Archiwum Fotogrametrii, Kartografii i Teledetekcji, vol. 28, pp. 125-136
ISSN 2083-2214, eISSN 2391-9477
DOI: 10.14681/afkit.2016.010

EXPERIMENT WITH REMOTELY PILOTED AIRCRAFT SYSTEMS IMAGERY FOR DTM MODELLING

ZASTOSOWANIE ZOBRAZOWAŃ POCHODZĄCYCH Z BEZZAŁOGOWEGO SYSTEMU LATAJĄCEGO DO BUDOWY NUMERYCZNEGO MODELU TERENU

Jarosław Wajs

Faculty of Geoengineering, Mining and Geology, Wroclaw University of Technology

KEYWORDS: RPAS, UAV, low-altitude photogrammetry, DSM, DTM, IQC

ABSTRACT: The current, appropriate and highly accurate digital terrain model (DTM) is one of the essential aspects of the spatial database in 3D open-pit mining monitoring. Remotely piloted aircraft systems (RPAS), named unmanned aerial vehicles (UAVs), are becoming standard platforms for moving the digital camera in space and allowing for the collection of aerial images. The images can be processed using computer vision (CV) and structure from motion (SfM) with the traditional, established procedures of photogrammetry. The presented work shows the processing workflow of low-cost multi-rotor UAV platforms, capable of acquiring the photogrammetric data with a single-lens reflex (SLR) digital camera and Agisoft PhotoScan post-processing software. Regarding the photogrammetric minimum constraints results, like digital surface model (DSM) / DTM and contour lines, textured point clouds can be produced. With high-quality UAV equipment and resources, this study is focused on the feasibility and adaptability analysis of low-cost UAV techniques and their applications for 3D mapping. The first tests were developed using the multimedia Pergola fountain in Wroclaw regarding image acquisition, big data problems and data reduction. The objective of the study is to determine the accuracy of the photogrammetry output and to evaluate the internal quality control (IQC) of the DSM of the region of interest (ROI) regarding the open-pit mine characteristics.

1. INTRODUCTION

In the last decade, the performance of technologies used for digital terrain modeling in open-pit mines has been improved through the acquisition of real-time measurements with steadily increasing accuracy (Wajs, 2015). The typical accuracy of the processed digital terrain model (DTM) is 10 cm in the planar directions and 20 cm in the z-axis. Moreover, structure from motion (SfM) has developed strongly (Remondino and Sabry, 2006) and application of Remotely Piloted Aircraft Systems (RPAS) technology for topographic mapping has recently significantly increased. The significant improvement of computer vision (CV) algorithms has meant that non-metric images from different sources are now applied in geodetic surveying. RPAS are referred to as unmanned aerial vehicle (UAV) platforms and are a valuable source for inspection and camera transportation up to visual line of sight (VLOS) ratings. Moreover, the integration of platform, global positioning system (GPS), inertial measurement unit (IMU) and cameras constitute UAVs that can deliver more useful image data sets.

In this paper, some minor feedback on UAV platforms is presented. Depending on the type of classification applied, we can say that there are two kinds of drones – fixed wing drones and multi-rotor wing drones. Multi-rotor wings are useful for inspection, and are frequently equipped with gimbals that allow for object tracking. The higher number of rotors and different types of motors allow for the movement of heavier sensors and the stability of the platform. The most important advantage of fixed wing UAVs is their long flight time and relatively wide area coverage as compared to multi-rotor drones. The post-processed product is fully metric thanks to the use of ground control points (GCPs). These points must be marked and measured before flight mission in the area of interest. The literature shows that the first tests of real-time kinematic (RTK) integration into unmanned aircraft systems (UAS) were missed. The use of RTK techniques could improve the quality of positioning to the decimeter level, but the system would thereby become too complex, expensive and heavy (Remondino *et al.*, 2011; Sawicki, 2012). Nevertheless, in the last few years, the GPS RTK receiver and IMU accelerometer and gyroscope sensors have been integrated.

