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The Journal of ***Advanced UAV*** is a peer-reviewed journal that publishes studies on UAV development, use, and earth sciences and is scanned in International Indexes and Databases. The journal Advanced UAV (AUAV), Unmanned Aerial Vehicle Systems (UAS), and Remote Piloted Aircraft Systems (RPAS), etc. focuses on the design and applications of unmanned aerial vehicles, including. Likewise, contributions based on unmanned water/underwater drones and unmanned ground vehicles are also welcomed.

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Investigation of accuracy of detailed verified by unmanned aerial vehicles with RTK system; The example of Ortakent-Bodrum Area

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Abstract

There has always been a sense of adoption of human beings and the knowledge to define their types, boundaries and areas, especially in terms of the immovables they own. It is known from past to present those measurements are difficult and require effort and time. However, with the developing technology, measuring systems have been renewed and new methods have emerged. With the new systems, project time and cost savings were achieved. Although the production of orthometric maps has accelerated thanks to the advances in remote sensing and photogrammetry, their accuracy compared to terrestrial measurements is questioned. In this study, it is aimed to investigate whether there are differences between the location information of the orthometric map produced by Unmanned Aerial Vehicles (UAV) and the location information of the data produced by Global Navigation Satellite Systems (GNSS), and to investigate the reasons for these differences, if any. The study area covers in Ortakent, Bodrum-Muğla. One of the most important features of the UAV used in the project is that it has a Real Time Kinematic GNSS system (RTK-GNSS). After measuring with UAV, the Digital Surface Model and orthophoto was produced. After the measurements made with the GNSS, triangulation was made and the undulations were subtracted and orthometric heights were obtained. Thus, the differences between the obtained values were determined by measuring with both the UAV and the GNSS system. These differences are very small like cm. It has been seen that the photogrammetric values created with Ground Control Points are more accurate than the photogrammetric values created without Ground Control Points.

1. Introduction

Photogrammetry is a science where spatial measurements and geometrically reliable products can be obtained through photographs. Through to the developing technology, the science of photogrammetry has been divided into different fields and started to be used in many fields [1].

The most important reason for the development of photogrammetry over time is that it accepts the principles of accuracy, flexibility and practicality, which are accepted as basic by the positive sciences [2-3].

Photogrammetry is a suitable tool for equipping information about human-made and natural objects such as terrain, vegetation, and urban features [4]. Photogrammetry and digital image-based processing techniques have an important role in making visualization technology practical and providing a low-cost workflow compared to traditional and geodetic surveys [5].

Unmanned Aerial Vehicles (UAV) technology emerges as a platform that provides innovations and develops in Photogrammetric map production [6]. Aerial image acquisition is carried out automatically or semi-automatically with remote control. Besides, UAVs provide great advantages in terms of low cost, speed, repeated measurements, convenience and accuracy [7]. UAVs include equipment such as camera, (multispectral infrared etc.), video, GNSS/INS (Inertial Navigation System).

High resolution Digital Surface Model and orthometric images created with UAVs are used to serve many areas [8]. UAVs can make high-resolution and 3D terrain measurements in areas that are life-threatening, sloping, and where people cannot normally access. UAVs with integrated systems such as the RTK system provide data with higher spatial accuracy.

Today, UAVs are used not only for map production, but also in applications such as agriculture, mining, determination of archaeological sites [9-10] and disaster management [11]. Especially in recent years, it has become one of the most preferred measurement methods in the field of engineering, because it provides practicality, speed, repeated measurement and high accuracy. UAV photogrammetry is a platform that has different sensors on it, can continuously provide the 3D coordinates of the platform, can also collect spatial data and optionally supports ground-controlled GNSS data. [12].

The aim of this study is to test the accuracy of the RTK integrated UAV according to the measurement data obtained from the ground control point measurement values and the measurement value differences without ground control point, and the measurement data obtained from the GNSS measurement, and to compare GNSS measurements and the final products produced from UAVs. In addition, it is aimed to present the advantages and disadvantages of UAVs in terms of cost, time and accuracy compared to conventional (classic) measurements.

2. Method

High resolution Digital Surface Model and orthometric images can be obtained with UAVs. Images obtained from UAVs can be easily processed by computers and software, and the final product can be reached in a short time [13].

Evaluation of high-resolution images obtained by UAV is a very difficult and time-consuming task by perform using classical photogrammetric approach software. For this purpose, computer vision techniques for processing datasets have been widely used in the evaluation of UAV images [14]. In addition to the high speed and accuracy provided by computer vision technologies, the minimal operator contribution they bring, the manual processes based on the visual activities of the operator, required for determining the common areas, which are the main and difficult stages, and creating the stereo model, are semi-automatic or automated [15].

Today, commercial software developed has its own algorithms for performing the internal routing and external routing stages. Thus, UAV images are directed geometrically with great success [16].

A small area was determined in Bodrum for the measurements to be made with UAV and GNSS, and assessments have been performed in this area.

2.1. Study Area

This study was carried out on an area of approximately 68000 m^2 in Muğla Province, Bodrum District, Ortakent Neighborhood. (Figure 1). A sloping area was preferred for the study area.

(a) (b)

Figure 1a. Google Earth Satellite Image of Study Area, **Figure 1b.** Orthophoto Image

2.2. Application

First, leveling was done to reach the orthometric heights in the study area and the orthometric heights of the points were obtained.

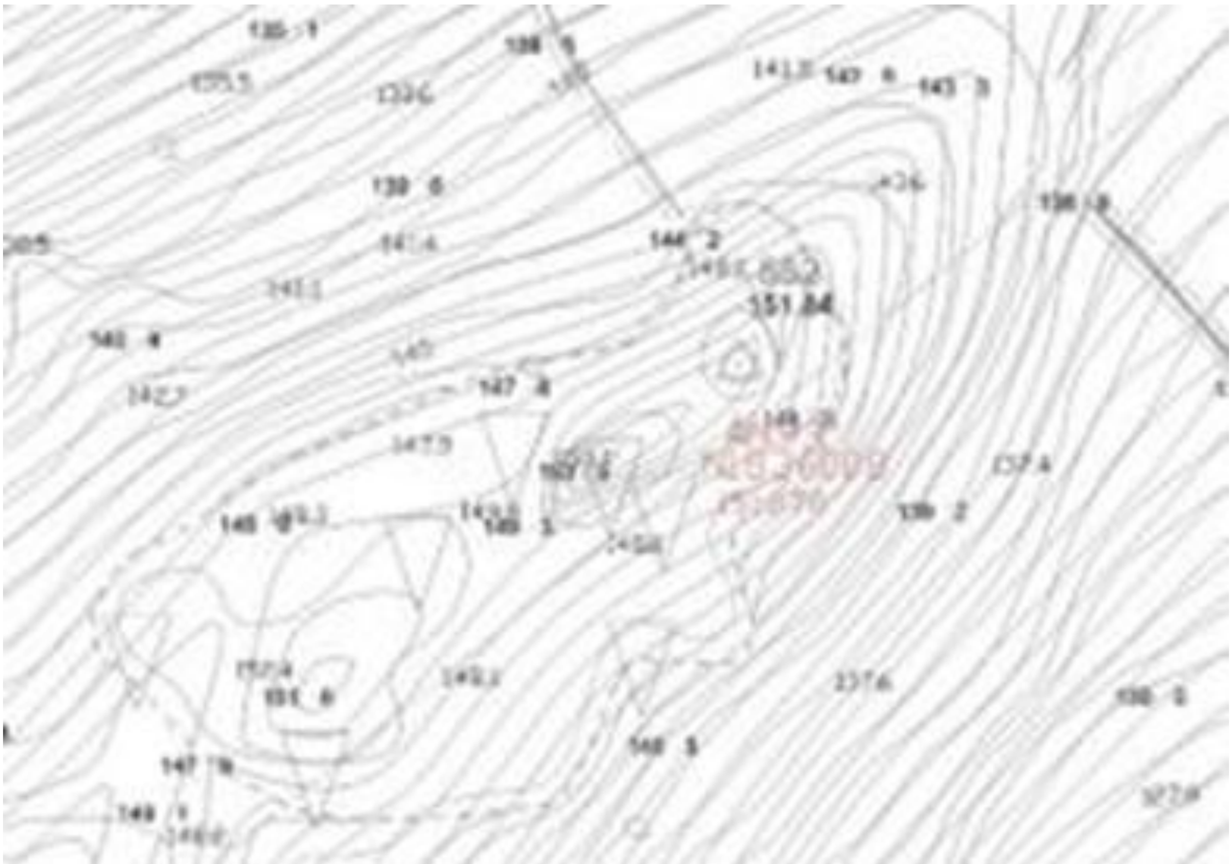

Figure 2. Triangulation on a base map

Then, plankote of the study area was made with CORS_RTK. Bodrum CORS Network was used for measurements made with GNSS. SOUTH NRS technology was used with 5 reference stations in Ortakent, Turgutreis, Göl-Türkbükü, Mumcular and Yaliciftlik Districts. Through by South NRS, VRS correction and physical correction are made and sensitive data is obtained with measurements. In the plankote process, all the details were taken in the land measurement. Triangulation was made in Netcad program and contour lines were created.

