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# The surface modelling based on UAV Photogrammetry and qualitative estimation

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ABSTRACT

Recently, the interest in Unmanned Aerial Vehicle (UAV) application in photogrammetric environment has increased in many countries. The fixed-wing UAV, the model of EPP-FPV with mounted digital camera *Canon S100* was used as a platform for images acquisition. Implemented means are low-cost, mobile and simple. Digital photogrammetry technology with *Pix4D* software application has been applied for UAV images processing and area mapping. High quality of images is a significant factor for the efficiency and accuracy generating standard mapping products. The correctness of digital surface models and orthophotos mainly depend on camera resolution, flight height and ground control point (GCP) accuracy. The paper reports on investigations how number of GCPs used for UAV image transformation influences the mapping results. The demand of such investigations arises because the flight paths with a fixed wing UAV have general form, in contrast to classical paths which are pricewise straight lines, as well as the flight significantly depends on weather conditions (especially on wind) and the platform shows considerable tilt because of its light weight. The results of DSM accuracy investigation demonstrate the quality of UAV Photogrammetry product with the use of appropriate number of GCPs.



## 1. Introduction

A few years back and up to now, the application of Digital Photogrammetry techniques for collecting cartographic data from images taken by digital cameras integrated in Unmanned Aerial Vehicles (UAV) has increased significantly. There arise such new modern terminologies as “UAV photogrammetry”, “UAV images”, etc. The emergence of UAV technology can be ascribed to technical developments of electronic components and the possibility of their integration in remotely controlled aircrafts [20,27]. The term UAV is commonly used in the Artificial Intelligence, Computer Science and Robotics, as well as in the Photogrammetry and Remote Sensing communities. “UAV photogrammetry” describes a photogrammetric measurement platform, which operates remotely controlled, semiautonomous or full autonomously without a pilot sitting in the vehicle [16].

UAV systems operation opens various new applications in the close range domain, combining aerial and terrestrial photogrammetry. It is a new near real time application and low-cost alternatives to the classical manned aerial photogrammetry [19,25,26]. Main features of UAV photogrammetry are considered with respect on costs (low-cost), flying altitude (low–high), capability of image acquisition in real-time such that quality depends on sensors features,

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flight performance (e.g. maximum flying speed for fixed wing vehicles 50–60 km/h), influence of atmospheric and environment conditions, windflaws, etc. Different types, classification, categorization of UAV's, applied for photogrammetric data acquisition are used [3,2].

Comparing the usage of UAVs and manned aircraft, UAV can be used in mapping of high-risk situations (e.g., disaster areas, mountains and volcanic zones, flood, earthquake and various accidents regions, etc.), without imminent danger to life of a pilot. With the UAV system, due to its small size, images can be taken very close to an object within very small space or in territories that are shielded by trees or water bodies, narrow city streets, etc. Cheap UAV vehicles are light, therefore amateur cameras can be integrated such that the image resolution and quality may not always meet the needs of the user. UAV application possibilities for mapping extends to very special needs, e.g. for the inventory of electrical lines, etc.

Using professional digital photogrammetric cameras allows generate high quality digital surface models (DSM) by image matching [1,7,12]. Such surface data are important for generating 3D building models, landscape visualization, roof shapes, canopy models, etc., as well as for generation and updating classical digital terrain models [6,11]. The production of orthophoto and digital elevation models (DEMs) became completely digital, mostly automatic and with short response of time [23,18]. These are the major factors ensuring success in gaining cartographic data from digital images.

Digital photogrammetry methods are applied for generation of orthophotographic maps. For this purpose, needs to generate a digital terrain model of the Earth's surface and digital aerial images geometry correction, which removes geometric distortions due to tilt of the camera, the central projection and terrain effects. The quality of the geometric image transformation essentially depends on the quality of the digital terrain model [8,9].

The interest in UAV Photogrammetry's great potential for digital photogrammetry applications is rising in many countries, as well as in Lithuania. Up-to-now the main fields of UAV application are the acquisition of cadastral area overlook images or for publicity needs.

The goal of this investigation is to evaluate the quality of DSM/DEM data generated using UAV photogrammetry techniques and to demonstrate application possibilities for cartographic data collection.

