ZESZYTY NAUKOWE AKADEMII MARYNARKI WOJENNEJ
SCIENTIFIC JOURNAL OF POLISH NAVAL ACADEMY

2017 (LVIII) 4 (211)

DOI: 10.5604/01.3001.0010.6751

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APPLICATION OF UNMANNED AERIAL VEHICLE (UAV) TO PHOTOGRAMMETRIC DEVELOPMENTS

ABSTRACT

The article presents the possibility of using unmanned aerial vehicle to perform selected photogrammetric studies. The first part shows the mathematical basis of aerotriangulation based on a series of images. Next, a photogrammetric system consisting of an unmanned aerial vehicle (UAV) equipped with a camera and specialized software for recording and processing images was presented. The main part shows the stages of the photogrammetric processing from the images i.e. mission plan of the incursion, creation of a thick cloud of points and a three-dimensional model. It also shows the analysis of the quality of the developed orthophotomap and a numerical model of the surface area, including photopoints by comparing them to orthographic images that are shared on Google. The final part contains generalized conclusions derived from the conducted research.

Key words:
UAV, 3D model, NMPT, orthophotomap, Pix4D.

INTRODUCTION

Photogrammetry surpasses other advantages of geodetic measurement methods due to the 'remote' method of measuring data collection. It allows field measurements to be performed in a short time in large areas that may be difficult to access. The susceptibility of photogrammetric methods to automation is another important advantage, and this applies to the dominant digital photogrammetry.

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The development of technology has enabled the use of unmanned aerial vehicles in nearly every aspect of human life. These aerial vehicles, commonly called drones, are used in the film industry, agriculture and forestry, as well as in building construction and mining. It should be noted that the UAV is mainly used by all uniformed forces — with the military being the leading institution. The rise and continuous development of 12 bases of Unmanned Aerial Vehicles in Mirosławiec is proof of this. The combination of knowledge of photogrammetry with the capabilities of modern UAVs has resulted in significant development of geodesy and cartography. Photogrammetric studies, such as the orthophotomap and the numerical model of land cover, are extremely accurate in presenting information when identifying unknown terrain. It is obvious that such information plays an enormous role in the activity of land reconnaissance and reconnaissance units, however, they can also be used in the Polish Navy — in particular in Lublin type mine transport naval operations (proj. 767). Thorough knowledge of coastal areas is a very important aspect of landing operations.

The work presents the process of producing Pix4D orthophotomap software and a numerical terrain model based on images obtained from UAV incursions. Other products used in photogrammetric software studies were also presented, including the introduction of the orthophotomap in Google Earth. Comparative analysis of the results obtained with the available studies of the same areas was also performed.

Commercial and publicly available equipment was used in order to carry out the studies and to illustrate the extraordinary possibilities that every user has. The applied methods lead to obtain highly accurate results with the possibility of their wider use.

COLLINEARITY AND AEROTRIANGULATION CONDITION

Most of the photogrammetric studies use a central projection because the easiest way is to obtain, reproduce and develop. Objects whose dimensions, positions and shapes are to be determined are recorded in photogrammetric photographs. These are perspective projections, so it is necessary to know the mathematical description of the image — the theory of the central projection [2, 3].

The photographic image is a central projection whose only imperfection, which should be noted, in reflecting the central projection is the imperfections of the lens used. They cause the projection rays to come out at a slightly different angle from the lens than to enter them. The resulting image error is called distortion. However, in high-end photogrammetric equipment, very high quality lenses are used to avoid distortion errors.

In order to compile the obtained images, calculations are made to which knowledge of the spatial position of the image in the coordinate system is required, that is, elements of internal and external image orientation. Internal orientation elements include the focal depth (the equivalent of a fixed camera) and the main point of the image (the rectangular projection of the centre of the projection on the plane of the image). On the other hand, elements of the external orientation of the image include the position of the X_0, Y_0 and Z_0 centre of projections and ω, φ and κ angular elements defining the layout of the image in the field layout [1].

