Geodesy and Cartography
ISSN 2029-6991 / eISSN 2029-7009
2023 Volume 49 Issue 2: 109–115
https://doi.org/10.3846/gac.2023.17239

UDC 528.716

INVESTIGATION OF THE ACCURACY OF DETERMINING PLANNED AND ALTITUDE COORDINATES BASED ON SURVEY DATA BY UNMANNED AERIAL VEHICLES

Oleksandr YANCHUK[1*], Serhii TROKHYMETS[1], Ruslan YANCHUK[1], Tetiana BUKHALSKA[2]

[1]Department of Geodesy and Cartography, Educational and Scientific Institute Agroecology and Land Management, National University of Water and Environmental Engineering, Rivne, Ukraine
[2]Department of Land Management, Cadastre, Land monitoring and Geoinformatics, Educational and Scientific Institute Agroecology and Land Management, National University of Water and Environmental Engineering, Rivne, Ukraine

Received 29 June 2022; accepted 27 May 2023

Abstract. Experimental studies of the accuracy of determining the plan and altitude coordinates were obtained from aerial photography materials and measured by a satellite receiver in real time. The study was conducted for aerial photography materials obtained from heights of 100 and 200 meters. In addition, the accuracy researched of using a different number of ground control points for georeferencing images – 18 and 5. Accuracy assessment was performed separately for the plain area and the area with rugged terrain.

Keywords: unmanned aerial vehicle, precision, coordinate, georeferencing, ground control point, shooting height.

Introduction

Nowadays, the use of unmanned aerial vehicles (UAVs) to perform production geodetic and cartographic tasks is growing rapidly. There are many reasons for this, and one of the main ones is the cost of removal, which is several times less than the classic means of removal. Among other reasons it is worth noting (Glotov et al., 2014): the ability to shoot from low altitudes and get higher resolution; perform perspective shooting and panoramic shots; mobile and prompt monitoring of changes in places inaccessible to ground surveying.

UAVs are occupying a growing sector in surveying every year. However, it should be remembered that in addition to specialized unmanned aerial vehicles, which are able to provide high-precision materials suitable for large-scale mapping and accuracy is not inferior to manned aerial photography systems, in recent years budget unmanned aerial vehicles have appeared on the market sufficient shooting accuracy to solve a wide range of problems with minimal economic costs (Yanchuk & Trokhymets, 2017).

Given that most surveying enterprises and organizations in Ukraine use in their work the budget development of unmanned aerial vehicles, the question of the accuracy of the materials obtained by such devices is relevant. Undoubtedly, there is a need to study how the accuracy of the obtained materials changes when the shooting height changes and when the number of ground control point used to georeferencing the images varies.

1. Analysis of research

Analyzing publications on the accuracy of survey and cartographic work using UAVs, you can find publications on analytical calculations of accuracy. It should be noted that often the preliminary calculation of accuracy is performed according to the simplest scheme, in which the main factor is considered to be the resolution of the digital camera. The final accuracy is actually taken as the resolution in the field, which according to many experts is completely unacceptable (Schultz et al., 2015). The choice of UAV photography parameters has to take into account a large number of additional conditions, including the state of the atmosphere, the possible altitude and speed of photography, operating time, aerodynamic characteristics of the UAV, etc. A detailed review of all factors and calculation of their impact is given in (Bosak, n.d.), but the accuracy is again calculated by very approximate expressions.

*Corresponding author. E-mail: *o.e.yanchuk@nuwm.edu.ua*

There are also publications (Lozynsky et al., 2016; Yanchuk & Trokhymets, 2017; Ferrer-González et al., 2020; Liu et al., 2022; Garcia & Oliveira, 2021), where the accuracy of the survey is assessed on the basis of experimental studies. As follows, in Yanchuk and Trokhymets (2017), the prospects of using unmanned aerial photography systems to create a planning and cartographic basis for the development of master plans of settlements are analyzed. The evaluation of the accuracy of the obtained results on the basis of experimental researches is carried out. It is established that the mean square errors of the planned and altitude position of the points are at the level: m_X = 0.10 m, m_Y = 0.12 m, m_H = 0.18 m. Thus, the obtained values meet the requirements for large-scale surveys. The paper concludes that with the use of low-budget non-professional UAVs in terms of detailed planned and high-altitude preparation of images, providing overlap of up to 70–80% and the use of specially designed software, you can get a quality planning and cartographic basis for master plans in a short time and with low economic costs.

