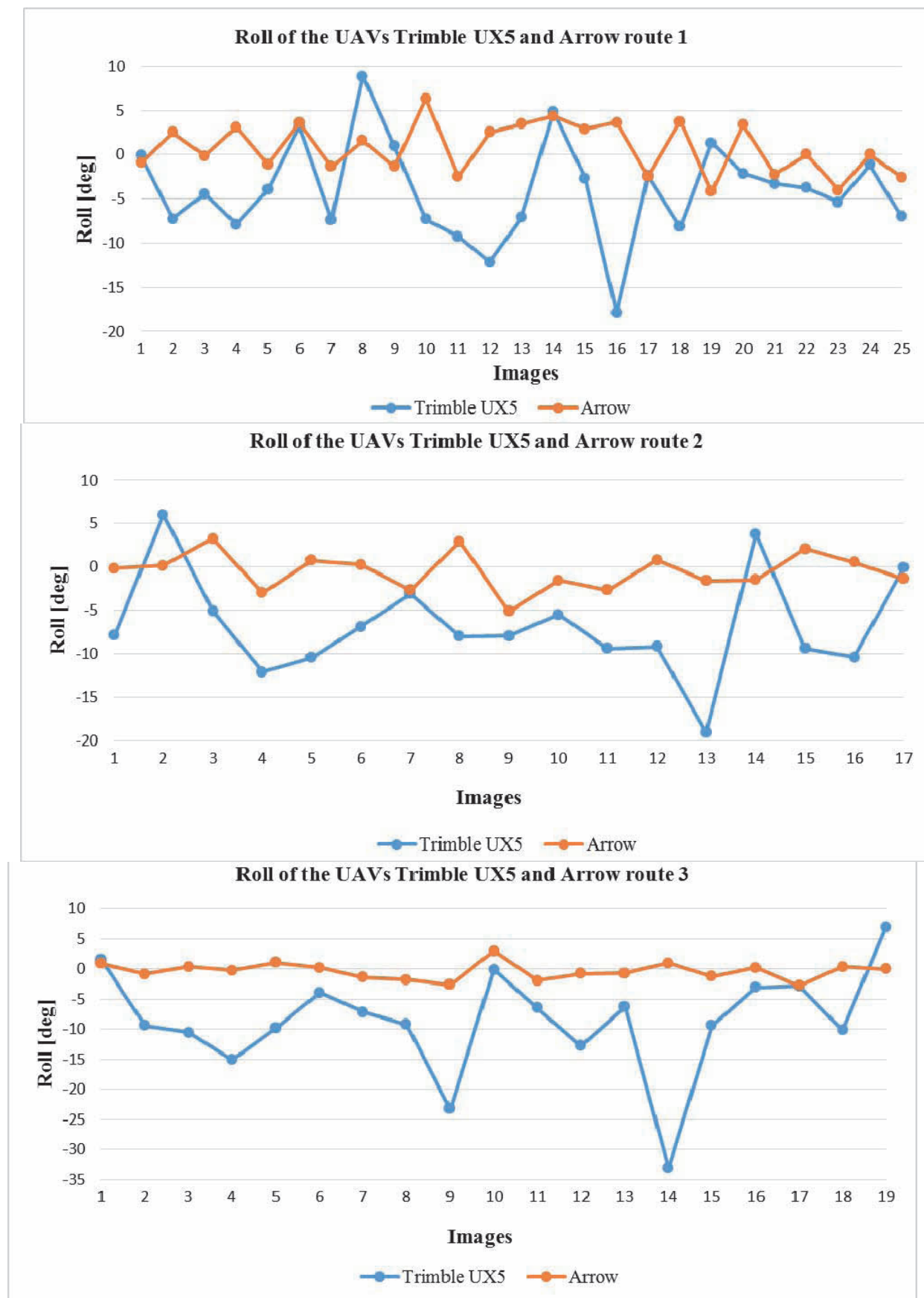*Fig. 4. Graphic yaw of the UAVs Trimble UX5 and Arrow to: routes 1, 2, 3*

