Collecting Spatial Data with Unmanned Aerial Vehicle

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Abstract

The paper briefly discusses the nature and advantages of unmanned aerial vehicle (UAV) as a spatial data acquisition method. This method and its possibilities are subject of scientific research in the area of geodesy, cadaster, architecture, construction of infrastructure objects and facilities, agricultural activities, cultural and historical heritage and even more over the last decades. This publication discusses in short, the principles and possibilities for creating a three-dimensional data model using the advantages of unmanned aerial vehicle. The building of University of Architecture, civil engineering and geodesy, situated in Semkovo resort, Blagoevgrad district is selected for the purpose of the task. Classical land surveying measurements with a total station and the data collected with an unmanned aerial vehicle are used for the creation of the three-dimensional model. A comparison and evaluation of the obtained model is made. The result of this evaluation indicates that the technology of unmanned aerial vehicle is efficient for representation of high-quality data with a wide scope of advantages such as high range, fast data collecting and processing.

Keywords: case study, spatial data, unmanned aerial vehicle, 3D model

Introduction

Three-dimensional modeling of buildings is a complex process that consists of recruiting spatial objects and subsequent processing to sift an accurate geometric model of the object. Geodetic techniques have always played an important role in data collection. New technologies for data collection and processing have enabled us to increase the amount and variety of information collected.

In the present work, the principles of classical geodetic measurements with a total station and aerial survey with an unmanned aerial vehicle (UAV) for collecting and processing spatial data are considered. The possibility of creating a three-dimensional model of a building in a forest area using both methods is described. Control distances were measured with a measuring tape to control the quality of the created model.

Unmanned aerial vehicles have been the subject of scientific research in recent decades in numerous scientific and applied fields such as land surveying, cadastre, architecture, construction of infrastructure objects and facilities, agricultural activities, cultural and historical heritage and others.

Nature of Spatial Datacollection with UAV

At the base of spatial data collection with UAVs is photogrammetry, which is a technology for determining the position and characteristics of objects from photographs (aerial) [1].

Structure from motion (SFM) is a photogrammetric imaging technique that allows the extraction of spatial data from multiple 2D images. The phenomenon of 3D perception originates from the idea of the human eye. With two eyes that perceive two slightly different pictures, we get the feeling of depth - 3D vision. The same concept is used for SFM. The set of identical points captured from two different positions allows one to specify a system of central projection equations where spatial coordinates can be specified along with the camera position and orientation and some additional camera parameters. Processing a large number of images in a batch is extremely challenging. It is not only necessary to identify characteristic point pairs and determine camera orientations, but also to provide dense point clouds for the largest pixels in the image. Most often, the final result of the procedure is a 3D network - a set of different triangles representing the surface [2].

Unmanned aerial vehicles (drone, UAV) are a component of an unmanned aerial vehicle system that includes an unmanned aerial vehicle, a ground controller and a communication system between the two. The flight of unmanned aerial vehicles can operate with varying degrees of autonomy: manual, semi-automated and autonomous modes [3].

The latest models of drones have intelligent flight controllers and modes such as Follow Me, Active Tracking, Waypoints, Return to Home and more.

The use of drones has seen significant growth in recent years. Flying technology is becoming better and more accessible to a wide range of specialists. Many engineers from various fields see the potential of this technology and strive to make full use of it.

Modern UAVs are complex electronic-mechanical systems that use the latest achievements of science in many fields. When in the hands of good professionals, they become a powerful tool for gathering geospatial information. One of the advantages of UAVs is: speed of capturing large areas, safety, high resolution, minimum number of specialists and low price.

UAVs can capture large objects in a very short time and with remote control, making this technology one of the safest ways to work. This is a remote method, i.e. there is no direct contact with the photographed object, which guarantees safety when filming landslides, swampy areas, dangerous terrains and hard-to-reach places. Compared to other methods, the use of drones can reduce the cost of the final product many times, while at the same time the quality is unmatched.

UAVs also have their disadvantages such as: invisible areas, limiting requirements and the need for high-quality specialists.

The use of 3D modeling technology requires high qualification of specialists. Unlike a simple GNSS or total station survey, a whole other level of knowledge is required here. Ease of operation with UAVs is quite misleading. Requires serious computer resource. Multiprocessor systems and powerful video cards combined with sufficient RAM and fast SSD drives are mandatory for a normal workflow with UAV data.