## 2. Technological features and methodology

During a single autonomous photogrammetric flight, the camera, mounted on the UAV platform, can collect thousands of images. The autonomous flight uses the autopilot board and PC software *Mission Planner*. It uses a digital map (e.g., from *Google Earth*), which is required for planning of the flight, namely by signifying waypoints. It helps controlling autonomous triggering of images and autonomous take-off and landing. The producer proposed the following *Mission Planner* features:

- Point-and-click waypoint entry, using *Google Maps*.
- Download mission *log* files and analyze them.
- Configure autopilot *Ardu Pilot Mega* (APM) settings for airframe.
- Interface with a PC flight simulator to create a full hardware-in-the-loop UAV simulator.
- See the output from APM's serial terminal.

Important features of the data quality are image resolution, clearly and tilt. After landing, collected images are checked, if required, a flight repeat. All jobs proceed in real time on the field. The UAV can be commanded by a PC based ground station which is connected via RF link [5]. An automatic flight needs a three axis gyroscope and acceleration meter, pressure sensor, air velocity sensor, 10 Hz GPS module, battery voltage sensor, 4 Mb memory chip integrated flight parameter storage and a telemetry module [21]. The universal workflow is accepted for image data acquisition: determination of Project Parameters (PP), Flight Planning (FP), Autonomous Photogrammetric Flight (APF) and Quality Check of the Data (QCD).

After capturing the images, using different platforms and sensors, main photogrammetric procedures are: aerial triangulation, images orientation (interior – definition of camera parameters, exterior – measurements of ground control points for each image), model definition (reconstruction of spatial geometry from two images, calculation using well known collinearity equations), creation of surface models, orthophoto generation, vector data collection for GIS or cartographic needs [4,14]. Establishing the relation between image and object coordinates, the ground control point's coordinates usually are measured using Global Positioning System (GPS).

Most software packages can process the UAV images. UAV block triangulation – images oriented and generated by the navigation unit of the UAV, leads to a reduction of the number of control points required for the orientation; DSM, orthophoto, 3D model – commercial software packages and existing in house-developed tools are used. Photogrammetric processing software categorizes into three classes based on their capability for processing of aerial, terrestrial and a combination of aerial and terrestrial images. It is recommended to evaluate the suitability of selected software packages for UAV data processing and usage in applications.

One of main procedure in digital photogrammetric image processing is Image Matching. Creating DTMs via image matching can be applied different methods. Some photogrammetric software uses method of correlation based image matching as in software package *LISA* [13], applied for experimental investigations for checking DEM. The used area-based matching (ABM) approach leads to good stereo pair correlation results. Area-based image matching compares the grey scale values of patches of two or more images and tries to find conjugate image locations based on similarity in those grey scale value patterns.

Homologous points on the overlapping area of images are automatically searched identifying the similar grey values of pixels. The target window's (pattern of image on the left image) size has influence on accuracy for searched points. Search window involves matched pixels for which correlation have to be evaluated. Evaluating the similarity of these two windows, the correlation coefficient has to be calculated with determination of target window shift [15,22].

The two digital image matrices being to match:

$$\begin{pmatrix} k \\ l \end{pmatrix} \leftrightarrow \begin{pmatrix} i \\ j \end{pmatrix}, \quad i = k + u, j = l + v, g_1(k,l) = ag_2(i,j) + b, \tag{1}$$

where $\begin{pmatrix} u \\ v \end{pmatrix}$ – shifts of target window on searched window (images are without noises), $a$ – contrast, $b$ – brightness.

A correlation coefficient is determined using the following formulae [10]:

$$\rho(u,v) = \frac{\sigma_{12}(u,v)}{\sigma_1\sigma_2(u,v)}, \tag{2}$$

where:

$$u = 0, \cdots, I - K,$$

$$v = 0, \cdots, J - L,$$

$$\sigma_1^2 = \frac{1}{KL}\sum_{k=1}^{K}\sum_{l=1}^{L}(g_1(k,l) - \bar{g}_1)^2,$$

$$\sigma_2^2(u,v) = \frac{1}{KL}\sum_{k=1}^{K}\sum_{l=1}^{L}(g_2(k+u,l+v) - \bar{g}_2)^2,$$

