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Investigation of the effects of different flight parameters on the accuracy of DEM generated using UAV systems

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Keywords
UAV
Orthomosaic
DEM
Rolling Shutter

ABSTRACT

Unmanned Aerial Vehicles (UAVs), can be controlled automatically or with the help of a remote control system, provide high spatial and temporal resolution images in addition to its advantages in terms of cost and time. Due to these features, UAV's have been widely used in studies such as map production, 3D modeling and volume calculation in recent years. In this study, it is aimed to investigate the effects of different flight parameters on the accuracy of Orthomosaic and DEM produced with UAV Systems. In addition, the rolling shutter effect and the use of pre-calibrated and automatic camera calibration parameters were also tested. For this purpose, a total of seven UAV flights were carried out at different heights, overlap ratios, angles and grids at a mining area located within the borders of Aksaray province. Agisoft MetaShape and Pix4D Mapper, which are widely used commercial software, were used to process the UAV images. In this study, 27 points were established and 3D coordinates of these points were measured using GNSS technique. 15 of these points were used as reference points and the remaining 12 points were used as check points. Accuracy analysis was performed by comparing the produced Orthomosaics and DEMs with the check points in the study area. CloudCompare and ArcGIS software were used in the comparison of the products as a result of the evaluation of the images. It is concluded that the Orthomosaics produced using 45^0 angle and DEMs with 60^0 angle has higher accuracy than the others. Point clouds and DEMs' produced using automatic and pre-calibrated camera calibration parameters show that the pre-calibrated images provide higher accuracy. Also, it is seen that when the rolling shutter effect is modeled, the horizontal and vertical accuracy is increased in all three flights with different flight parameters in this study.

1. INTRODUCTION

Unmanned Aerial Vehicle (UAV), whose usage area has become more and more widespread in recent years; It is an aircraft that does not physically have a pilot or a passenger, can only carry measurement equipment such as a camera, laser scanning device, video camera, GNSS (Global Navigation Satellite System) and completes its flight automatically or remotely (Döner et al., 2014). Today, UAV platforms have become an important data source that allows inspection, surveillance and analysis for different disciplines and different application areas in photogrammetric data production (Psirofonia et al., 2017; Makineci and Karasaka, 2021). The use of UAVs for civilian purposes, which were primarily developed for military purposes, has been after the Second World War with the development of technology, and the first and most important regulation of air transportation was signed as a result of the Chicago Conference in 1944 and includes regulations related to civil aviation (Coşkun, 2020). In Turkey, legal regulations regarding UAVs were prepared by the General Directorate of Civil Aviation on February 22, 2016 (SHT-FCL, 2019).

With the developing photogrammetric sensor, platform and remote sensing technologies, UAV has become an increasingly common platform, as it provides low cost, high spatial and temporal resolution opportunities compared to conventional aerial photogrammetry (Akay and Özcan 2017; Şasi

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and Yakar 2018). Today, although UAVs usage for military, security and intelligence purposes still continues, since they can be easily used for civilian purposes and to reach up-to-date data fast and more economical way, they make important contributions to disciplines such as geomatic, mining, geology, civil and environmental engineering, and are also widely used for scientific purposes. UAVs; used in many technical areas such as in cartography (Orthomosaic production, digital terrain model (DTM), digital elevation model (DEM), excavation-filling calculations, area-volume calculations, etc.), observing environmental change, monitoring of weather conditions, observation of coast and coastline, detection of mining areas, agricultural applications (land classification, soil analysis, determination of crop productivity), monitoring of natural disasters, archaeological studies, architecture and landscape studies, 3D city modeling, city silhouettes and hobby areas such as creating movies, filming and sports activities (Çömert et al., 2012; Coşkun, 2020; Makineci et al., 2020a; Makineci et al., 2021).