The significant improvement of CV algorithms allowed for non-metric images from different sources to be applied in geodetic surveying (Clapuyt, 2016). The UAV platforms as an aspect of remote sensing (Toth *et al*., 2015; Dandois and Ellis, 2010) are a valuable source for inspection and camera transportation up to VLOS ratings. Moreover, the full working system creates the UAVs that deliver more useful images data sets within photogrammetry minimum constraints (Shahbazi, 2015). These images overlap and CV matching algorithms allow for photo alignment and point cloud generation to form specified image data sets (Yilmaz, 2010).

In recent years, the performance of such technologies has been improved through the acquisition of digital terrains in real time with steadily increasing accuracy. Moreover, the digital surface model (DSM), hereafter the DTM, is the most important composite database in building information modeling (BIM). It allows for the monitoring of industrial processes to produce maps of changes and 4D maps.

2. MOTIVATION

Given terrestrial photogrammetric measurements applied to 3D digital terrain modeling in open-pit mines presented by Gawin (2009) and Patikowa's aerial approach (2004), it is possible to start with remotely piloted low-cost UAS. RPAS are usually called UAVs and are platforms equipped with non-metric digital cameras that can easily acquire high-resolution aerial imagery, allowing for dense point cloud generation, followed by surface model creation and orthomosaic production. The various UAV platforms have been presented by Toth (2016). The area that can be covered during one flight depends on the ground sampling distance (GSD). The GSD is the size of area represented by each pixel in a digital photo. Due to the low flight altitude, a high resolution of 2 cm GSD was achieved. Similar tests were presented by Toth (2015) regarding UAV and classical metric airborne mapping photogrammetry systems. RPAS have limited ground coverage due to their flying altitude and duration. They are capable of covering an area up to 0.5 km^2 and acquiring geospatial data. They offer a viable alternative to high-performance airborne systems using low-cost sensors and platforms. Moreover, RPAS are better suited for irregular and difficult-to-access area data acquisition, such as DTM modeling of open-pit mine slopes and dumping areas (Remondino, 2011). The aims of this study were to set platform and sensor configurations, acquire data and georeferencing regarding the region of interest (ROI) and generate point clouds including comparison with light detection and ranging (LiDAR) data sets. One of the objectives was to assess the accuracy of the selection and use of RPAS in DTM production. This analysis was based on statistical evaluation, point cloud comparison and visual examination of testing data acquired via a low-cost hexacopter platform equipped with a non-metric digital camera. The optical imagery was processed using Agisoft PhotoScan Professional software. This point cloud generation tool allows for the processing of data of varying quality and density, as well as the performance evaluation of RPAS technology.

3. EXPERIMENT

3.1 Study area

The chosen ROI is presented in Figure 1. The study area is located in eastern Europe, in south-western Poland. The Pergola fountain, Wroclaw, is located in the Lower Silesia district. The geometry of the ROI is colored in blue semi-ellipse and highlighted with a red circle. The size of the covered area is about 220 m by 250 m, covering approximately 0.06 km^2. The testing field is situated in the northern part of the Centennial Hall complex. The study area covers the semi-undulated area.

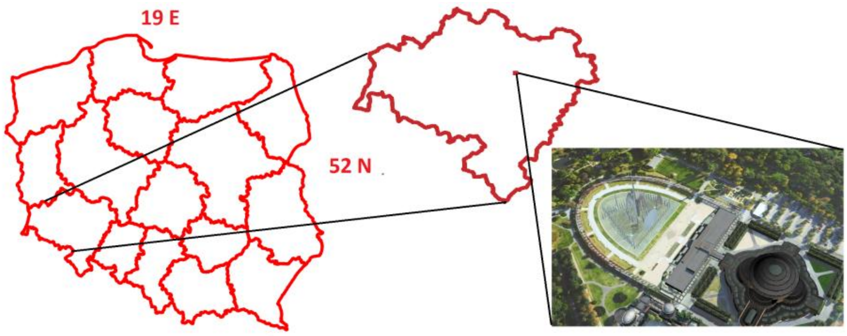

Fig. 1. ROI - Pergola fountain, Wroclaw is located at Lower Silesia district.