$$\bar{g}_1 = \frac{1}{KL}\sum_{k=1}^{K}\sum_{l=1}^{L}g_1(k,l),$$

$$\bar{g}_2 = \frac{1}{KL}\sum_{k=1}^{K}\sum_{l=1}^{K}g_2(k+u,l+v).$$

$\sigma_1$ – standard deviation of pixel grey value in target window,
$\sigma_2(i,j)$ – standard deviation of pixel grey value in search window,
$\sigma_{12}(i,j)$ – covariation,
$g_1$ – pixel grey value in target window,
$g_2$ – pixel grey value in search window,
$k$, $l$ – rows and columns in target window,
$N$ – number of pixels in pattern and target windows,
$\bar{g}_1$ – mean pixel's grey value in target window,
$\bar{g}_2$ – mean pixel's grey value in search window.

The area-based matching parameters, using LISA software for UAV images processing, are specified as the following: pixel size for DTMs (not less than 0.2 m); minimum correlation coefficient (0.7–0.8) required for a pair of conjugate points to be considered as correspondence; correlation window size used to examine a small defined area, looking for matches to a topographic feature (the smallest window size is 5 × 5 square pixels), use a larger, e.g., 11 × 11 or 17 × 17 square pixels for higher resolution images in order to achieve more reliable matching results, but the process takes longer.

## 3. Experimental procedures

Experimental fly using UAV with equipped digital camera was executed by Space Science and Technology Institute (SSTI), Lithuania. The very high requirements for flight planning and realization did not apply, performing a short flight and acquiring image data. Executing of the flight was important dependence on good weather, still wind and optimal flying height. UAV flight was executed over the area of Naujakiemis, a region of Vilnius. The flight area is about 80 ha. The site was partly pawn flatlands. The mean altitude of area is about 125 m; the maximal height difference in the area is approx. 10 m.

*Image data acquisition: technical means, UAV performance*. The fixed-wing UAV platform, model *EPP-FPV* and camera *Canon S100* were used for the image data acquisition.

The *EPP-FPV* is a robust, low cost, low weight UAV platform with foam construction, a wingspan of 1.8 m and a weight of around 4 kg. Its speed is about 14 m/s. It is able to fly up to 30 min on low wind conditions. Therefore, the maximum flight distance is approx. 25 km, taking into account energy for climbing and landing. The flying height can be chosen in the range – from 150 m to 300 m, depending on the required image resolution. The UAV platform guidance is fully automatic, semi-manual or manual. Take-off and landing on flat surface is automatic or manual. Autopilot *Ardu Pilot Mega* (APM) is used for automatic guidance. It is based on the *Arduino* embedded system. The flight planning programme *Mission Planner* allows simple and fast guidance of the automated fly.

Images have been taken using high-resolution consumer camera *Canon S100*. The camera's main features are: the nominal focal length is 5.2 mm; the 1/1.7″ CCD sensor incorporated has 12.1 Mega pixels. The integrated GPS module allows determining geodetic coordinates of projection center for each image during the flight with an accuracy of up to 2–3 m; the maximum frame size of image is 4000 × 3000 pixels. The camera was mounted under the airframe. Prior to a flight the camera is calibrated. The *Ardu Pilot* operates not only the UAV, but also is managing the camera exposition; therefore, image collection is fully computer assisted.

The UAV flight was controlled with telemetry module; therefore, the density of the waypoints was close to the planned distances. The flight paths are not standard (see Fig. 1).

The flight strips were generated as six polygons with 184 images in total. The flights were performed at a height of approx. 150 m above ground in order to collect images at a Ground Sample Distance (GSD) of up to 10 cm. GSD is determined using following formula:

$$GSD = p\frac{H}{c}, \tag{3}$$

where $p$ – CCD pixel size, $H$ – flying height, $c$ – camera focal length.

*Photogrammetric processing of images*. For the following study 17 images have been selected for photogrammetric mapping (Fig. 2).