In order to obtain the coordinates of a point in the reference system, based on photogrammetric imagery, it is necessary to take the projection rule into account that the centre of projections, the terrain and the point on the image lie on one straight line. This means that the vector of the R projection radius is collinear with the vector in r space. These vectors have a common origin and differ only in length. The ratio of these lengths is denoted by λ and is referred to in the literature as a scale factor [8]

$$|R|:|r| = \lambda. \tag{1}$$

Orientation of the image in space is described by ω, φ and κ angular orientation elements — the same angles, which determine the orientation of the image in the terrain layout. This orientation can be represented by the A matrix.

$$A = \begin{bmatrix} \cos\varphi \cdot \cos\kappa & -\cos\varphi \cdot \sin\kappa & \sin\varphi \\ \cos\omega \cdot \sin\kappa + \sin\omega \cdot \sin\varphi \cdot \cos\kappa & \cos\omega \cdot \cos\kappa - \sin\omega \cdot \sin\varphi \cdot \sin\kappa & -\sin\omega \cdot \cos\varphi \\ \sin\omega \cdot \sin\kappa + \cos\omega \cdot \sin\varphi \cdot \cos\kappa & \sin\omega \cdot \cos\kappa + \cos\omega \cdot \sin\varphi \cdot \sin\kappa & \cos\omega \cdot \cos\varphi \end{bmatrix}. \tag{2}$$

Thus the **collinearity condition** can be written as follows

$$R = \lambda \cdot A \cdot r. \tag{3}$$

By substituting the value of the symbolic matrix, the vector coordinates and the transformation for the r vector are obtained

$$\begin{bmatrix} \mathrm{x} \\ \mathrm{y} \\ -\mathrm{c}_k \end{bmatrix} = \frac{1}{\lambda} \cdot \begin{bmatrix} \mathrm{a}_{11} & \mathrm{a}_{12} & \mathrm{a}_{13} \\ \mathrm{a}_{21} & \mathrm{a}_{22} & \mathrm{a}_{23} \\ \mathrm{a}_{31} & \mathrm{a}_{32} & \mathrm{a}_{33} \end{bmatrix} \cdot \begin{bmatrix} X - X_0 \\ Y - Y_0 \\ Z - Z_0 \end{bmatrix}. \tag{4}$$

where:

c_k — fixed camera (equivalent to focal depth);

$X,\ Y,\ Z$ — field terrain coordinates points.

The collinearity equation is used to determine the coordinates of a point in the image layout based on field coordinates.

In order to determine the measurement data of one stereogram of aerial photography, it is necessary to know the elements of the external orientation of both images, thus the coordinates of the centre of projections and angles of rotation. These elements can be identified in the initial stage by developing a stereogram based on at least three points with already known field coordinates — image points photographed in the images.

This procedure is justified when developing a single stereogram of images, but it would be difficult to develop a larger area. The solution is **aerotriangulation**. This is the definition of the most likely model parameters describing the relationship of the field coordinates and the image coordinates of the homologous points, by connecting images into a single spatial network [6]. The main aim of aerotriangulation is to designate the elements of the external orientation of the images — X_0, Y_0, Z_0, ω, φ, κ.

We distinguish block aerotriangulation from independent images and aerotriangulation from independent models depending on the basic unit from which the block image is made.

Aerotriangulation is a process preceding the further development of aerial photography. Designated elements are necessary for further measurement development. It provides the opportunity to develop a large area covered by a large number of images.