Three-dimensional object/surface model of the ground, DEM and orthomosaics produced by UAVs are used in various studies (Ozcan and Akay, 2018; Ulvi and Toprak, 2016). The development in the field of photogrammetry led to the emergence and development of the concept of 'Digital Photogrammetry' in the early 1990s as a continuation of analog and analytical photogrammetry. In this process, vector contour lines and DEMs with higher quality and resolutions have replaced the contour lines on the printed topographic maps. DEM, which is defined as the digital representation of topography, is a suitable structure to show the constantly changing topographic surface of the earth (Gündoğdu, 2003). The fact that three-dimensional models, DEMs and orthomosaics that can be obtained quickly from UAVs are a general data source for hydrological, geomorphological and other three-dimensional applications and the widespread use of digital topographic data reveals the importance of these data (Moore et al., 1991; Thomson et al., 2001; Makineci and Karabörk, 2016; Karabörk et al., 2021).

As DEMs are a stand-alone product, DEMs produced are also used in geodetic and photogrammetric data collection, editing and correction, Orthomosaic production, and topographic map production (Erdoğan and Toz, 2009). With the produced DEM data, volumetric change analyzes can be evaluated in terms of temporal and spatial, in addition, length and area calculations of the surface and temporal change analyzes can be performed with high accuracy with orthomosaics and three-dimensional object/surface model data (Moore et al., 1993; Eltner et al., 2017; Rusnák et al.,2018; Akay et al., 2021).

Within the scope of this study, it is aimed to determine the effects of flight heights, camera angles, overlap ratios and grid sizes on the accuracy of orthomosaics and DEMs produced by UAV photogrammetry. In addition to that, the effect of rolling shutter and pre-calibrated camera calibration parameters were tested in different flights within the scope of this study.

2. MATERIAL and METHOD

2.1 Study area

Within the scope of this study, an open mine of approximately 15 hectares was selected as a study area in the town of Ortaköy, Hacımahmutuşağı (E:38° 44', B:33° 56'), located approximately 40 km northeast of Aksaray city (Figure 1). The determined area is a marble area and there are cut and filling sections. In the area chosen as the study area, the elevation values vary between 1409 m and 1444 m, and the height differences are approximately 35 meters.

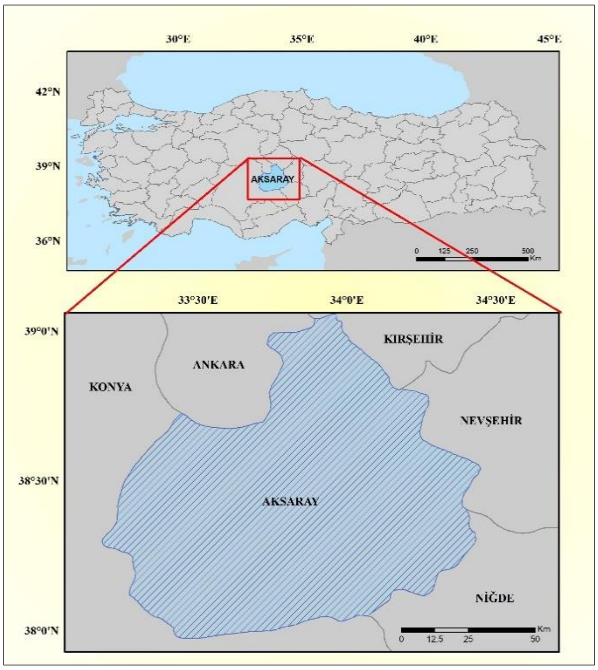

Figure 1. Study area

The absence of wooded areas and high voltage lines in the study area provided convenience in UAV measurements. In the marble field selected as the study area, there are 662812.5 m^3 filling area, 69511.14 m^3 splitting area, 9107,322 m^2 stock area, 17103 m^2 factory area and 173.171 m^2 construction site.

2.2 Establishment of Ground Control Point (GCP)

GCPs homogeneously distributed over the work area are needed in order to calculate the interior and exterior directions of the photographs taken by the UAV, to test the accuracy of the outputs to be produced, and to define them in a reference system. GCPs are established in areas where the topography changes rapidly (>50m), with a maximum distance of 250 m between the points. Twenty-seven GCPs established in the study area were measured using a dual frequency CHC-I80 GNSS receiver with Network-RTK method in ITRF96 datum in UTM 33-3 coordinate system. In addition, twelve points selected homogeneously from twenty-seven GCPs were used as check points in the image processing steps.

