



## Assessing the spatial accuracy of UAV-derived products based on variation of flight altitudes

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### Keywords

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### ABSTRACT

Unmanned Aerial Vehicles (UAVs), which can carry a variety of payloads, and be operated automatically or manually with ground control stations. Nowadays, UAVs can make photogrammetric flight plans and obtain photogrammetric data with existing sensor systems. Automatic data acquisition processes provide lower cost, and high spatial and temporal resolution images in a short period of time compared to other measurement methods. As a result, orthomosaics, dense point clouds and digital surface models (DSMs) are produced and these UAV-derived data are used in various disciplines such as constructions, geomatics, earth sciences, etc. In this study, the same flight plans were realized with an UAV at different altitudes and all aerial images were obtained with the same integrated digital camera. As a result of the processing of images acquired from different altitudes, orthomosaics, DSMs and point cloud were produced. In this study, it is aimed to compare the length, areal and volumetric differences of a small geostationary object. Ground control points (GCPs), which were collected by RTK-GPS (Real-Time Kinematic) in conjunction with the flight integrated into data production process in order to highly accurate product. Ultimately, cross-correlation has been done with the produced data and the terrestrial measurement. Results show that the dimension of the object depend on the flight altitude as expected, however the volumetric changes vary due to the uncertainties in the raw point cloud data.

## 1. INTRODUCTION

Unmanned aerial vehicles (UAVs) can produce surface data with low cost, temporal and spatial resolution data compared to terrestrial and remote sensing methods. UAVs can provide a lot of information related to the surface with the various sensors they have or can be integrated. When UAVs photogrammetric techniques are also compared with satellite and aerial survey, UAVs can provide very high resolution data quickly with high accuracy and low cost (Akar 2017; Eltner et al. 2017; Psirofonia et al. 2017; Thumser et al., 2017).

UAV photogrammetric studies can be performed with automatic or semi-automatic flight plans. Aerial photographs overlapping with flight plans are obtained and photogrammetric processing steps are performed. Point cloud, orthomosaics and DSMs are produced rapidly and accurately by taken photographs from UAVs, dimensions of objects and surface are performed so that information about surface and objects can be obtained (Pérez et al. 2013; Tampubolon and Reinhardt 2015).

DSMs and 3D object models were produced with high accuracy as a result of processing aerial photographs obtained with UAV, which were used to model historical artifacts and calculate the volume of the earth surface (Ulvi and Toprak 2016; Ulvi 2018; Şasi and Yakar 2018). The dimensions of measurements can be performed with different data obtained at different altitudes with UAVs. The area and volume of the objects on the surface can be calculated with the point cloud, DSM and 3D models produced with and without GCPs. Therefore, the measured values of dimensions are very close to the actual values. It was observed that the differences vary according to the objects. In addition, the error values of large objects were found to be in the order of centimeters. As a result of the volumetric analysis, it could be seen that similar results were obtained in the point cloud. In addition, it was seen that the volumetric measurements could be obtained close to the actual values in the analyzes performed with the 3D models. (Akay and Ozcan 2017; Ab Rahman et al. 2017; Stalin and Gnanaprakasam 2017).

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Therefore, UAVs can provide data at any time within specified flight rules and weather conditions. The combination of terrestrial control points and UAV data enables high accuracy data generation. However, with the new generation UAV with PPK (Post-Processed Kinematic), or RTK (Real-Time Kinematic) system, no ground measurements are required to produce high resolution data. Recent studies showed that when the photogrammetric studies performed with UAVs, point cloud data, orthomosaic and DSM can be produced. Therefore, environmental and temporal change analyzes can be performed (Akay and Ozcan 2017; Eltner et al. 2017; Ozcan and Akay 2018a; Ozcan and Akay 2018b Rusnák et al. 2018).

## 2. STUDY AREA

In this study, UAV flight altitudes have been changed to investigate the accuracy of UAV data and the changes in the dimension of the small green objects was examined (Fig. 1). The study was carried out with a green box in the form of a rectangular prism of small size located on river drainage system. The study area is located in the Büyük Menderes basin located within the borders of Aydın province in the Aegean Region. Figure 1 shows the associated study area on the river drainage system and the ground control points (GCPs) used in the study.



