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Orthophoto production and accuracy analysis with UAV photogrammetry

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Abstract

Undoubtedly, Unmanned Aerial Vehicles (UAVs) are one of today's most functional technology products. In recent years, UAVs integrated with different sensors and transformed into harmony with advanced technology are developing rapidly and used in various applications to obtain spatial data. With UAV photogrammetry, images of target areas can be obtained quickly, at low cost, with high accuracy, and up to date. In addition to the advantages and success of existing methods for orthophoto production in large areas with classical photogrammetry, it is observed that the accuracy of these methods decreases in detecting changes in geometric properties, especially in small-scale areas. For this reason, obtaining geometric accuracy with the desired precision, which is of great importance in orthophoto production with UAV photogrammetry, has made it the basis for preference over classical methods. In this study, autonomous flights were carried out with DJI Mavic-2 Pro UAV in the selected pilot region, and orthophoto, Digital Elevation Model (DEM), and Digital Terrain Model (DTM) were produced as a result of processing the images obtained. To determine the geometric accuracy of the orthophoto, its coordinates were measured by the CORS-GPS method, and ten ground control points (GCP) were used. As a result of the accuracy analysis of the produced orthophoto, the spatial accuracy in the easting (ΔE) direction is ±6.9 cm, the spatial accuracy in the northing (ΔN) direction is ±7.8 cm, and the spatial accuracy in the height (ΔH) direction is ±10.3 cm.

1. Introduction

The map production is usually a time-consuming process depending on the project's purpose, scale, and accuracy. However, with the advances in technology in recent years, unmanned aerial vehicles (UAVs) have been used in the field of remote sensing (RS) and photogrammetry, which produce high- accuracy data and produce high-accuracy results in a short time [1, 2]. The UAV history dates back to 1850 and was first used for military purposes [3]. Later, aerial vehicles were developed for photogrammetric purposes and were integrated into this field, and thus the name "UAV Photogrammetry" took its place in the literature. UAV photogrammetry describes a photogrammetric measurement platform that works remotely, semi-autonomously, or autonomously with a digital camera [4]. The camera carried by UAVs provide high-resolution aerial photographs at a low cost way in cloudy weather where the ground view is not clear [5]. In addition to optical cameras, thermal or infrared, multispectral, hyperspectral, and Light Detection and Ranging (LiDAR) sensors can be mounted on UAVs to increase their data collection capabilities [6]. In this way, it is possible to detect wideband ranges within the electromagnetic spectrum [7]. To ensure spatial accuracy and precision, which is an important issue, especially in cartography activities, the Global Navigation Satellite Systems (GNSS) may also be included in its structure[8]. In this way, a fully-integrated UAVs have been created [9]. The use of UAVs in photogrammetry studies, whose hardware and software are developed day by day, has become widespread, and UAV technology has allowed the acquisition of overlay photographs suitable for photogrammetric purposes [10].

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Today, aerial photographs obtained with this application method are evaluated with photogrammetric compilation processes and final products such as digital elevation model (DEM), digital terrain model (DTM), and orthophoto are obtained [11]. An orthophoto is an image which has vertical projection position through differential correction or ortho-rectification [12]. In other words, they are images with a fixed scale at each point and show the current state of the terrain by eliminating errors caused by obliquity and rotation effects and topographical height differences that occur in aerial photographs[13]. Orthophotos, which express the current situation of the land are obtained by associating satellite images or aerial photos of an area with DEM [14]. Unlike aerial photographs, since they have a high spatial resolution, angle, distance, and size measurements can be made [15].