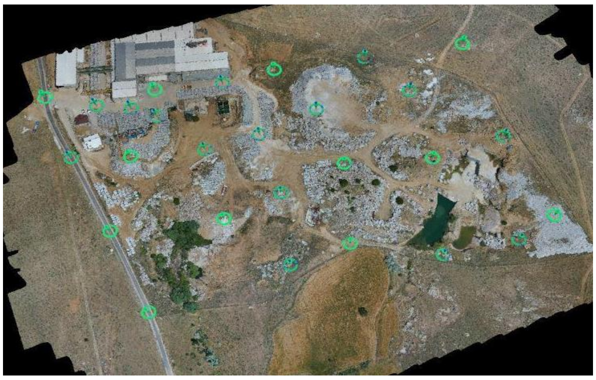

Figure 2. Location of the GCPs in the study area

In order to increase the visibility in the photographs obtained by using the UAV, the control points were prepared as a light and 20 × 20 cm square on a dark background and a rectangle with a width of 20 cm and a length of 40 cm, 20 cm away from the square (Figure 3). GCPs have been installed in open areas and care has been taken to ensure that there are no obstacles such as buildings or trees within this cone of vision.

Figure 3. Example of the GCPs established in the study area

2.3 UAV Flights

Within the scope of the study, Mavic II UAV was used for point cloud, DEM and orthomosaic production by performing UAV flights with different altitude, angle, overlap ratios, single and double grid (DG).

During the preparation stage before the flight, the settings of the camera integrated into the UAV were made, the path to be followed by the UAV within the working area boundaries was determined, and the images of the working area were obtained by performing the flights according to the previously determined flight plans. In addition, all flights in the study area were completed on the same day to minimize the sunlight effect (Öztürk et al., 2017; Akay et al., 2021). The properties of the images taken at different angles, heights and overlap ratios of the study area are shown in the Table 1.

Table 1. Flight parameters and number of images used in the study

Flight No.	Altitude (m)	Overlap ratio	Angle (°)	Num. of images
1	120	%80 %60	90	123
2	100	%90 %70	90	456
3	100	%80 %60	90	171
4	100	%80 %60 (DG)	90	527
5	100	%80 %60	45	400
6	100	%80 %60	60	236
7	Free flight			169

As a result of 7 UAV flights carried out with different parameters in the study area, approximately 2,000 images were taken.

2.4. Image processing and validation

There is many software for photogrammetric evaluation of high resolution images obtained from UAVs. However, evaluating a large number of images obtained using UAVs with classical photogrammetric approach software is a time-consuming and difficult task. For this reason, as a result of the developing technology, more advanced software has been used in recent years. In the process of UAV images, using the Structure from Motion (SfM) algorithm, high resolution point clouds, DEMs and orthomosaics are produced from consecutive serial photographs (Akay et al., 2021). Classic photogrammetry techniques require high-precision 3D position and orientation parameters of the camera and GCPs in order to create a geometric model. However, in SfM algorithm, model geometry, camera position and orientation parameters are solved simultaneously and automatically (Atak, 2018).

The SfM method ensures that the photos obtained with UAVs are matched according to the characteristics of the objects in the photos by arranging the camera parameters and their positions. First of all, a low-density point cloud is produced with the objects matched in the photographs, and dense point cloud is produced by compacting the points in the less-dense point cloud data. Mesh, DEM and orthomosaic productions are performed on the dense point cloud, respectively (Snavely et al., 2008). In this study, Pix4D Mapper and Agisoft Metashape software were used to evaluate the obtained images and produce point clouds, orthomosaics and DEMs. During the preliminary evaluation processes, camera calibration and external orientation parameters are calculated using the SfM algorithm, and these orientation parameters were used as input parameters in the production of the outputs. In addition, Cloud Compare and ArcGIS software were used for the compare the generated photogrammetric products with GNSS points.