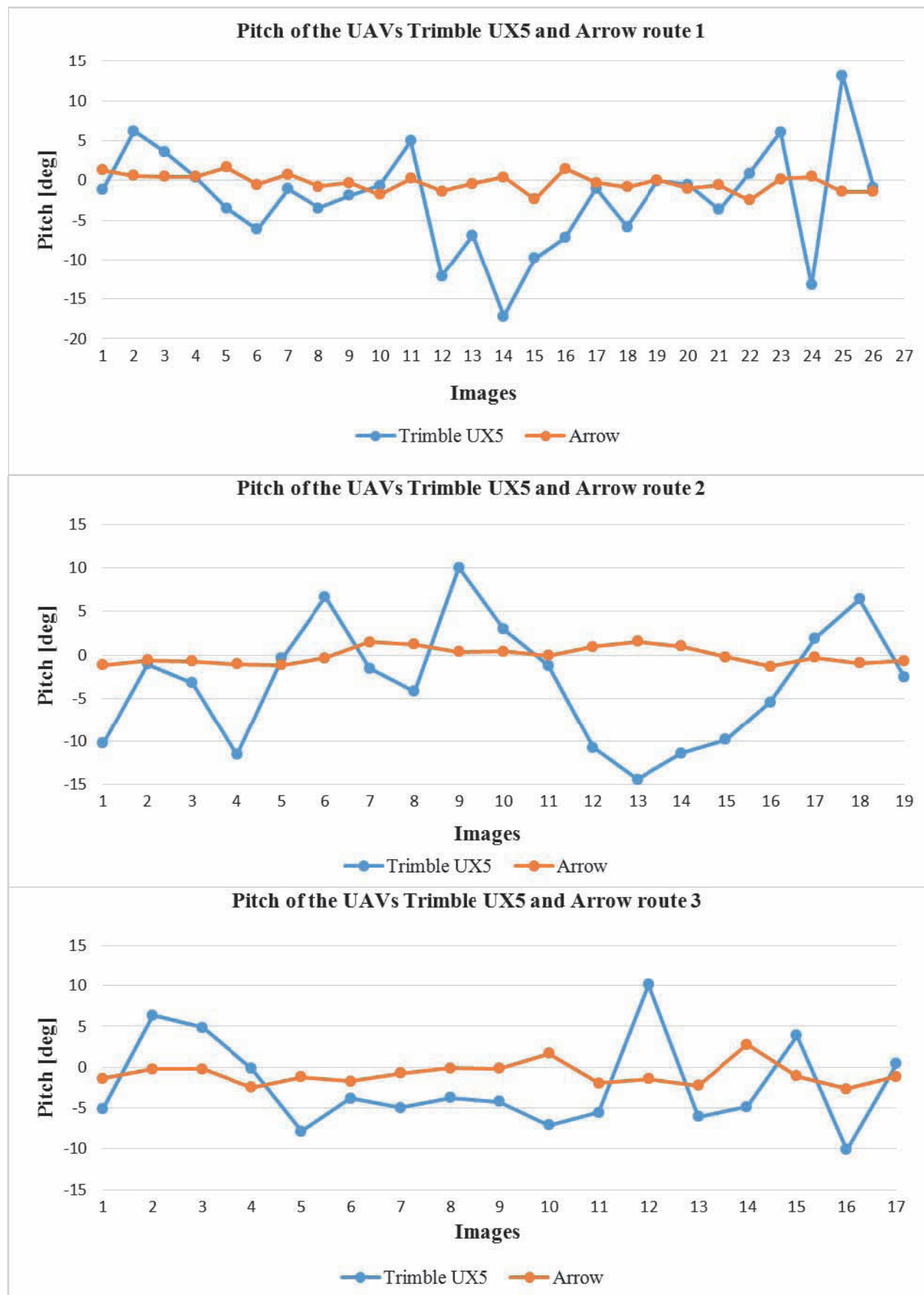*Fig. 5. Graphic roll of the UAVs Trimble UX5 and Arrow to: routes 1, 2, 3*