Orthophoto production of an area requires many steps such as pre-flight planning, data acquisition, calibration and image processing. During the application of each step, different types of errors will appear on the orthophotos and these errors affect the final product [16]. Therefore, accuracy should be evaluated for digital orthophotos. In this evaluation phase, different parameters are used, and the overall accuracy is determined according to the values on these parameters. Numerous studies have been conducted on the production of orthophoto maps obtained by UAVs, and it has been determined that UAVs ensure international spatial quality standards [17–20]. However, ground control points (GCP) are established on the land to detect the spatial errors during orthophoto production. These points are measured with Real-Time Kinematic (RTK) measurements or Continuously Operating Reference Stations (CORS) system working in TUSAGA-Active System to be used as exterior orientation parameters [21]. 3D accuracies of digital orthophoto images and the methods used are shown in the "Accuracy Standards for Digital Geospatial Data March 2014" directive implemented to affect the American Society for Photogrammetry and Remote Sensing (ASPRS)[22].

This study aims to analyze the accuracy of the products produced by UAV photogrammetry. Within the scope of the survey, orthophoto, DEM, and DTM of the selected pilot region were delivered. In addition, the location data to determine the accuracies were obtained with the GPS/GNSS receiver, and the results were compared and analyzed.

2. Material

To investigate the spatial accuracy of the produced orthophotos, 10 GCPs were installed in the study area, and the coordinate values were measured with the GPS/GNSS technique. Then the orthophoto production stage is started. In this section, grids whose midpoint coordinates are defined in the field coordinate system are defined. Then, the midpoint coordinates of the pixels in these grids are taken from the DEM, and the interior and exterior orientation parameters are calculated from image coordinates. Afterward, interpolation is made by calculating pixel coordinate values from image coordinates (Fig. 1).

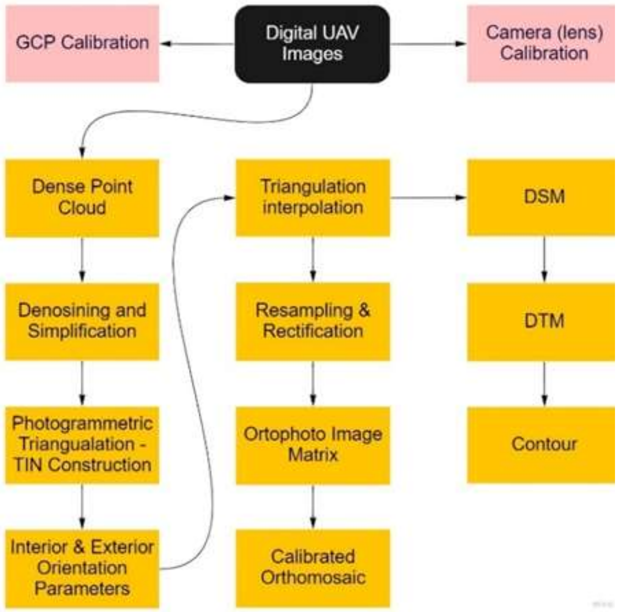

Figure 1. The flow chart of the methodology

2.1. Study Area

Within the scope of the study, Ida Madra Geopark, Sindirgi district Zindankayasi Archaeological site (Phrygian altar) (Fig. 2) was chosen as the test area to produce orthophoto images, analyze their accuracy and compare the resulting surface models.