Camera calibration is more common today due to the widespread use of digital cameras and their use in the field of computer vision along with photogrammetry. In the past decades, while all of the calibration process steps were done manually, many process steps such as creating the calibration field and calculations are done automatically with the advanced software used today. The accuracy of camera calibration directly affects the process of extracting accurate information from photographs and producing reliable 3D models. For this reason, it is aimed to be done with the highest possible accuracy (Özdemir ve Duran, 2017). In this study, in addition to investigating the effect of different flight parameters of the produced photogrammetric outputs, in order to determine the effect of camera calibration parameters on the produced point cloud and DEM, first of all, the images of Flight 3 (Table 1) were evaluated in Agisoft MetaShape software and the camera calibration parameters were obtained automatically. Afterwards, camera calibration parameters were determined as a result of photogrammetric triangulation using images of flights at different heights (120m, 100m and free flight) and then, these calibration parameters were used as pre-calibrated values.

In the validation step, horizontal and vertical root mean square error (RMSE) of the orthomosaics and DEMs' calculated using Equation 1 and 2 given below as;

$$\mu_{xy} = \sqrt{\frac{\mu_x^2+\mu_y^2}{2}} \quad (1)$$

$$\mu_z = \sqrt{\frac{\sum \Delta z_i^2}{n_z}} \quad (2)$$

Where, Δz is the difference between reference coordinates of check points and calculated coordinates of check points, n_z is the number of check points used. Adjustment results of the flights obtained through Pix4d Mapper quality reports.

In point cloud comparison, CloudCompare and coordinates of the GNSS points was used to obtain mean distances and standard deviations (std.) between products. First of all, the point cloud to be compared and the point file or other model to be compared with this point cloud are imported into the software regarding the same coordinate frame. After both data are imported, first the approximate distances and then the signed distance and standard deviation values can be calculated over the software interface. As a result of these steps, histograms and bars reflects the difference between products can be produced according to the user's request.

In the DEM comparison, ArcGIS' "raster calculator" tool was used to extract elevation values from DEMs and match all these values with GNSS points. After that, vertical rms values of DEMs' are calculated using Equation 2.

In particular, cameras that are integrated with commercial UAVs and cannot be separated are generally low-cost and low-power sensors are used. These cameras cause a disadvantage called rolling shutter. This effect distorts the images of moving objects, causing the entire image not to be perceived at the same time (Ait-Aider, et al., 2006). The effect in question increases even more when the UAV is exposed to more vibration, so it is not suitable to fly especially in heavy wind conditions. The rolling shutter effect is a compelling reason for creating 3D models of moving objects. Even if the displayed object or area is stationary, the fact that the UAV is in motion still causes this effect (Vautherin, et al., 2016). However, the latest developments in the SfM software used allow to obtain sufficient accuracy with these cameras by modeling this effect (Raczynski, 2017). Therefore, in order to reveal the impact of the rolling shutter effect on the images, this effect was tested using flights with different heights and grid ratios within the scope of this study (Table 4).

3. RESULTS and DISCUSSION

The orthomosaics and adjustment results of the quality reports, obtained as a result of the evaluation process of the study using Pix4d Mapper were compared with the coordinates of 12 check points measured using GNSS technique, and their horizontal and vertical accuracies were obtained (Table 2). Then, "raster calculator" tool of ArcGIS software was used to calculate the differences of the DEMs' and 12 check points measured with GNSS and results of these analysis is also given in Table 2. In addition to the 7 flights were performed in the study area within the context of this study, 60^0 and 90^0 angled flights with 100 m and 80x60 overlapping ratio were combined together and re-evaluated. The results from this re-created flight obtained as a result of the accuracy analysis in both horizontal and vertical components with rms values are presented in Table 2. Also, point clouds that produced from images with different flight parameters processed in Pix4D Mapper software were compared using CloudCompare with the coordinate values obtained from 1300 points measured using Network-RTK GNSS technique in the study area (Table 3).

