Low aerial imagery – an assessment of georeferencing errors and the potential for use in environmental inventory

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Abstract: Unmanned aerial vehicles are increasingly being used in close range photogrammetry. Real-time observation of the Earth's surface and the photogrammetric images obtained are used as material for surveying and environmental inventory. The following study was conducted on a small area (approximately 1 ha). In such cases, the classical method of topographic mapping is not accurate enough. The geodetic method of topographic surveying, on the other hand, is an overly precise measurement technique for the purpose of inventorying the natural environment components. The author of the following study has proposed using the unmanned aerial vehicle technology and tying in the obtained images to the control point network established with the aid of GNSS technology. Georeferencing the acquired images and using them to create a photogrammetric model of the studied area enabled the researcher to perform calculations, which yielded a total root mean square error below 9 cm. The performed comparison of the real lengths of the vectors connecting the control points and their lengths calculated on the basis of the photogrammetric model made it possible to fully confirm the RMSE calculated and prove the usefulness of the UAV technology in observing terrain components for the purpose of environmental inventory. Such environmental components include, among others, elements of road infrastructure, green areas, but also changes in the location of moving pedestrians and vehicles, as well as other changes in the natural environment that are not registered on classical base maps or topographic maps.

1. Introduction

In the classical photogrammetry known till date, images that are subsequently used to design topographic maps, orthophotomaps, and other photogrammetric products, are obtained with the help of traditional manned airplanes and specially designed large format cameras. It is worth mentioning that photogrammetric equipment of this kind can collect images on a very large area; however, this involves a high financial outlay

(Ahmad, 2011). We are now witnessing a great demand for small area mapping, yet the application of the classical forms of image acquisition makes the process very costly and therefore unfeasible (Ahmad and Samad, 2010). Photogrammetric products obtained using unmanned aerial vehicles are a great alternative to satellite and aerial images (Zhang and Kovacs, 2012). These days, there is a great need for surveying small areas. In such cases, using a classical aerial or photogrammetric camera becomes uneconomical (Pérez et al., 2013). This means that UAVs are becoming an excellent alternative as a tool to obtain aerial imagery by way of close range photogrammetry (Sanecki at al., 2016). It must be emphasised, however, that using this technology requires further research and application work so that proper methodology can be developed, thus enabling greater automatisation of the process (Gallacher, 2015).

Topographic surveying aimed at inventorying the elements of the environment, associated with classical field mapping, involves work on the basis of topographic maps and databases on the scales 1:10,000 and 1:25,000; for larger areas, the 1:50,000 scale is also acceptable (Richling, 2007). The environment mapping process is usually performed using the BDOT database (Baza Danych Obiektów Topograficznych, Polish for "A Database of Topographic Objects") and – in order to localise the given element of the environment – a mobile device, i.e., a smartphone or a tablet, additionally equipped with a GPS module, capable of visualising an orthophotomap as a topographic base (Halik et al., 2015). Thanks to the use of such a surveying tool, it is possible to obtain planar accuracy up to 5 m on the scales of 1:10,000-1:50,000 (Medyńska-Gulij, 2015). In surveying, detail points that are subject to the process are divided into three groups, based on the required accuracy of the measurements. Elements of the natural environment make up mostly the second and third group of detail points, while clearly identifiable objects that maintain a fixed shape and location over a long time belong to the first group(Minister of Internal Affairs and Administration, 2011a).

The currently binding legal regulation governing the execution of topographic surveys is the Regulation of the Minister of Internal Affairs and Administration of 9 October 2011 on the technical standards of carrying out topographic surveys, processing the results of those surveys, and registering them in the National Geodetic and Cartographic Resource (Minister of Internal Affairs and Administration, 2011a). In accordance with Article 15 of the said regulation, it is permissible to carry out topographic surveys using other methods, technologies, and techniques of surveying than the ones described in the regulation, but only on condition that the person conducting them provides a technical report including their detailed description and a mathematical analysis of the accuracy of the data obtained. While using an unmanned aerial vehicle with data recording equipment for surveying purposes, one must abide by the relevant rules applying to photogrammetric measurements, which are outlined in the said regulation.