Figure 3. Plankote of the application area

Figure 4. Bodrum CORS Network [17]

After these processes, 4 Ground Control Points were established in the area where the flight will be made. Ground Control Points are of great importance in terms of providing a more accurate and sensitive balancing of routing parameters with the GNSS/IMU receiver, which is the integrated system of the UAV. Ground Control Points are homogeneously distributed and painted with red to be visible. It is also established in places that can be distinguished according to the terrain conditions.

Figure 5. Presentation of ground control points in the working area through the software program

South Galaxy G1 Plus (IMU) GNSS set was used for the measurement of Ground Control Points in the study (Figure 3). GNSS has IMU technology that does not require calibration and is not affected by magnetic field. Its positioning in the Real-Time Kinematic Network has an accuracy of ±8 mm+0.5 ppm horizontally and ±15 mm+0.5 ppm vertically. There is SurvX program as software. For the measurement of 4 Ground Control Points, six one-minute epoch measurements were made at each point with GNSS. And these measurements were averaged. These measurements were obtained from Bodrum CORS Network.

Figure 6. DJI South Galaxy G1 Plus (IMU)

After measuring the Ground Control Points, a flight plan was made for the flight area. For orthophoto production, flights were carried out with DJI Phantom 4 RTK, which has both automatic and semi-automatic features (Figure 8).

Figure 7. Flight Area

Figure 8. DJI Phantom 4 RTK

DJI Phantom 4 RTK consists of integrated camera system with 1/20'' sensor, 5472×3648 maximum image size, ISO 100-6400 (manual), 24mm equivalent focal length, aerial optimized f/2.8 wide-angle lens.

DJI Phantom 4 RTK weighs approximately 1.4 kg and has a maximum flight time of 30 minutes. In addition, Positioning Accuracy in Multi-Frequency Multi-System High Precision RTK GNSS is: Vertical 1.5 cm +1 ppm, (RMS); Horizontal is 1 cm + 1 ppm (RMS).

The fact that the DJI Phantom 4 RTK has the RTK feature is important for position correction. It provides position correction by receiving data from satellites and fixed base station.

The flight with the UAV was carried out in Ortakent-Bodrum in July, when the temperature was 32 °C. Flight planning was carried out with 70% horizontal overlap and 80% vertical overlap. It was flied from a height of 80 meters and 242 photographs were taken.

The formation flow of images created by using computer and software programs is shown in Figure 9.

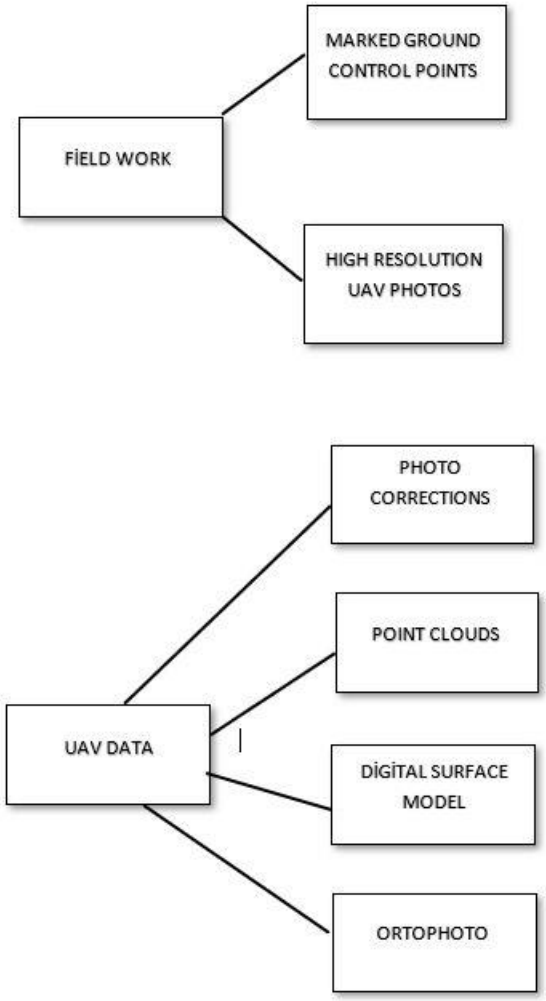

Figure 9. Study Workflow Display

The images obtained from the UAV were evaluated with Pix4D software. From these images, first point cloud, condensed point cloud, then Digital Surface Model and Orthophoto were created. The Digital Surface Model is a mathematical surface on which the position and height information of the surface are created by including the objects on the surface (building, tree, power line, etc.).

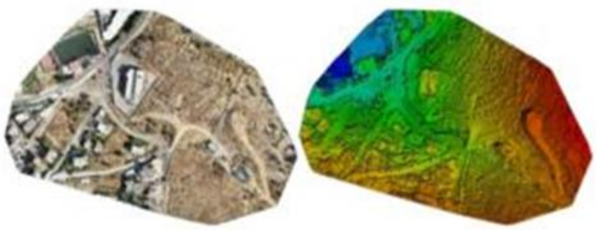

Figure 10. Orthophoto and digital surface model of the study area

Ground control points are marked by entering coordinates in Pix4D program. The matching process has started on the marked photos. With Automatic Aerial Triangulation and Bundle Block Adjustment (block balancing with images), the Pix4D program automatically optimizes and calibrates the camera, also corrects atmospheric and systematic errors. In the program, the Structure from Motion (SFM) method is used when creating a 3D model from photographs.

SfM method is used to create 3D models with photogrammetric method. SfM has been translated into Turkish as Motion Based Structural Detection. SfM photogrammetry technique has emerged as a cost-effective and practical modeling tool that has become increasingly popular in recent years in parallel with the development of computer hardware and software capabilities. (Westoby vd., 2012). SFM photogrammetry is a revolutionary, low-cost and user-advantaged photogrammetric technique that has been used in recent years, enabling wide-scale work on high-resolution datasets. The SfM technique, in biological image perception, corresponds to the perception of humans (and other living things) of the 3-dimensional environment around them from two-dimensional moving images formed in the retina layer in the eye. Based on photogrammetric measurement processes, SfM provides three-dimensional modeling of objects based on matching objects in a series of photographs taken at different locations with a certain overlap ratio [18-20].

3. Results

GCP coordinates obtained from classical CORS measurements, point coordinates formed by including GCP points in the Pix4D program after UAV measurement and coordinates formed as a result of UAV measurement without GCP are shown in Table 1.

Table 1. GCP coordinates obtained from CORS, photogrammetric valuation with GCP and without GCP

	CORS			Photogrammetric Valuation			Photogrammetric Valuation withot GCP		
P.N	X(m)	Y(m)	H(m)	X(m)	Y(m)	H(m)	X(m)	Y(m)	H(m)
GCP_1	4102350.380	531705.810	59.098	4102350.383	531705.814	59.128	4102350.376	531705.816	59.218
GCP_2	4102373.940	531717.616	63.280	4102373.928	531717.618	63.321	4102373.910	531717.618	63.380
GCP_3	4102370.771	531761.753	70.774	4102370.783	531761.743	70.807	4102370.756	531761.742	71.574
GCP_4	4102317.212	531739.518	65.495	4102317.216	531739.497	65.529	4102317.216	531739.492	66.425

The values obtained by using the GCP in the UAV measurement with the RTK integrated system and the values obtained without the GCP in the UAV measurement, the root mean square errors and position errors calculated from these values are shown in Table 2.