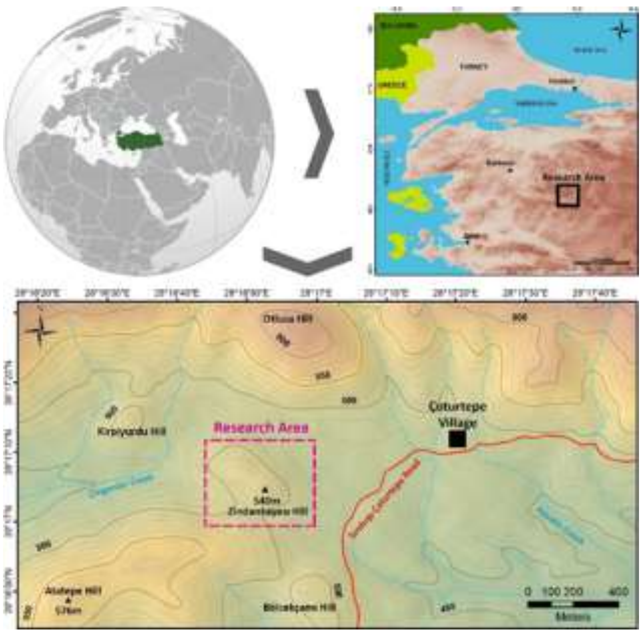

Figure 2. Study area

2.2. Data Acquisition

Within the scope of the study, the horizontal (Northing, Easting) and vertical (Ellipsoidal height) coordinate information of the GCP to be used for location accuracy were measured with the FOIF A90 geodetic GNSS receiver connected to the TUSAGA-Active system. The measurement process was carried out as a total of 50 epochs. In addition, 10 control points (CP) were measured over the land to examine the 3D accuracies of orthophoto maps. The image of GCP and CP points are given in Figure 3.

