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3D MODELS BASED ON UAV IMAGES AND GNSS TECHNOLOGY IN THE FIELDS OF ARCHITECTURE, CIVIL ENGINEERING, SPATIAL PLANNING, AND ENERGETICS

Abstract

The paper presents projects in the fields of architecture, spatial planning and energetics, in order to analyze the quality of 3D terrain models obtained by combining photogrammetry using drone images (UAV) and terrestrial measurements obtained by GNSS technology. In terms of geometric accuracy, the geometry of the reconstructed point clouds was controlled in three different projects. The achieved geometric accuracy met the criteria of required accuracy defined by clients. Further, the paper provides an overview of the advantages and disadvantages of such a methodology, as well as a review of the legislation that accompanies UAV systems in Bosnia and Herzegovina / Republika Srpska.

Keywords: 3D model, UAV, GNSS technology

3D МОДЕЛИ НА ОСНОВУ UAV СНИМАКА И GPS ТЕХНОЛОГИЈЕ У ОБЛАСТИМА АРХИТЕКТУРЕ, ГРАЂЕВИНАРСТВА, ПРОСТОРНОГ ПЛАНИРАЊА И ЕНЕРГЕТИКЕ

Сажетак

У раду су представљени пројекти из области архитектуре, просторног планирања и енергетике, у сврху анализе квалитета 3Д модела терена добијених комбинацијом фотограметрије примјеном снимака беспилотне летјелице (UAV) и терестичких мјерења добијених примјеном GPS технологије. У погледу геометријске тачности у склопу сва три пројекта спроведене су контроле геометрије реконстуисаних тачака. Постигнута геометријска тачност је испунила критеријуме захтјеване тачности. Даље кроз рад даје се осврт на предности и недостатке једне овакве методологије, као и осврт на законску регулативу која прати UAV системе на просторима Босне и Херцеговине/Републике Српске.

Кључне ријечи: 3D модел, UAV, GNSS технологија

1. INTRODUCTION

Geodesy, as an extremely practical scientific discipline, used the potential of information and technological development of society and led to the possibility of modernization in data collection procedures. Solutions developed exclusively for military purposes are now available for civilian use. One of them is a drone that has a camera or laser scanner on its platform. By definition, UAV (*Unmanned Aerial Vehicle*) is a device used for flying without the direct presence of the pilot or other crew member in/on the device itself [1]. The control of such an aircraft is performed with the help of a system for remote flight control and navigation or based on a previously defined flight path. The drone is certainly the most common synonym for UAV.

The division of unmanned aerial vehicles can be defined based on the maximum mass of the unmanned aerial vehicle during takeoff, range, ie. distances about the control/base point, flight altitude, construction, type of engine/drive, degree of flight autonomy and purpose. The maximum mass of the drone during takeoff varies from a few hundred grams to several tons. The distance to the control/base point can reach up to 500 km in the model of military-tactical drones. Flight altitudes range from a few hundred to several thousand meters.

Legislation that accompanies unmanned aerial vehicles on the territory of Bosnia and Herzegovina (and thus the Republika Srpska) is trying to keep pace with the development of technology, which greatly facilitates their application in geodesy, ie. in the fields of photogrammetry and remote sensing. In the territory of Bosnia and Herzegovina, drones with a maximum take-off mass of up to 25 kg may be used for civilian use. For performing, works from the air, and the official category to which photogrammetric recordings belong, BHDCA (Bosnia and Herzegovina Directorate of Civil Aviation) provides privileged flying opportunities, with the obligatory consent of the organization of the same name. This is mostly reflected in the maximum allowable altitude of drones (other categories, non-commercial and commercial operations must not exceed 120 m), as well as the maximum distance of the drone from the operator (for other categories this value is a maximum of 500 m) [2].

In terms of construction, two types of drones have been singled out for photogrammetry. These are multi-copters and unmanned aerial vehicles with fixed wings (Figure 1). Of course, it is important to accent that both types of these devices have advantages and disadvantages. Fixed-wing aircraft can reach higher altitudes and "cover" a larger area than multi-helicopters in the same period time. On the other hand, they require a specific space for takeoff and landing, the wind is a big obstacle, and the important fact is that they can not stay in one place in the air (which is the advantage of multi-copters, for example, while shooting facades with camera). The choice of aircraft for a particular photogrammetric survey will in any case depend on a number of factors, such as the scope of work, the location of the site, obstacles, and accuracy requirements.

Figure 1. *Unmanned aerial vehicles that have found their application in photogrammetry [3], [4]*

The question remains whether photogrammetry / remote sensing detection by drones will become an indispensable way of collecting data in certain branches of geodesy, ie. in jobs and projects on which architects, civil engineers and technicians, spatial planners, computer scientists, mechanical engineers, and experts in related sciences work. This paper presents examples from practices that were successfully implemented during 2021. The following text will present the methodology of data collection and processing, analysis of the obtained results as well as a review of the advantages and disadvantages of drone photogrammetry.