Fig. 6. Graphic pitch of the UAVs Trimble UX5 and Arrow to: routes 1, 2, 3

Analysis

1. Graphs of the values of the yaw angles of UAV Arrow (Fig. 4) indicate that the maximum deviation from the course ranges from -5º to +5º. Such results are explained by the fact that the yaw angle was automatically compensated by turning the aircraft for the angle of deviation from the course. At the same time, yaw angles of the Trimble UX5 UAVs range from -25º to +15º, which is beyond the tolerance limits.

2. From the graphs of the roll angles of the UAV Arrow (Fig. 5), it can be seen that the angles range from -6º to +5º, which is explained by the stabilization of the structure. The roll angles of the Trimble UX-5 UAV range from -34º to +9º, which indicate that these elements are not really acceptable, as it is known from the experience of image processing by the analytical method that these values should not exceed 10–12°.

3. From the graphs of the values of the pitch angles of the UAV Arrow (Figure 6), it can be seen that the angles range from -3º to +4º, which, as mentioned above, are due to the stabilization of the aircraft. The pitch angles of the Trimble UX-5 UAV range from -15º to +14º, which also exceeds the tolerance.

To assess the accuracy of determining the coordinates of points of the terrain, there were 57 marked points. Coordinates of control points were determined when conducting horizontal and vertical tie-in by GPS-receivers Trimble R7 in RTK mode. After creation of orthophotomaps, in the Digitals software package, using these materials, the coordinates of the above-mentioned control points were measured and the MSE were founded. MSE for planned coordinates were: $m_x = 0.19$ m, $m_y = 0.11$ m, which confirms the ability to create orthophotomaps in scale of 1:2000.

Scientific novelty

The UAV Arrow was developed and investigated, the application of which allows aerial surveying and to process large-scale orthophotomaps with the required accuracy

Practical significance

The possibility of using materials obtained from the results of aerial surveying with UAV Arrow to process orthophotomaps at a scale of 1:2000 was proven.

Conclusions

As a result of experimental work, the following conclusions can be drawn:

1. Several UAV models have been developed and tested, and design and technological features were defined for the development of UAVs for topographical aerial survey.

2. UAV Arrow was designed and researched.

3. Possible problems associated with the launch of the UAV Arrow, in respect to DC, and the glide path were identified and were eliminated during the research.

4. Comparative analysis of the values of the angular elements of external orientation of the images obtained from aerial surveying with the UAV Arrow and Trimble UX5 was carried out.

5. It is proven that the use of UAVs Arrow allows to create orthophotomaps at a scale of 1:2000 with the corresponding accuracy of planned coordinates.

6. The prospect of further research is to progress the UAV and to improve flight stabilization in order to reduce the angular values of external orientation of the images.

REFERENCES

Altena B., Goedeme T. Assessing UAV platform types and optical sensor specifications. ISPRS–Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 2014. Vol. II-5, pp. 17–24.

Hadjimitsis D., Clayton C., Hope V. An assessment of the effectiveness of atmospheric correction algorithms through the remote sensing of some reservoirsInternational Journal of Remote Sensing, 2004, Vol. 25, vol. 18, pp. 3651–3674.

Haletskyi V., Hlotov V., Kolesnichenko V., Prokhorchuk O., Tserklevych A. *Analiz eksperymentalnykh robit z stvorennia velykomasshtabnykh planiv silskykh naselenykh punktiv pry zastosuvanni BPLA.* [Analysis of experimental work on the creation of large-scale plans of rural areas in the application of UAVs] Geodesy, cartography and aerial photography. Vol. 76, 2012, pp. 85–93.

Haletskyi V., Hlotov V., Kolesnichenko V., Prokhorchuk O., Tserklevych A. *Druhyi etap eksperymentalnykh robit z aeroznimannia silskykh naselenykh punktiv* [The second phase of the experimental work aerial surveing villages with UAV], Lviv, 2012, pp. 274–277.