3.2 Photogrammetry constraints

Classical photogrammetry (i.e., passive sensing) allows for the reconstruction of depth from two images that act as a stereo pair. One advantage of photogrammetry is its non-contact sensing that allows for the measurement of inaccessible but visible areas. Taking images is relatively easy and permits acquisition large-scale data. It allows for both 2D and 3D sensing. For 3D measurement, it is necessary to measure GCPs and match these with homological points regarding CV photogrammetric conditions. This remote sensing technique allows for the acquisition of data and reconstruction of the model in real time.

Through the development of digital techniques, close-range photogrammetry has been used to perform geodesy work related to the construction, expansion and movement of the ROI. Close-range non-metric photogrammetry based on image matching and digital computing has been presented by Yakar and Yilmaz (2008), and SfM principles have been demonstrated by Westoby *et al*. (2012). Moreover, a great advantage of digital photogrammetry is the ability to record dynamic scenes over specific time periods. The automated data processing of multi-image alignment is accessible in photogrammetric software packages.

3.3 UAV platform and sensor

In this study, a rotary RPAS self-made low-cost system created by Wroclaw University of Technology was used for data acquisition. The multi-rotor UAV platform used is shown in Figure 2. This UAV integrates GPS, IMU and Pixhawk Autopilot. The platform can carry payloads of up to 3 kg and is suitable for this study. The UAV system is flown semi-autonomously and returns to its original point. The multi-rotor platform is stable, vibrates little and is capable of capturing sharp images during a flight mission (Thakar and Ahmad, 2011). The digital camera was mounted on an IMU gimbal which absorbed the multi-rotor vibrations. In addition, the camera was stabilized in the nadir view. A Canon PowerShot A810 with 5 mm focal length was used. The maximum flying altitude was 100 m above surface level due to local regulations. One hundred and ninety-six images were acquired and saved to a 765 MB SD card.

Fig. 2. The low-cost self-made hexacopter RPAS platform and applied compact digital camera that were used in this experiment, with some image samples.

4. METHODOLOGY

The methodology of this work was divided into five phases: sensor calibration, mission planning, data acquisition, data processing and internal quality control (IQC). This research methodology is presented in Figure 3. The measurement campaign took place in September 2015. Data acquisition was conducted using the UAV platform. The mission was developed in Mission Planner, subject to relevant constraints (Tahar, 2015). The maximum flying altitude was set based on RPAS limitations, which, according to regulations, cannot fly higher than 100 m above the ground. Due to the low altitude, a resolution of 2 cm GSD was achieved. Similar tests have been presented by Remondino *et al*. (2011) and Bakuła and Ostrowski (2012).

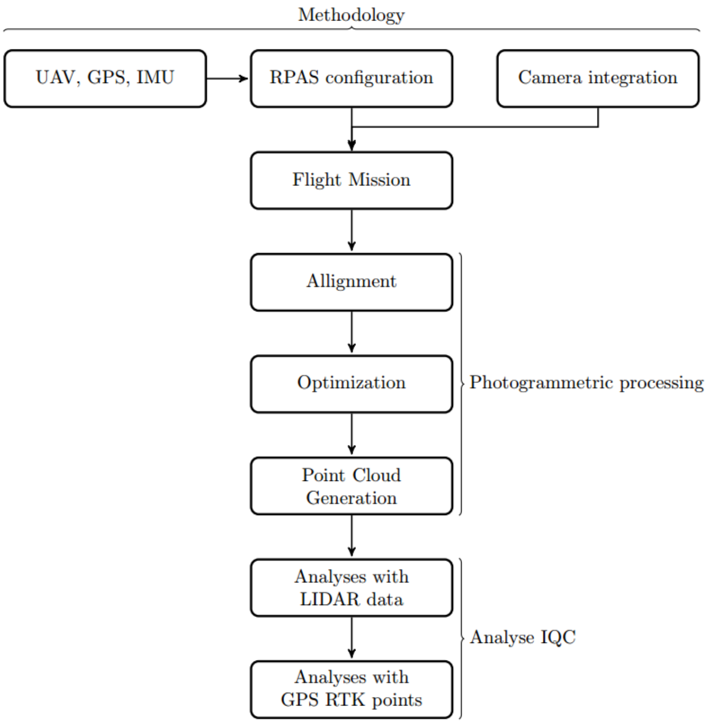

Fig. 3. Research methodology.