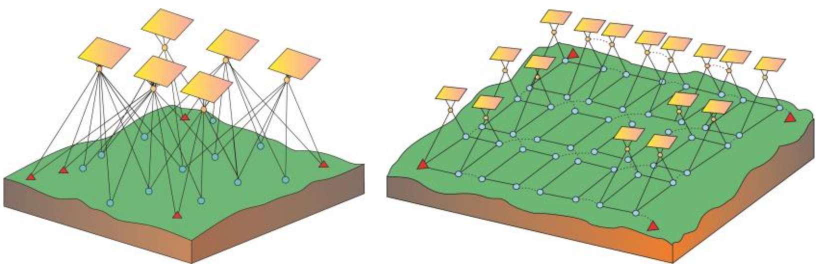

Fig. 1. Aerotriangulation network: independent beam method and independent model method [own study based on 10]

STUDY METHOD

The DJI manufactured UAV Phantom 3 Advanced was used for the study [9]. The Quadrocopter is equipped with navigation devices such as the GPS/GLONASS positioning system or magnetic compass. The use of these devices allows the set position in the air to be maintained, and also compensates for the wind effect. It also includes a Sony EXMOR 1/2.3 " matrix camera with 12.4 MP. The camera lens has an equal 94° viewing angle, focal length of 20 mm and f/2.8 brightness. The ISO sensitivity for images ranges from 100 to 1600, with a shutter speed of 8 s to 1/8000 s. The image resolution taken for photogrammetric studies is 4000 x 3000. The 3-axis gimbal is responsible for the stabilization of the camera so that the camera optical axis is tilted from –90° to +30°. The UAV is powered by a lithium-polymer 4480 mAh battery allowing up to 23 minutes of flight time. he Lightbridge video transmission system is noteworthy, which enables real-time, high-resolution transfer of images to a mobile device. The transmitter works on frequencies from 2.400 GHz to 2.483 GHz [4].

Fig. 2. Control Gear with Phantom 3 Advanced [9]

The Huawei P8 Lite smartphone was paired with the control software, which used the following software applications: DJI GO, Ctrl+DJI and Pix4D Capture [12]. The first one was used to calibrate the camera and the transmitter, and with the second application, the battery charge status and flight parameters, such as 2D position and altitude coordinates, and current speed were monitored. The exact route of the aircraft was planned with the Pix4D Capture application, the estimated mission time was calculated, and the flight height was determined based on the percentage of overlapping images (*overlap*).

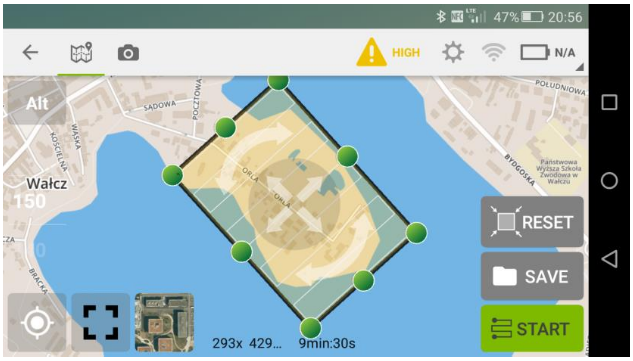

Fig. 3. Main Window Capture Pix4D program

Then, secondly, the application for autonomous control of the UAV was applied at the time of the planned mission. Full automation of the flight ensures high accuracy of the programmed flight parameters. As a result, a series of images of known positions and elements of the external orientation were obtained.

The computer hardware used during the test is the Packard Bell Easynote TS11HR with the Intel(R) Core(TM) i5-2450M, 6GB processor DDR3 RAM memory and NVIDIA GeForce 610M graphics card. Pix4D Mapper Pro is used as photogrammetric software. This program is a solution for converting UAV images into a spatially oriented two-dimensional mosaic, three-dimensional terrain models or so-called point clouds. The software offers the ability to perform numerical terrain modeling and orthophotomaps with their implementation to a variety of geospatial systems. Thanks to the introduction of ground control points, a very high accuracy of the results is obtained.

CONDUCTED STUDIES

The UAV incursion was carried out over the peninsula located on one of the water reservoirs of the Wałeckie — Zamkowy lakeland.