This article is an attempt at assessing the usefulness of the unmanned aerial vehicle (UAV) technology as a tool for surveying small areas for the purposes of environmental inventory. Field inventory can be more widely defined as classical

mapping making use of the GPS-GIS technologies (Halik et al., 2015) as well as mobile technologies (Halik and Medyńska-Gulij, 2016). The main objective of the conducted study was to propose a method of constructing a ground control network with the help of UAV flights, with an accuracy of about 10 centimetres(which is suitable for an environmental inventory of an area covering about 1 ha), with reference to traditional surveying methods and recommendations laid out in the official regulations. It became necessary to design a photogrammetric model on the basis of UAV-acquired photographs and their georeference based on photogrammetric control established via the GNSS technology. The main objective of the study, though, was to assess the planar accuracy of the generated photogrammetric model by comparing the lengths of real vectors between ground control points and the corresponding vectors calculated on the basis of the model. The study was conducted for the purpose of environmental inventory of an area of approximately 1 ha. The planar accuracy considered satisfactory for the photogrammetric model would be an accuracy of below 30 cm. The researcher also took into consideration the Polish regulations concerning traditional geodetic surveys.

2. Methodology

The research was conducted in the following stages: preliminary preparation in the office, establishing control points, acquiring and georeferencing the aerial images, and a geodetic assessment of accuracy. In order to perform this assessment, the researcher analysed the results of planar accuracy of the photogrammetric products obtained on the basis of the ground control point network established. According to Kurczynski (2015), the changing position of the Sun, the momentary state of the atmosphere, and the varying topography of the terrain visible in the field of view of the recording device, translate into varying brightness, contrast, and colour distribution in the obtained image. Field work was done in April, by way of eight flights scheduled at approximately 20-minute intervals, at the following times: 6:13 PM, 6:34 PM, 6:56 PM, 7:14 PM, 7:34 PM, 7:47 PM, 8:11 PM, and 8:31 PM. Such a design of the flight schedule resulted in obtaining various degrees of sunlight on the studied area. The area that was chosen by the researcher was the area directly adjacent to the building of Collegium Geographicum.

In the project preparation stage, a key role was played by cartometric materials downloaded from a map portal, on the basis of which it was possible to define the flight zones for the unmanned platform (Kędzierski et al., 2014). On the basis of the map portal in question (www.geoportal.gov.pl), it was established that the area was approximately 1 ha in size and that there were no big differences in relative elevation. The studied area featured, among other things, elements of road infrastructure such as roads, sidewalks, roads for pedestrians and vehicles, parking lots, as well as buildings and street furniture. There were also environmental elements, which included: lawns, trees, and bushes. It is worth mentioning that the unmanned platform's ability to

transmit the video image in real time makes it an excellent tool for monitoring any anthropogenic changes that are not represented on base maps, cadastral maps, and topographic maps. Such elements include: the volume of pedestrian traffic and all other kinds of traffic, as well as any effects of human activity, i.e., environmental degradation in the form of illegal landfills or destroyed green areas. In view of the above, one might suppose that changes in land use on an area of approximately 1 ha might be observed on the basis of an orthophotomap obtained with the aid of an unmanned aerial vehicle (UAV).

2.1. Establishing ground control points

The level of surveying accuracy required by the law depends on the accuracy class that the measured object belongs to and the database that the survey results will be uploaded into. The databases that are of particular importance here are the ones listed in Article 4 of Acts 1a and 1b (Geodetic and Cartographic Law), concerning, among other things, the land and property register and the geodetic register of the utilities network, for which the accuracy of the measurements will be much higher than for the BDOT10k database described in Article 4 of Act 1a, Item 8 (Geodetic and Cartographic Law). It should also be noted that in accordance with Paragraph 10 of Act 1 (Minister of Internal Affairs and Administration, 2011b), the criterion for classifying the databases concerning the orthophotomap into one of the seven classes is the terrain pixel size, which may range from 0.05 to 5.00 m.