Camera calibration was achieved via self-calibrating bundle adjustment in Agisoft PhotoScan Professional. In the simulation model, GCPs and check points (CPs) were established using the GPS RTK technique with reference to ASG-EUPOS. A large number of ground points were measured as natural CPs to provide a comprehensive test field and to verify the performance accuracy of UAS. In the test area, ground-level points were measured using the GPS RTK technique with accuracies for XY of ±0.03 m and for elevation of ±0.05 m. Control points were set on different types of surfaces (asphalt, target, fields). Before photogrammetric flight, the mission planning involved the calculation of the study area, number of strips acquired, pixel size, photo scale, flying altitude and percentage of side lap and end lap. In general, the images should overlap by approximately 80%, and 200% for neighboring strips of flight. All the acquired images were processed by using the photogrammetric software, Agisoft PhotoScan Professional. The most important issue was tie points matching, as presented in Figure 4a. The GCPs were applied for geometry improvement, as presented in Figure 4b. In the first tests, systematic error and drift of the iterative algorithms in photo alignment matching in PhotoScan are clearly visible.

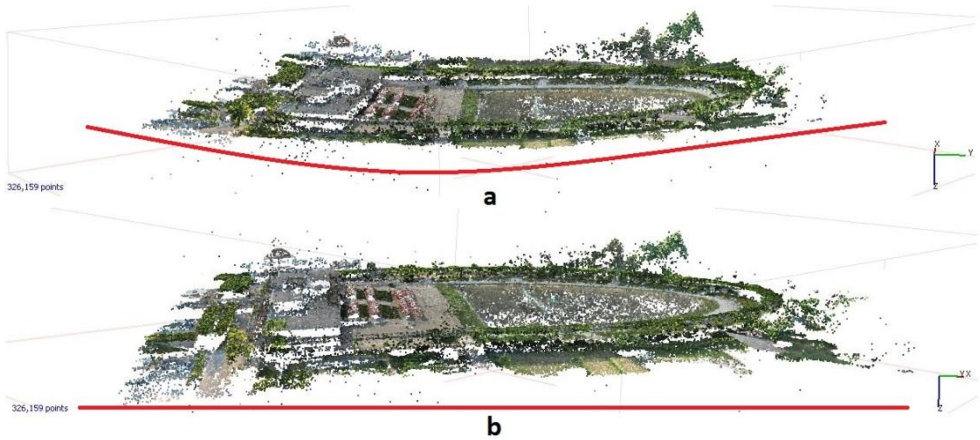

Fig. 4. Dense cloud, (a) without GCPs and (b) with GSPs optimization. The red line shows the systematic error before (a) and after (b) optimization.

The next step was the estimation of the point dense cloud. The final point cloud comprised approximately 24 million points. The image overlap is presented in Figure 5a. The flight strips were parallel to one another. Overlap of 80% was established in RPAS. Figure 5b presents the results of digital terrain modeling (265.595 points per square meter) and texturing. The final DTM product capacity is approximately 0.5 GB. The easiest way to resolve the problem of big data is point cloud faltering and DTM reduction via simplification, though this may lead to key value losses.

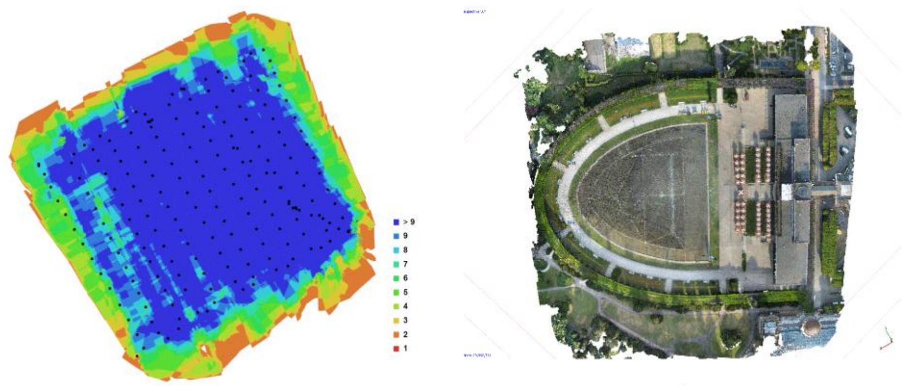

Fig. 5. Camera locations and image overlap (a) (b) resulted DTM.