**Figure 1.** Aerial photo of the study area and GCPs

## 3. DATASETS and METHODS

In the study, different data were produced by performing flights with an UAV and these data were compared with the actual dimension, area and volume

measurements of an object. The flowchart of the processing steps is shown in Figure 2.

UAV flights were performed according to the same flight plan parameters at different altitudes. The DJI Phantom 3 Pro UAV used in the study, which has an

integrated GPS / Glonass system and a 12.76 MP digital camera, is about 1.5 kg. When the integrated digital camera specifications are examined, it has FOV 94°20 mm (35 mm format equivalent) lens, ISO Range is 100-1600 for photographs and image size of camera is 4000×3000. UAV flights were performed at altitudes of 10 m, 40 m, 70 m and 100 m. Table1 shows the UAV flight

parameters and the errors of each flight performed at different altitudes. Flight plans were made according to the legal limits and environmental factors (power pole, tree, base station, etc.). Depending on the coverage area, as the flight altitude increased, the number of photographs decreased and 117 images were acquired in the study area.

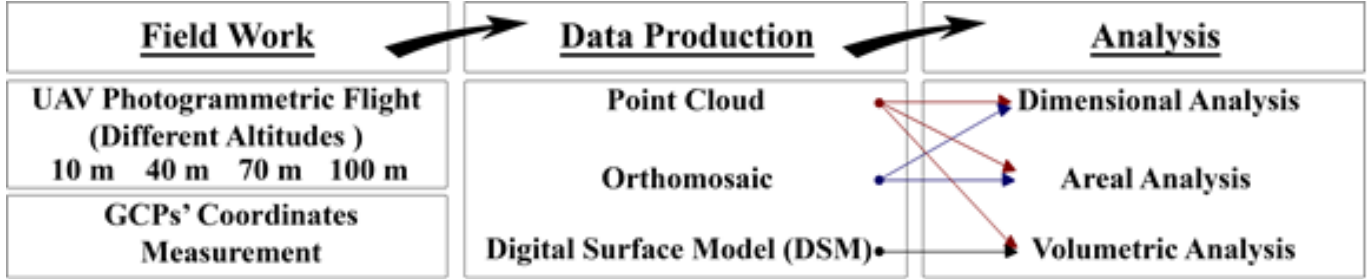


Figure 2. Flowchart of the processing steps

Table 1. Specifications of the UAV data

Flight Alt. (m)	# of images	Overlap ratio (%)	# of GCPs	Image coord. error (pix)	RMSE (m)
10	59	85-85	4	0.203	0.009
40	31	85-85	4	0.192	0.006
70	15	85-85	4	0.190	0.014
100	12	85-85	4	0.198	0.021

GCPs were homogeneously selected from the corners of the study area and the GCPs' coordinate measurements were performed by RTK method after the UAV's flights. GCP measurements were combined with UAV-derived data processing to produce data with high accuracy. Table 2 shows the coordinates of the measured GCPs.

Table 2. Coordinates of the GCPs

GCP #	X (m)	Y (m)	Z (m)
1	530573.296 ± 0.026	4151401.272 ± 0.026	39.385 ± 0.026
2	530573.206 ± 0.026	4151393.874 ± 0.026	39.321 ± 0.026
3	530555.596 ± 0.032	4151393.286 ± 0.032	39.279 ± 0.032
4	530555.949 ± 0.026	4151400.648 ± 0.026	39.285 ± 0.026

The X, Y and Z coordinates of objects in aerial photographs were calculated with GCPs, external orientation parameters and key points after the bundle block adjustment. Then, the root mean square error (RMSE) values were calculated by square root of the sum of the error of each point (ei) divided by total number of GCPs (N) in all directions for each flight to produce data with high accuracy (Eq. (1) (Pix4D 2020). The calculated RMSE values are shown in Table 1. Besides, the image coordinate error values were less than half pixel value.