2. METHODOLOGY

Photogrammetric survey with the help of UAV has found practical application within projects in the field of architecture, construction, spatial planning and energetics in the territory of the Republic of Srpska. Specific tasks, presented in this paper, are related to:

- Development of a 3D model of the quarry for the purpose of monitoring the amount of stone ore excavation (Project 1),
- Development of a 3D model of the business zone for the needs of designing its reconstruction (Project 2), and
- 3D reconstruction of the industrial zone (facilities and terrain) for the needs of solar park design (Project 3).

It is important to note that in all these cases, the accent was placed on meeting the technical requirements of the tasks (in terms of accuracy and density of generated spatial data) and safe execution of data collection by drone in accordance with all prescribed laws to which these works are subject.

2.1. AREA OF PHOTOGRAMMETRIC SURVEY AND COVERAGE OF THE FIELD

Prior to the planning of the work from the air, a general check was performed on whether the survey area was banned from flying unmanned aerial vehicles, ie. whether a BHDCA permit is required. Figure 2 shows exactly one such location, where the territory (around Banja Luka airport) is divided into zones with a special regime for flying drones. The red zone prohibits flying, the blue zone requires BHDCA approval, while the gray zone sets limits on the maximum height of the drone.

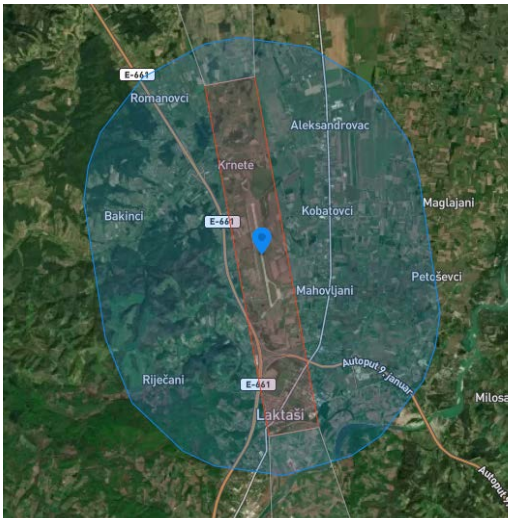

Figure 2. *Prohibition and restriction zones for UAV [5]*

2.1.1. Project 1

The quarry in question is located on the territory of the municipality of Laktaši in the village of Drugovići. It can be reached by the highway on January 9 (about 700 meters from the Drugovići exit) or on the main road Banja Luka-Prnjavor. The approximate area of the quarry is 18.5 ha. The subject of the survey was its southern and south-eastern branches, with an area of 3.2 ha, ie. the dimensions of the object to be photographed (average length and width) were 250 m and 130 m. The maximum relative height difference of the part of the quarry that was photographed was 60 m. The request of the client was defined on the basis of the allowed deviation of the geometric accuracy. For the detailed points it was 10 cm with respect 3 axes.

2.1.2. Project 2

The business zone is located in the municipality of Šipovo. Its distance from the municipal center is 400 m (on the left side of the Jezero-Šipovo road from the direction of Jezero). It includes a gas station with accompanying sales facilities (which are on two levels/flors), three industrial halls (for storage of pellets and other wood products, repair of machinery and vehicles), external storage of wood raw materials, and accompanying road and utility infrastructure. The average dimensions of the subject were 200 m in length and 100 m in width. The maximum allowed deviation of detailed points (defined by the client) was 5 cm.

2.1.3. Project 3

The industrial zone that was the subject of the survey is located on the territory of the city of Prijedor. The area survey covers a total area of 2 ha. On this surface, there are industrial facilities, warehouses, water towers, tool shops, warehouses of secondary raw materials, garages, and transformer stations. Unlike the previous two projects, the client required a more detailed reconstruction of the associated facilities. Emphasis is placed on the roof structure in order to obtain a base for the design of solar panels on these surfaces.

2.2. DATA COLLECTION METHOD

Data (photographs and coordinates of orientation/control points) for all three projects, were collected in the same way, ie. a combination of a drone (has an integrated GNSS receiver, but is not good enough to independently achieve the required accuracy of the reconstructed points) and GNSS terrestrial measurements (using the RTK method) are combined.

Figure 3. *Overview of orientation points used in Project 1*

The drone used on these projects is the DJI Phantom 4 Pro V2.0. Its take-off weight is 1375 g. The flight duration (using one battery) is 25 min. It has an integrated GNSS receiver that receives GNSS and GLONASS satellite constellation signals. The digital (integrated) camera (Table 1) is connected by a 3-axis gimbal. It can be rotated towards the nadir, which allows vertical shots.