The increase of UAVs in the airspace leads to the need to regulate this activity. Unfortunately, some of the legal requirements are quite restrictive and may prevent flights in a certain area at a certain time.

Although data collection is done from the air, where visibility is supposed to be best, there are areas that remain hidden, especially during seasons when there are leaves on the trees.

A case study of 3d modelling in forest area

The Range of Case Study

The object of the research is the buildings of University of Architecture, civil engineering and geodesy, situated in Semkovo resort, Blagoevgrad (Fig. 1-a). They are located at 1620 meters above sea level in southern Rila mountain, 17 km north of the town of Belitsa, region Blagoevgrad. The complex consists of 8 buildings (Fig. 1-b). The buildings are of interest because they are located in a mountainous area and are surrounded by high vegetation (spruce and pine forests) and thus the advantages and disadvantages of the methods used can be indicated, which is also the purpose of the present study.

(a) (b)

Fig. 1. The range of case study

UAS Survey

The UAS survey was carried out using a DJI Phantom 4Pro. The first activity that was carried out for this study was to scour the area for obstacles and select the locations of ground control points (GCP). GCPs are used in order to increase the accuracy of the final digital products and their georeferencing in a selected coordinate system [4].

12 ground control points (Fig. 2) were selected so that they would be clearly visible in the aerial survey.

Fig. 2. Scheme with the location of the GCP

Four of the point are known (control) point (point pt4, pt30, lt3 and lt20), and the remaining points are additionally stabilized with permanent signs (geodesic nails) and temporary signs. The coordinates of the new points were determined using classical total station measurements. The next workaround is GCP signaling. Paper marks and paint were used to mark the points (Fig. 3).

(a) (b)

Fig. 3. GCP signals

The route and flight boundaries were fixed using Pix4DCapture and DJI Pilot, which are flight planning and control software. This professional software was used to outline the site, highlight the mapping area and generate flight paths automatically.

Pix4DCapture is a specialized drone flight planning and control software that is compatible with DJI, Parrot and Yuneec series UAVs. It is also widely used for drones specifically designed for agriculture such as Bluegrass and Parrot's Disco-Pro AG. The software has 5 different missions (polygon, grid, double grid, circular and free flight) that are tailored for different purposes.

Three flights were made with Pix4DCapture. The first flight was done with a Grid Mission, where the user defines the dimensions of a rectangle in which the drone will fly along one axis. A flying height of 70 meters is set. As a result of the shooting, 97 photographs were obtained (Fig. 4-a).

For the creation of a 3D model of the building, 2 more flights were made with the selected Circular Mission flight plan, in which a radius of a circle around the object is defined. The flights were made at a flying height of 50 meters. As a result of the shooting, 59 photos were obtained (Fig. 4-b).

(a) (b)