**Fig. 1.** Autonomous flight paths on experimental area in Google Earth application.

The photogrammetric software package *Pix4D* has been used for experiment. *Pix4D* is professional processing software, developed at Computer Vision Lab in Switzerland, and can be applied for converting thousands of images, taken by lightweight unmanned aerial vehicle or aircraft into geo-referenced 2D or 3D surface models and point clouds (http://pix4d.com). As well as, *Pix4D* introduces a new software package *Pix4Dmapper* with included the *rayCloud*, a new concept extending the stereo view triangulation and increasing the accuracy of 3D modelling results. This innovative processing solution combines ideas from computer vision with the accuracy of traditional photogrammetry workflows to achieve the highest accuracy possible when using UAV imagery. The package *Pix4D* with modules *Desktop* and *Cloud* were used for experimental investigations. *Desktop* module is commercial software with a lot of possibilities for orthophoto generation, surface modelling, etc. *Cloud* module is extension of *Desktop* – a digital photogrammetric workstation. This software package has fully automated workflow, is flexible, data input – scalable, output data – easy editable and on-site quality assessment is instant.

A certain amount of points (e.g. base of electricity poles, well's covers, building corners, etc.), clearly identified in the images, were selected, coordinated using GPS (*Trimble R6*) and were used as ground control points (GCP) for exterior image orientation. The ellipsoidal height of GPS points is determined with accuracy – up to ±30 mm. The average accuracy of ground control point positioning by the GPS (determining of planimetric coordinates) is about 15 mm. For getting the best results for exterior image orientation, and because images from UAV are significantly tilted, as many ground control points (measured by geodetic technique) as possible are required. On the test

**Fig. 2.** Location of images selected for photogrammetric processing.

area 12 control points were measured by GPS. The distribution of GCPs is shown in Fig. 3.

The first step of image processing – camera calibration for determining the parameters of the interior orientation. These are: focal length, frame size, pixel size, coordinates of principal point ($x$ and $y$) and values of distortions. Software *Pix4D* calculate initial and optimized values of interior orientation parameters: focal length initial – 5.465 mm, optimized – 5.419 mm; principal point coordinates – $x = 3.758$, 3.746 mm; $y = 2.842$, 2.822 mm, radial distortion – −0.041, −0.045 mm.

For our investigations orthophotos generation was carried out in two ways:

- Solely using coordinates of projection centers (PCC) as control points which are determined by the UAV's GPS during the time of each camera exposition.
- Using 10 and 5 ground control points, whose coordinates were determined by GPS on the field.

Such selection was made in order to determine how appropriate number of ground control points used for UAV images transformation influences the mapping results when building orthophoto maps. The demand of such investigations arises because the flight paths have general form (see Fig. 1), in contrast to classical paths which are pricewise straight lines, as well as the flight significantly depends on weather conditions (especially on wind) and the UAV platform shows considerable tilt, mainly because of its light weight.

Generated orthophoto covers about 70,000 $m^2$ of the test area. Fig. 4 shows the orthophotos, overlaid onto vector map. A first analysis of the two results can be performed visually by comparing the orthophoto with the vector data of a map. As visually seen (Fig. 4a) features, e.g. roads, in orthophotos are significantly distorted – up to 3 m, when images rectification was performed only with the GPS coordinates of the projection canters, but without GCPs. The features discrepancies are negligible when using five or ten GCPs.

## 4. DSM evaluation

Digital surface (situation) model (DSM) contains height values at the top of objects on the terrain and needs for generation of orthophoto images. Such model should be evaluated getting qualitative mapping product from images. The DSM can be improved when use certain number of GCPs, their coordinates determined by geodetic measurements. Fig. 5 shows visual representation of generated surface models: significantly distorted, when only use projection centers coordinates; and real surface situation, when use particular number of GCPs. Analyzing color surface representation, it is clearly seen differences of generated models.

The quality of generated data set (applying 10 GCPs) was investigated evaluating absolute accuracy that expresses the position error of a reference GCPs. The accuracy of check points, not involved in image transformation, not exceeds the half of image pixel size. Images resolution is 180 × 180 dpi; image pixel size (from dpi) is 0.141 mm. The scale of images is approx. 1:700.

The rule of thumb for UAV photogrammetry datasets accuracy is in order of twice of GSD in $x$ and $y$ direction and three times GSD in the altitude. Otherwise, the producers (as *Trimble* Corporation) declares such UAV data accuracy limitations:

- Average and max errors in $x$ and $y$ directions are one and 1.6 times GSD, respectively;
- Average and max errors in $z$ direction are 1.6 and 2.5 times GSD, respectively.