A) B)

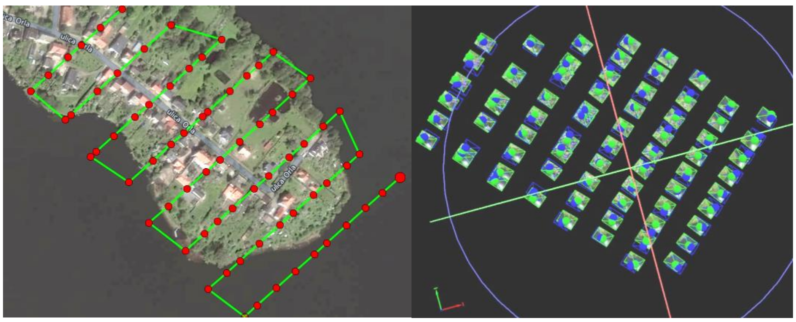

Fig. 4. A) UAV flight trajectory; B) the offset between the initial and the calculated shooting position [own study]

There were 73 images covering the area of 11.8 ha. Figure 4 shows the trajectory of the UAV, as well as the offset between the initial and the calculated shooting position (difference between green and blue dots). They are superimposed on 80% (*overlap*), on each of them on average 42195 so-called characteristic points (*keypoints*).

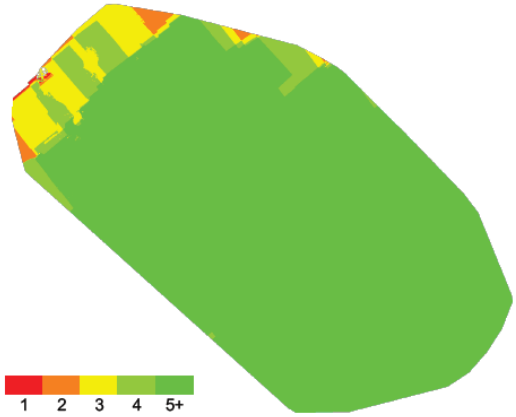

Fig. 5. Number of images covering the same area [own study]

The above figure shows the overlapping of adjacent images. The colours red, orange and yellow indicate low overlap, which results in poor results during processing, while the green areas indicate that the same point is in at least four images. The higher the level of multiple coverage, the greater the match value is and characteristic points, which directly affects the quality of the obtained photogrammetric work.

Using the Pix4D application [12] the image processing process was done as an orthophotomap and a numerical model of land cover. In the first stage of the process, the World Geodetic System 1984 coordinate system was established and the spatial location information from the EXIF metadata was retrieved. By choosing a FC300S_3.6_4000x3000 (RGB) camera model all the parameters necessary for further processing and execution of photogrammetric studies were obtained.

The second processing step was to calculate and account for the angular misalignment error for the individual elements of the external orientation of the image (ω, φ, κ), results are shown below.

Tab. 1. Single image orientation error [own study]

Element of external orientation	Average square error (*RMS — root mean square*) [degrees]
ω	1.686788
φ	0.968795
κ	3.578905

In the third step of processing the image, common points were automatically generated (*tie points*) and photocopies were added (*GCP — Ground Control Points*). Photometric measurements were made in the field using specialist geodetic equipment [11]:
- Leica VIVA GS10 receivers;
- Leica CS15 controllers;
- Leica GLS30 telescopic poles;
- Leica AS10 SmartTrack antennas.

GNSS RTK method was used for measurements (*Real-Time Kinematic*); this allowed us to get accurate geographic coordinates up to 0.014 m.

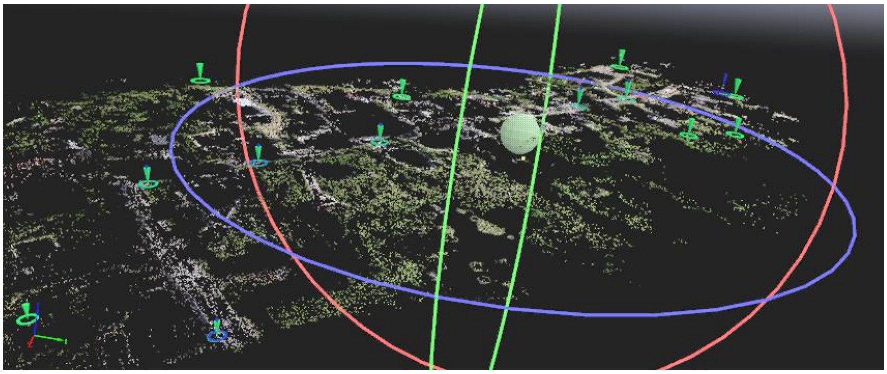

Fig. 6. Automatically generated common points together with photocopies (GCP) [own study]