In labor (Lozynsky et al., 2016), a three-dimensional model of the Lviv solid waste landfill was created on the basis of TRIMBLE UX-5 UAV removal materials and its volume was calculated. One of the tasks considered in the mentioned work was to establish the accuracy of determining the coordinates of the survey materials. Therefore, the authors found that for different shooting heights (260, 280, 300 m) the accuracy of determination varies between 0.20–0.26, 0.15–0.19 and 0.25–0.33 m for coordinates x, y, z in accordance.

The publication (Liu et al., 2022) analyzes the accuracy depending on the number of ground control points in the area of about 0.5 km^2 with a height difference of about 55 meters taken from a height of 110 m UAV FEIMA D2000. It is concluded that the reference points should be evenly distributed over the shooting area and at least one point should be located in the central part of the shooting to reduce the "dome effect". When the density of the anchor points reached more than 12 / km^2 and 10 / km^2, respectively, the change in vertical and horizontal errors was not significant.

In Garcia and Oliveira (2021), the accuracy for a site with an area of 11.92 ha depending on the flight altitude (21–40 m), with different number of ground control points (0, 3, 4, 5, 8, 10) and different percentage of overlap: longitudinal (60–90%), transverse (40–80%). The best results were obtained with an overlap of 80% / 60% (respectively longitudinal/transverse), with a ground sample distance 1 cm, altitude 31 m, using a pre-calibrated camera and at least 5 ground control points.

In research (Ferrer-González et al., 2020) the accuracy of aerial photography materials of linear objects depending on the number of ground control points and their configuration is considered. The best result was obtained when the ground control points were located on both sides of the studied road. For a linear object with a length of 2.1 km, errors of the planned position of 0.029 m and a height of 0.057 m (using 9 ground control points) and 0.028 m and 0.055 m, respectively (with 11 ground control points) were obtained.

Given the significant number of factors that affect the accuracy of the final survey materials and the significant number of publications in recent years that analyze the accuracy of UAV mapping, we consider it important to investigate the accuracy at two different heights and different points of reference in the plains and rugged terrain.

2. Research methods

The aim of the work is to assess the accuracy of determining the planned and altitude coordinates of the materials of the survey by unmanned aerial vehicles by comparing with the control values of the coordinates determined by satellite observations.

In particular, the study establishes the accuracy of determining the plan and altitude coordinates of the materials obtained from the survey of the unmanned aerial vehicle DJI Phantom 4 Pro . The study was performed for two shooting options (height 100 and 200 meters) and two options for georeferencing to all available in the territory of 18 ground control points and the minimum required 5 points (the scheme is shown in Figure 1). Accuracy assessment is performed by the deviation of the coordinates of 98 points determined from the orthophoto and digital terrain model from the control coordinates. The control coordinates are determined by field geodetic measurements using a Leica 1200 satellite receiver in real time. These 98 points are combined into two networks – regular in the plains and irregular in the area with rugged terrain. Planned coordinates of points are obtained from the orthophoto of the area, and altitude – from the altitude map of the digital model of the area. Points are placed on control markers in the Agisoft software product PhotoScan and exported to dxf format.

The territory of the training geodetic landfill near the village of Khotyn, Rivne district, Rivne region and the existing network of planning and elevation points, the coordinates of which are known from multiple repeated measurements.

The following points were used in the study to georeferencing the images: 28, 29, 30, 14A, 27, 31, 21, 34, 26, 33, 12A, 32, 11, 25, 24, 23, vatm1, vatm2. They are located evenly throughout the planned shooting area (Figure 1).

In the performed research the accuracy of determination of coordinates at various quantity of ground control points is checked. Therefore, in addition to the mentioned 18 points, another variant of georeferencing images was performed – at 5 points: 27, 14A, 35, 11, 23 (shown in green in Figure 1).

To make it easier to find items in the photos, they are marked. At the first stage, a trench was removed around each point to remove the grass cover (Figure 2a). To increase the contrast of the display of the point in the image, they were marked (sprinkled) with sand in the form of a circle with a diameter of 1 m (Figure 2b).

Figure 1. Ground control points of the training geodetic landfill used to georeferencing the images

a) b)

Figure 2. Marking of ground control points: a – trench; b – sprinkling with sand

The accuracy of the determination is studied in the plains and in the area with pronounced relief. In this area there is a meadow with a uniform sloping relief (central part) and a hill with a pronounced rise in height over 20 meters (southwestern part) (Figure 3).