$$RMSE = \sqrt{\frac{\sum_{i=1}^N (ei)^2}{N}} \quad (1)$$

In this study, point cloud, DSMs and orthomosaics were produced from the images obtained by an UAV. The length, areal and volumetric dimensions of the small green object in the point cloud, DSM and orthomosaic were compared with the actual dimensions of the object measured locally. Nowadays, UAV photogrammetry method provides low cost and time advantage compared to remote sensing techniques. The UAV photogrammetry method allows the production of high resolution point cloud, DSM and orthomosaic data from sequential series of photographs with the Structure-from-Motion (SfM) method. The SfM method enables the matching of objects in the UAV's images by arranging the camera parameters and their positions. By matching the objects in the images and generating the tie points, a sparse dense point cloud

is produced. Dense point cloud is produced by densification of sparse point cloud data. As a result of producing three dimensional polygon network model with dense point cloud, DSM and orthomosaic productions are realized respectively (Snively et al. 2008). Prior to the image matching process, GCPs, which are measured in the study area are integrated into the system for each flight at different altitude to produce highly accurate last product. Table 3 shows the specifications of the data produced at different altitudes in the study. The actual length measurements and area values of the upper surface of the green box object were calculated and compared with orthomosaics and point cloud data. However, both the length and area values were calculated by calculating the upper surface length measurements of the green box over the orthomosaics. In the point cloud data, lengths were calculated by taking sections on the point cloud data of green box in order to determine the width and length measurements of the green box.

In the point cloud data, lengths were calculated by taking sections on the point cloud data of green box in order to determine the width and length measurements of the green box. Comparisons of actual length and area values were made with different data produced with different UAV flight altitudes. Figure 3 shows cross and length sections of point cloud data produced at different altitudes. It was seen that the small size of the object cannot keep its rectangular shape as the UAV flight

altitude increases and the rolling of the edges starts in the point cloud data. Therefore, it was seen that differences occur in each measurement.

**Table 3.** Dataset resolutions and point cloud densities of each flight plan

Flight Alt. (m)	Dense of Point Cloud (m <sup>3</sup> )	DSM Spatial Res. (m)	Ortomosaic Spatial Res. (m)
10	348395.00	0.004	0.004
40	6233.86	0.018	0.018
70	1026.81	0.031	0.031
100	383.10	0.044	0.044

The width, length and area calculations performed on the point cloud and orthomosaic data produced with images obtained at different altitudes were shown in Table 4. When the actual width and length of the green box were compared with orthomosaic and point cloud data, it was observed that the error value was increased with the altitude of flight. However, the error value was found to be between 0.1 and 2.4 cm. In addition, it was observed that the data at consecutive altitude had closer measurements. Besides, the width and length measurements obtained from point cloud data had closer values to orthomosaic measurements.

When the area measurements of the object were compared, it is seen that the data of the flight performed at an altitude of 10 m gave a closer result to the actual size. In addition, when the areal values of the data produced from different altitudes were compared, it was seen that they had differences between 0.34% and 3.7% proportional to the actual dimension. In areal measurements, it was observed that point cloud data approached actual measurements more than orthomosaic data. As a result, it was seen that the closest value to the actual areal value belongs to the point cloud obtained at an altitude of 10 m as expected.

The actual volume value of the green box was compared with the point cloud and DSM data of different altitudes. Figure 4 shows DSM and orthomosaic images of the green box produced at different altitudes.