When using unmanned aerial vehicles (UAVs), the proper planning of the flight and the correct design of the ground control point network play an important role (Nex and Remondino, 2014; Stępień et al., 2016). When the platform is not equipped with an inertial navigation system (IMU), or when the satellite signal is inaccessible or insufficient for it to work properly, it is necessary to establish control points in order to carry out the georeferencing process in the preliminary stage of processing the obtained images in the office (Anai et al., 2012; Barazzetti et al., 2010; Eugster and Nebiker, 2008; Wang et al., 2008). A distinction should be made between two kinds of points: targeted points, whose targeting is done directly before the flight, and non-targeted points, which are a set of clearly recognisable detail points, so-called natural points (Kędzierski et al., 2014). The targeted points are usually used for large-scale imagery (scale 1≥2,000), while in the case of smaller scales, it is more common to use natural control points (Kurczyński, 2014). Images obtained with the use of UAV platforms are often taken obliquely; that is why it is advisable for the number of ground control points on the surveyed area to be big (Ruzgienė et al., 2015). For the purposes of this study, both targeted and non-targeted control points were established; 44 points in total (Fig. 3). The targeted control points were established in the field using wooden, 30-centimetre-long poles with a diameter of 6 cm (Fig. 1). The stakes were additionally marked with yellow fluorescent paint, in order to be clearly identifiable in the picture (Siebert and Teizer, 2014).

Fig. 1. A photogrammetric control point targeted with a pole

On the studied area, distinctive elements were also singled out to serve as detail points. These included rainwater drainage grates, places where the kerb visibly collapsed, outlines of fences, and street furniture. Those elements were treated in the study as non-targeted ground control points, and, together with the targeted control points, they accounted for the external orientation of the images obtained.

The ground control points established on the studied area were to be surveyed using geodetic techniques such as satellite observation (GNSS) or tacheometry (Siebert and Teizer, 2014). The method of measuring Ground Control Points that is considered the best is Real Time Kinematics (RTK), which contributes to minimising distortion (De Kock and Gallacher, 2016). In this study, the surveying of the established control points was done with the help of the GNSS technique and the Trimble R4 Model 3 receiver. It should be added that in accordance with the Regulation on technical standards of conducting topographic surveys, processing their results and uploading them into the National Geodetic and Cartographic Resource(Minister of Internal Affairs and Administration, 2011a), the establishment of ground control points is permissible using the RTN method; as for the RTK method, it is acceptable only when the tying in is done with reference to at least two reference stations and the network is adjusted using the method of least squares. Bearing in mind the main aim of the study as it was defined at the beginning, i.e., assessment of the usefulness of the unmanned aerial vehicle (UAV) technology for the purposes of environmental inventory, and being aware that there was no need for such a level of accuracy as required e.g. in geodetic support of construction projects, the researcher decided to omit the adjustment of the results via the method of least squares. Due to the technical parameters of the network of reference stations in Poland, i.e., ASG-EUPOS, the use of kinematic measurements (RTK) yields horizontal accuracy of 0.03 m, and vertical accuracy of 0.05 m (Ryczywolski et al., 2008).

For the purposes of this study, the above parameters were considered very good and sufficient, and the RTK method was used for surveying the control points. During the surveying campaign, the coordinates of each of the points were established on the basis of the average of 30 GNSS RTK measurements with a one-second interval; then, they were defined in the planar rectangular coordinate system "2000" (ETRS89/ Poland CS2000 zone 6; axis meridian 18º E). In the surveying process, the localisation and the attribute data of the established points are obtained (Medyńska-Gulij, 2015). All the coordinates obtained during the surveying were then imported into the C-GEO program, where they were listed in a tabular form (Tabele 1). Figure 2 shows spatial distribution of the established ground control point network.