Table 2. Error Values Obtained with GCP and without GCP

Error amounts of coordinates with GCP			Error amounts of coordinates without GCP			
di Differences (cm)						
dx	dy	dh	dx	dy	dh	dx
0.3	0.4	3.0	-0.4	0.6	12.0	-0.4
-1.2	0.2	4.1	-3	0.2	10.0	-3
1.2	-1.0	3.3	-1.5	-1.1	8.0	-1.5
0.4	2.1	3.4	0.4	-2.6	9.3	0.4

Table 3. Root Mean Square and Position Errors as a Result of Photogrammetric Valuation (cm)

With GCP				Without GCP			
RMSEx	RMSEY	RMSEH	Mxy	RMSEx	RMSEY	RMSEH	Mxy
1.02	1.37	4.01	1.71	1.96	1.67	11.47	2.57

The coordinates of the SGK wall measured from the CORS Network in Plankote, the coordinates reached by the UAV measurement with the GCP, the coordinates obtained by the UAV measurement without the GCP, and the calculation of these values and the square mean and position errors are shown in Table 3.

Table 4. Coordinates of SGK Wall Measurement

	CORS			With GCP			Without GCP		
P.N	X (m)	Y (m)	H (m)	X (m)	Y (m)	H (m)	X (m)	Y (m)	H (m)
1	4102362.496	531691.116	58.502	4102362.515	531691.049	58.520	4102362.536	531691.033	58.602
2	4102363.870	531691.869	60.124	4102363.868	531691.872	60.168	4102363.875	531691.865	60.199
3	4102370.846	531696.789	60.239	4102370.849	531696.783	60.298	4102370.851	531696.781	60.304
4	4102384.430	531706.266	60.395	4102384.428	531706.268	60.450	4102384.433	531706.273	60.525
5	4102394.459	531713.365	62.019	4102394.465	531713.355	62.038	4102394.469	531713.351	62.109
6	4102406.182	531721.709	63.419	4102406.194	531721.672	63.809	4102406.212	531721.644	63.539
7	4102413.354	531726.542	63.638	4102413.347	531726.537	63.680	4102413.345	531726.529	63.718

Table 5. Root Mean Square and Position Errors as a Result of Photogrammetric Valuation (cm)

With GCP				Without GCP			
RMSEx	RMSEY	RMSEH	Mxy	RMSEx	RMSEY	RMSEH	Mxy
1.01	2.47	4.55	2.67	2.14	4.40	10.47	4.89

Figure 11. SGK Building and Wall Measurement

The wall length of the SGK Building was obtained from Cors Network, UAV measurement with GCP and UAV measurement without GCP. The results are shown in Table 6.

Table 6. The Wall Length of the SGK Building

Method of Measurement	Lenght (m)
Coordinates Obtained From CORS	62.00
Coordinates Obtained as a Result of Photogrammetric Valuation	61.98
Coordinates Obtained as a Result of Photogrammetric Valuation Without GCP	61.97

4. Discussion

This study reveals that UAV photogrammetry is an ideal system for orthophoto. Photogrammetric method is getting fast results and more office work in comparison with classical surveying methods. In the study, it was determined that GCP markings should be shown more clearly. If GCPs increase and distribute more homogeneously, the accuracy will be higher.

UAV flights were carried out in Bodrum's summer heat, at noon During flights at high temperatures, the engine is overworked so that the drone can hover. As the battery life decreases, the flight time decreases and the efficiency of the UAV decreases.

The data obtained from the study, which was carried out by selecting a small area, shows us that UAV photogrammetry will improve with even more widespread use.

5. Conclusion

In this study, the accuracy of photogrammetric measurement with UAV was investigated. Orthophoto data and CORS measurements were compared. In the study, it was observed that the error values were a few cm. When the result values in the tables are examined, it is seen that the x, y and H error values obtained as a result of the measurements made with GCP points are less than the measurements made without GCP. When the result values are examined, photogrammetric measurements made with GCP contain less errors than photogrammetric measurements without GCP. Position errors (Mxy) are below 5 cm even in measurements without GCP, which is an indication of the advantage of UAVs with RTK systems. In all measurements, the error values of the orthometric height component were higher. However, it is seen that the orthometric height component gives much more accurate results in the measurements made with GCP. In addition, as a result of the wall measurement of the SGK Building, it was seen that there was a difference of 2 cm in the measurement made with GCP and 3 cm in the measurement made without GCP with the length of the wall. In this study, the measurements made with the UAV with the RTK integrated system require less effort, time and cost, and the measurements must be made of control points, etc. and should be supported by ground surveying method. Thus, it is seen that more accurate results are obtained. Although the study was carried out by selecting a small area, it can be thought that UAV systems will develop and become more widespread in the future with errors in the cm unit and the desired accuracy can be achieved without the need for GCP.

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Author contributions

Hazal Altuntabak: Conceptualization, Methodology, Software, Writing-Original draft preparation, **Ercenk Ata:** Data curation, Validation. Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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Determining the change in burnt forest areas with UAV: The example of Osmanbey campus

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Abstract

Satellite data provides information about the fire and makes a significant contribution to damage assessment and improvement studies. Especially with multi-band satellite systems, it is possible to precisely identify and quickly map the fire damaged areas. However, satellite systems may be insufficient in terms of both temporal and spatial resolution. In addition, it is not always applicable in terms of cost according to the area of the working area. Unmanned Aerial Vehicles (UAVs), which have become widespread in many disciplines in recent years and in which imaging systems are integrated, provide new opportunities in this regard. UAVs are relatively more economical, user-friendly and provide high spatial resolution, providing convenience and speed in examining land changes in a short time. It is possible to make different analyzes according to the features of the integrated imaging system. In this study, Triangular Greenness Index (TGI) was produced by using a UAV system with a digital camera with visible bands. The study area is the forested area damaged in the fire that occurred in 2020 on the Osmanbey campus of Harran University. The data used for the study were obtained from two UAV flights one week after the fire and two years later. Both flight altitudes were 120m. While the rate of green space in the study area was 0.3% after the 2020 fire, it was observed that this rate increased to 0.54% in 2022. Thus, the areas that were not damaged immediately after the fire and the areas that grew green after two years were determined. expressions should not be included in essence.

1. Introduction

Forests are indispensable ecosystems for humans and all other species. These ecosystems, which have been formed as a result of many years, have suffered heavy losses in recent years due to climate change and human effects [1]. Forest fires are among the natural disasters where this effect is felt the most. In recent years, forest fires have occurred in much larger areas with the effect of global warming and last much longer than in the past. In this context, information is needed at every stage from the planning to management of forests as well as to understand and follow the causes of forest fires, which cause great ecological and economic damage [2-3]. This information is basically obtained by satellite and aerial photographs from past to present. Aerial photographs, which are used more frequently with the advantage of higher resolution, are used in forestry: producing forest maps, taking inventory, tracking wildlife and forest fires [4].

UAV has been frequently used in engineering projects since last decade. Pond volume determination [5], landslide site [6-8], rockfall site [9], cultural heritage modelling [10-16] and soil erosion [17] are the most used ones.

The field of forestry, which obtains its basic information needs from aerial photographs, has also kept up with the developing technology and has started to use Unmanned Aerial Vehicles (UAV) to obtain these aerial photographs. UAVs are frequently used in forestry activities due to their advantages such as more compact, high resolution image acquisition and low cost compared to satellite and aircraft systems. High-resolution image data obtained from the UAV is converted into useful information necessary for the forestry field by using various image processing techniques [18]. Image processing techniques are frequently used for the detection of forest fires, as well as the examination of medical images, object recognition, detection of plant diseases [19]. In addition, UAVs can also be used for the purposes of detecting forest fire areas, examining the situation, and monitoring reforestation. It is important to obtain observations and data by UAV in these areas, as reclaiming the burned forest areas as forest is a long process that needs to be followed. In particular, the difference between the photographs obtained by the UAV flights made at certain time intervals can be revealed by using image processing techniques. In this way, it can be ensured that forest areas are healed quickly by monitoring the forest development in the burned areas and by intervening when necessary. In addition, these images are evidence and provide a basis for early detection and intervention of illegal human activities that attempt to build in burnt forest areas. In this context, the use of UAVs for forestry activities is a milestone in terms of providing fast and low-cost useful information.