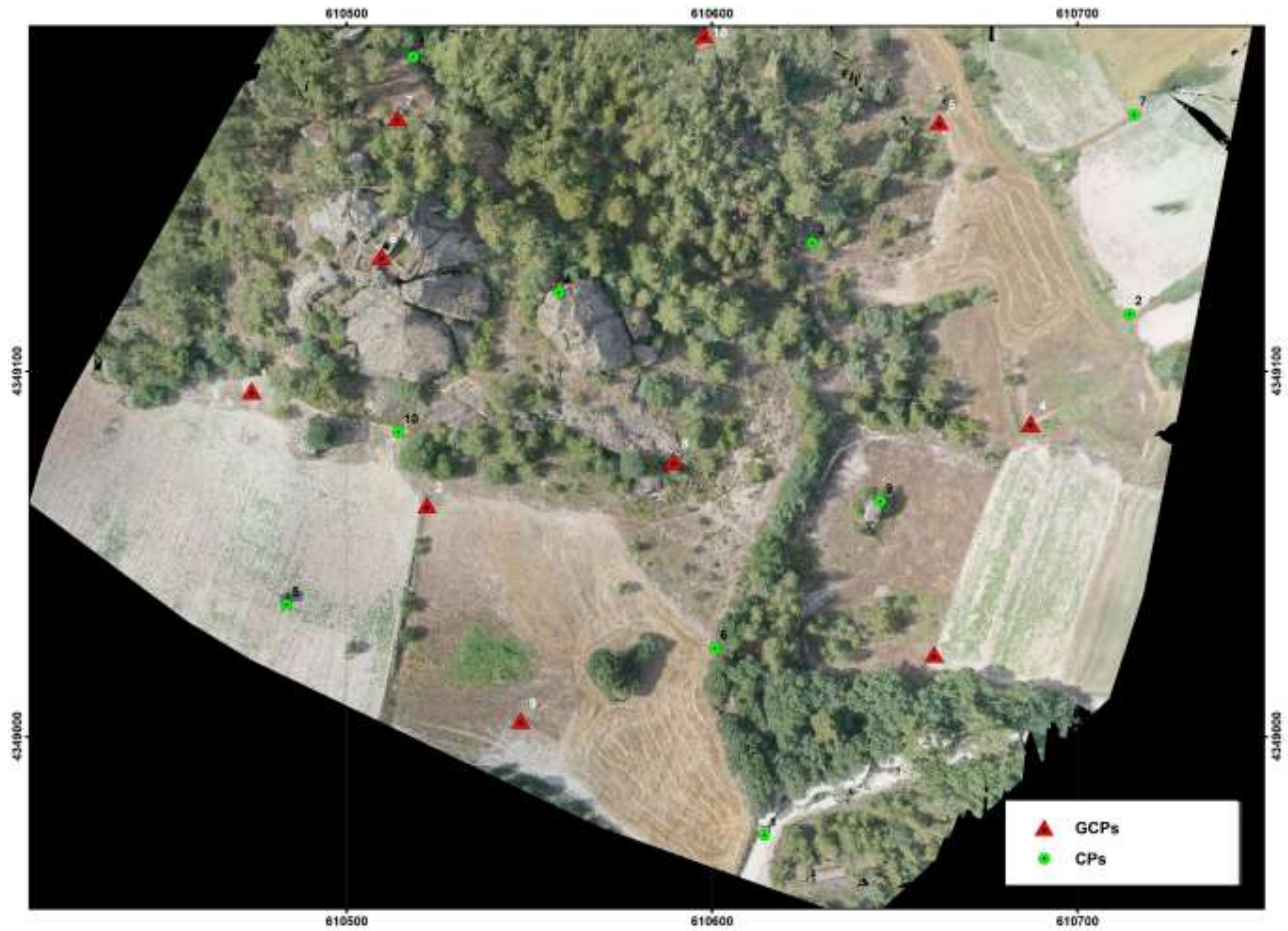

Figure 3. GCP and CP points

After the necessary spatial measurements were made for accuracy assessment, flight planning was carried out to produce high-resolution orthophotos, DEMs, and DTMs of the study area with the UAV. In this planning, in addition to the take-off and landing information of the UAV, data such as flight altitude, overlay ratios of the images obtained, resolution information, and image acquisition angle are included. A view from the flight plan and management screen is shown in Figure 4.

Figure 4. The flight plan and management screen

After the planning stage, autonomous flights were made with the DJI Mavic 2 Pro UAV with Hasselblad 20MP/UHD 4K Gimbal camera features. The flight process was carried out for approximately 25 minutes, at 50 m from the ground, with a longitudinal overlap rate of 80% and a transverse overlap rate of 70%. In addition, a total of 126 images of the study area with a resolution of 159x255 m were obtained at 1.25 cm/px ground sampling distance (GSD), and the field study was completed.

2.3. Assessment of Data

After the flight process, the data produced by the UAV and GPS were transferred to the workstation for photogrammetric compilation and orthophoto production. In the application, photogrammetric compilation processes were made with Pix4D Mapper. The Structure From Motion (SFM) method is widely used to assess the data obtained using UAVs for photogrammetric purposes. Unlike conventional photogrammetry, this method does not need interior orientation parameters. Instead, it calculates the camera calibration and orientation parameters using enough GCP [10]. In addition, it performs scene modeling with bundle adjustment by mapping details on multiple images taken with specific ratios of overlap [23–25]. Earth science, especially in recent years [26, 27], geomorphology analysis [28], agriculture [29], and archaeology [30], the SFM technique is widely used in applications such as high-resolution images that allow you to work on a low-cost, and easy-to-use is the application of photogrammetry [31, 32].

3. Method

3.1. Accuracy Assessment

Different methods are used to assess the accuracy of the products obtained by photogrammetric methods. In studies conducted for this purpose, techniques such as Proportional Error, Root Mean Square Error (RMSE), and Probabilistic Error are generally used [5, 6].

3.1.1. Root Mean Square Error

In this study, the RMSE method was used for accuracy assessment. This method is described as the square root of the mean of the difference in orthophoto or DEM coordinates produced with the measured reference GCP and CP coordinates [33]. First, calculate the RMSE in the northing (N) direction ($RMSE_N$) in equation 1, the RMSE in the easting (E) direction ($RMSE_E$) in equation 2, the RMSE in the height (H) ($RMSE_H$) in equation 3 and the horizontal spatial error ($RMSE_{NE}$) The mathematical expression used for this is shown in equation 4.

$$RMSE_N=\sqrt{\frac{\sum \Delta N^2}{n}} \tag{1}$$

$$RMSE_E=\sqrt{\frac{\sum \Delta E^2}{n}} \tag{2}$$

$$RMSE_H=\sqrt{\frac{\sum \Delta H^2}{n}} \tag{3}$$

$$RMSE_{NE}=\sqrt{RMSEN^2+RMSEE^2} \tag{4}$$

where ΔN is the difference between the northing coordinates, ΔE is the difference between the easting coordinates, and n is the number of points.