**Fig. 3.** Distribution of ground control points (marked by red triangles) on the test area. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Therefore, data sets from UAV Photogrammetry at experimental area (when GSD = 10 cm), the accuracy limitations would be applicable: average and max errors in $x$ and $y$ directions – 10.0 cm and 16 cm; average and max errors in $z$ direction – 16 cm and 25 cm.

We now investigate the exterior accuracy by comparing the created DSM's surface data with data from geodetic measurements.

The accuracy of the image height points was investigated comparing UAV image data with geodetic control. Root Mean Square (*RMS*) error and Standard deviation StD ($\sigma z$) has been calculated using formulae (4) and (5), thus reducing influence of systematic errors influence [24].

$$\sigma_z = \sqrt{\frac{1}{n}\left(\sum \Delta^2 Z - n\bar{\Delta}^2 Z\right)}, \tag{4}$$

$$(RMS)^2 = \sigma_z^2 + \bar{\Delta}^2 Z, \tag{5}$$

where $\Delta Z = Z_{img} - Z_{geod}$, $\bar{\Delta}Z$ – mean of deviations, $n$ – number of check points.

Dataset for accuracy investigation involves of 55 check points (well seen on the images) and coordinates of these points were measured on the test area using GPS.

Determined *RMSE* for the height points are: 2.255 m, when not using GCPs; 0.072 m with five GCPs, and 0.057 m with ten GCPs. Results of UAV image point's height accuracy assessment calculating StD ($\sigma_z$) using generated DSM is presented in Fig. 6. Standard deviations value was determined, respectively: 2.508 m, 0.086 m and 0.071 m. Thus the inclusion of additional five control points does not too much reduce the absolute precision, there the bias are eliminated.

For point heights the deviations comparing with geodetic control measurements have been defined: min. – −0.06 m, max. – 0.14 m and mean – 0.11 m, when used ten GCPs. A systemic error was found. These errors are reduced by calibration of the GPS and the camera.

The overlap of images is important for getting high-quality mapping product. When number of overlapped images is only two or three it could lead to poor quality of generated product. Best results can be obtained when over 5 images are overlapped. Fig. 7 (color[1] diagram) shows number of overlapping images generating orthophoto mosaic in the test area. Approximately 80% of area images are overlapped of 4–5 images, that is acceptably.

Digital elevation model (DEM) contains height values situated on real terrain (earth) and such model can be used to derive contour lines. DEM quality control is needed for getting qualitative mapping products from images and involves interior and exterior accuracy evaluation. Interior accuracy can be defined by stereo measurements. Exterior accuracy – comparison created DEM's terrain point elevation with data from geodetic or GPS measurements.

The DEM can be improved when the measured height errors ($dh$) are determined and used as corrections [17]. The DEM improvement is based on defined errors between two orthophotos.

The errors of height are calculated using the following formula:

$$dh = dx\frac{h}{b}, \tag{6}$$

where $d_x$ – parallax between two images; $h$ – point height in DEM, $h = Z_{01} - Z_{DEM}$; $Z_{01}$ – elevation of left image projection center; $Z_{DEM}$ – elevation of DEM point.

The generated DEM and orthophotos using software *LISA*, one dataset with GCPs, from UAV images have been checked for DEM improvement. 3D point's coordinates of selected 26 points onto orthophotos were exported from automatically generated DEM. The maximal height error $dh$ is 0.25 m, calculated using formulae (6). Generated

[1] For interpretation of color in Fig. 7, the reader is referred to the web version of this article.


**Fig. 4.** Generated orthophoto with vector data overlaid (red dot shows fragment of situation for comparative analysis): (a) images rectification using PCC, (b) applying 10 GCPs. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

