IMPACT OF GROUND CONTROL POINTS (GCPS) DISTRIBUTION AND UNMANNED AERIAL VEHICLE (UAV) FLIGHT PARAMETERS ON ACCURACY OF DIGITAL SURFACE MODEL (DSM)

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Abstract

Low-altitude UAV photogrammetry is a rapid and inexpensive method of acquiring spatial information. For this reason, its popularity has been growing steadily for several years, also on the surveying market. The use of new measurement techniques should be preceded by an analysis of factors affecting the accuracy and the quality of the products created. Nevertheless, there are no guidelines defining methods of data collection by means of the UAV allowing for generation of high quality surveying products. This article aims to study the accuracy of Digital Surface Model (DSM) and ortophotomaps obtained using the UAV, depending on configuration of photogrammetric control network and overlap of photos. For this purpose five UAV flights were conducted differing in forward and side overlaps of photos. Four different configurations of photogrammetric control network were also used. In total, 20 data sets have been developed. Theirs accuracy was verified using 68 check points and reference Digital Terrain Model (DTM).

Key words: UAV, DSM, accuracy, photogrammetric control, overlap of photographs

Introduction

Introducing a new technology to a market allows to reduce working time and necessary workload. It also minimizes costs. Low-altitude UAV photogrammetry is not an exception. Thanks to launching the UAVs equipped with non-metrical digital cameras on the surveying market, new opportunities opened up for users. The UAVs, commonly known as "drones", cannot only replace classic aircraft with photogrammetric cameras but even overtake them on many levels. The UAV flights are much shorter than those of manned aircraft. Nevertheless, the UAVs allow to take pictures from smaller shooting distances and provide access to even most unavailable (or even dangerous for operator) terrains (ĆWIĄKAŁA et al., 2018; DEWEZ et al., 2016; HSIEH at al., 2016; NEDJATI et al. 2016; NEUGIRG et al., 2015). This is due to their smaller size and greater manoeuvrability. The UAV flights are much cheaper. They are much better suited to studies on relatively small areas (HACKNEY, CLAYTON, 2015).

Modern software and computing capabilities of today's computers allowed to reduce the time of UAV-based data processing. With little effort wide range of photogrammetric products can be obtained, for example: DTM, DSM, ortophotomaps (BENASSI et al., 2017; JAUD et al., 2016). This is due to the Structure from Motion (SfM) technology. The application of the SfM to generate digital 3D models from a series of overlapping 2D images has strongly increased. And it is because it is the fast, inexpensive and highly automated method.

The airspace legislation is a factor that makes using the UAVs more difficult (PUNIACH et al., 2016; STÖCKER et al., 2017). In Poland, there is also the problem of adapting the existing regulations on aerial and satellite imagery databases, orthophotomaps and DTM to the current development of technologies and creation of the aforementioned products based on data from the UAVs.

Despite many advantages of unmanned systems there is a question about the accuracy of the UAV-based photogrammetric products. The key element is ground sampling distance (GSD), which depends mainly on the UAV flight level and the camera sensors and lenses used to take measurements. Another factor which affects the accuracy of the products generated on the basis of UAV data is topography of the area which is the subject of the research. The method used to georeference the products is also an important issue. In this case, it is very important to design the optimal configuration of photogrammetric control network. Additionally, attention should be paid to selecting the appropriate forward and side overlaps of photos. These are aspects that are currently the subject of many studies. The impact of the distribution and number of ground control points (GCPs) on the accuracy of the UAV-based products is investigated (FORLANI et al., 2018; PRAJWAL et al., 2016; TAHAR, 2013). The optimal overlap of the photos obtained from the UAV is also analyzed (DANDOIS et al., 2015; MESAS-CARRASCOSA et al., 2015; TORRES-SÁNCHEZ et al., 2018). However, no research has been carried out to analyze these two factors simultaneously, which is the purpose of this article. It is important to mention, that the analysis were based on the reference DTM and the large set of check points.

Material and methods

The study area was not varied terrain. The object, with the area of about 4 ha, was used for agricultural purposes. It is located in Jerzmanowice (Poland), nearby the Ojców National Park. Five UAV photogrammetric missions over the studied area were assumed to be carried out. They differed from each other in terms of the forward and side overlaps of photos (Table 1). The image overlap parameters applied are the most commonly used during studies carried out by means of the UAVs (DANDOIS et al., 2015). It is worth mentioning that the UAV maintained a constant flight altitude relative to the underlying terrain (during all flights). Thereby the GSD was constant for each data set. The photogrammetric mission projects were carried out in the DJI Ground Station software. The DJI S900 hexakopter was used for measurements. The device was equipped with non-metrical digital camera Sony Alfa 6000, which position was stabilized with gimbal.