Hlotov V., Kolesnichenko V., Prokhorchuk O., Tserklevych A. *Analiz i perspektyvy aierofotoznimannia z BPLA* [Analysis and prospects of aerial surveying from UAV]. Lviv, 2013, pp. 5–10.

Hlotov V., Tserklevych A., Zbrutskyi O., Kolisnichenko V., Prokhorchuk O., Karnaushenko R., Haletskyi V. *Analiz i perspektyvy aeroznimannia z*

bezpilotnoho litalnoho aparata [Analysis and prospects of aerial surveying from unmanned aerial vehicle]. Vol. I (27), 2014, pp. 131–136.

Hlotov V., Hunina A. *Porivnialnyi analiz suchasnykh metodiv opratsiuvannia velykomasshtabnykh planiv* [Comparative analysis of current methods of processing large-scale plans]. Geodesy, cartography and aerial photography. Vol. 83, 2016, pp. 53–63.

Hlotov V., Kolesnichenko V. *Rezultaty ekspery-mentalno-vyprobuvalnykh robit* [Results of

experimental and test work], Lviv, 2010, pp. 164–169.

Mahiny A. S. and Turner B. J. A Comparison of Four Common Atmospheric Correction Methods. Photogrammetric Engineering & Remote Sensing. 2007. Vol.73, pp. 361–368.

Smith M., Edward J., Milton G. The use of the empirical line method to calibrate remotely sensed data to reflectance. International Journal of Remote Sensing. 1999. Vol. 20, pp. 2653–2662.

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РОЗРОБЛЕННЯ ТА ДОСЛІДЖЕННЯ БПЛА ДЛЯ АЕРОЗНІМАННЯ

Мета. Розробити БПЛА для топографічних аерознімальних цілей та дослідити його особливості і відповідність виконання поставлених завдань. **Методика.** Науковці Інституту геодезії Національного університету "Львівська політехніка" та виробничники фірми Abris Design Group послідовно розробляли та досліджували декілька моделей БПЛА з метою створення досконалого зразка, за допомогою якого можливо проводити аерознімання для топографічних цілей. У результаті раніше проведених експериментальних робіт визначено технічні вимоги до створення аерознімальних БПЛА. Саме за цими вимогами сконструйовано одну з останніх розробок БПЛА Arrow. Для апробації створеної моделі літака розроблено технологічну схему випробування з метою визначення конструкторських недоліків та отримання відповідних кондиційних матеріалів аерознімання для подальшого опрацювання: створення великомасштабних топографічних планів та ортофотопланів. **Результати.** У результаті проведення експериментальних робіт із застосуванням БПЛА Arrow виявлено можливі проблеми, пов'язані з запуском БПЛА та наведені засоби їх усунення. В результаті апробаційного аерознімання з БПЛА Arrow отримано 132 знімки з 7 маршрутів. Для проведення оцінки точності визначення координат точок місцевості, на ділянці дослідження замарковано 57 контрольних точок. Координати контрольних точок визначалися під час проведення ПВП GPS-приймачами Trimble R7 у режимі RTK. Після створення ортофотопланів у програмному пакеті Digitals на цих матеріалах виміряні координати вищеозначених контрольних точок і визначені СКП. СКП планових координат становили: $m_x = 0,19$ м, $m_y = 0,11$ м, що підтверджує можливість створення планів у масштабі 1:2000. **Наукова новизна.** Розроблено та досліджено БПЛА Arrow, застосування якого дає змогу виконувати аерознімання та опрацьовувати великомасштабні ортофотоплани з необхідною точністю. **Практична значущість.** Доведено можливість застосування матеріалів, отриманих за результатами аерознімання з БПЛА Arrow, для опрацювання ортофотопланів в масштабі 1:2000.

Ключові слова: безпілотний літальний апарат; аерознімання; цифрова знімальна камера, ортофотоплан.