Various vegetation indices related to plant cover and chlorophy ll content. In literature, vegetation indices are used precision agriculture [20-21], drought [22-24], plant yield [25-26], detection of irrigation inhomogeneities [27], evaluating of post fire vegetation recovery [28], vegetation [29] and forest [30] monitoring, assessment of forest fire damage [31].

Healthy plants show more reflection in the near infrared (NIR) and green wavelengths than in other wavelengths. Red and blue wavelengths are absorbed. At this point, various indices have been developed to detect healthy vegetation on satellite images. The indexes developed depending on the visible region (Vis), Vis+NIR and Red-NIR bands reflection range are given in Table 1.

Table 1. Reflection range indexes

Region	Indexes	Equation	Reference
Visible (Vis)	Triangular Greenness Index	$TGI = -0.5[(\rho_r - \rho_b)(\lambda_r - \lambda_g) - (\rho_r - \rho_g)(\lambda_r - \rho\lambda_b)]$	[32]
Visible	Green Leaf Index	$GLI = (2\lambda_g - \lambda_r - \lambda_b)/(2\lambda_g - \lambda_r - \lambda_b)$	[33]
Visible	Visible atmospherically resistant index	$VARI = (\lambda_g - \lambda_r)/(\lambda_g - \lambda_r - \lambda_b)$	[34]
NIR- RED	Ratio vegetation index (also called simple ratio)	$RVI = \lambda_n/\lambda_r$	[35-36]
NIR- RED	Normalized difference vegetation index	$NDVI = (\lambda_n - \lambda_r)/(\lambda_n + \lambda_r)$	[37-38]
NIR- RED	Soil adjusted vegetation index	$SAVI = (1 + 0.5)(\lambda_n - \lambda_r)/(\lambda_n + \lambda_r + 0.5)$	[39]
Vis-NIR	Enhanced vegetation index	$EVI = 2.5(\lambda_n - \lambda_r)/(\lambda_n + 6.\lambda_r - 7.5\lambda_b + 1)$	[40]
Vis-NIR	Triangular vegetation index	$TVI = 0.5[120(\lambda_n - \lambda_g) - 200(\lambda_r - \lambda_g)]$	[41]
Vis-NIR	Chlorophyll vegetation index	$CVI = \lambda_n.\lambda_r/\lambda_g{}^2$	[42]
Notations:	$\rho_{r,b}$: represent the center of wavelenghts $\lambda_{b,g,r,n}$: Blue,Green, Red, NIR reflections		

Satellite data provides information about the fire and makes a significant contribution to damage assessment and improvement studies. Especially with multi-band satellite systems, it is possible to precisely identify and quickly map the fire damaged areas. However, satellite systems may be insufficient in terms of both temporal and spatial resolution. In addition, it is not always applicable in terms of cost according to the area of the working area. Unmanned Aerial Vehicles (UAVs), which have become widespread in many disciplines in recent years and in which imaging systems are integrated, provide new opportunities in this regard. UAVs are relatively more economical, user-friendly and provide high spatial resolution, providing convenience and speed in examining land changes in a short time. It is possible to make different analyzes according to the features of the integrated imaging system. In this study, Triangular Greenness Index (TGI) was produced by using a UAV system with a digital camera with visible bands.

2. Method

2.1. Study Area

In this study, the change in the forestation area of Harran University Osmanbey campus, which was damaged in the fire that occurred in 2020, was examined (Figure 1).

This region is an important area for Şanlıurfa. Because Harran University Osmanbey campus forestation area is the second largest area in the center of Şanlıurfa. Turkey's forest assets are 32% on average according to the surface area of the provinces, and Şanlıurfa forest assets are around 1% as the ratio of the city's surface area together with Ağrı and Iğdır.

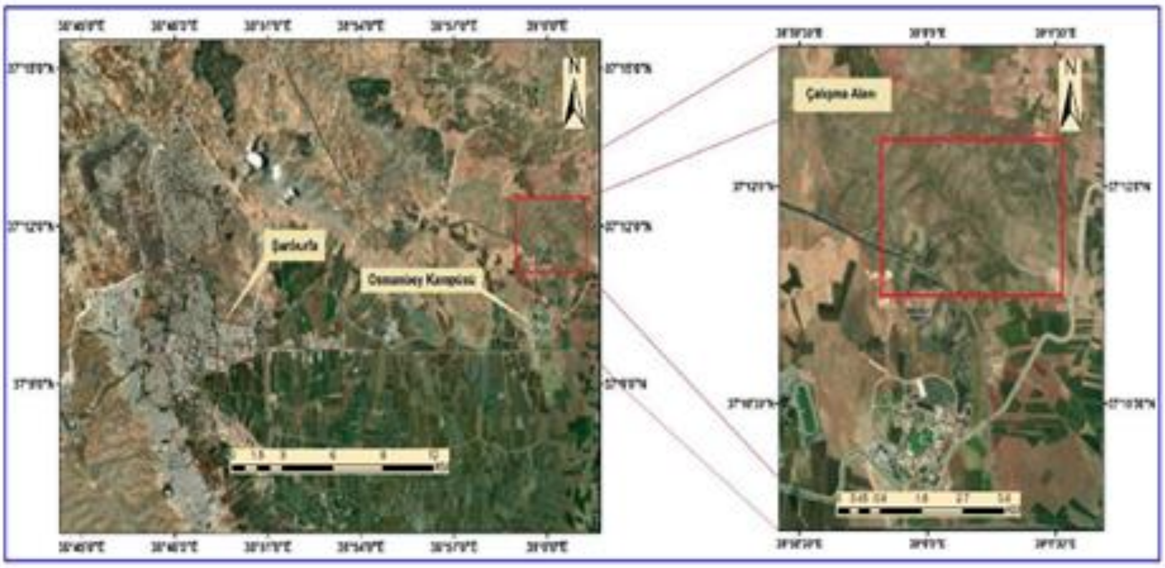

Figure 1. Study area: Harran University Osmanbey campus

2.2. Triangular Greenness Index

TGI (Triangular Greenness Index) was established in 2013 by Hunt et al. suggested by using visible (RGB) bands. This formula is designed to be sensitive to chlorophyll content (green color). It is a fast and advantageous method for situations where there is no infrared band. It is recommended as a low-cost method of monitoring plants, especially with digital cameras mounted on low-flying aerial platforms. It is reported to give very similar results with NDVI in green plant detection. Equation 1 is used in the analysis.

$$TGI = (GREEN - 0.39 * RED - 0.61 * BLUE) \quad (1)$$

3. Results

The study was carried out with UAV flights at two different times. The first flight took place in July 2020, one week after the fire. The second flight was carried out in March 2022. Both flights took place at an altitude of 120m. transverse and longitudinal overlaps are 70%. DJI Mavic 2 pro was used for the flight. The DJI Mavic 2 Pro was launched in late 2018 and was the first consumer drone to feature a one-inch sensor and adjustable aperture. The camera fitted to the Mavic Pro 2 is a Hasselblad L1D-20c, providing a full-frame equivalent focal length of 28mm with ISO 100-12,800 available for stills and ISO 100-6400 available for video.

RGB photos from both flights were processed in Pix4D software. As a result, the orthophoto of the region is obtained. TGI images were obtained using both orthophotos RGB bands. The resulting TGI images are given in Figure 2.