Accuracy assessment is performed by the deviation of coordinates at checkpoints, which are marked in the form of two networks. One is regular, with evenly spaced points in the form of a grid of squares with vertices every 50 meters. It covers a large part of the meadow and is located on a flat area with gentle terrain. It contains 60 checkpoints. The second network is irregular, located on the territory with a pronounced relief and checkpoints are set in the characteristic points of the relief. It contains 38 checkpoints (Figure 3).

The checkpoints are fixed with wooden pegs 25–30 cm long. Their coordinates, which are then used as control, are determined by a Leica 1200 satellite receiver in real time from the System Solutions network of stations (System Solutions, n.d.). To make it easier to find checkpoints in the photos, they are marked. For this purpose, plastic plates with a diameter of 22 cm were used, which were attached to pegs (Figure 4).

Aerial survey planning was performed in the Drone Deploy program at altitudes of 100 and 200 meters. Longitudinal overlap of images – 75%, transverse – 65% for both shooting heights.

Agisoft Metashape software was used to process the survey materials (Agisoft PhotoScan, n.d.).

To assess the accuracy, the deviation of the standard coordinates of the checkpoints (measured in the field in RTK mode) from the coordinates obtained in-chamber conditions on the orthophotoplan and altitude map is calculated. Since the initial georeferencing of the images

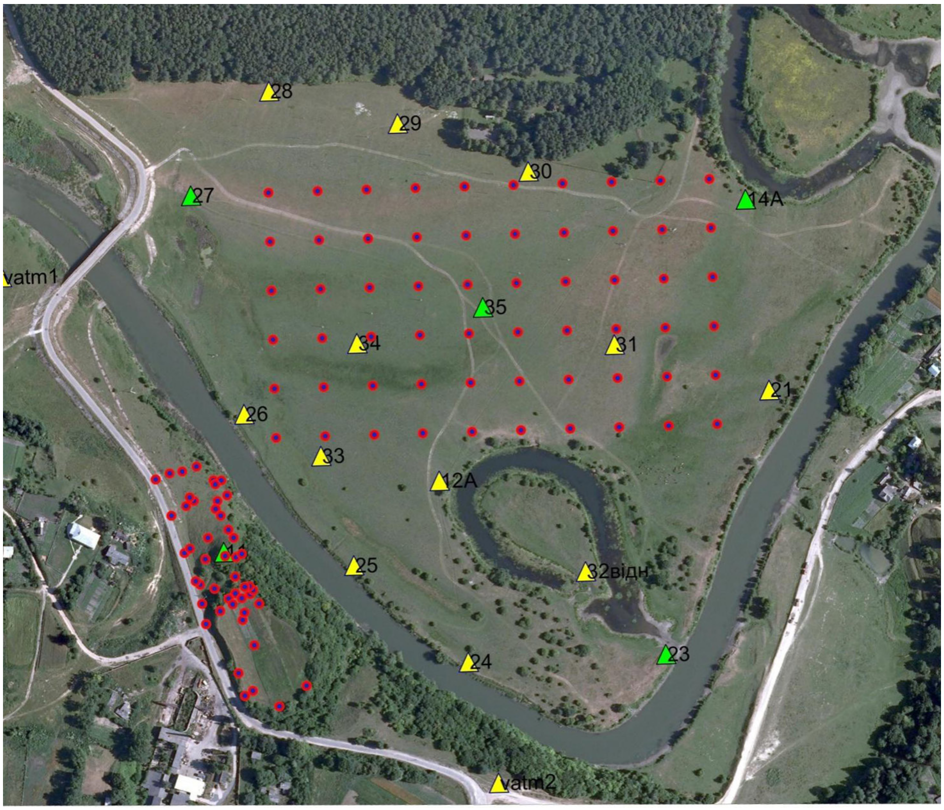

Figure 3. Layout of con the plains (center) and in the area with pronounced relief (southwest)

Figure 4. Marking of checkpoints of regular and irregular network

was performed in the coordinate system SK-63, we can calculate the deviations along the x, y axes and heights H. Based on the obtained deviations we can calculate the root mean square errors of determining the increments of coordinates m_x , m_y and heights m_H (Voitenko, 2003):

$$m=\sqrt{\frac{\left[V_i V_i\right]}{n-1}}, \qquad (1)$$

where V_i – deviation of reference and defined coordinates; n is the number of control points.