4. Results

As a result of the assessment of the data obtained, 126 high-resolution aerial photographs of the study area obtained by the autonomous flights of the UAV were used, using an orthophoto with a spatial resolution of 1.74 cm (Figure 5), a DEM with a spatial resolution of 8.67 cm (Figure 6) and a 1.74 cm (Fig. 7) was produced at cm spatial resolution. ArcMap 10.4 software was used for the accuracy assessment of the produced orthophoto. In addition, the coordinate values obtained from the images and models were compared on horizontal and vertical surfaces using the GCP and CP coordinate values measured with the GPS/GNSS receiver.

Within the scope of the study, the results of the products produced by the UAV photogrammetry method were compared with the results obtained using satellite-based measurement techniques, and an accuracy assessment was made. The spatial information received over the orthophoto and measured by the GPS/GNSS receiver is shown in Table 1, with the differences occurring at each point. Using these calculated differences, $RMSE_E$= ±6.9 cm and $RMSE_N$= ±7.8 cm in the horizontal direction were determined. Therefore, the horizontal spatial error is $RMSE_{NE}$=10.4 cm. In addition, the DEM produced as a result of the topographic data acquisition process and the DEM produced by the UAV were compared, and the vertical direction was determined as $RMSE_H$ = ±10.3 cm at the same reference points.

A DEM of the study area was produced using the height values obtained by topographic acquisition with the GPS/GNSS receiver, and this model was compared with the DEM produced by the UAV. The comparison was made over the pixel values with the exact location on both DEMs. In the comparison process made by taking the pixel differences, the two height models determined differences between -14 cm and +24 cm.

Figure 5. Orthophoto produced by UAV

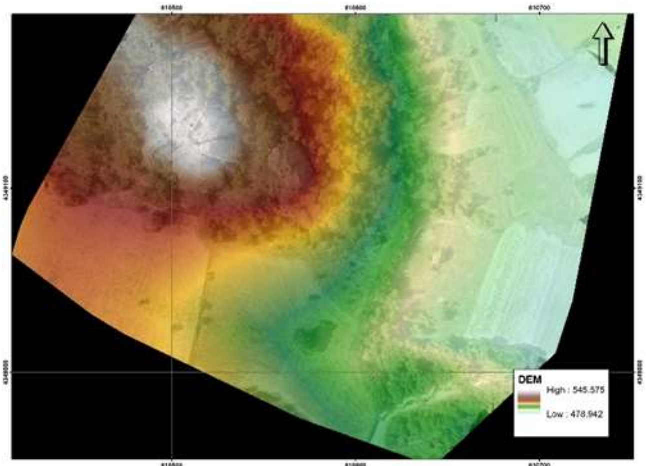

Figure 6. DEM produced by UAV

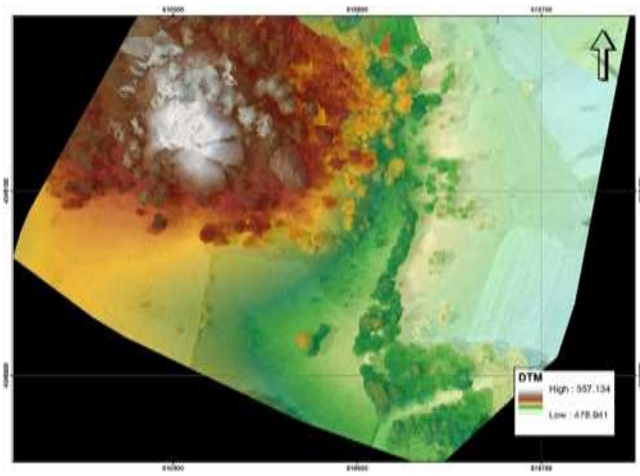

Figure 7. DTM produced by UAV

Table 1. Position information and coordinate differences of the points used for control purposes