Table 1. UAV flight parameters.

Flight parameters	**Value**				
Flight No:	1	2	3	4	5
Flight height:			90 m		
GSD:			2 cm		
Forward overlap:	80%	75%	70%	65%	60%
Side overlap:	60%	55%	50%	45%	40%
Number of photos	270	261	181	157	115

Resource: Own study.

Before the UAV flights were performed, 100 ground targets were evenly distributed (in 25 m distance) over the research area. Their coordinates were determined by the RTN GNSS method with the Leica GPS1200 receiver in reference to the ASG-EUPOS reference stations. The coordinates were assumed to be accurate to 0,03 m (horizontally) and to 0,05 m (vertically). The four configurations of 10 points were selected from among all measured points. They were four different variants of GCPs distributions (Fig. 1). The remaining points were used as check points (68 points which did not serve as the GCP in any of the configurations of the photogrammetric control network).

984 images were obtained as a result of the measurements. They were subject to further development in the Agisoft Photoscan software. In total, 20 data sets have been developed (five UAV flights, each developed for four configurations of the GCPs). The first stage of data processing was initial alignment of the photos. For this purpose, the coordinate of images' projection centers recorded by the GNSS receiver working in autonomous mode mounted on the UAV board were used. The final alignment of the photos was conducted after uploading the coordinates of the GCPs and their indicating on all photos. At the same time, the camera calibration parameters were determined. The dense point clouds were then generated. On their basis the DSMs were created. Due to the lack of surface elements such as buildings and high vegetation it can be assumed that the resulting DSMs are simultaneously the DTMs. The final step of photos processing in the Agisoft PhotoScan software was mosaicking, which resulted in the orthophotomaps with 1,8 cm pixel resolution.

The last stage of work in the Agisoft Photoscan software was to indicate all check points (Fig. 2) and read their spatial coordinates from the generated photogrammetric products.

During field work, an independent measurement of relief was also performed. It was done by mean of the RTN GNSS and tachymetric methods. The DTM has been created in the MeshLab software using the coordinates of 1200 surveyed points (Fig. 3). It was the reference DTM used in further analysis.