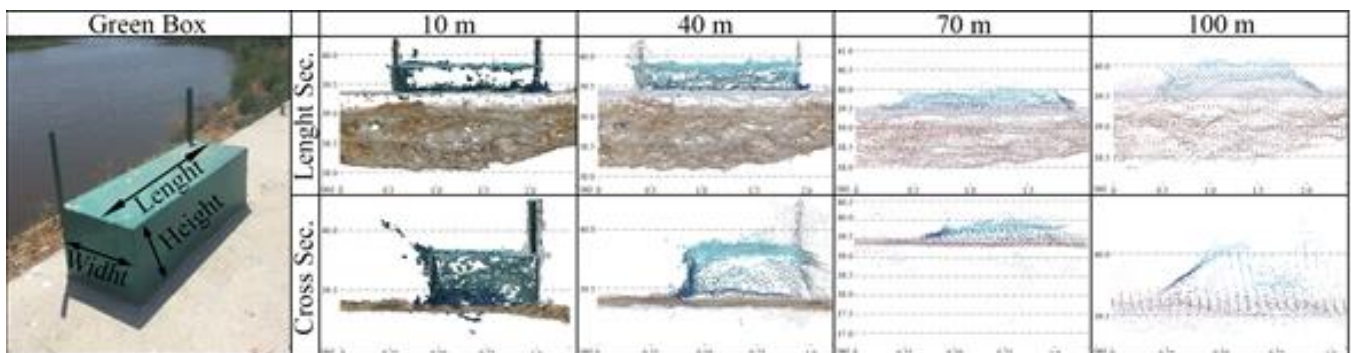
It was observed that the small size of the object could not keep its quadrilateral shape and the height of the object decreased with increasing UAV flight altitude.

The volume calculations of the point cloud and DSM data of different altitude and the differences between the actual volume value were shown in Table 5. When the volume values of the green box were examined, it was seen that the error value of the volume value increased as the altitude of flight increased and this error value was between -32,262 cm<sup>3</sup> and 186,948 cm<sup>3</sup>. The closest value to the actual volume values was found in the point cloud and DSM data of the flight performed at an altitude of 10 m.

When the actual volume values and the point cloud data produced from different altitudes were compared, the error rate were varying between 7% and 17%, respectively. This value was found to be between 13% and 46% actual value and DSM data, respectively. When the volume values were compared, it was seen that the point cloud data gave more accurate values than the DSM data. Volumetric differences between the two data varied between 88,257 cm<sup>3</sup> and -136,812 cm<sup>3</sup>.

Figure 5 shows the change of the areal and volumetric values of the green box with graphs. As the areal measurements are examined, it could not be seen that there was a decrease or increase in direct proportion with altitude between the actual value and the point cloud and orthomosaic measurements. In the orthomosaic data at an altitude of 40 m, the areal value above the actual value was obtained. Similarly, the areal value in the point cloud data obtained at an altitude of 70 m was seen as a value above the actual value. In addition, it was observed that the point cloud data were found to be closer to the actual areal value than the orthomosaic data.

The volumetric analysis results showed that both the point cloud and DSM data have different values compared to the actual volume value as the altitude increases. The volumetric values at 10 m altitude were higher than the actual measurements in both data types.



**Figure 3.** Representation of cross and length sections of point clouds

**Table 4.** Dimensions and area values of orthomosaic and point cloud

Flight Alt. (m)	Orthomosaic						Point Cloud					
	Width (cm)	Length (cm)	Area (cm <sup>2</sup> )	$\Delta l$ (cm)		$\Delta S$ (cm <sup>2</sup> )	Width (cm)	Length (cm)	Area (cm <sup>2</sup> )	$\Delta l$ (cm)		$\Delta S$ (cm <sup>2</sup> )
				$\Delta W$	$\Delta L$					$\Delta W$	$\Delta L$	
Actual Dim	55.0	153.5	8,442.50	-	-	-	55.0	153.5	8,442.50	-	-	-
10	54.4	152.9	8,317.76	-0.6	-0.6	-124.74	54.6	153.6	8,386.56	-0.4	0.1	-55.94
40	55.8	152.8	8,526.24	0.8	-0.7	83.74	54.6	153.2	8,364.72	-0.4	-0.3	-77.78
70	53.7	151.3	8,124.81	-1.3	-2.2	-317.69	56.5	152.4	8,610.60	1.5	-1.1	168.1
100	53.7	150.9	8,103.33	-1.3	-2.6	-339.17	53.4	150.6	8,402.04	-1.6	2.9	-40.46