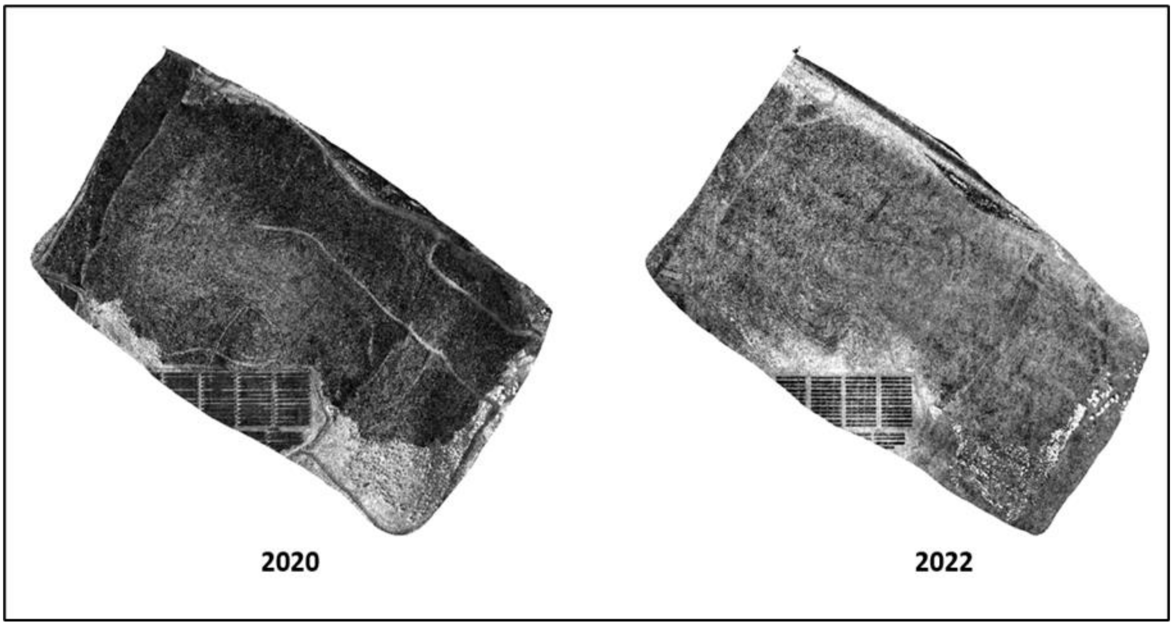

Figure 2. TGI images of Harran University Osmanbey campus for 2020 July and 2022 March

4. Discussion

When the TGI images obtained are examined, some changes can be noticed. The study area is the forested area damaged in the fire that occurred in 2020 on the Osmanbey campus of Harran University. The data used for the study were obtained from two UAV flights one week after the fire and two years later. Both flight altitudes were 120m. While the rate of green space in the study area was 0.3% after the 2020 fire, it was observed that this rate increased to 0.54% in 2022. Thus, the areas that were not damaged immediately after the fire and the areas that grew green after two years were determined. expressions should not be included in essence. When the areas with circle, triangle and square signs are examined, it is clearly seen that there are growths in some of the newly greening trees in some regions (Figure 3).

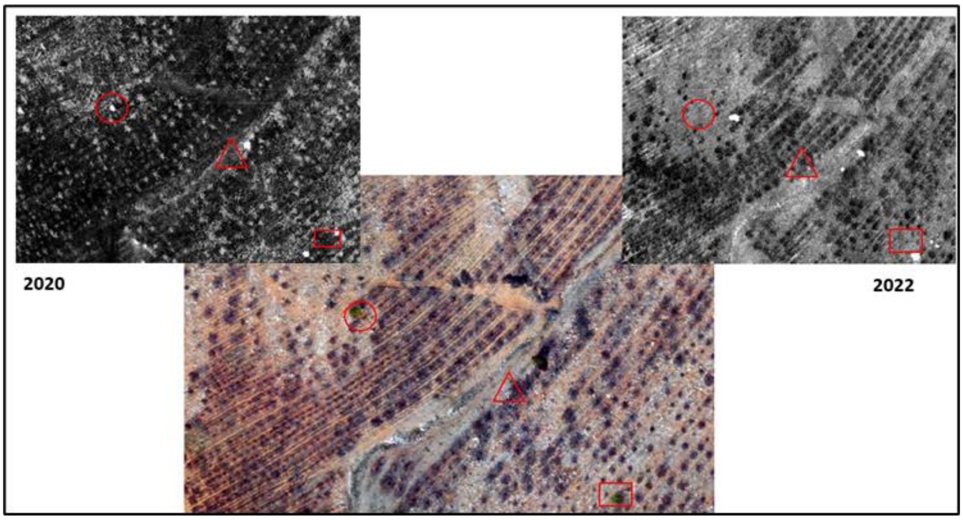

Figure 3. Growths and newly greening trees in the region

5. Conclusion

It is a fast and advantageous method for situations where TGI Infrared band is not available. It is recommended as a low-cost method for monitoring plants, especially with low-flying aerial platforms. Although it is mentioned that it gives similar results with NDVI in green plant detection, there are warnings that it also detects green objects. While the rate of green space in the study area was 0.3% after the 2020 fire, it was observed that this rate increased to 0.54% in 2022. Thus, the areas that were not damaged immediately after the fire and the areas that grew green after two years were determined.

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Author contributions:

Nizar Polat: Conceptualization, Methodology, Software **Abdulkadir Memduhoğlu:** Data curation, Writing-Original draft preparation, Software, Validation. **Şeyma Akça:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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Production of orthophoto by UAV data: Yaprakhisar example

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Abstract

Unmanned aerial vehicles (UAV) are used in many areas today. It has an intensive usage area especially in the discipline of surveying engineering. Undoubtedly, UAV is the new favorite tool of photogrammetric methods, which is one of the map production methods of survey engineering, which is intertwined with technology. Due to its ease of use, time saving and sufficient accuracy, the UAV has found a place in the field of aerial photogrammetry in a short time in small and medium-sized fields. In this study, orthophoto map of Yaprakhisar village of Aksaray province was produced using UAV data. eBee SenseFlay was used in the study. The obtained orthophoto and real field data were compared. It has been observed that the results are of sufficient accuracy.

1. Introduction

Unmanned aerial vehicles (UAV) systems and applications are increasingly used by many institutions, organizations, commercial enterprises and academic circles for different purposes. In parallel with the increase in land use, management and monitoring studies, the need for location-based information is constantly increasing day by day. By using modern terrestrial, air and satellite-based technologies, the data needed together with Geographic Information Systems are collected, analyzed and results can be presented in various ways more quickly and accurately than ever before [1].

One of the methods adopted in order to obtain the spatial data needed in recent years is the use of UAVs. A UAV is a vehicle that can move automatically or semi-automatically depending on a flight plan, or is flown by remote control by a pilot on the ground or in another vehicle. UAV-based data collection and mapping can provide sufficient accuracy needed in many fields, especially agriculture, forestry, urban planning, geology and disaster management.

Depending on the carrying capacity and features of the UAV platform, it can be equipped with video cameras, thermal or infrared camera systems, multispectral cameras, LiDAR sensors or a combination of these technologies. In addition, the UAV may include GNSS/INS (Global Navigation Satellite System/Inertial Navigation System) system, barometric altimeter and compass systems. Such an integrated system is often referred to as an Unmanned Aerial Vehicle System (ISP).

There are various methods such as Global Positioning Systems (GPS), terrestrial geodetic surveys, LIDAR, terrestrial laser scanner, conventional aircraft, photogrammetry and remote sensing that produce location-based data. It is a technology that can produce accurate and sensitive data based on location in UAV. UAVs will be the most important data source generating data for many disciplines in the future [2].

UAVs are vehicles that can fly continuously automatically or semi-automatically according to aerodynamic flight principles, and move without a flight crew (pilot). The UAV can fly in remotely controlled, semi-automatic or fully automatic techniques and can carry cameras, sensors, communication equipment or other equipment. UAVs have a much smaller structure than conventional manned aircraft, so they are much easier and more economical to transport [3]. On the other hand, real-time kinematics (RTK) positioning systems can be attached to UAVs, and thus images with more precise location information can be obtained.

A three-dimensional (3D) model should be used in applications such as virtual reality, communication, and automatic orientation. For example, during industry quality assessment, it is important to create a 3D model of buildings before and after a disaster, in tourism, architecture and 3D urban planning. In such studies, UAVs are used very effectively and efficiently [4].