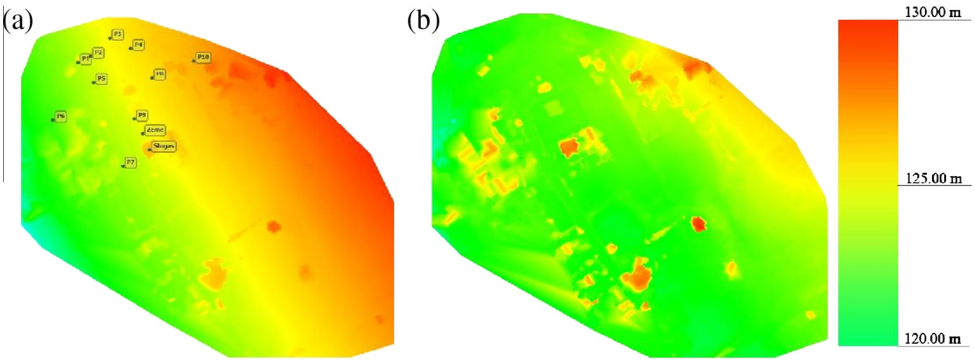


**Fig. 5.** Generated surface models searching quality dependence on georeferencing: (a) non GCPs, (b) used 10 GCPs.

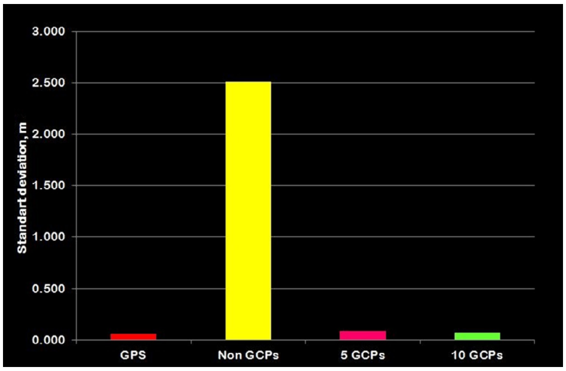


**Fig. 6.** DSM height points accuracy assessment determining StD.

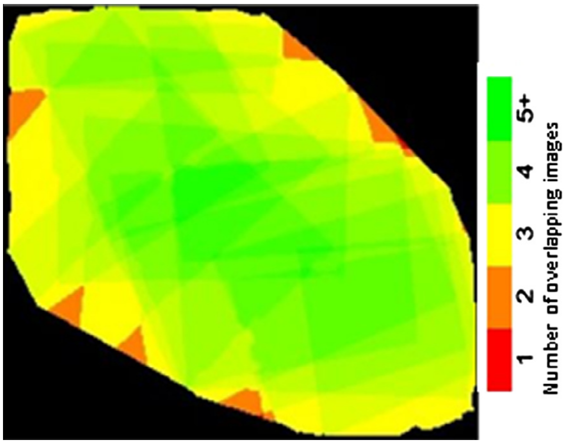


**Fig. 7.** Images overlapping on test area.

terrain model can be corrected regarding determined height errors.

## 5. Conclusions

UAV Photogrammetry is the new valuable tool and provides low cost, small area, prompt data collection applicable for immediate image processing. The autopilot system guarantees a correct flight path, and auto-controlled camera trigger. The interest in UAV system's great potential for digital photogrammetry application is rising rapidly.

The UAV flight strips over experimental area were generated as not straight patches as requires traditional aerial photogrammetry, fly had dependence on wind and vehicle was under the considerable tilt, geodetic coordinates of each image projection center was available with not high accuracy, i.e. of about 2 m. Because of such factors, upraises the demand for checking correctness of photogrammetric production elaborated from UAV images.

The software *Pix4D*, used for experimental images processing, calculate initial and optimized values of interior image orientation parameters, here results shows significant values of radial distortion – up to 45 μm.

The analysis of two mapping products (vector data onto orthophoto) shows significant distortions (even up to 3 m), in case when UAV images rectification was performed only with PCCs (not using GCPs). Decreasing the number of GCPs from ten to well distributed five points, the features discrepancies are negligible.

DSM accuracy investigation in consideration with geodetic measurements of check points shows, that when used only PCPs, estimators of accuracy (*RMSE* and *StD*) for the height points reach value up to 2 m. This confirms that received data is suitable for small-scale mapping.

For the DSM, when images were processed with ten and five ground control points, the average *RMSE* and *StD* values are respectively: 0.064 m and 0.078 m. Therefore, processing the UAV images, gained with high-resolution digital camera, when flying height is about 150 m and images are overlapped by more than 4 images, the DSM accuracy is of required accuracy level (not exceed limitation of 25 cm) when for image transformation use optimal number of GCPs – up to five. This proves a high accuracy of point's height measurement applying UAV Photogrammetry method, actually when configuration of flights strips are not traditional.

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