The error of the planned position m_{plan} is calculated by the formula:

$$m_{plan}=\sqrt{m_x^2+m_y^2}, \qquad (2)$$

where m_x, m_y are the root mean square errors of determining the coordinates on the x and y axes, respectively.

Thus, the errors in determining the coordinates along the x, y, plan and altitude axes are calculated position at different height surveing and different number of ground control points. And also the mentioned errors in the general and separately for plain and rugged terrain are calculated.

3. The results of the research

At the first stage, the estimation of the accuracy of determining the coordinates from the data of shooting from a height of 100 meters and georeferencing at 18 ground control points was calculated. The scheme of the used ground control points and the estimation of the accuracy of their position is shown in Figure 5. The calculated RMS errors for each axis and the planned and elevated position in general and separately for flat and rugged terrain are shown in Table 1.

In the second stage, the estimation of the accuracy of determining the coordinates based on the data of shooting from a height of 200 meters and georeferencing at 18 ground control points was calculated. The scheme of the

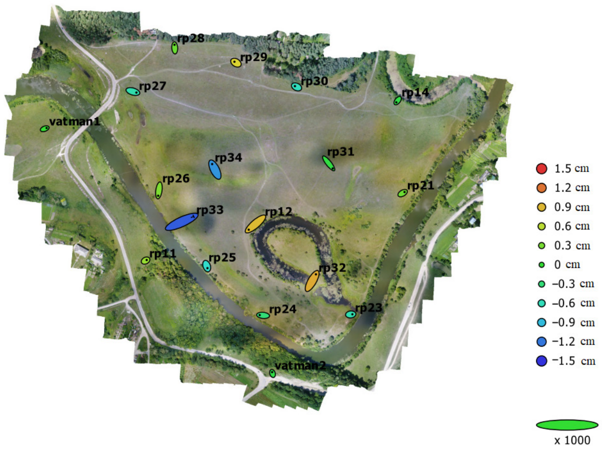

Figure 5. Diagram of the 18 ground control points used and assessment of the accuracy of their position when georeferencing data from a height of 100 meters

Table 1. RMS with height of 100 meters and georeferencing at 18 ground control points

RMS	Relief characteristics		In general
	flat	rugged terrain	
m_x	0.033	0.063	0.048
m_y	0.033	0.029	0.031
m_{plan}	**0.046**	**0.069**	**0.057**
m_H	**0.102**	**0.110**	**0.105**

used ground control points and the estimation of the accuracy of their position is shown in Figure 6. The calculated root mean square errors for each axis and the planned and elevated position in general and separately for flat and rugged terrain are shown in Table 2.

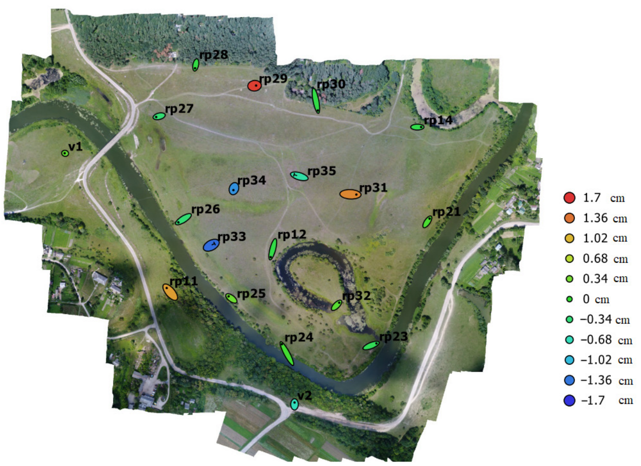

Figure 6. Diagram of the 18 ground control points used and the assessment of the accuracy of their position when georeferencing data from a height of 200 meters

In the third stage, the estimation of the accuracy of determining the coordinates according to the data of shooting from a height of 100 meters and georeferencing at 5 ground control points was calculated. The scheme of used ground control points and assessment of the accuracy of their position is shown in Figure 7. Calculated RMS errors for each axis and planned and elevated position in general and separately for flat and rugged terrain are shown in Table 3.