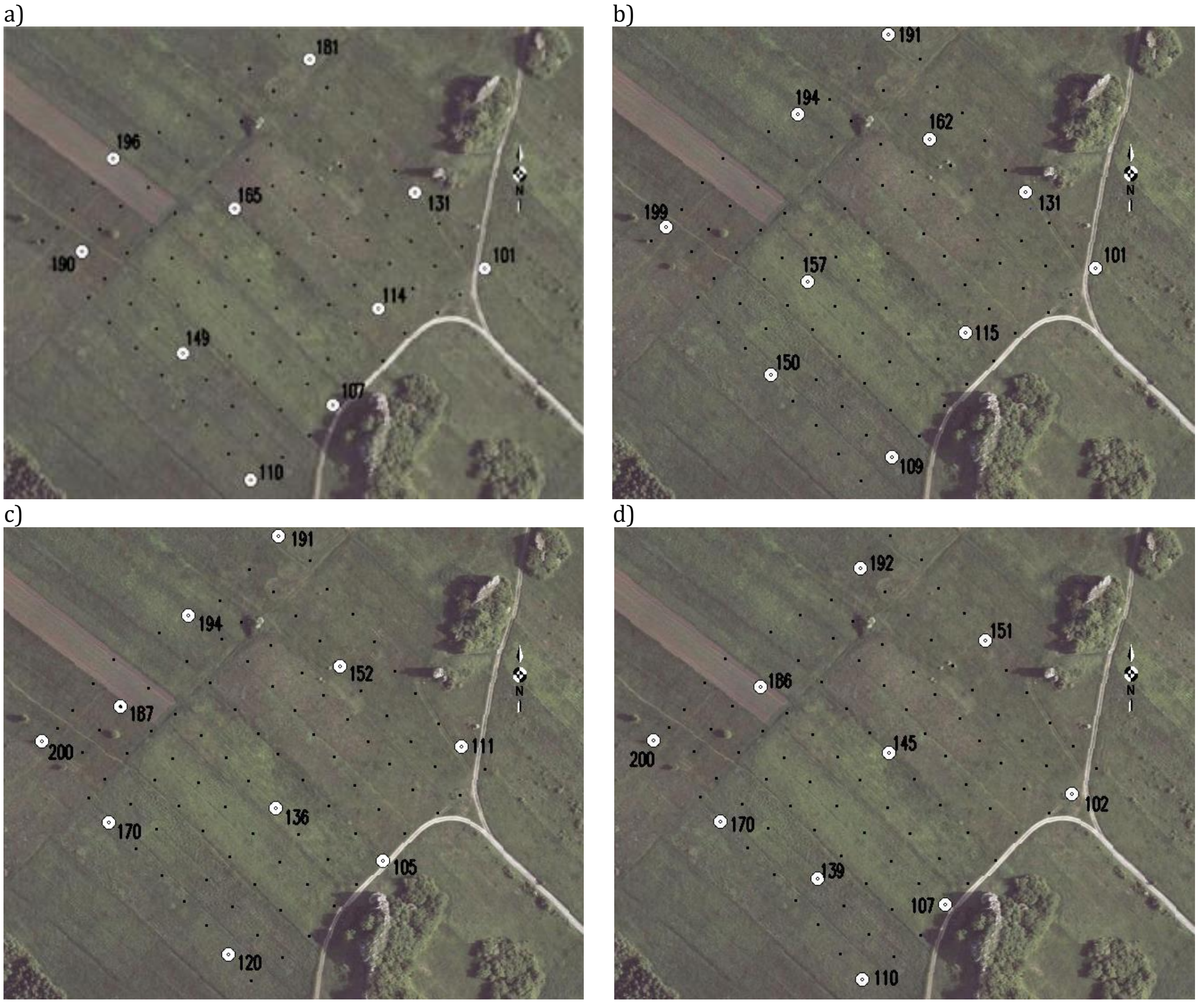


Fig. 1. GCPs distribution: a) configuration I; b) configuration II; c) configuration III; d) configuration IV.
Source: Own study.

Results and discussion

The assessment of the accuracy of the DSM and the orthophotomaps was started with the analysis of the GCPs errors obtained in the aerotriangulation process. The analysis were carried out for each data set (5 flights, 4 GCPs distributions). The root mean square errors (RMSEs) received are summarized in Table 2. The RMSE of the horizontal point position did not exceed 0,071 m and the RMSE of the point height did not exceed 0,152 m. However, these parameters cannot be identified with the accuracy of the generated photogrammetric products.

According to the Polish law, verification of the quality of the aerotriangulation process is carried out using independent check points (REGULATION, 2011). Their coordinates should be measured on models created on the basis of aerotriangulation results and in the field. In this study, 68 check points were used, the coordinates of which were obtained in the Agisoft Photoscan software and compared with the coordinates determined by the GNSS RTN method. Based on those differences, the RMSEs of the check points for every data set were determined (Table 3). The results are also illustrated in a form of graph showing relation between the errors and the overlaps of the photos for each of four configuration of photogrammetric control network (Fig. 4).

The RMSE of the horizontal check point position is ranging between 0,017 m and 0,062 m. On the other hand, the RMSE of check point height reaches values ranging from 0,023 m to 0,086 m. These values meet the accuracy requirements formulated in the Polish law (REGULATION, 2011). According to them, in case of digital photos with no more than 0,100 m pixel resolution, the differences in coordinates between the photogrammetric and the field measurements at each of the check point cannot exceed 0,15 m for the X and Y coordinates and 0,21 m for the Z coordinate. All check points met this condition, which proved the creation of the correct photogrammetric products in terms of the accuracy. It should be noted here that the Polish regulations concerning the creation of orthophotomaps and DTM came into force before the era of widespread application of the UAVs in surveying. Therefore, they are not adapted to the UAV-based photogrammetric products.