The fourth stage of the processing was to generate a thick cloud of points (*Densified Point Cloud*). This made it possible to create a grid of triangles (*Triangle Mesh*), which represents the numerical terrain model of the project being executed. This model can be depicted with:
- textured — textures generated from images are superimposed on triangles;
- monochrome hue — triangles of arbitrary color are shaded according to the angle of incidence of virtual suns;
- colour — the triangles are coloured according to the light received with virtual three suns (presentation of orientation of each surface);
- colour height (*altitude RGB, topography*) — triangles are coloured using RGB or topographic colours;
- thermal colours — triangles are coloured according to the channel value of the thermal colour palette.

A) B) C)

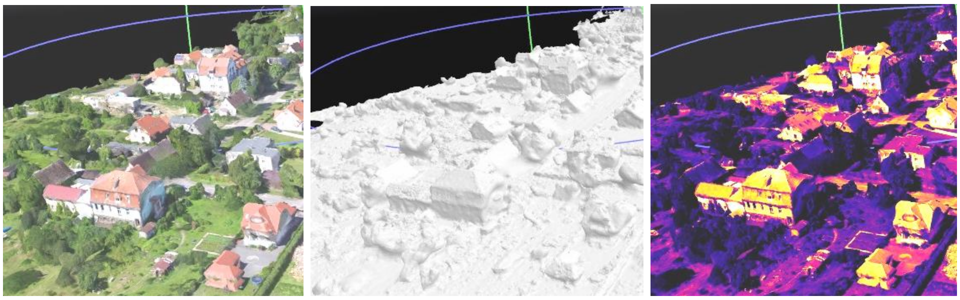

Fig. 7. Fragment of 3D model: A) textured; B) monochrome; C) thermal [own study]

Using a triangular grid or a previously generated densely populated cloud, users can perform a series of length measurements of arbitrary segments and portions of any area (fig. 8).

A) B)

Fig. 8. A) length measurement of sections; B) surface measurement (using *Triangle Mesh*) [own study]

The next step of the image processing was to obtain a digital representation of the landform and the objects on it — NMPT numerical model of land cover (*Digital Surface Model*), and raster, cartometric terrain image — orthophotomaps (*orthophoto*). It should be noted that an orthophotomap is created based on NMPT, and this is created on the basis of a thick cloud of points. Thus, the quality of the generated point cloud and its correct editing has a significant impact on the quality of the final NMPT and orthophotomaps.

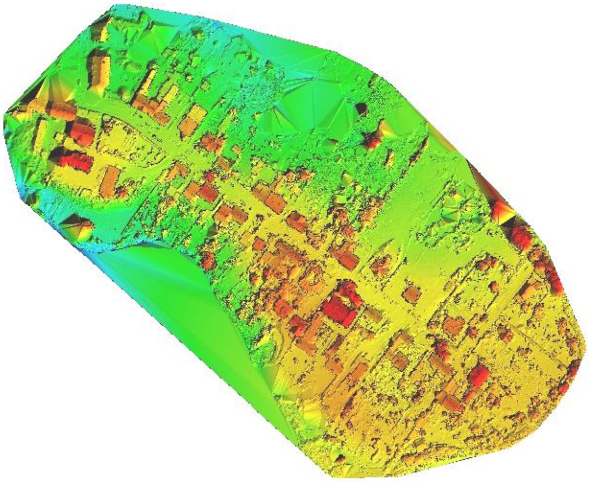

Fig. 9. Obtained numerical model of land cover — NMPT [own study]

Below the numerical model of land coverage is precisely illustrated, obtained by comparing its approximation with an orthophotomap.