The reference data were acquired from the database managed by the Head Office of Geodesy and Cartography, which comes from IT System of the Country's Protection (ISOK), where the DTM was filtered from LiDAR data sets. Figure 6 provides some example data of the ROI and the referenced LiDAR DTM.

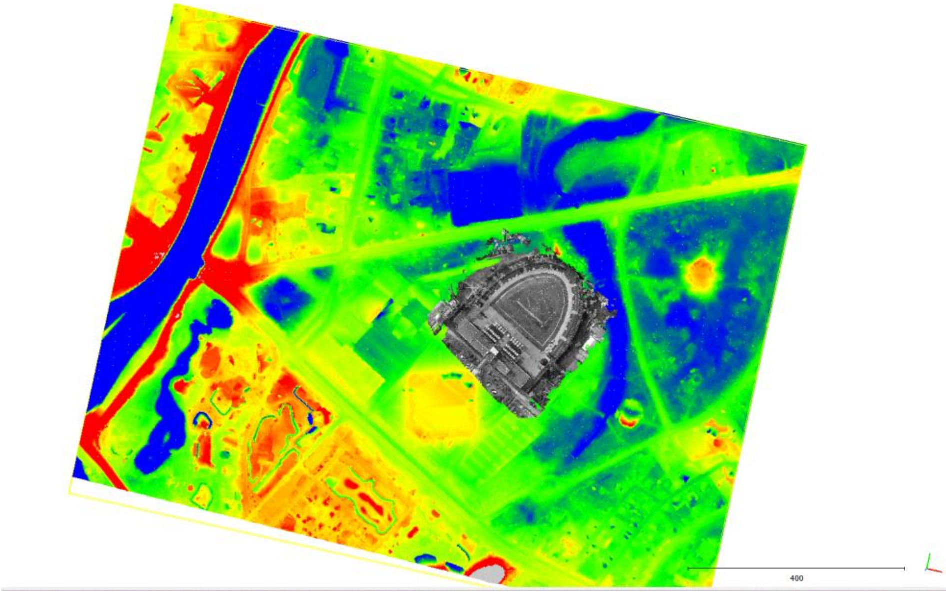

Fig. 6. DTM from UAV on the referenced LiDAR DTM data set from ISOK. The master LiDAR data set was clipped to the ROI and the IQC was estimated locally.

5. RESULTS AND FUTURE WORK

Post-processed results were compared with georeferenced data (Dyamit, 2015; Halla, 2011). The main objective was to provide an accuracy assessment of the internal quality control of the processed point clouds. The results show that the root-mean-square error (RMSE) in XY is smaller than for the Z coordinate. Based on the measured points with the portion presented in Table 1, the RMSE value for GCPs XY coordinates is ±0.10 m. The point-to-point analysis in the Z-axis allows for the estimation of the RMSE, which is 0.15 m. The procedure of accuracy assessment of point clouds from UAVs was tested by Wierzbicki *et al*. (2015), Sentise *et al*. (2014) and Hlotov *et al*. (2015). In this approach, the fully processed georeferenced point cloud was adjusted into the reference DTM from LIDAR data. The comparison of LiDAR-filtered DTM, called ‘master’ data, and DTM processed from UAV, called ‘slave’ data, shows that the accuracy of the points clouds in the planar directions are equal (Figure 7). Moreover, the systematic offset in the Z-axis is clearly visible and coursed by DTM. If we do not apply the robust estimation, the buildings and vegetation thus cause biases. The CPs manually extracted from the point cloud and measured by GPS RTK in situ show that RMSE in the planar directions is approximately 10 cm and in the Z-axis is 20 cm, which corresponds to the results presented by Jozkow and Toth (2014). The estimated offsets show that the planar accuracy is more precise than the estimated 3D elevation from photo pairs, which is caused by photogrammetric constraints. The application of control points allows for the reduction of systematic errors caused by IMU sensors. The control points were fixed at the corners and in the center of the ROI. This allowed for the alignment of the images to reconstruct the model without random drifts. In addition, the CPs were measured using the GPS RTK technique. The results of the biases in the X-, Y- and Z-axes for 10 randomly selected points are listed in Table 1. Future work will be based on DTM to DSM and DTM to DTM analysis from different platform and sensor applications.