Tabele 1. A list of the coordinates of ground control points and independent check points

Number	X	Y	H	Nr	X	Y	H
osn	5814916.14	6428028.01	85.701	23	5815026.74	6428041.42	85.210
2	5814922.26	6428023.89	85.607	24	5815020.40	6428045.47	85.106
3	5814925.13	6428014.95	85.615	25	5815017.54	6428054.37	85.025
4	5814922.49	6428008.06	85.677	27	5814980.53	6428053.99	84.740
5	5814964.13	6428114.80	85.114	osn2	5814918.21	6428116.72	86.075
6	5814966.50	6428107.37	85.138	osn3	5814907.70	6428088.70	86.463
7	5815025.70	6428045.66	85.146	osn4	5814931.03	6428099.09	86.270
8	5815026.38	6428043.74	85.153	osn5	5814932.46	6428083.66	86.341
9	5814946.87	6428042.62	85.463	osn6	5814953.01	6428093.46	86.152
10	5814947.80	6428042.91	85.429	osn7	5814962.70	6428048.74	85.359
11	5814968.85	6428099.88	85.174	osn8	5814916.11	6428054.25	86.435
12	5814973.15	6428086.30	85.255	osn9	5814885.03	6428042.37	86.664
13	5814975.59	6428078.64	85.179	osn10	5814908.07	6427991.69	85.933
14	5814978.06	6428071.01	85.078	osn11	5814923.77	6428003.67	85.740
15	5814980.33	6428058.66	84.861	osn12	5814978.12	6428021.05	85.258
16	5814982.13	6428059.24	84.868	osn13	5814971.82	6428050.62	85.152
17	5814984.99	6428057.57	84.844	osn14	5814914.66	6428032.19	85.720
18	5814986.90	6428058.11	84.841	osn15	5814933.76	6428045.62	86.060
19	5815018.97	6428065.55	84.959	osn16	5814948.16	6428049.65	86.068
20	5815023.91	6428062.00	85.046	osn17	5814944.04	6428064.20	86.083
21	5815024.46	6428059.98	84.911	osn18	5814929.69	6428059.92	86.049
22	5815028.06	6428037.22	85.279	osn45	5815020.36	6428061.34	84.978

Fig. 2. Spatial distribution of the established ground control point network

2.2. Acquiring and georeferencing the aerial images

Taking into consideration the area calculations previously made on the basis of the map portal (www.geoportal.gov.pl), it was decided that the most appropriate unmanned aircraft to collect the imagery would be a multirotor. The chosen quadcopter, DJI Phantom 2, is capable of an approximately twenty-minute flight and it is equipped with a GoPro Hero 4 Black Edition camera. The recording device with focal length of 3 mm takes photographs in the resolution of 12 megapixels. Taking into account that the study concerned the accuracy of georeferencing for the purpose of environmental inventory, the researcher deemed it unnecessary to conduct an initial calibration of the camera or distortion modeling on the basis of Brown's distortion model as used in the Agisoft Lens software. Hence, the calibration was based on metadata from the camera used in the study, saved in the EXIF file of every photograph, and on the established control points (on-the-job calibration).

The first stage of processing the obtained data was carried out in the Agisoft PhotoScan software, a tool for 3D visualisation, surveying, and mapping, which makes it possible to process images with the help of appropriate algorithms and digital photogrammetric techniques. The software in question is an excellent tool for processing the imagery obtained with the use of unmanned aerial vehicles (Siebert and Teizer, 2014). All the photographs selected in the course of data harmonisation,

obtained during eight flights carried out at approximately 20-minute intervals, were imported to the software. The acquired aerial images were a set of single photographs, which were then uploaded into chosen photogrammetric software to be converted into a photomosaic (De Kock and Gallacher 2016). The individual photographs differed slightly in terms of their altitude and their angle to the studied area. It should also be noted that the degree of overlap for the obtained images was 80%, with every image covering all of the studied area and all the ground control points established on it. The first stage of georeferencing the images was done on the basis of the EXIF file containing metadata about the photographs; this stage consisted in representing their relative internal orientation (Siebert and Teizer, 2014). It should be added that this process is not performed in any particular coordinate system specified by the user, but in an internal coordinate system of the software. Considering the geomatic application of the images, it is necessary to georeference them (Uysal et al., 2015). For that purpose, the researcher chose the planar coordinate system "2000", zone 6 (EPSG: 2177). This coordinate system is identical with the one in which the ground control points were previously defined.