A) B)

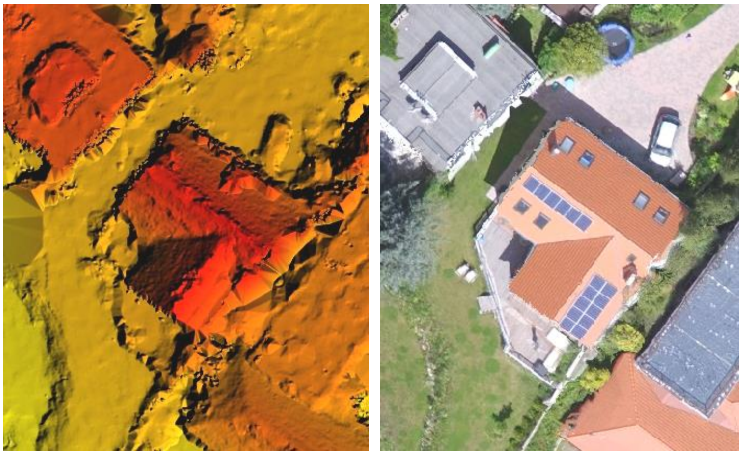

Fig. 10. A) fragment of NMPT; B) fragment of orthophotomap [own study]

The program allows you to record Pix4D orthophotos as a kml type file. This makes it easy to overlay them with orthotics made available by Google in the Google Earth and Google Maps environments. This makes it easy to evaluate the quality of the orthophotomap.

Fig. 11. Received orthophotomap imposed in Google Earth

Figure 12 A) an orthophotomic shift is shown against the one provided in Google Earth before adding the photomaps. However figure 12 B) presents an orthophotomap calibrated by the introduction of *GCP*.

A) B)

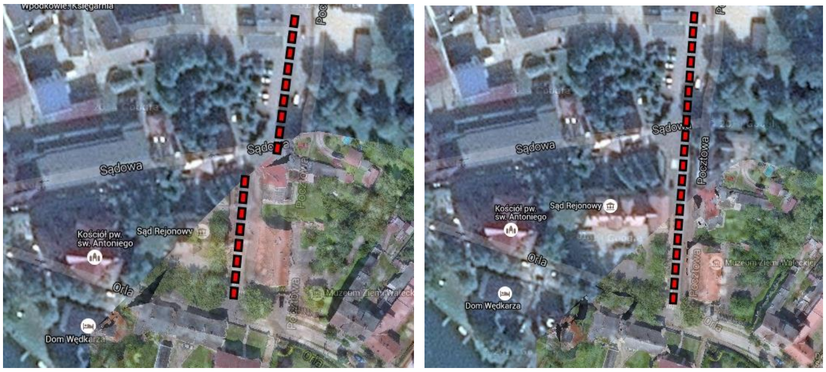

Fig. 12. A) orthophotomap shift against the one provided in Google Earth;
B) ortofotomap calibrated by introducing GCP [own study]

Figure 13 A) and B) shows a very large difference between the orthophotomap developed during the research and orthophotomap obtained from Google resources. The multiplicity of visible details is the result of high terrain resolution (*GSD — Ground Sampling Distance*) being 4.13 cm for the assumed UAV flight height and the technical parameters used to shoot the camera.