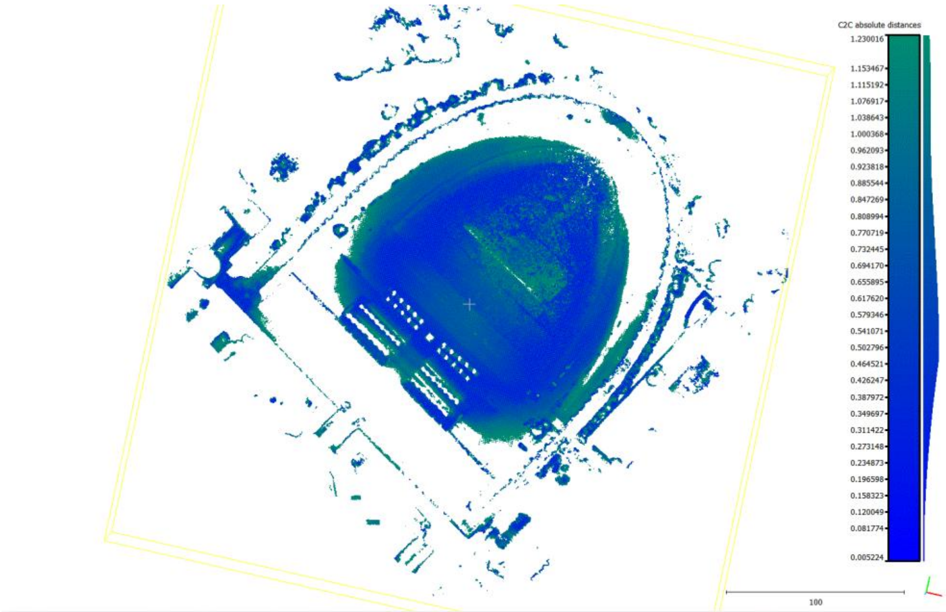

Fig. 7. Estimated normal distances between the RPAS point cloud and reference data. The mean bias was 0.5 m. The graph on the right side represents the histogram of the normal point-to-mesh distances. The systematic offset is caused by calculation of the normal distances between the master DTM (mesh) and analyzed DTM of the ROI.

Table 1. Estimated offsets in the X-, Y- and Z-axes on measured CPs using GPS RTK. The table includes the portion of 10 CPs for precise point-to-point biases analysis.

Nr	ΔX [m]	ΔY [m]	ΔZ [m]
1	0.089	0.05,9	-0.081
2	0.044	-0.021	0.112
3	0.023	-0.084	0.068
4	0.068	-0.073	-0.121
5	0.055	0.032	-0.055
6	-0.075	0.044	0.171
7	-0.035	-0.092	0.091
8	0.009	-0.033	0.064
9	-0.022	-0.059	0.140
10	-0.093	-0.011	-0.109

6. CONCLUSIONS

In the last decade, CV science has been evolving. The SfM presented in Westoby *et al.* (2012) has been developed. Currently, close-range photogrammetry principles are well investigated and image matching techniques are more effective. This shows that photogrammetry from UAS could be a good alternative for large area digital surface modeling. With the increasing use of non-metric camera photogrammetry, the time and cost required will decrease. The limitation of this system is its payload, stability and DTM registration. In open-pit mines, bare earth represents the majority of the area, and this fact shows that close-range non-metric photogrammetry could hold great potential in the future. This approach is appropriate to acquiring data for DTM modeling. A priori, DTM rebuilds slave data, which is subtracted from the a posteriori master data DTM stage. Processed pathways permit access to geospatial data quality comparable to classical geomatics surveying techniques. Regarding classical measurement techniques, the results show that only DTM data significantly influence the results. The processed IQC shows that the georeferenced point cloud from the UAS is fully metric on 10 cm in the planar directions and 20 cm in the Z-axis. The resulting point clouds can be applied for DTM modeling in open-pit mines and engineering applications.