Images obtained with high sensitivity in very low flight using UAVs can be produced at a lower cost than images obtained from conventional aerial photogrammetry [5]. The maps, which are formed as a result of processing the aerial photographs obtained by the photogrammetric method by eliminating the optical errors and containing the three-dimensional coordinate information, are called orthophoto maps. Measurements can be taken and drawings can be made on these maps.

In the literature, it is seen that the location accuracy can reach up to ±2 cm depending on the region, especially in orthophoto maps created from aerial photographs taken from UAVs with GPS with RTK feature. Orthophoto maps have richer detail and visual information than linear maps. With UAV technologies, production in small and medium-sized fields can be done more easily, quickly and with sufficient accuracy. It is one of the indispensable bases for many professional disciplines. In this study, the orthophoto map of the region and a 3D settlement model were obtained with the application made in Yaprakhisar village of Aksaray province and carried out with the UAV.

2. Unmanned Aerial Vehicles

For the first time in history, an unmanned vehicle was used in a military incident, which was recorded as the first unmanned aerial attack. This event happened in 1849, when the Austrians sent explosive -filled unmanned balloons to Venice, Italy. The development and production of aircraft with the aim of flying truly remotely, that is, unmanned, coincides with the First World War for the first time. Here, Unmanned Aerial Vehicles, which are defined as flying vehicles that do not contain humans and can be controlled from the ground thanks to a communication system. In short, UAVs, came into active use especially after the Second World War [6].

UAVs provides a great advantage over normal aircraft due to its low production, purchasing, fuel and flight costs [7-8]. More importantly, these vehicles do not pose a risk of injury or loss of life during the mission, as they are uncrewed. For the same reason, they are lighter than conventional aircraft and can stay in the air longer with the same amount of fuel [9].

On the other hand, the disadvantages for UAVs are that their danger perception ability is not as strong as a human, that they can pose a danger if the ground control connection is broken, and that they are vulnerable to air attacks by manned aircraft. However, these disadvantages are tried to be minimized with R&D activities in data transfer and artificial intelligence technologies. On the other hand, further increasing the flight times will allow these vehicles to be used widely in the near future [10].

Uysal et al [11] aimed to produce the Digital Terrain Model (DTM) of the Şahitler Kayası Höyük using UAV photogrammetric techniques and to perform an accuracy analysis on an area of approximately 5 ha in the Şahitler Kayası location in the center of Afyonkarahisar. In their study, they established a total of 27 GCPs in the application area, 5 homogeneously, and obtained the coordinates of GCPs in ITRF96 datum by RTK method with Stonex S9 GNSS (Global Navigation Satellite Systems - Global Positioning Satellite Systems) device. Images were captured from an average height of 60 m with the Canon EOS digital camera on the UAV. As a result of their study, they evaluated the accuracy of the DTM with 30 control points and determined a vertical sensitivity of 6.62 cm. They stated that the usage of UAVs and photogrammetric techniques together will make significant contributions to the work done in this field in terms of accuracy, speed, cost and product diversity.

Şenol and Kaya [12] stated that in order to create a 3D model, a field study of the model should be done. In order to create a 3D model of a structure, they added data collection with UAV to their data collection methods. They wanted to minimize the field work with the data collection methods, and for this purpose, they were able to collect data without the need for field work. In addition, they informed that models can be created with various software from images of UAV, terrestrial and rough areas.

Unmanned aerial vehicles are divided into groups according to their various features and usage purposes. The most important reason for this grouping is to see if UAVs are suitable for the projects they are used in, in terms of purpose and features.

UAV and its applications have started to be used in many areas today. Although the first use of the UAV, which provides general convenience in every area it is used, was for military purposes, it has spread to a wide range from hobby use to project and analysis purposes. Some of the usage areas are obtaining digital terrain models, digital elevation models, digital surface models, city maps, geographic information system, land information system, three-dimensional model creation. Pond volume determination [13], landslide site [14-16], rockfall site [17], cultural heritage modelling [18-24] and soil erosion [25] are the most used ones.

3. Application

Yaprakhisar village of Aksaray province was chosen as the application area (Figure 1). The eBee SenseFly with real-time kinematic positioning feature was used in the study (Figure 2). 709 pictures were taken with a camera with 18.2 Mpixel resolution at 6.01 cm ground sampling interval. Orthophoto maps were produced by evaluating the pictures in the PIX4D mapper program. In addition, dense point cloud, digital elevation model and digital terrain model of the study area were produced. The products obtained are shown in figures 3, 4, 5, 6, 7 and 8. Accuracy analyzes were made with the help of the points measured on the obtained orthophoto and in the field.