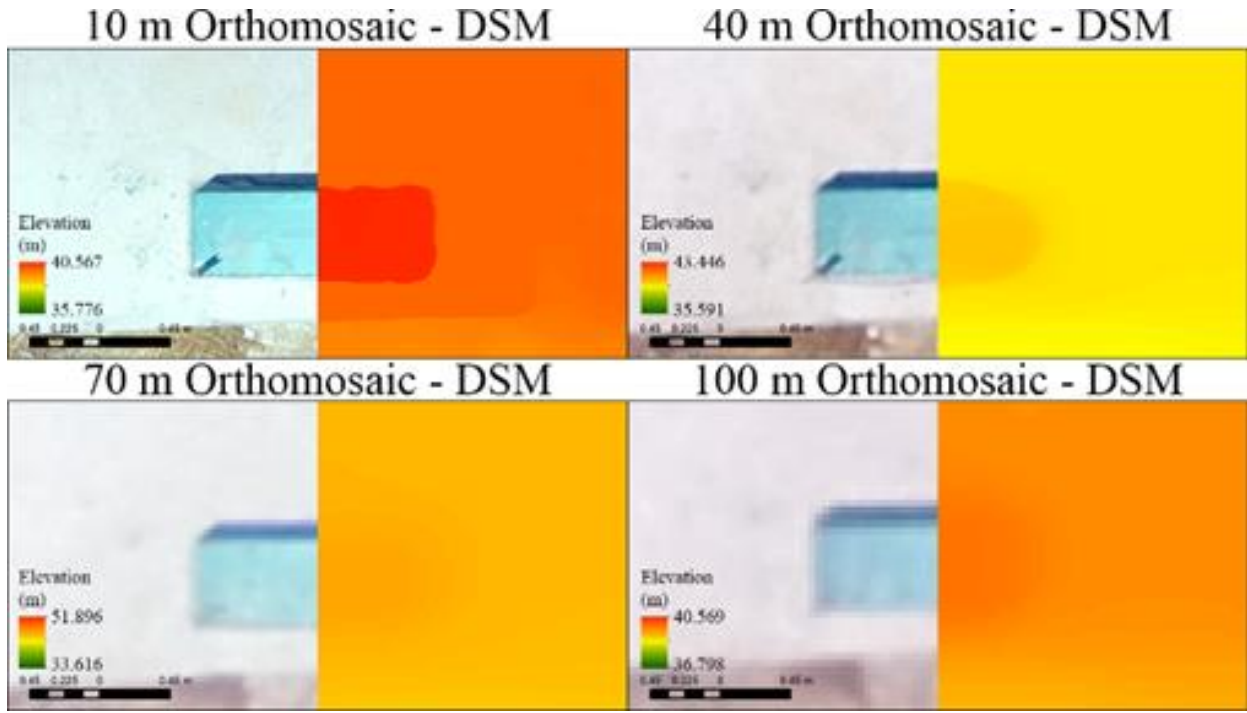


Figure 4. Representation of green box with orthomosaic and DSM data

Table 5. Volume values of point clouds and DSMs

Flight Elevation (m)	Point Cloud		DSM		PC-DSM (cm <sup>3</sup> )
	Volume (cm <sup>3</sup> )	$\Delta V$ (cm <sup>3</sup> )	Volume (cm <sup>3</sup> )	$\Delta V$ (cm <sup>3</sup> )	
Actual Volume			404,395		
10	436,657	32,262	460,390	55,995	-23,733
40	388,612	-15,783	286,180	-118,215	102,333
70	351,233	-53,162	240,900	-163,495	110,333
100	339,400	-64,995	217,447	-186,948	121,953