Table 2. RMS with height of 200 meters and georeferencing to 18 ground control points

RMS	Relief characteristics		In general
	flat	rugged terrain	
m_x	0.031	0.065	0.049
m_y	0.037	0.061	0.049
m_{plan}	**0.048**	**0.089**	**0.069**
m_H	**0.093**	**0.086**	**0.089**

Figure 7. Diagram of the used 5 ground control points and assessment of the accuracy of their position when georeferencing data from a height of 100 meters

Table 3. RMS with height of 100 meters and georeferencing at 5 ground control points

RMS	Relief characteristics		In general
	flat	rugged terrain	
m_x	0.027	0.067	0.046
m_y	0.030	0.039	0.033
m_{plan}	**0.040**	**0.077**	**0.057**
m_H	**0.117**	**0.249**	**0.179**

In the fourth stage, the estimation of the accuracy of determining the coordinates based on the data of shooting from a height of 200 meters and georeferencing at 5 ground control points was calculated. The scheme of the used ground control points and the estimation of the accuracy of their position is shown in Figure 8. The calculated root mean square errors for each axis and the planned and elevated position in general and separately for flat and intersected relief are shown in Table 4.

For clarity, the results are presented in the form of graphs (Figures 9–10). Analyzing the obtained results, it should be noted that the planned errors in all considered variants of the study do not exceed 0.1 m. That is,

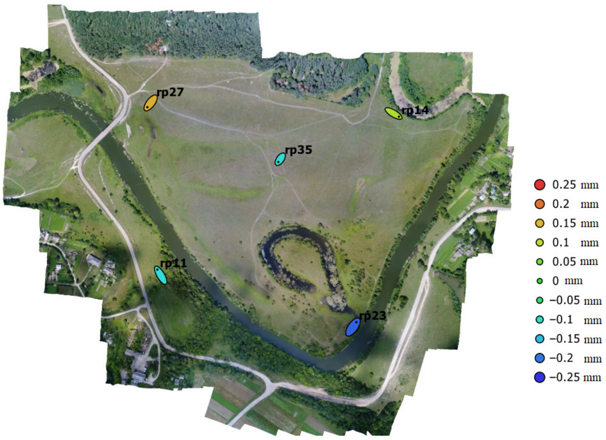

Figure 8. Diagram of the 5 ground control points used and assessment of the accuracy of their position when georeferencing data from a height of 200 meters

Table 4. RMS with height of 200 meters and georeferencing to 5 ground control points

RMS	Relief characteristics		In general
	flat	rugged terrain	
m_x	0.047	0.051	0.049
m_y	0.038	0.048	0.042
m_{plan}	**0.061**	**0.070**	**0.065**
m_H	**0.094**	**0.069**	**0.084**

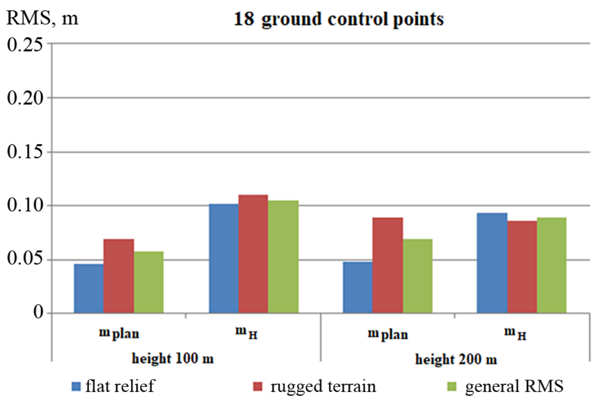

Figure 9. Graph of the obtained RMS at 18 ground control points

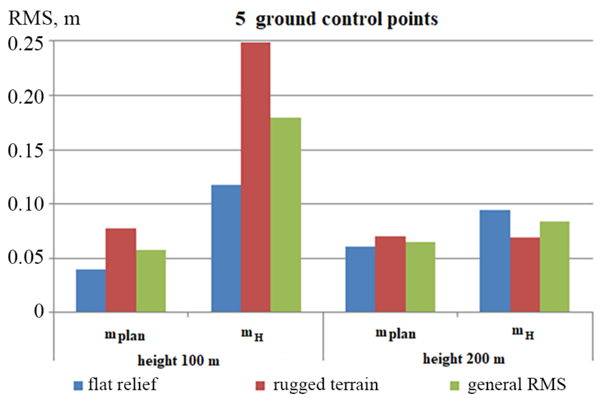

Figure 10. Graph of the obtained RMS at 5 ground control points

the height of the survey, the nature of the terrain and the number of ground control points did not significantly affect the accuracy of coordinates. While the errors of altitude position increased significantly when removing from a height of 100 meters and using only ground control points – for rugged terrain errors are almost twice the errors for the plains.