Table 1.Characteristics of the DJI Phantom 4 Pro V2.0 drone camera

Focal length (f)	35 mm
Sensor width (WS)	35.9 mm
Sensor height (HS)	24 mm
Field of View (FOV)	37.8 °
Active pixels	20 million

Prior to the implementation of data collection, a detailed flight plan was prepared (Table 2), which includes the length and width of the area to be recorded (L and W), the height of the aircraft (H), Ground Sample Distance (GSD), longitudinal and transverse overlaps of attached photographs (LO and SO), longitudinal and lateral movement of the drone (LS and SS), number of shots per survey line (NI), number of shooting lines (NS), and the total number of shots (TI).

Table 2.Flight Plan for Project 2

L	200 m
W	100 m
H	40 m
GSD	5 mm
LO	75 %
SO	75 %
LS	6.84 m
SS	6.84 m
NI	29
NS	15
TI	426

2.3. DATA PROCESSING

The processing of the collected data (photographs and coordinates of orientation points) was performed using the 3Dsurvey program. The processing procedure is extremely intuitive and follows the following steps:

- Opening a new project and uploading photos,
- Adding telemetry to photographs (based on the aircraft model or by importing an additional document containing information related to the position of the cameras' center at the time of exposure),
- Choice of horizontal and vertical date/projection,
- Montage photos and create points cloud with connections points,
- Geo-referencing of the project (based on the coordinates of orientation points),
- Reconstruction of the dense point cloud (4 possible densities),
- Making of a digital surface model,
- Making of a orthophoto.

3D models for all three projects were delivered in the form of point clouds, so the reconstruction of the dense point cloud was the last step in the processing. The duration of individual phases within Project 2 is shown in Table 3.

Table 3.Step-by-step data processing time for Project 2

Upload photos	4 min
Adding telemetry and selecting geodetic dates	8 min
Making points clouds of the connections points	1 h 25 min
Geo-referencing	1 h 15 min
Reconstruction of the dense point cloud	6 h 32 min

3. RESULTS, ANALYSIS AND DISCUSSION

According to the program manufacturer's declaration, the geometric error of details (arbitrary points from the cloud) has a value 2.5 times higher than the maximum error of the orientation points. In order to be convinced of the truth of this statement, geometry checks were performed at checkpoints. In the case of Project 1, "redundant" orientation points were set up in the field, which did not enter the geo-reference process. They served as checkpoints. Information on their position was collected during field measurements with a geodetic GNSS receiver and after the reconstruction of a dense cloud of points, a comparison of the digitized point from the cloud and recorded with an instrument was made (Table 4). In Projects 2 and 3, in addition to the control points, clearly visible details (edges of sidewalks, terraces, manhole covers) were read with a geodetic GNSS receiver in order to control the geometry of the reconstructed points. The analysis of the comparison shows that the detailed points from the cloud (in all Projects) met the set accuracy requirements.

For each point obtained from the point cloud, in addition to its geometry, the color is copied in the RGB system based on photographs, ie. the point cloud got a real-world texture. This fact allows 3D modeling of terrain and objects with the help of unmanned aerial vehicles to give a multi-purpose product. Through the Projects, this was reflected in the following way:

- In Project 1, it was clear where the extraction of stone ore was performed and based on that, find out how much ore was exploited and in which part (Figure 4),
- In Project 2, using the CAD module of the 3Dsurvey program, details (for which no field sketch was kept at all) were mapped by layers, which were later merged in AutoCAD (Figure 5),
- In Project 3, in addition to the geometry of the buildings necessary for the design of the solar park, a solution was obtained that provides a clear insight into the current state (collapse) of roofs and walls of industrial buildings (Figure 6).

Table 4.Project result parameters

Project parameters	Project 1	Project 2	Project 3
Number of photos used	348	419	1321
Number of points in the 3D model	70 million	118 million	87 million
Average geometric accuracy of georeferencing [mm]	11	7	16
Total data processing time	8 h 44 min	7 h 22 min	10 h 17 min