Figure 1. Study area

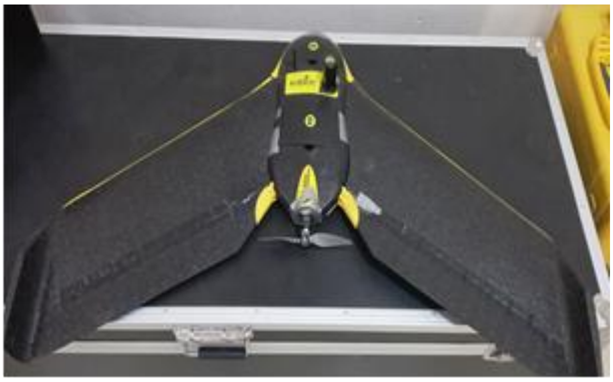

Figure 2. eBee SenseFly

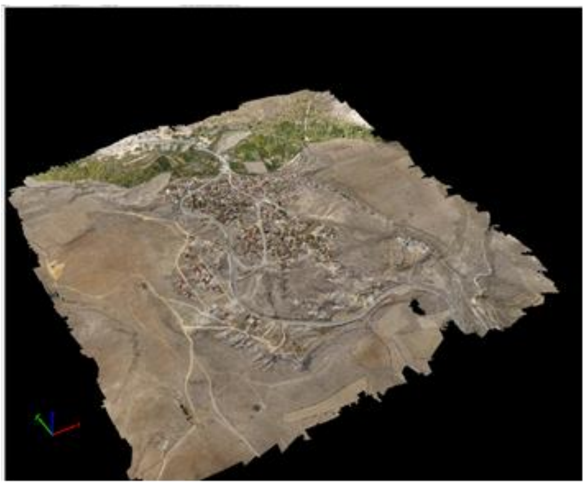

Figure 3. Dense Point Cloud

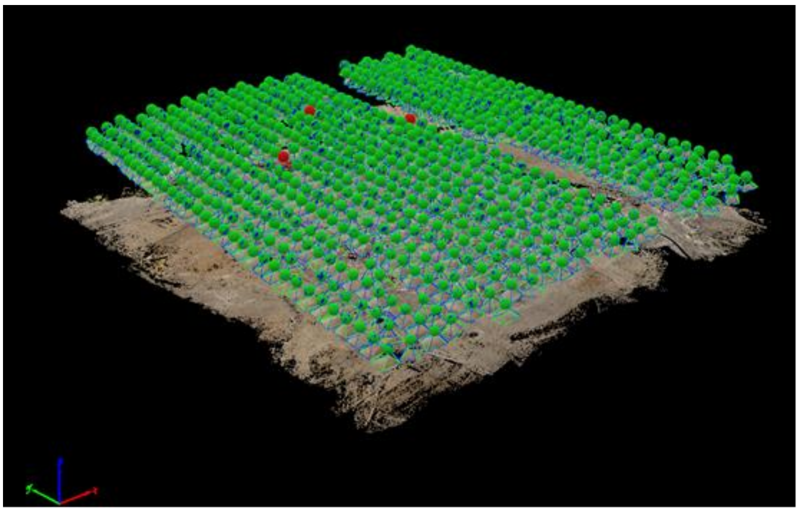

Figure 4. Picture locations

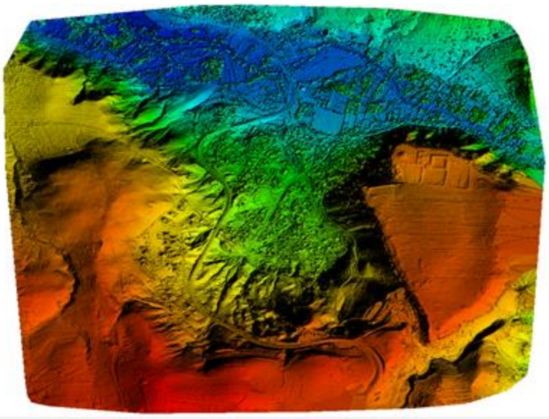

Figure 5. Digital Terrain Map

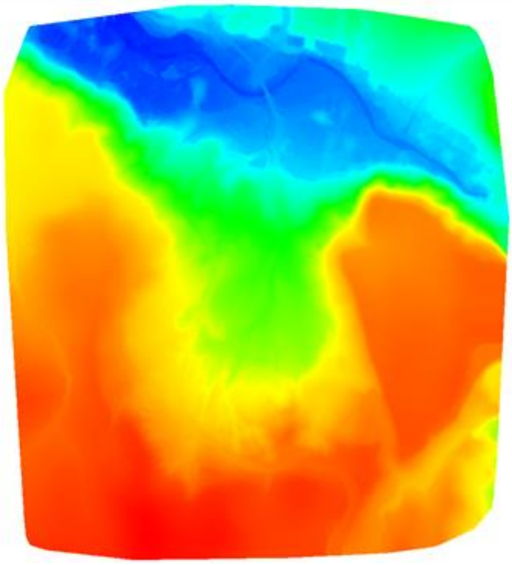

Figure 6. Digital Surface Map

Figure 7. Orthophoto

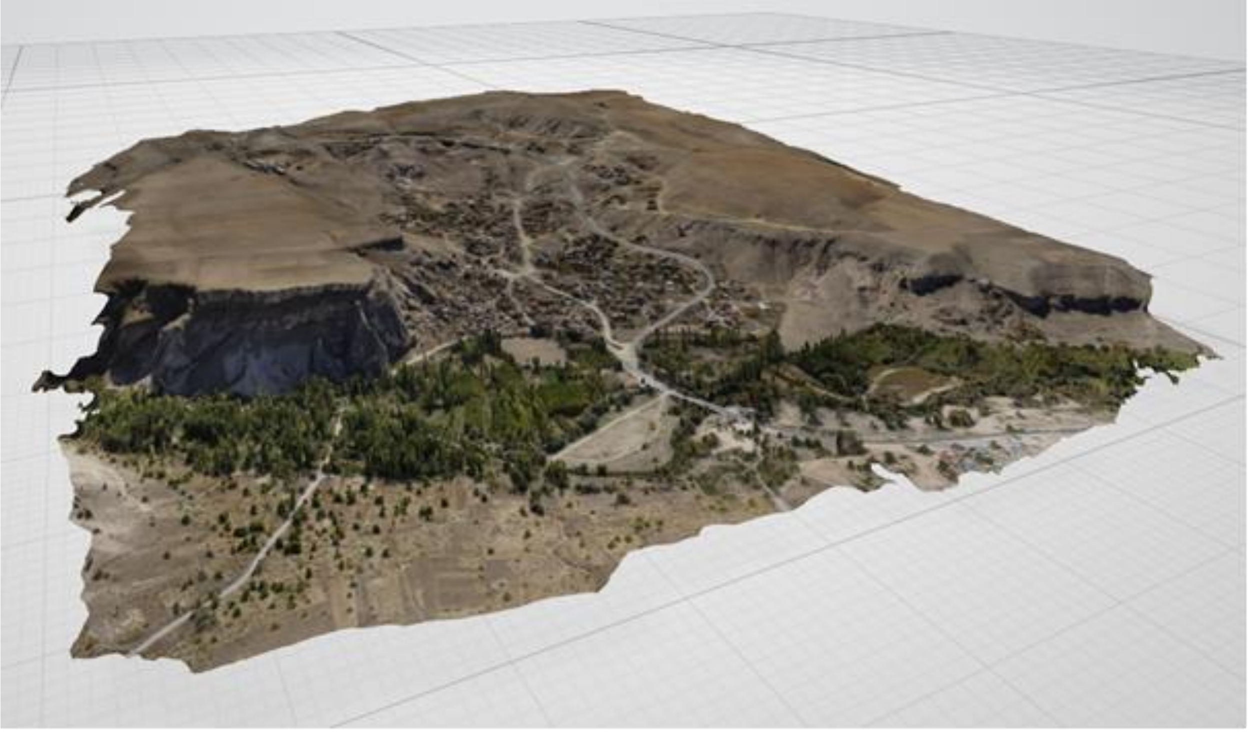

Figure 8. 3D Model of the study area

4. Results

An area of 3.2246 km^2 was used in the study. After block balancing, the mean square error was 1.392 cm. In the control measurements made at the detail points, it was determined that mx= 1.467 cm, my= 1.467 cm, mz= 2.739 cm. Due to the high difference in height in the study area, the height error was higher than the position errors. In addition, a detail overlay was made on the orthophoto map obtained from the study area and the existing map and it was seen that the results were quite sufficient (Figure 9 and Figure 10).

Figure 9. Detail overlay on the produced orthophoto and the existing map

Figure 10. Close view of the detail point

5. Conclusion

In this study, orthophoto map, three-dimensional model, digital terrain model and digital elevation models of Yaprakhisar village of Aksaray province were obtained. As a result of the study, it was revealed that the orthophoto map produced was of sufficient accuracy as stated in the literature, and the detail overlapping made with the existing existing map produced by the geodetic method of the study area. UAV is successfully applied in obtaining spatial and visual data that will be required for many engineering projects. In addition, many disciplines are able to obtain the necessary data and make the necessary analyzes and planning in appropriate accuracy, time and cost-effective studies with UAV data.

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Author contributions:

Nusret Aktan: Conceptualization, Methodology, Software **Adem Çolak:** Data curation, Writing-Original draft preparation, Software, Validation. **Hacı Murat Yılmaz:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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Modelling of its surroundings and Selime Cadhetral by UAV data

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Abstract

Historical and cultural heritages are the common values of all humanity. They are rare works that contain traces of the religious, cultural and social lives of human beings from the past to the present. It is important to pass them on to future generations. For this reason, documentation and restoration studies of such heritages are also important in terms of human history. Documentation studies can be done with traditional methods, as well as with Unmanned Aerial Vehicles (UAV) data, in a fast and sensitive way. In this study, three-dimensional modeling studies were carried out on the UAV data of the Selime Cathedral, the largest cathedral of Cappadocia. Documentation of such cultural heritages and obtaining three-dimensional models are considered important both for the sake of preserving the heritage and for viewing it visually in the virtual environment under appropriate conditions.

1. Introduction

Unmanned aerial vehicles (UAV) systems and applications are increasingly used by many institutions, organizations, commercial enterprises and academic circles for different purposes. In parallel with the increase in land use, management and monitoring studies, the need for location-based information is constantly increasing day by day. By using modern terrestrial, air and satellite-based technologies, the data needed together with Geographic Information Systems are collected, analyzed and results can be presented in various ways more quickly and accurately than ever before [1]. In the last decade, too many engineering projects have been solved using UAV. Pond volume determination [2], landslide site [3-5], rockfall site [6], cultural heritage modelling [7-13] and soil erosion [14] are the most commonly usage area of UAV.

One of the methods adopted in order to obtain the spatial data needed in recent years is the use of UAVs. A UAV is a vehicle that can move automatically or semi-automatically depending on a flight plan, or is flown by remote control by a pilot on the ground or in another vehicle. UAV-based data collection and mapping can provide sufficient accuracy needed in many fields such as agriculture, forestry, urban planning, and disaster management.

Depending on the carrying capacity and features of the UAV platform, it can be equipped with video cameras, thermal or infrared camera systems, multispectral cameras, LiDAR sensors or a combination of these technologies. In addition, the UAV may include GNSS/INS (Global Navigation Satellite System/Inertial Navigation System) system, barometric altimeter and compass systems. Such an integrated system is often referred to as an Unmanned Aerial Vehicle System (ISP).

There are various methods such as Global Positioning Systems (GPS), terrestrial geodetic surveys, LIDAR, terrestrial laser scanner, conventional aircraft, photogrammetry and remote sensing that produce location-based data. It is a technology that can produce accurate and sensitive data based on location in UAV. UAVs will be the most important data source generating data for many disciplines in the future [15].