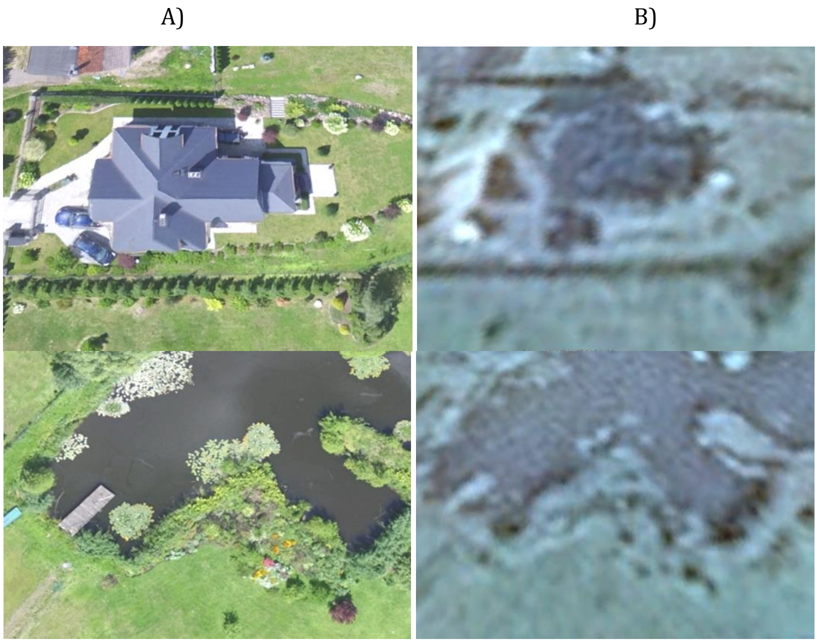

Fig. 13. A) compiled orthophotomap; B) the orthophotomap obtained from Google [own study]

Figure 14 Reflectance map is created, like the orthophotomap, based on NMPT, but also using the values of the selected parameters from the EXIF data.

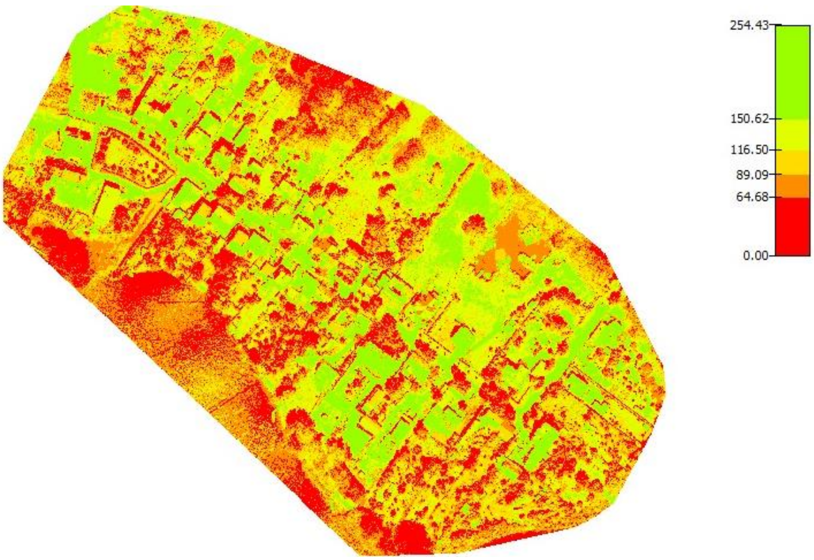

Fig. 14. Map with reflective properties of terrestrial objects (*Reflectance map*) [own study]

It is also possible to compile the map in shades of gray, blue, red, and warm colours. The goal is to give each pixel a value indicating the object's level of reflection.