Table 2. Position accuracy of photogrammetric products produced using different flight parameters

Flight Parameters				Orthomosaic (cm)	Adjustment results			DEM (cm)
FN	Altitude (m)	Overlap (%)	Angle (°)	RMS XY	RMS X	RMS Y	RMS Z	RMS Z
1	100	80x60	90	2.30	1.63	2.83	4.60	5.30
2	100	80x60 DG	90	2.03	1.69	2.32	4.39	5.84
3	100	80x60	45	1.52	1.68	1.32	3.06	5.27
4	100	80x60	60	1.82	1.38	2.17	3.93	3.87
5	100	90x70	90	1.49	1.33	1.61	4.14	5.42
6	120	80x60	90	1.94	1.23	2.45	3.24	5.86
7	100	80x60	60-90	1.67	1.63	1.69	3.45	4.84

When the Table 2 is examined, it is seen that the orthomosaics produced from using 90x70 overlap ratio gives the best results in orthomosaics. Also, results of the flight of 45^0 angle are close to 90x70 overlap ratio results with only a difference about 3 mm. In Table 2, values in the quality report of the adjustment results of the flights indicate that, flight 3 with the 45^0 angle images used while processing has higher accuracy than the others in both Y and Z component. When the rms values obtained by comparing the DEMs with the 12 check points are examined in Table 2, it is seen that unlike the orthomosaic and quality reports, the DEM produced from photographs 60^0 angle flight, gives better results than the DEM produced from photographs taken at a 45^0 and 60^0-90^0 angle and other flight parameters.

When the results obtained from this study are compared with similar studies in the literature, in Öztürk et al., (2017), orthomosaics produced from photos taken at a 45^0 angle were found to have higher accuracy. In this respect, the results obtained from the two studies are in agreement. When the accuracy values of the DEM are examined, it is seen that the accuracy decreases as the flight altitude increases and more accurate results are obtained as the overlap ratio decreases. In addition, the results obtained from this study are compatible with the results obtained from other studies (Mesas-Carrascosa et al., 2016; Akay et al., 2019; Şenkal, 2018) evaluated according to height and overlap ratio.

Table 3. Accuracy comparison of the point clouds with different flight parameters

Flight Parameters				Point clouds (cm)
FN	Height (m)	Overlap (%)	Angle (°)	Mean distances
1	100	80x60	90	8.40
2	100	80x60 DG	90	5.91
3	100	80x60	45	5.20
4	100	80x60	60	7.13
5	100	90x70	90	5.93
6	120	80x60	90	7.11
7	100	80x60	60-90	9.33

When the mean distances of the point clouds given in Table 3 are examined, it is seen that the point cloud produced from the photographs with an angle of 45^0 has higher accuracy than others. Considering only the overlap ratios, it is seen that the 90x70 overlap ratio gives the best results in point clouds. When only the height parameter was changed, it was concluded that the point cloud produced from the photographs taken from 120 m had higher accuracy. When the all accuracy values obtained as a result of single and double grid flights are examined, it is seen that double grid gives significantly better results in point clouds. When all parameters are evaluated together, it is seen that the point cloud produced from photographs with an angle of 45^0 gives the best result.

To reveal the influence of the camera calibration parameters on photogrammetric products such as point cloud and DEM, images obtained from Flights 2, 6 in Table 2 and free flight were combined together and evaluated using Agisoft MetaShape software (Kılınç-Kazar et al., 2022; Sağdıç et al., 2022). Using the images of these flight, camera calibration parameters, the focal length (f) and the calibrated focal length (c) were calculated and these values were fixed during the re-evaluation of the 1st flight and comparisons were made on the generated point cloud and DEM. Point clouds and DEMs' produced using automatic and pre-calibrated camera calibration parameters were compared with the 1300 points measured using the GNSS technique, and the calculated distances and rms values between them were shown in Table 4.