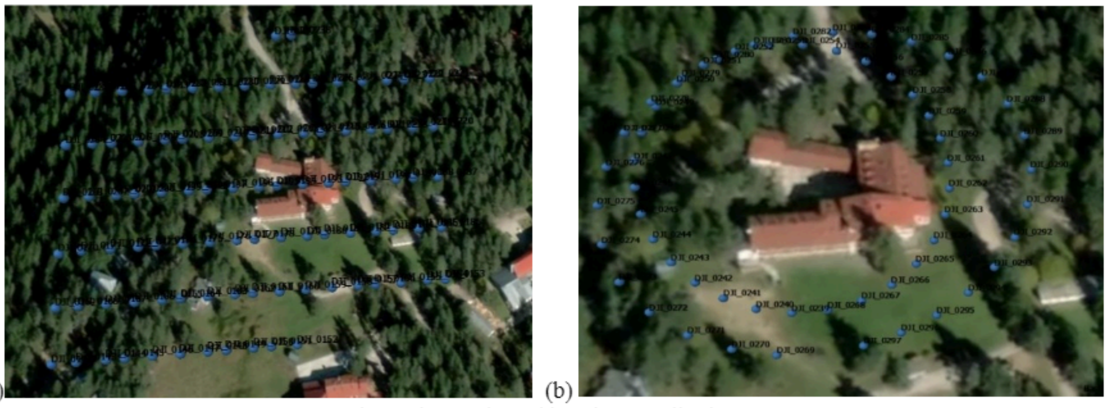

Fig. 4. Photos taken with a Pix4D application

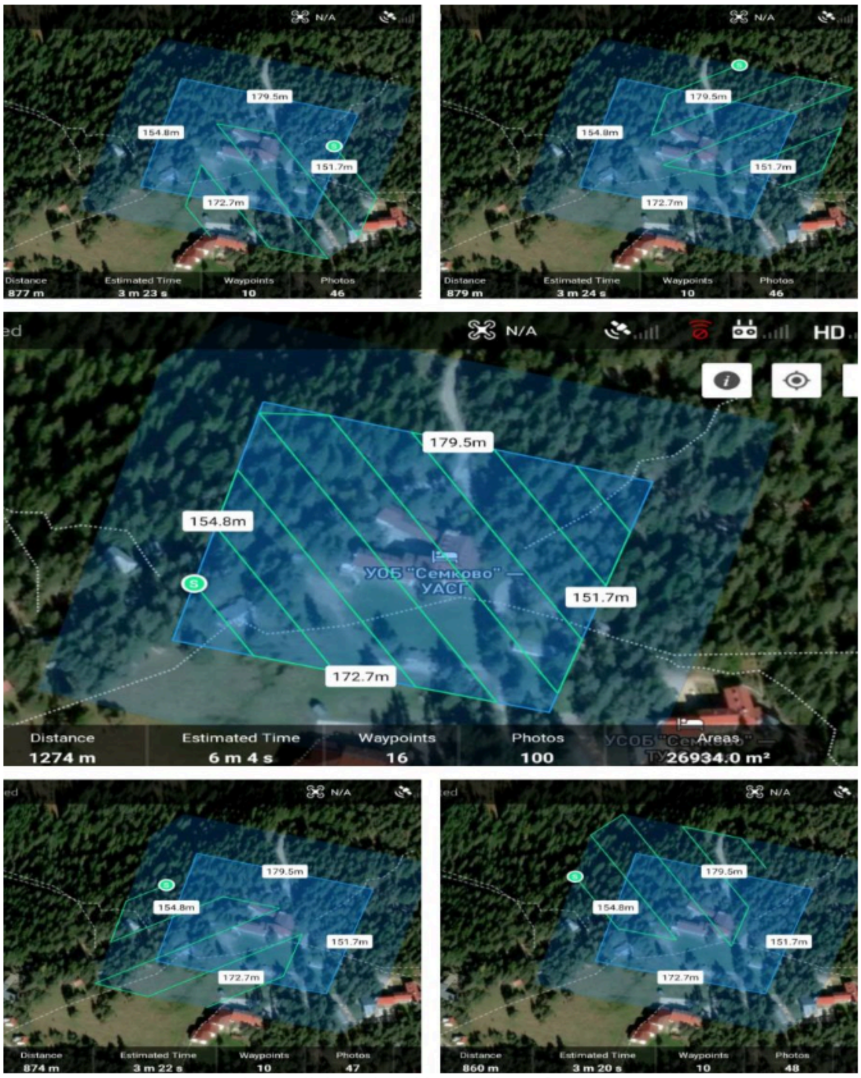

Fig. 5. Flight paths with DJI Pilot software

With the DJI Pilot software application, 5 flights (Fig. 5) were performed at a flying height of 70 meters and an "Oblique" flight plan suitable for 3D modeling of buildings. The first flight is in nadir shooting mode, with the frontal overlap of the shots being 80% and the side overlap being 75%. The remaining 4 flights are at a set angle of 45 degrees of the optical axis of the camera relative to the direction of flight. They have a frontal overlap of 70% and a side overlap of 60%. As a result of this shooting, 188 photos were obtained.

UAS Survey Creating a 3D Model

The first stage of processing is the alignment of the 335 photos to each other. This is an automated process where the software looks for characteristic points in each image and matches them to the rest of the photos.

The camera position for each image is also found. This position is determined by the elements of internal orientation (focal length, distortion and center point) and external orientation (coordinates of the center of photography and angular elements – ω, φ, κ). The external and internal orientation parameters are calculated using automatic aerotriangulation by applying a batch block equation. The result of this stage is a point cloud of tie points of the images and also visualizes the position of the camera for all the images (Fig. 6).