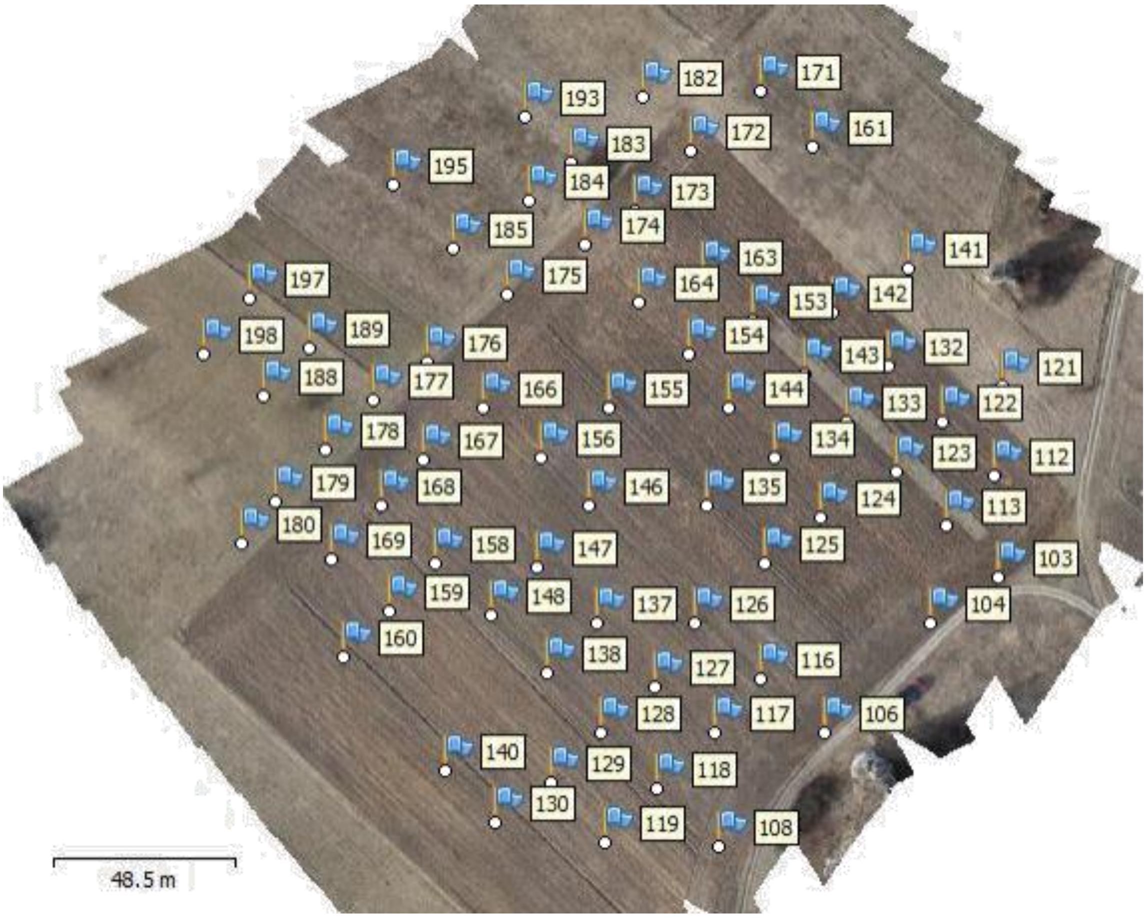


Fig. 2. Distribution of GCPs and check points.
Source: Own study.

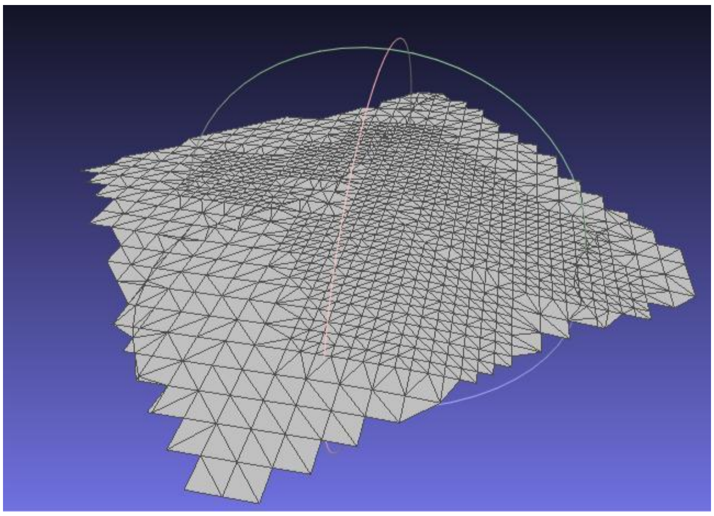


Fig. 3. Reference DTM created in MeshLab.
Source: Own study.

Table 2. RMSE of control points.