Table 4. Comparison of the camera calibration parameters

	Point Cloud		DEM
Calibration parameters	Mean Distance (cm)	std. deviation (cm)	rms (cm)
Automatic	8.40	12.60	5.3
Pre-calibrated	7.70	12.60	3.4

When mean distances and rms values that given in Table 4 is examined, it is seen that the differences in automatic calibration and pre-calibrated values reaching 1 cm. For this reason, it is clearly seen that in both point cloud and DEM gives better result when the images are pre-calibrated. Therefore, like other studies in the literature (Raczynski, 2017; Özdemir and Duran, 2017; Makineci et al., 2020b) performing pre-calibration before producing 3D models and other photogrammetric products is necessary.

A rolling shutter camera is used in the UAV used in this study. For this reason, images are obtained row by row and the entire image is not recorded at the same time. Therefore, this effect needs to be modeled. In Table 5, the results obtained when the rolling shutter effect of 3 flights, whose flight parameters are given below, is modeled and not modeled using Agisoft MetaShape.

Table 5. Results of the rolling shutter effect

Flight Param.	Model	X error (cm)	Y error (cm)	Z error (cm)	Total (cm)	Image (pix)	rms Z in DEM (cm)
100m 80x60	Without rs	2.61	1.92	6.70	7.44	0.81	5.30
	With rs	1.99	2.03	6.18	6.80	0.81	4.36
120 m 80x60	Without rs	3.29	2.83	6.22	7.59	0.52	5.86
	With rs	3.27	2.82	6.22	7.57	0.52	2.28
100m DG	Without rs	3.17	1.81	4.60	5.88	0.80	5.84
	With rs	2.07	1.55	4.49	5.18	0.70	5.41

Error values given in Table 5 are examined, it is seen that the errors of the check points decrease when the rolling shutter effect is modeled in all 3 flights. Although there are no significant changes in the horizontal and vertical directions in the images taken from a height of 120 meters, it is seen that this effect reaches values up to 1 cm in the x component and 0.5 cm in the vertical direction in the flights using 100 meters' height, 80x60 overlapping ratio and double grid. When the height component rms of DEMs' are examined that given in Table 5, it is seen that modelling the rolling shutter effect has a positive effect on the results.

4. CONCLUSIONS

In this study, firstly, photogrammetric products (Orthomosaic and DEM) generated by using images obtained with different height, angle and overlap ratios in a mining area in Aksaray province were compared in terms of accuracy. As a result of the comparisons made by considering different parameters, it was seen that, in orthomosaics, images taken at an angle of 45^0 were more accurate, and in DEMs, images evaluated with 60^0 angle flight give the best results. It is thought that the reason for this is that the sun's rays are suitable with the photo angle and that more data is produced in the outputs produced using the oblique shooting angle compared to the vertical image shooting angle. When the overlap ratios and grid sizes are compared with each other, it was seen that the orthomosaics, produced from the larger overlap ratio and double grid were more accurate than the others, while the situation is the opposite for DEMs.

Also, point clouds that produced from images with different flight parameters were compared with the coordinate values obtained from 1300 points measured using Network-RTK GNSS technique in the study area and it is seen that the point cloud produced from photographs with an angle of 45^0 gives the best result when all parameters are evaluated together.

In addition, within the scope of the study, the effect of camera calibration parameters on photogrammetric products such as point cloud and DEM was investigated. According to the findings of this study, it is clearly seen that better results are obtained in both point cloud and DEM when pre-calibration is performed on the images obtained using UAV systems.

Also, an another investigation was carried out to determine the effects of rolling shutter camera-based errors on different flight parameters due to the fact that the UAV used in the study has a rolling shutter camera. According to the findings of this study, it was observed that better results were obtained when the rolling shutter effect was modeled in all flights with different flight heights and grid sizes. For this reason, according to the results obtained from this study, it was concluded that this effect should be modeled in studies performed with UAV systems that using mostly rolling shutter cameras.

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Author Contributions

Elif Bulut: Conceptualization, Data curation, Methodology, Software, Writing-Original draft preparation. **Ferruh Yilmaztürk:** Supervision, Methodology, Writing, Reviewing and Editing.

Conflicts of Interest

The authors declare no conflict of interest.

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