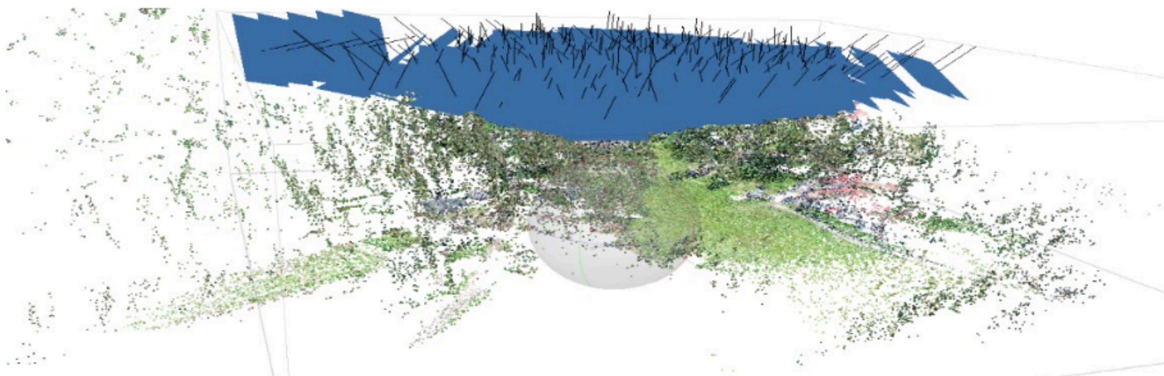

Fig. 6. Tie point cloud and visualizes the position of the camera

Before moving on to inputting and learning the ground control points, a cloud of tie points is clearing should be done to improve the final product. In generating of this cloud, there are many wrongly defined tie points and what we want is to filter and remove them. The following filtrations are applied:

- Reconstruction Uncertainty - High reconstruction uncertainty is typical for points reconstructed from nearby photos with small baseline. Such points can noticeably deviate from the object surface, introducing noise in the point cloud [5];
- Reprojection Error - High reprojection error usually indicates poor localization accuracy of the corresponding point projections at the point matching step. It is also typical for false matches [5];
- Projection Accuracy - This criterion allows to filter out points which projections were relatively poorer localized due to their bigger size[5].

A result is a cloud of points that contains 180 057 points.

The coordinates of the ground control points are entered into the Agisoft Metashape Professional system. Eight of the points in the individual images were recognized (Fig. 7). The total error of all control points is 2.5 cm. Optimization of camera parameters and calculation of rotation and translation matrices, as well as a scale factor for the accurate georeferencing of the cloud, were performed.

The remaining measured GCPs were used to control the obtained results and for this reason their recognition was not done (Fig. 8).

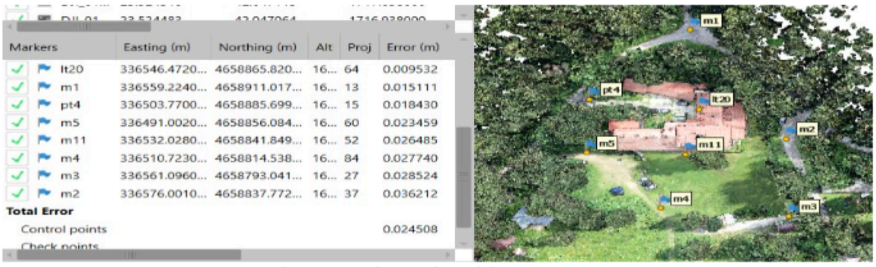

Fig. 7. Entering and marking GCPs

Fig. 8. Checking for unknown GCPs

The most time-consuming process in this processing is the generation of the dense point cloud. Its formation is carried out by calculating the already determined position of the camera and elements of external orientation. The point cloud itself is not a final product, but for some surveying purposes it may be sufficient. It can be said that at this stage we have a fairly detailed point model, which differs from classical methods only in the number of captured detailed points.

The duration of creating the dense point cloud is 1 hour and 25 minutes. It consists of 90 631 660 points that have spatial coordinates and color (Fig. 9).


Fig. 9. Dense point cloud

Point clouds give a full and exact representation of the building geometry [6].

Based on the dense cloud of points, a three-dimensional model of non-overlapping triangles was created, which for better visualization was textured (Fig. 10). A surface spatial object is the outer or uppermost layer of a tangible object or space, as the term is most commonly employed. It is the part of the object that is first experienced by an observer using their senses of sight and touch, as well as the part that interacts with other materials [7].