It should be noted that 473 images were used to create an orthophotoplan based on materials taken from a height of 100 meters. Shooting resolution 2.61 cm / pixel. 120 images were used to create an orthophoto plan based on materials taken from a height of 200 meters. Shooting resolution 5.25 cm / pixel.

Conclusions

Summarizing the results obtained, the following conclusions can be drawn:

- in most of the considered cases RMS are within 0.1 m, except for the error of altitude position on rugged terrain at a height of 100 meters and 5 ground control points. In our opinion, this can be explained by the larger number of images that need to be georeferencing together at a shooting height of 100 meters. Therefore, with a significant number of images, 5 ground control points are not enough to accurately determine the heights of the points;
- with a sufficient number of ground control points, the accuracy of determining the coordinates according to the survey from different heights does not differ significantly;
- the error of the elevation position slightly exceeds the error of the planned position;
- the obtained errors provide requirements for the accuracy of the creation of topographic plans at a scale of 1:1000-1:2000 (excluding errors of altitude position at a shooting height of 100 meters and 5 ground control points) (Pro zatverdzhennja…, 1998);
- errors in rugged terrain slightly exceed the errors in the plains and generally meet the requirements for the accuracy of topographic plans at a scale of 1:500.

References

Agisoft PhotoScan. (n.d.). Retrieved January 20, 2022, from http://www.agisoft.com/

Bosak, K. (n.d.) *Secrets of UAV photomapping*. Retrieved June 27, 2022, from http://s3.amazonaws.com/DroneMapper_US/documentation/pteryx-mapping-secrets.pdf

Ferrer-González, E., Agüera-Vega, F., Carvajal-Ramírez, F., & Martínez-Carricondo, P. (2020). UAV photogrammetry accuracy assessment for corridor mapping based on the number and distribution of ground control points. *Remote Sensing*, *12*(15), 2447. https://doi.org/10.3390/rs12152447

Garcia, M. V. Y., & Oliveira, H. C. D. (2021). The influence of flight configuration, camera calibration, and ground control points for digital terrain model and orthomosaic generation using unmanned aerial vehicles imagery. *Boletim de Ciências Geodésicas*, *27*(2). https://doi.org/10.1590/s1982-21702021000200015

Glotov, V., Tserklevich, A., Zbruckij, O., Kolisnichenko, V., Prokhorchuk, O., Karnaushenko, R., & Galecky, V. (2014). Analysis and perspectives aeroshooting process with unpiloted aircraft. *Present-Day Achievements of Geodetic Science and Production*, *1*(27), 131–136 (in Ukrainian).

Liu, X., Lian, X., Yang, W., Wang, F., Han, Y., & Zhang, Y. (2022). Accuracy assessment of a UAV direct georeferencing method and impact of the configuration of ground control points. *Drones*, *6*(2), 30. https://doi.org/10.3390/drones6020030

Lozynsky, V. A., Nikulishyn, V. I., Tretyak, K. R., & Shilo, Ye. O. (2016). Method for determining the volume Lviv solid waste landfill by using archival mapping materials and UAV TRIMBLE UX-5. *Geodesy, Cartography and Aerial Photography*, (83), 64–82 (in Ukrainian). https://doi.org/10.23939/istcgcap2016.01.064

Pro zatverdzhennja Instrukcії z topografichnogo znimannja u masshtabah 1:5000, 1:2000, 1:1000 ta 1:500 (GKNTA-2.04-02-98) [On approval of the Instruction on topographic surveying in the scales of 1:5000, 1:2000, 1:1000 and 1:500]. (1998, April 09). Retrieved June 27, 2022, from https://zakon.rada.gov.ua/laws/show/z0393-98#Text (in Ukrainian).

Schultz, R. V., Krelstein, P. D., Malina, I. A., & Voitenko, S. P. (2015). The issue of calculating points positioning accuracy for aerial photographs from unmanned aerial vehicles. *Engineering Geodesy*, (62), 124–137 (in Ukrainian).

System Solutions. (n.d.). Retrieved January 20, 2022, from https://systemnet.com.ua/ (in Ukrainian)

Voitenko, S. P. (2003). *Mathematical processing of geodetic measurements. Measurement error theory*. KNUBA (in Ukrainian).

Yanchuk, R. M., & Trokhymets, S. M. (2017). Creating cartographic basis for developing master plans of settlements on materials of aerial surveys using unspecialized inexpensive UAV. *Bulletin of the National University of Water and Environmental Engineering*, *1*(17), 32–39 (in Ukrainian).