Fig. 3. A targeted and a non-targeted point of photogrammetric ground control

For the georeferencing process, the researcher chose control points located in the furthest parts of the studied area. Increasing the distance between the tie-up points was meant to increase the accuracy of georeferencing the whole image. What proved to be a problem was that it was not possible to use the same points for georeferencing the different images. This was because the images varied in terms of the range of the photographed area. For this reason, the rectification process was conducted on the basis of ten control points so that for every image it would be possible to point out control points located in the furthest parts of the studied area (Fig. 5). The remaining control points that did not take part in the georeferencing were to be used later to verify the accuracy of the process (Gonçalves and Henriques, 2015).

Fig. 4. Ground control points used in the georeferencing process

As a result of the performed rectification of the obtained images on the basis of the assumed ground control network, the total value of RMSE (root mean square error) was calculated – a value that specifies the deviation of the original data of the tie-up points from the data calculated on the basis of the model (Kršák et al., 2016). For calculating the RMSE, the following formula was used:

$$\text{RMSE} = \pm \sqrt{\sum_{i=1}^{n} \frac{\left(X_{i,est} - X_{i,in}\right)^2 + \left(Y_{i,est} - Y_{i,in}\right)^2 + \left(Z_{i,est} - Z_{i,in}\right)^2}{n}}$$

where:
$X/Y/Z_{i,in}$– the actual value of a particular coordinate
$X/Y/Z_{i,est}$– the estimated value of the coordinate

Calculations were made for each of the points taking part in the georeferencing. The obtained results allow a conclusion that the worst of the points in terms of the georeferencing accuracy was point osn11, the best – point 6. The total error of georeferencing in the study was slightly above 8 cm, which corresponds to 0,55 of pixel size (Fig. 2).

Table 2. Calculations of error on the basis of the chosen ground control points

Label	X error (m)	Y error (m)	Z error (m)	Total (m)	Image (pix)
osn11	0.15	0.01	0.05	0.16	0.445
osn3	0.00	-0.03	0.00	0.03	0.567
5	0.04	0.06	-0.03	0.08	0.472
8	0.02	-0.05	0.06	0.08	0.444
osn2	-0.01	0.02	-0.01	0.02	0.466
3	-0.05	-0.06	-0.02	0.08	0.497
osn14	0.01	0.05	0.03	0.06	0.859
2	-0.06	-0.03	0.00	0.06	0.647
22	0.00	0.08	-0.07	0.11	0.516
6	0.00	0.01	0.01	0.02	0.465
Total	0.06	0.05	0.04	0.08	0.552

Additionally, in order to carry out further analyses of accuracy, the researcher exported from the PhotoScan software an orthomosaic built from all the images used, saved in the TIF format.

3. Geodetic assessment of accuracy

The RMSE result obtained in the georeferencing process had been calculated on the basis of the ground control points that had previously been measured and used to tie in the images (Uysal et al., 2015). For an additional check of the obtained photogrammetric model, the researcher decided to compare the actual distances between the ground control points with the ones calculated on the basis of the generated photogrammetric model (Smaczyński, 2015). In order to complete this step, the exported georeferenced orthomosaic was imported into the ArcMap 10.4.1 software and the distances were measured (Figure 6).
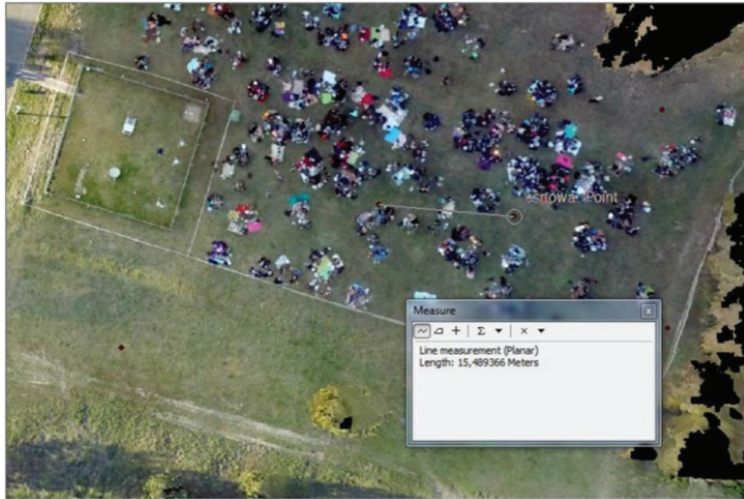
Fig. 5. Vector calculation in the ArcMap software