Data set No	Flight No	GCPs distribution	RMSE [m]				
			m_X	m_Y	m_Z	m_{XY}	m_{XYZ}
N1_I	1	I	0,053	0,046	0,046	0,070	0,084
N2_I	2	I	0,048	0,053	0,049	0,071	0,087
N3_I	3	I	0,037	0,024	0,017	0,044	0,047
N4_I	4	I	0,043	0,036	0,152	0,056	0,162
N5_I	5	I	0,019	0,021	0,091	0,028	0,095
N1_II	1	II	0,051	0,042	0,089	0,066	0,111
N2_II	2	II	0,045	0,053	0,033	0,069	0,077
N3_II	3	II	0,032	0,025	0,059	0,041	0,072
N4_II	4	II	0,029	0,018	0,074	0,034	0,081
N5_II	5	II	0,018	0,014	0,055	0,023	0,060
N1_III	1	III	0,051	0,046	0,073	0,069	0,100
N2_III	2	III	0,018	0,021	0,041	0,027	0,049
N3_III	3	III	0,025	0,027	0,026	0,037	0,045
N4_III	4	III	0,023	0,017	0,061	0,029	0,067
N5_III	5	III	0,029	0,042	0,049	0,051	0,071
N1_IV	1	IV	0,051	0,046	0,077	0,068	0,103
N2_IV	2	IV	0,011	0,011	0,035	0,016	0,038
N3_IV	3	IV	0,033	0,025	0,071	0,042	0,083
N4_IV	4	IV	0,024	0,016	0,085	0,029	0,090
N5_IV	5	IV	0,018	0,014	0,067	0,023	0,071

Resource: Own study.

Table 3. RMSE of check points.

Data set No	Flight No	GCPs distribution	RMSE [m]				
			m_X	m_Y	m_Z	m_{XY}	m_{XYZ}
N1_I	1	I	0,049	0,037	0,051	0,062	0,051
N2_I	2	I	0,053	0,032	0,057	0,061	0,057
N3_I	3	I	0,035	0,027	0,037	0,044	0,037
N4_I	4	I	0,032	0,029	0,059	0,043	0,059
N5_I	5	I	0,017	0,023	0,037	0,029	0,037
N1_II	1	II	0,036	0,036	0,086	0,051	0,086
N2_II	2	II	0,036	0,032	0,062	0,048	0,062
N3_II	3	II	0,028	0,028	0,035	0,040	0,035
N4_II	4	II	0,019	0,014	0,058	0,024	0,058
N5_II	5	II	0,012	0,017	0,058	0,021	0,058
N1_III	1	III	0,040	0,043	0,076	0,059	0,076
N2_III	2	III	0,012	0,020	0,040	0,024	0,040
N3_III	3	III	0,018	0,021	0,031	0,028	0,031
N4_III	4	III	0,014	0,020	0,063	0,025	0,063
N5_III	5	III	0,019	0,029	0,059	0,035	0,059
N1_IV	1	IV	0,043	0,036	0,052	0,056	0,052
N2_IV	2	IV	0,011	0,014	0,023	0,018	0,023
N3_IV	3	IV	0,028	0,019	0,029	0,034	0,029
N4_IV	4	IV	0,016	0,009	0,029	0,018	0,029
N5_IV	5	IV	0,012	0,012	0,031	0,017	0,031

Resource: Own study.

First of all, the impact of the UAV flight parameters (overlaps of photos) on the accuracy of the generated photogrammetry products was examined. For this purpose, the relation between the RMSE of the horizontal and vertical point position and the overlap of the photos taken during each flight with the same photogrammetric control network configuration has been investigated (Fig. 4). In all cases, it was noticed that the errors of the X and Y coordinates decrease with increasing forward and side overlaps of the images. A similar trend was not found considering the errors of the height coordinate.

Next, it was checked whether the configuration of the photogrammetric control network affects the RMSE of the horizontal and vertical check points positions (Fig. 5). This comparison did not allow to identify any notable relation between the GCPs distribution and the errors obtained– the errors of the photogrammetric products are similar to each other regardless of the configuration of the photogrammetric control network (for the same forward and side overlaps of the photos).

a) b)

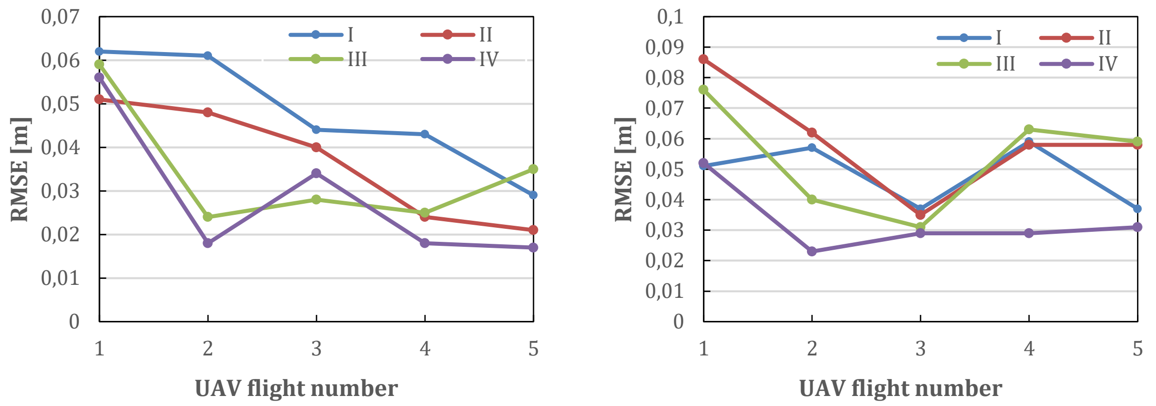


Fig. 4. RMSE of check points depending on flight parameters (overlaps of photos)
for four GCPs distributions (I-IV): a) errors of horizontal point position; b) errors of vertical point position.
Source: Own study.