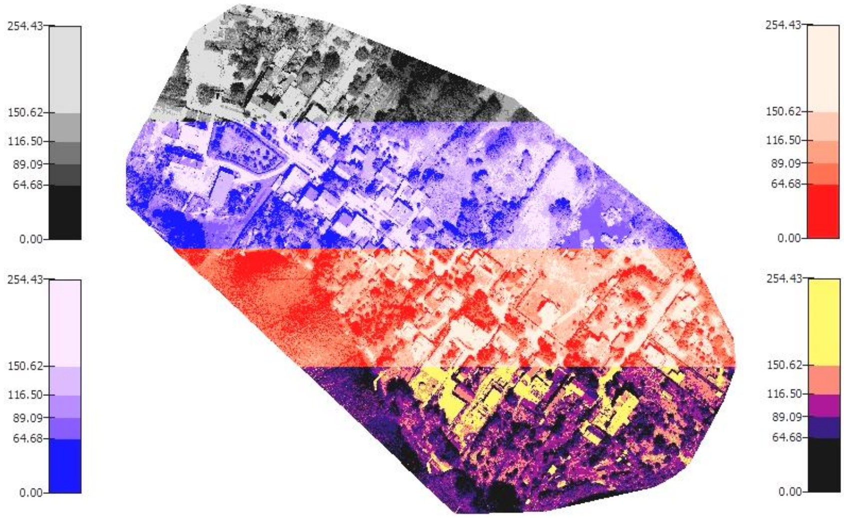

Fig. 15. Possibility of colouring the map with reflective properties of terrestrial objects [own study]

It should be noted that the above-described study is mainly used when the input data is multi-spectral or thermal. Pixel values on such maps are shaped by factors such as ISO sensitivity, shutter speed, optical or subject illumination [13].

CONCLUSIONS

1. The obtained results confirmed the hypothesis that photogrammetry surpasses its advantages by other geodetic measurement methods. It allows you to register very large areas in a short time and at a low cost, and move them to the intimate conditions. Remote registration allows measurements to be performed in difficult-to-reach or life-threatening areas in direct measurements.
2. Meteorological conditions should be taken into account in the planning process. Precipitation and very strong wind make it impossible to perform UAV incursions. Large clouds negatively affect the results as they reduce the contrast of the images. The perfect conditions for incursions are clear skies, lack of wind and the high altitude of the Sun in the sky.

3. The execution height of the incursion should be appropriately selected. The high altitude incursion allows for proper registration of small water reservoirs, vegetation and afforestation, and thanks to the lower height, the orthophotomap obtained is characterized by high resolution.
4. Particular attention should be paid to the use of natural photomultiplier or artificial photomultiplier during the manufacture of the orthophotomap and the numerical model of land cover. The use of specialized geodetic equipment for measurements greatly enhances the accuracy of the design.
5. The number of images taken affects the time it takes to process the data. The greater the ratio of reciprocal image overlays, the more pictures that will be taken in a given area. In order to get as many points as possible, an overlap of 80% should be maintained, this will ensure that all pictures are seamlessly linked. The main parameter of computer hardware influencing data processing speed is the amount of available RAM and a processor with a graphics card.
6. A study has shown how impressive the ability of any institution to use unmanned aerial vehicles for photogrammetric purposes. The ability to quickly obtain the results shown in the work should result in a twofold response. It is good to use the presented methods to obtain information about the area of possible operations. On the other hand, however, this possibility should lead to counteracting such maneuvers on the part of the opponent.

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ZASTOSOWANIE BSP DO OPRACOWAŃ FOTOGRAMETRYCZNYCH

STRESZCZENIE

W artykule przedstawiono możliwość wykorzystania bezzałogowych statków powietrznych do wykonywania wybranych opracowań fotogrametrycznych. W pierwszej części przedstawiono podstawę matematyczną aerotriangulacji wykonywanej na podstawie serii zdjęć. Następnie zaprezentowano wykorzystany podczas badań system fotogrametryczny złożony z bezzałogowego statku powietrznego (BSP) wyposażanego w kamerę oraz specjalistyczne oprogramowanie służącego do rejestracji i przetwarzania zdjęć. W zasadniczej części przedstawiono etapy procesu wykonywania opracowania fotogrametrycznego ze zdjęć, tj. plan misji wykonywanego nalotu, tworzenia zagęszczonej chmury punktów oraz trójwymiarowego modelu. Ukazano w niej także analizę jakości opracowanej ortofotomapy i numerycznego modelu powierzchni terenu, z uwzględnieniem fotopunktów, przez porównywanie ich z ortoobrazami udostępnianymi w serwisie Google. Część końcowa zawiera uogólnione wnioski wyprowadzone na podstawie przeprowadzonych badań.

Słowa kluczowe:
BSP, model 3D, NMPT, ortofotomapa, Pix4D.