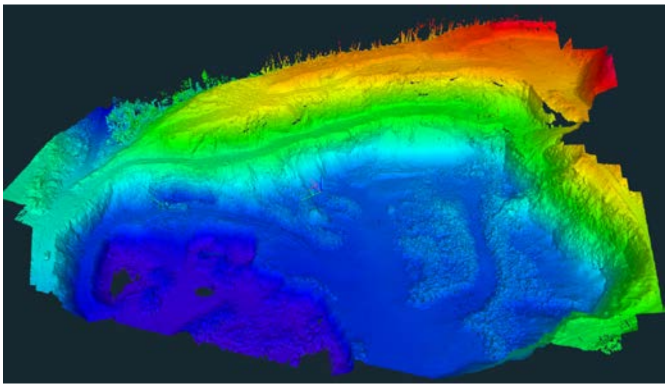

Figure 4. *3D model of the quarry with the help of a hypsometric scale*

Figure 5. *Part of the point cloud with mapped details*

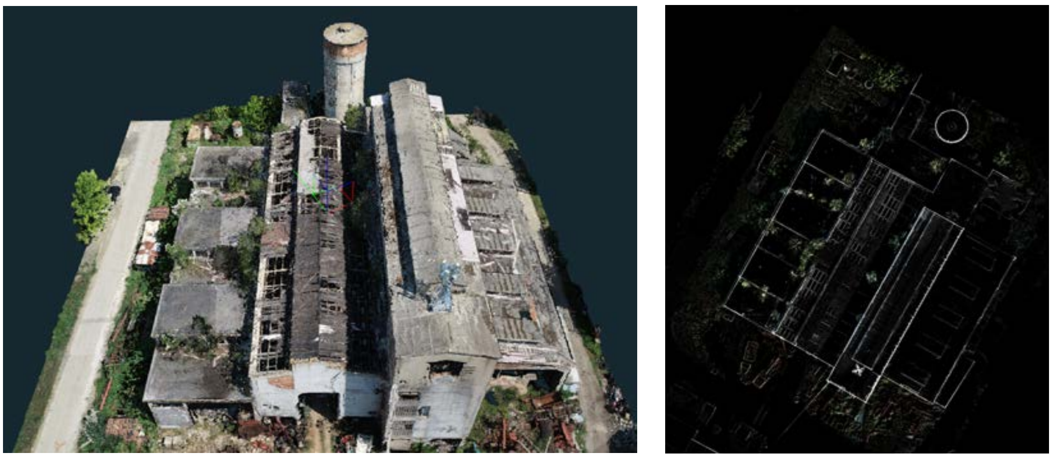

Figure 6. *3D view of the industrial zone model (left view) with automatically generated "X-ray" image of the walls (right view)*

4. CONCLUSION

The shortcomings of the described methodology are not numerous, but certainly not negligible. Before the implementation of the project, several test flights were performed to define the best way to perform future air data collection operations. Applications that enable the automatic realization of flight and photogrammetric recording were tested. At that moment, none of them proved to be reliable, so each of the flights was controlled directly by the drone operator. Reduced or excessively large transverse/longitudinal folding of photos in the model is one of the potential problems that can be caused by manually guiding the drone. If there is too little overlap, the reconstruction will not be adequate. On the other hand, too much overlap will create redundant photos that will slow down the data processing procedure. The time that the drone will spend in the air will certainly increase. In addition, the general problem of photogrammetry is the reconstruction of surfaces that are uniform, such as aluminium roofs. This problem can be avoided by increasing the operational altitude of the aircraft, so that the photos "capture" another detail that will be crucial for finding the tie points and later reconstructions of the dense point cloud. This measure can impair positional accuracy and Ground Sample Distance (GSD). Absolute accuracy assessment RMSE for 3D spatial coordinates is 11.1 mm in project 1, RMSE for 3D spatial coordinates is 7.10 mm in project 2, and RMSE for 3D spatial coordinates is 16.3 mm in project 3. Accuracy is reported at the 95% confidence level. Relative changes in the RMSE show a clear decrease with an increasing mean distance. The technology that is present in the field of photogrammetry provides solutions that can speed up the data collection procedure. Unmanned aerial vehicles are being developed that collect data on the principle of Real-Time Kinematic (RTK) and Post-processed kinematic (PPK) methods. The costs of such equipment should certainly be taken into account, as well as the possibility of their cost-effectiveness. For practical examples, which are presented in this paper, drones are a great solution for obtaining 3D models. The results with their quality (in terms of geometric accuracy) and quantity (which surpasses all geodetic measurements except laser scanning / LIDAR) meet absolutely all the technical requirements set by the clients. In the near future, photogrammetry / remote sensing of drones will become an indispensable way of collecting data in certain branches of geodesy, ie in jobs and projects involving architects, civil engineers and technicians, spatial planners, computer scientists, mechanical engineers and experts.

LITERATURE

[1] U.S. Department of transportation-Federal Aviation Administration (FAA). (2013). Integration of Civil Unmanned Aircraft System (UAS) in the National Airspace System (NAS) Roadmap. (First Edition) [On-line]. Доступно на: www.faa.gov/uas/resources/policy_library/media/uas_roadmap_2013.pdf [7.2.2022.]

[2] Правилник о условима за извођење летачких опрација дроновима. Закон о ваздухопловству Босне и Херцеговине („Службени гласник Бих“, број: 39/09 и 25/18).

[3] DJI. „https://www.dji.com/phantom-4-rtk” [17.2.2022.]

[4] WINGTRA. „https://wingtra.com/”[17.2.2022.]

[5] DJI. „ https://www.dji.com/flysafe/geo-map” [19.2.2022.]