The difference between a 3D model and a point cloud is that the model is a finished product that can be integrated into GIS or CAD software. With the dense cloud, a large volume of spatial data is available, which has to be modeled yet in order to be integrated into such systems.

At a later stage, after creating the model of the physical object, it is possible to create a building information model (BIM), whose task is to create technical documentation of existing buildings [8].

Fig. 10. Textured 3D model

Quality control

During the field work, control distances were measured on the buildings. After obtaining the 3D model via UAV, control distances were also measured in Agisoft's graphical environment. A total of 38 control distances were measured to evaluate the models. The differences between the control distances and their corresponding measured distances from the 3D model were formed, where possible:

$$\partial S = S - S^{o} \qquad (1)$$

where S^{o} is the distance between 2 points from the model, S – the same control distance.

The mathematical expectation and the root mean square error is calculated and a check for gross errors was made:

Tab. 1. Quality control.

№	Directly measured distances, [m] (1)	3D model - UAV, [m] (2)	Diference, [cm] (1)-(2)
1	1.62	1.600	2.0
2	0.32	0.309	1.1
3	0.89	-	-
4	0.24	-	-
5	0.12	-	-
6	0.88	-	-
7	2.26	-	-
8	0.99	-	-
9	0.29	0.274	1.6
10	1.80	-	-
11	2.07	2.050	2.1
12	1.45	1.440	0.8
13	0.38	0.402	-2.0
14	1.36	1.371	-1.1
15	3.80	3.770	3.0
17	3.35	3.360	-1.5
18	1.53	-	-
19	0.39	0.381	0.4
20	1.46	-	-
21	1.56	1.520	4.4
22	1.56	-	-
23	4.91	4.890	2.0
24	1.51	1.510	-0.4
25	3.56	-	-
26	0.56	0.563	-0.3
27	2.15	-	-
28	1.61	-	-

№	Directly measured distances, [m] (1)	3D model - UAV, [m] (2)	Diference, [cm] (1)-(2)
29	2.09	2.060	3.1
30	3.80	3.790	1.0
31	6.25	6.240	1.0
32	2.06	2.080	-1.7
33	7.15	7.160	-1.0
34	1.23	1.230	-0.3
35	3.71	3.680	3.0
36	2.23	2.220	1.0
37	2.00	2.020	-2.0
38	2.74	2.750	-1.0
		Mx=	0.7
		mx=	1.9
		3mx=	5.8

$$M_x = \frac{1}{n}\sum_{1}^{n} \partial S_i \quad (2)$$

$$M_x = \frac{1}{n}\sum_{1}^{n} \partial S_i \quad (2)$$

$$m_x = \sqrt{\frac{\sum_{1}^{n} \partial S_i^2}{n}} \quad (3)$$

The results are given at Table 1.

Conclusion

Collecting geospatial information with the UAV and coordinating the GCP took 3.5 hours. The office work that was needed to create the 3D model is 4 hours. The model was created based on the cloud, which contains 90,631,660 points.

UAVs have their advantages in the process of collecting spatial data. Compared to classical methods, the duration of aerial photography is a much shorter process, a team of many people is not needed, and for small areas, processing does not take a long time. The process of making the 3D model is automated and includes minimal human resources.

The results show that collecting geospatial data of buildings in forest areas with the help of UAVs has its disadvantages (Fig. 11), caused by the difficulty of photographing the hidden facade elements. In forested areas where evergreen tall vegetation predominates, there are many areas that remain hidden and cannot be photographed using this method.

Fig. 11. Disadvantages of 3D models obtained by aerial photography with a UAV

Using a UAV alone is not sufficient to obtain a complete 3D model, due to the difficulty of capturing the hidden facade elements. A high-quality and complete model can be created by a combination of several methods - aerial surveying with UAV and classical methods or laser scanning.

At a later stage, the data from the created models can be entered into a GIS environment. GIS are used very often for data presentation and analysis, to support decision-making in management, to monitor development and identify changes in the urban environment [9]. The use of GIS for such research is to represent the change of the urban environment through the use of two-dimensional and three-dimensional modeling, as well as spatio-temporal analyzes [10].

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