a) b)

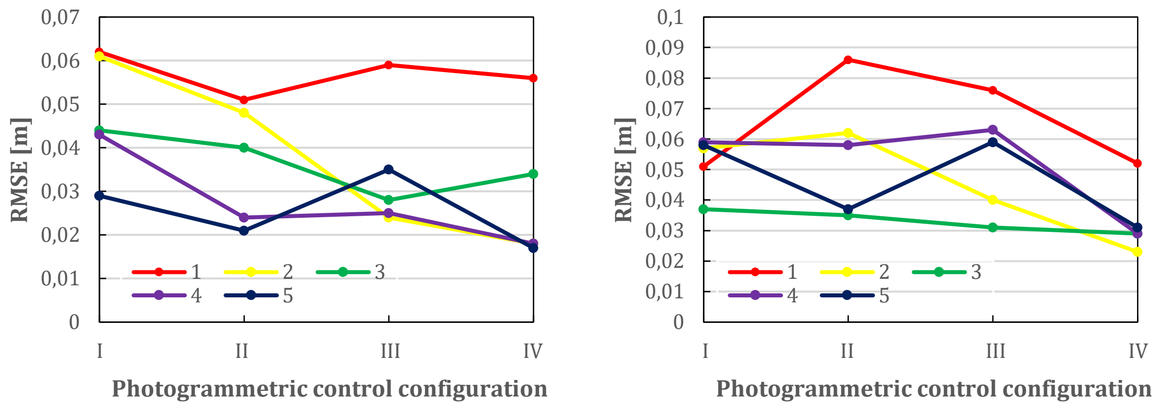


Fig. 5. RMSE of check points depending on GCPs distribution for five UAV flights:
a) errors of horizontal point position; b) errors of vertical point position.
Source: Own study.

The comparison of dense point clouds generated on the basis of all 20 sets of data with the reference model (Fig. 3) was the next stage of analysis. The comparisons were made in the CloudCompare software. The analysis, however, did not allow to determine the impact of the GCPs distribution and the overlaps of photos on the height accuracy of the UAV-based photogrammetric products. It was noticed that the land cover had a much greater impact on the obtained results – the biggest differences between the reference model and the dense point clouds were observed in the area covered by low vegetation (Fig. 6). The problem of low-altitude UAV photogrammetry as data-source methods for terrain covered in low vegetation is currently being studied (GRUSZCZYŃSKI et al., 2017).

The last stage of the analysis was to perform maps of the distribution of coordinates deviations at the check points. By overlapping studies made with the same overlaps of the images and the changing configuration of the photogrammetric control network it was found that both the magnitude and the direction of the deviations are constant regardless of the GCPs distributions (Fig. 7a). However, deviations obtained with one control network configuration and changing image overlaps change their direction and value (Fig. 7b).

Conclusions

The main objective of this work was to analyze the impact of the UAV flight parameters (photo overlap) and the configuration of the photogrammetric control network on the accuracy of the photogrammetric products. The analysis of the accuracy showed that regardless of the change in the studied factors, all the products (DSM, orthophotomap) met the accuracy criteria specified in Polish regulations.