ACKNOWLEDGEMENT

I would like to thank JEDI Scientific Association Wroclaw University of Science and Technology for his cooperation and support in this work. This work was funded by the Wroclaw University of Science and Technology, Poland through statutory research grant 0402/0146/16.

LITERATURE

Bakuła K., Ostrowski W., 2012. Zastosowanie cyfrowej kamery niemetrycznej w fotogrametrii lotniczej na wybranych przykładach. *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, *24*, pp. 11-20.

Clapuyt F., Vanacker V., Van Oost K., 2016. Reproducibility of UAV-based earth topography reconstructions based on Structure-from-Motion algorithms. *Geomorphology*, 260, pp.4-15.

Dandois J.P., Ellis E.C., 2010. Remote sensing of vegetation structure using computer vision. *Remote Sensing*, 2(4), pp.1157-1176.

Gawin A., 2009. Using digital terrestrial photogrammetry to update numerical map in opencast mines, *Górnictwo i Geoinżynieria*, 33, pp. 127-135.

Hlotov V., Siejka Z., Kolesnichenko V., Prokhorchuk O., Tserklevych A., Babiy L., 2015. The analysis of the results of aerial photography experiments on the basis of a developed UAV model. *Infrastruktura i Ekologia Terenów Wiejskich*, IV/3, pp. 1329–1350.

Haala N., Cramer M., Weimer F. and Trittler M., 2011. Performance test on UAV-based photogrammetric data collection. *Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 38(1/C22), pp.7-12.

Jozkow G., Toth C., 2014. Georeferencing experiments with UAS imagery, *ISPRS Annals Photogrammetry Remote Sensing and. Spatial Information Science*, II-1, 25-29.

Patikova A. 2004. Digital photogrammetry in the practice of open pit mining. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Science*, 34, pp. 1-4.

Preuss R., 2014. Automatyzacja procesu przetwarzania danych obrazowych. *Archiwum Fotogrametrii, Kartografii i Teledetekcji*, 26, pp. 119-127.

Remondino F., Sabry EL-H., 2006. Image-based 3D modelling: A review, *The Photogrammetric Record*, 21.115, pp. 269-291.

Remondino F., Barazzetti L, Nex F., Scaioni M., Sarazzi D., 2011. UAV photogrammetry for mapping and 3d modeling – current status and future perspectives, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XXXVIII-1/C22 UAV-g 2011, Conference on Unmanned Aerial Vehicle in Geomatics, Zurich, Switzerland.

Tahar K.N., Ahmad A., Akib, W.A.A.W.M., 2011. UAV-based stereo vision for photogrammetric survey in aerial terrain mapping. *Computer Applications and Industrial Electronics (ICCAIE),* IEEE International Conference on, pp. 443-447.

Tahar, K. N. Multi rotor UAV at different altitudes for slope mapping studies, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* XL-1/W4, 9-16.

Toth CH., Jozkow G., Grejner-Brzezinska D., 2015. Mapping with Small UAS: a point cloud accuracy assessment. *Journal of Applied Geodesy,* 9(4), pp. 213-226.

Toth C., Józków G., 2016. Remote sensing platforms and sensors: A survey. *ISPRS Journal of Photogrammetry and Remote Sensing,* 115, *22–36.*

Sawicki P., 2012. Bezzałogowe aparaty latające UAV w fotogrametrii i teledetekcji – stan obecny i kierunki rozwoju, *Archiwum Fotogrametrii, Kartografii i Teledetekcji,* 23, pp. 365–376.

Shahbazi M., Sohn G., Théau J., Ménard P.2015. UAV-based point cloud generation for open-pit mine modelling, *ISPRS International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences,* 40(1), pp. 313-320.