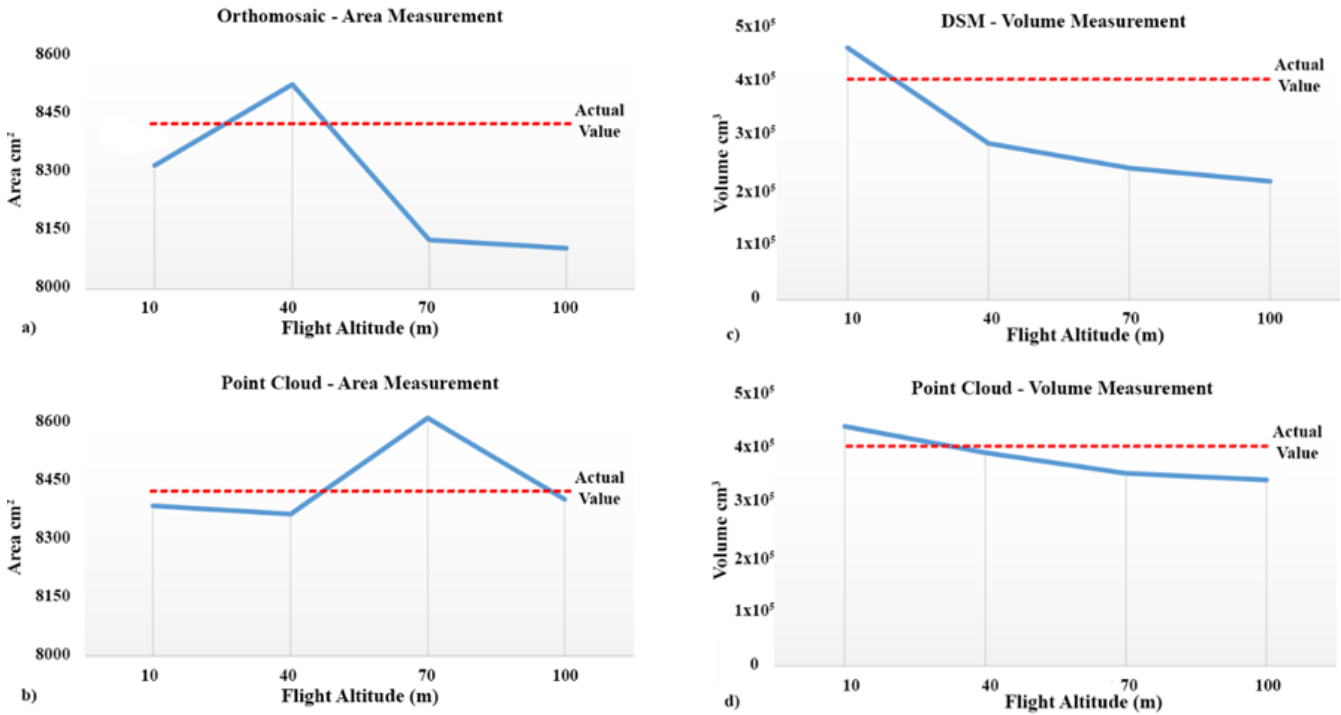


Figure 5. Change graphs of measurements depending on UAV altitude; a) Orthomosaic - area measurement, b) Point cloud - area measurement, c) DSM - volumetric measurement, d) Point cloud - volumetric measurement

5. CONCLUSION

In this study, the actual width, length, area and volume values of a fixed small green box on the river drainage system were compared with the data obtained

from UAV flights at different altitudes. Point cloud, DSM and orthomosaic data of the green box were produced in order to make comparisons between different data models and to analyze width, length, area and volume

value. Herewith, in the comparison of UAV-derived dimensions with the actual values, it was observed to be similar in all flights. However, the best volumetric similarity achieved only at the lowest flight altitude. As flight altitude increased, it was seen that the volume values were distant from the actual value. Besides, it has been found that small objects could not keep their shape as the flight altitude increases. It can also be evincible that the point cloud data maintain the object shape better the DSM.

Consequently, UAV data can be used in width, length and area calculations of small objects, but UAV-derived point cloud data should be purified before using in volumetric calculations depending on the error rate determined in centimeters. Recently, UAVs were used in various projects instead of the traditional photogrammetry methods due to their low cost, practicality and capabilities. In the near future, it is not hard to estimate that UAVs will allow users to get last products without any uncertainties with the development of various payloads and processing techniques.

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