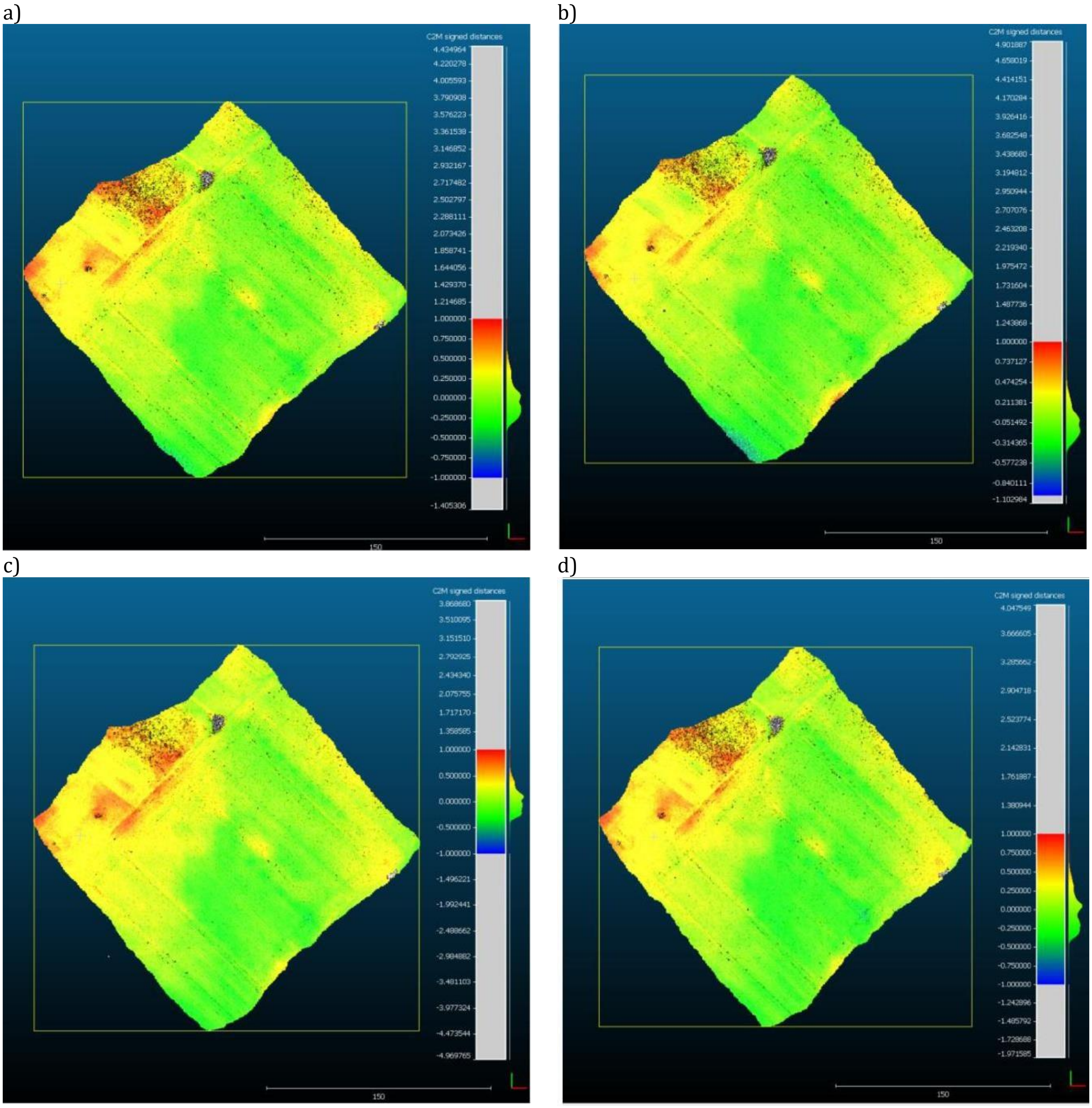
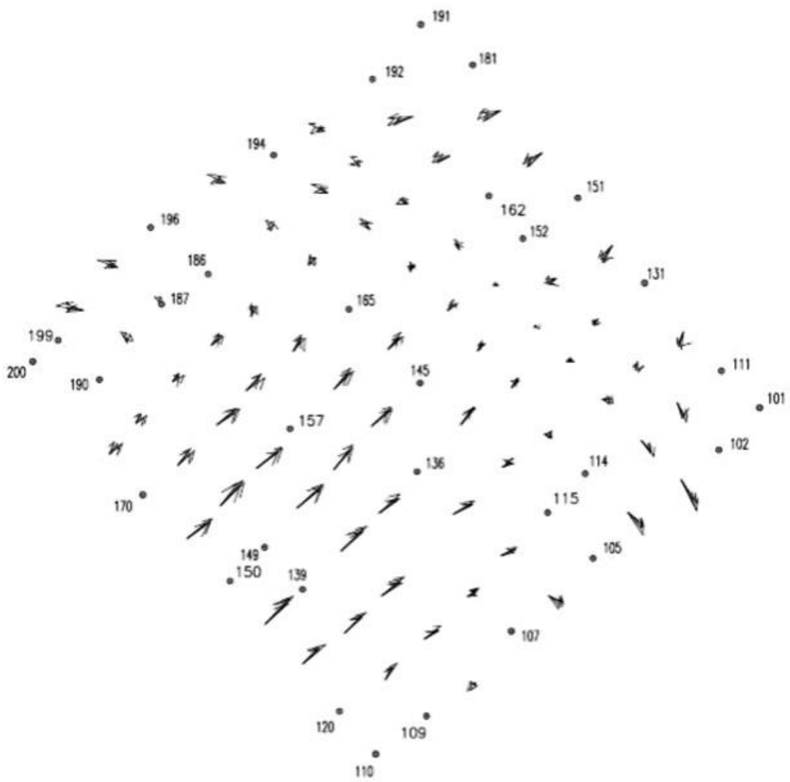


Fig. 6. Comparison of dense point clouds with reference model for data sets:
a) N1_I, b) N1_II, c) N1_III, d) N1_IV.
Source: Own study.