What the researcher treated as actual distances between particular ground control points was the data from the RTK GNSS survey, where the distances were measured in the C-GEO software (Figure 7).
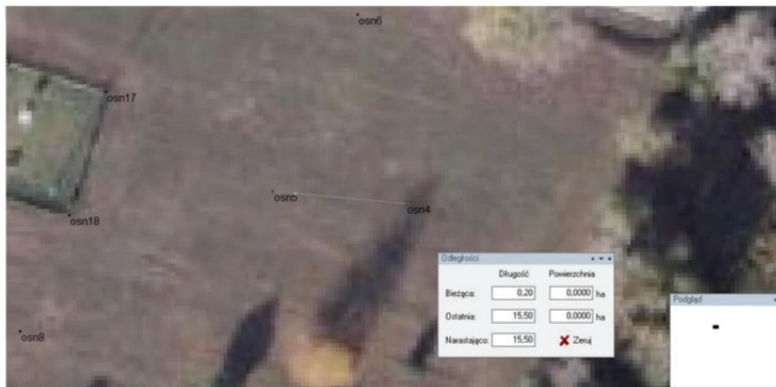

Fig. 6. Vector calculation in the C-GEO software

The obtained values of the measured distances – both from the output photogrammetric model of the georeference process and from the model treated as the actual one – were compared and presented in Figure 8. The values between the dashes constitute the actual distances between the established ground control points. The distances in the brackets are a product of the survey conducted on the cartometric model that was the output of the georeferencing process. The compared results are additionally presented in Table 3.
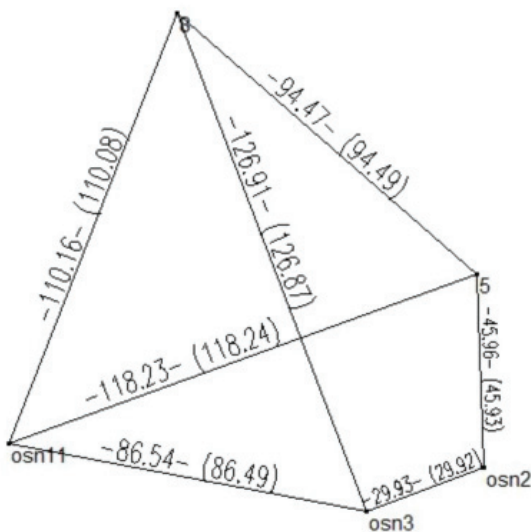
Fig. 7. Vectors based on ground control points

Table 3. The comparison of distances between the GCPs on the actual and the estimated
photogrammetric model

GCP	real model (m)	estimated model (m)	Δd (m)
osn11 − 8	110.16	110.08	0.08
8 − 5	94.47	94.49	0.02
5 − osn2	45.96	45.93	0.03
osn2 − osn3	29.93	29.92	0.01
osn3 − osn11	86.54	86.49	0.05
osn11 − 5	118.23	118.24	0.01