	Orthophoto (m)			GPS/CORS (m)			Difference (m)= Orthophoto(m)-GPS/CORS(m)		
Point Name	**Northing (N)**	**Easting (E)**	**Height (H)**	**Northing (N)**	**Easting (E)**	**Elliosoidal Height (H)**	**Δ(N)**	**Δ(E)**	**Δ(H)**
GCP 1	4349094.753	610473.944	516.21	4349094.806	610473.884	516.29	-0.053	0.060	-0.080
GCP 2	4349063.439	610521.964	507.83	4349063.525	610522.061	507.70	-0.086	-0.096	0.129
GCP 3	4349022.589	610660.717	483.02	4349022.579	610660.705	483.04	0.010	0.012	-0.015
GCP 4	4349085.814	610687.080	483.75	4349085.852	610687.038	483.81	-0.037	0.042	-0.056
GCP 5	4349168.259	610662.209	484.75	4349168.235	610662.236	484.72	0.024	-0.027	0.036
GCP 6	4349131.640	610509.544	545.15	4349131.663	610509.518	545.18	-0.023	0.026	-0.034
GCP 7	4349169.478	610513.836	533.28	4349169.617	610513.991	533.07	-0.138	-0.156	0.207
GCP 8	4349075.440	610589.323	502.65	4349075.531	610589.425	502.52	-0.091	-0.102	0.136
GCP 9	4349004.362	610547.608	500.16	4349004.379	610547.589	500.13	-0.017	0.019	0.026
GCP10	4349192.111	610597.773	500.92	4349192.114	610597.769	500.92	-0.003	0.004	-0.005
CP1	4348973.053	610614.265	495.73	4348973.033	610614.243	495.76	0.020	0.023	-0.030
CP2	4349115.717	610714.172	481.75	4349115.722	610714.178	481.74	-0.005	-0.006	0.008
CP3	4349135.190	610627.389	494.56	4349135.197	610627.396	494.55	-0.007	-0.007	0.010
CP4	4349121.643	610557.962	524.24	4349121.484	610558.141	524.00	0.159	-0.179	0.239
CP5	4349036.130	610483.455	507.47	4349036.108	610483.480	507.50	0.022	-0.025	-0.033
CP6	4349024.277	610600.719	493.04	4349024.379	610600.834	492.88	-0.103	-0.115	0.154
CP7	4349170.327	610715.442	480.29	4349170.423	610715.335	480.43	-0.096	0.108	-0.144
CP8	4349186.089	610518.126	523.20	4349186.098	610518.136	523.18	-0.009	-0.010	0.013
CP9	4349064.380	610645.973	488.30	4349064.367	610645.958	488.32	0.014	0.015	-0.021
CP10	4349083.430	610514.105	513.39	4349083.365	610514.178	513.30	0.066	-0.074	0.098

5. Conclusion

In the study, the UAV photogrammetry method was utilized as an alternative to classical aerial photogrammetry, and the spatial accuracy of the obtained products was examined. As a result, the horizontal spatial accuracy of the orthophotos produced within the scope of the study was determined as ±10.4 cm and the vertical spatial accuracy as ±10.3 cm. According to these results, it was concluded that the UAV photogrammetry method could be used to produce maps at different scales. In addition, when DEMs produced by the UAV photogrammetry method and DEMs created using satellite and space techniques are compared, their spatial accuracy has shown that they can be alternative methods to each other.

The UAV photogrammetry can model and map archaeological details to record cultural heritage. In studies where precise modeling will be carried out, higher accuracy data acquisition can be achieved by mounting a lidar system on the UAVs.

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Author contributions

Ramazan Güngör: Conceptualization, Methodology, Writing-Original draft preparation, Software, Validation, Visualization, Investigation, **Melis Uzar**: Methodology, Writing-Reviewing and Editing, **Bilal Atak**: Data curation, Writing-Original draft preparation, **Osman Salih Yılmaz**: Writing-Reviewing and Editing, **Erdal Gümüş**: Data curation, Software and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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