As a result of the analysis it was found that the height errors of photogrammetric products obtained for various data sets (variable overlap of images and variable configuration of the photogrammetric control network) are similar to each other. It has not been noticed that in the analyzed area their distribution depended on the above-mentioned factors. The importance of vegetation cover is much greater. The product generated from the UAV images is DSM and not DTM.

a)



b)

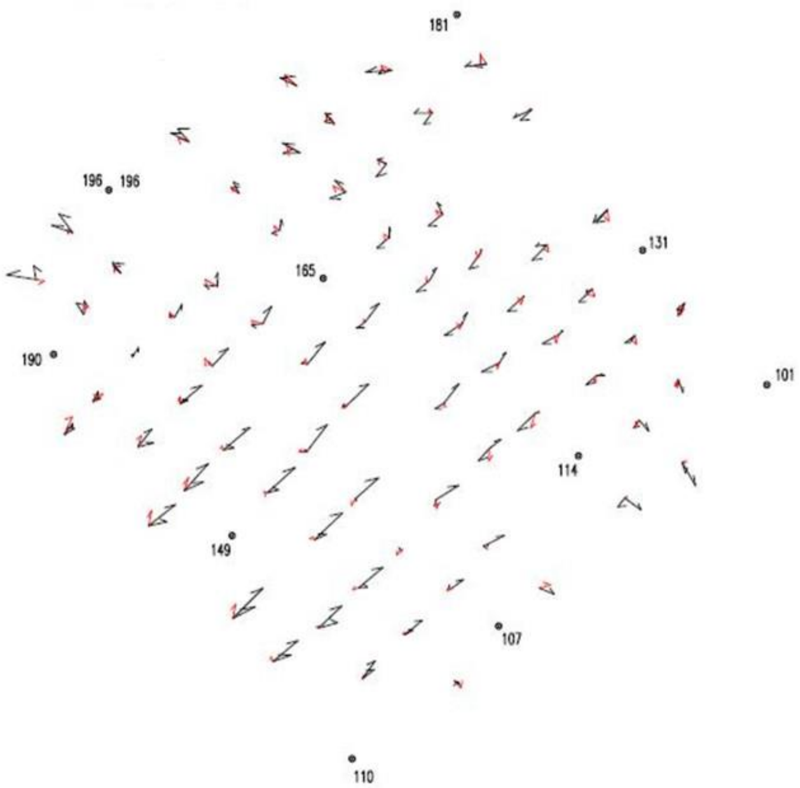


Fig. 7. Map of deviations distribution at check points:
a) with changing GCPs distribution (for data sets: N1_I, N1_II, N1_III and N1_IV);
b) with changing overlap of the photos (for datasets: N1_I, N3_I and N5_I).
Source: Own study.

There was no clear correlation between the accuracy of the products and the configuration of the photogrammetric control network. Both the direction of the deviations and their size were similar regardless of the GCPs distribution (with identical forward lap and side lap of the photos). It is important to mention, that each of analyzed GCPs distribution was designed in a manner consistent with the principles of establishing a photogrammetric control network – the points were evenly distributed throughout the study area.

The correlation between the overlap of images and the UAV-based photogrammetric products accuracy has been noticed. With identical configurations of control network, the errors obtained decreased with the reduction of the overlaps. What is more, changes in the directions and size of deviations at the check points were observed when the overlaps of the photos were modified. It should be noted, however, that each UAV flight was designed in accordance with the practice of the scientific community. No extreme cases with very low overlaps were applied in the studies.

In summary, the low-altitude UAV photogrammetry allows to achieve high accuracies that meets the requirements of the law. However, it should be remembered that a large influence on the height errors has the land cover. The key factor determining the horizontal accuracy of the studies is the overlaps of images. The overlaps from 60%/40% to 80%/60% (forward overlap/side overlap) used in the studies gave a similar result with a noticeable tendency of accuracy decrease with the increasing overlaps of photos (with the correct configuration of the photogrammetric control network).

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