Besides, the researcher conducting the study decided to carry out an additional, independent check of the calculations performed. Such a procedure should be performed on fully independent check points (ICPs) that did not directly participate in the process of external orientation of the obtained images (Toutin and Chénier, 2004). Similarly as in the case of GCPs (ground control points), the procedure was performed both on the actual data model and the output photogrammetric model. The results were presented in Figure 8 and additionally compared in Table 4.
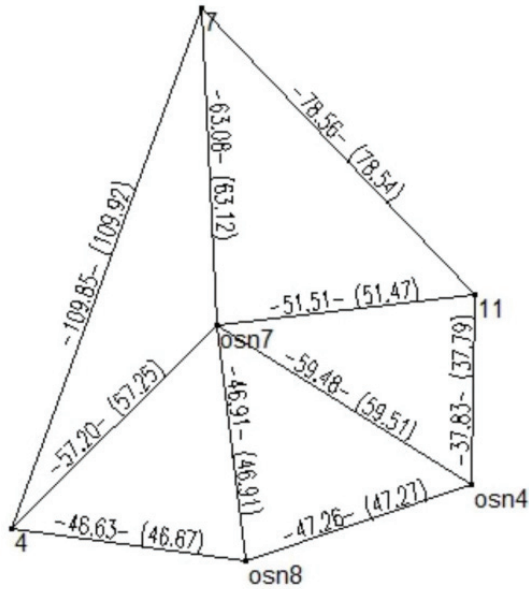
Fig. 8. Vectors based on independent check points of the tie

Table 4. The comparison of distances on the actual and estimated photogrammetric model

ICP	real model (m)	estimated model (m)	Δd (m)
4 – 7	109.85	109.92	0.07
7 – 11	78.56	78.54	0.02
11 – osn4	37.83	37.79	0.04
osn4 – osn8	47.26	47.27	0.01
osn8 – 4	46.63	46.67	0.04
4 – osn7	57.20	57.25	0.05
7 – osn7	63.08	63.12	0.04
11 – osn7	51.51	51.47	0.04
osn4 – osn7	59.48	59.51	0.03
osn8 – osn7	46.91	46.91	0.00

4. Conclusion

The necessity of conducting environmental inventory measurements on an area of about 1 ha calls for adopting a specific level of accuracy, intermediate between the accuracy of the classical topographic method (not accurate enough) and that of the geodetic method (more accurate than required for this type of research). The calculated total error in tying the images was below 9 cm. This allows a favourable assessment of using the unmanned aerial vehicles to obtain images that will be used for constructing an orthophotomap accurately representing the location of the featured objects. It should be emphasised that in the study in question, surveying was done on the basis of eight photographs obtained during eight flights, differing in the degree of sunlight in the studied area. Those photographs were used to generate a photomosaic, which then became a basis for further analyses of accuracy in comparison to traditional satellite surveys. The comparison of the length of vectors measured in the field with the ones obtained from the photogrammetric model testified to the high accuracy of georeferencing the low aerial images. Thanks to the fact that the studied area features a lot of distinctive linear objects, it is possible to obtain smaller georeferencing erros and thus a more accurate photogrammetric model, which is not the case for less diverse areas. This might stem from the difficulty of using the algorithms of photogrammetric software for recreating the internal orientation of the obtained images, which forms the foundation for further research. A photogrammetric product designed in such a way might have further practical applications. The proposed methodology will be most useful for monitoring changes in land use on housing estate areas and managing elements of the environment, also the anthropogenic ones. The inertial navigation system that unmanned platforms might be equipped with does not, unfortunately, fulfil its function, especially where there is interference of the GNSS signal. Besides, the results obtained in the study must relate to the basic legal norms and regulations on geodesy and cartography. For this reason, it is necessary to establish a ground control point network, which is indispensable to tie the images properly. Such points should be properly targeted and clearly visible in the images. In addition, the control network should cover the studied area in such a way that it is possible to clearly identify at least three points in every image. The control points not taking part in the georeferencing process should serve as independent check points of the tie.

It is becoming necessary to describe the condition of the natural environment components, especially their changes caused by the local anthropogenic processes. This is possible thanks to the use of official databases, supplemented with individual data obtained via the UAV-assisted surveying (Bielecka and Medyńska-Gulij, 2015). On the national level, geographic information systems are used for purposes of surveillance and security. The cyclic observation of the Earth's surface in real time, together with the use of the GIS technology, make the proposed photogrammetric model a useful tool for documenting changes in elements of the natural environment on an area of approximately 1 ha. A practical application of the proposed method

of constructing ground control might be, for example, its use by the emergency and security services (Wielebski and Medyńska-Gulij, 2013).

Acknowledgments

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