Westoby M. J., Brasington J., Glasser N. F., Hambrey M. J., Reynolds J. M., 2012.'Structure-from-Motion' photogrammetry: A low-cost, effective tool for geoscience applications. *Geomorphology,* 179, pp. 300-314.

Wierzbicki D., Kedzierski M., Fryskowska A., 2015. Assesment of the influence of UAV image quality on the orthophoto production, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences., XL-1/W4, pp. 1-8.*

Yakar M., Yilmaz H. M., 2008. Using in volume computing of digital close range photogrammetry, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.* Vol. XXXVII. Part B3b.

Yilmaz H. M., 2010. Close range photogrammetry in volume computing, *Experimental Techniques,* 34(1), pp. 48-54.

ZASTOSOWANIE ZOBRAZOWAŃ POCHODZĄCYCH Z BEZZAŁOGOWEGO SYSTEMU LATAJĄCEGO DO BUDOWY NUMERYCZNEGO MODELU TERENU

SŁOWA KLUCZOWE: bezzałogowy statek powietrzny, dron, fotogrametria niskiego pułapu, numeryczny model terenu, numeryczny model pokrycia terenu, kontrola jakości danych

Streszczenie

Aktualny, poprawny oraz dokładny numeryczny model terenu (DTM) jest jednym z podstawowych elementów w przestrzennej bazy danych w modelowaniu trójwymiarowym kopalń odkrywkowych. Zdalnie sterowane systemy powietrzne (RPAS) znane w nomenklaturze branżowej pod nazwą bezzałogowe statki latające (UAV) coraz częściej stanowią doskonałą platformę do wyniesienia kamery w przestrzeń lotniczą niskiego pułapu. Wykorzystując fotogrametryczne warunki wykonywania zdjęć lotniczych oraz komputerowe przetwarzanie obrazów cyfrowych (CV) oraz algorytmy (SfM) możliwe jest przetwarzanie danych do generowania numerycznego modelu pokrycia terenu (DSM) oraz ortomozaiki z kamer niemetrycznych.

Prezentowana praca pokazuje ścieżkę opracowania danych z kamer niemetrycznych (SLR) oraz kontrola jakości danych wynikowych (IQC) uzyskanych w oprogramowaniu Agisoft PhotoScan Professional. Do badań wykorzystana została nisko kosztowa platforma wielowirnikowca składająca się z hexakoptera wyposażona w autopilot Pixhawk oraz trójosiowy stabilizator kamery. Prace testowe wykonane zostały na objekcie testowym fontanna Pergola we Wrocławiu, która stanowiła testowy rejon opracowania (ROI). Wyniki pokazują, iż przy wykorzystaniu wiedzy fotogrametrycznej i wykonaniu odpowiedniej sekwencji zdjęć z pułapu lotniczego oraz inwestycji odpowiednio rozmieszczonych fotopunktów (GCP) istnieje możliwość opracowania produktu finalnego z wymaganą decymetrową dokładnością.

Celem niniejszej pracy było zbadanie dokładności wewnętrznej (IQC) oraz spójności danych uzyskanych z pułapu bezzałogowego statku latającego przy wykorzystaniu zobrazowań z kamery niemetrycznej. Opracowany produkt wynikowy numerycznego pokrycia terenu (DSM) z oprogramowania Agisoft PhotoScan Professional poddany został dalszym analizom. Dane referencyjne stanowił zbiór chmury punktów z projektu ISOK. Wyniki prac ukazały, że produkt finalny opracowany w oparciu o małoformatową kamerę niemetryczną charakteryzuje się stosunkowo wysoką dokładnością. Mobilność systemu oraz duża szybkość pozyskania danych przez bezzałogowe systemy latające stanowi przewagę dla opracowań NMT dla wybranych obszarów zainteresowania.

Dane autorów / Authors details:

mgr inż. Jarosław Wajs
e-mail: jaroslaw.wajs@pwr.edu.pl
telefon:+48 713206873

Przesłano / Submitted 21.11.2016
Zaakceptowano /Accepted 30.12.2016