UAVs are vehicles that can fly continuously automatically or semi-automatically according to aerodynamic flight principles, and move without a flight crew (pilot). The UAV can fly in remotely controlled, semi-automatic or fully automatic techniques and can carry cameras, sensors, communication equipment or other equipment. UAVs have a much smaller structure than conventional manned aircraft, so they are much easier and more economical to transport [16]. On the other hand, real-time kinematics (RTK) positioning systems can be attached to UAVs, and thus images with more precise location information can be obtained.

A three-dimensional (3D) model should be used in applications such as virtual reality, communication, and automatic orientation. For example, during industry quality assessment, it is important to create a 3D model of buildings before and after a disaster, in tourism, architecture and 3D urban planning. In such studies, UAVs are used very effectively and efficiently [17].

There are many internal and external factors that cause the deterioration of cultural heritages until today [18-19]. These artifacts have survived to the present day by being exposed to many negative factors such as negligence, destruction by people, war, earthquake, fire, flood, etc [20-22]. For this reason, it is very important that the cultural heritages that can be preserved, which cannot be reproduced and cannot be returned, have to be documented in a non-destructive way down to the smallest point [23].

Photogrammetry, with the latest developments, offers the opportunity to take pictures with UAV. This facility allows fast and economical 3D modeling of objects on the earth's surface with the help of photographs taken by the UAV [24]. This provides the opportunity to reach even the most difficult point that is difficult to reach. Different photogrammetric approaches have been used to create 3D models [25]. There are many studies on this subject in the literature. 3D modeling studies find application in many different areas. The 3D model creation studies also form the basis for the documentation and protection of cultural heritage and survey studies when necessary. In this study, 3D modeling studies of UAV data of Selime Cadet, the largest cathedral of Cappadocia, were carried out.

2. Application

Selime Cadet located in Selime town of Aksaray province was chosen as the application area (Figure 1). Selime lived the Hittite, Assyrian, Persian, Roman, Byzantine, Danishment, Seljuk, Karaman and Ottoman Empires. The unconditional obedience of the people of Orthodox faith living in the region to the decisions to be issued from the Selime cathedral and monastery, and the key with the cross sign they made inside the church reveals the importance of this place in the past [26].

At the exit to Selime cathedral and monastery, we encounter a high corridor, which is part of the caravan route where camels were taken. Because of the market established in Selime, caravans were coming to Selime and camels were being taken up to the middle part of the cathedral for the safety of the caravans. Selime Cathedral and Monastery were built on top of this part for those who want to rest and worship. Structures carved into the rocks and mostly built as churches bear the traces of Byzantine art. It is also noteworthy that the upper part of the cathedral was built as a fortress. The walls and positions still exist today [26].

One of the most important features of Selime Kale Monastery is that it is the place where the clergy in the region were trained. Regional meetings and military base are located here. The first loud ritual was held in Selime Cathedral. Selime is the biggest monastery of Cappadocia. Kale Monastery Church is one of the largest religious organizations in Cappadocia. Monastery VIII. century. with XI. century, and the figured frescoes in the church are from the X. century. with the end of XI. YY. dated between their heads. There are depictions such as the ascension of Jesus, the Annunciation, and the Virgin Mary. The kitchen in the cathedral draws attention. In the kitchen, which was built in the form of a pyramid, oil lamps were built to illuminate the surroundings and there are other connected rooms next to it. Selime Monastery, on the other hand, was built as a two-storey courtyard. This is where loud liturgy, military and district meetings are held [26].

Selime Kadetra 513 pictures were taken with an 18.2 MP resolution camera at a 6.31 cm ground sampling interval. The eBee SenseFly UAV with real-time kinematic positioning was used in the study (Figure 2). A three-dimensional model was produced by evaluating the pictures in the PIX4D mapper program. In addition, dense point cloud, digital elevation model, orthophoto and three-dimensional model of the study area were produced. The products obtained are shown in Figures 3, 4, 5 and 6. Accuracy analyzes were made with half of the points measured on the obtained orthophoto and in the field.

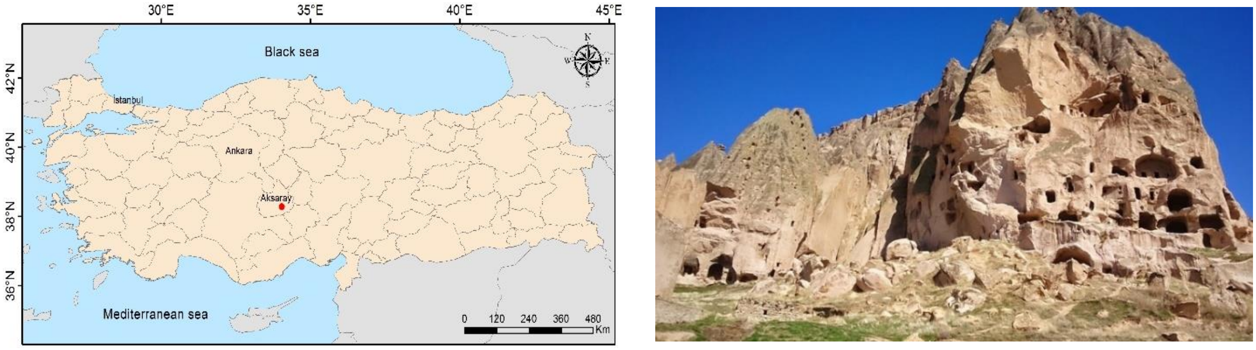

Figure 1. Selime Cadhetral

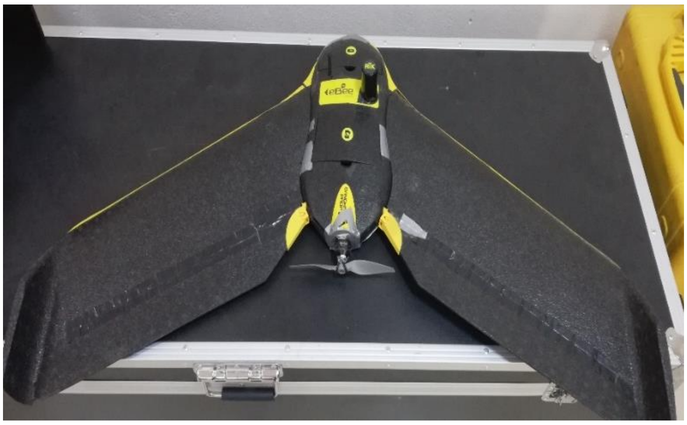

Figure 2. eBee SenseFly

Figure 3. Dense Point Cloud

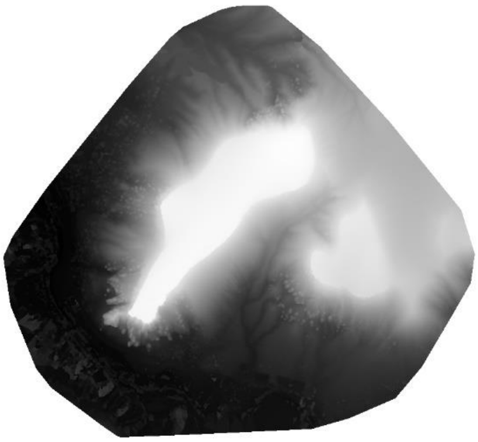

Figure 4. Digital Terrain Map

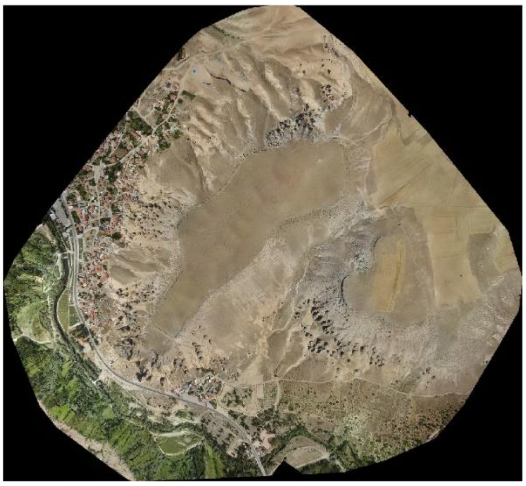

Figure 5. Orthophoto

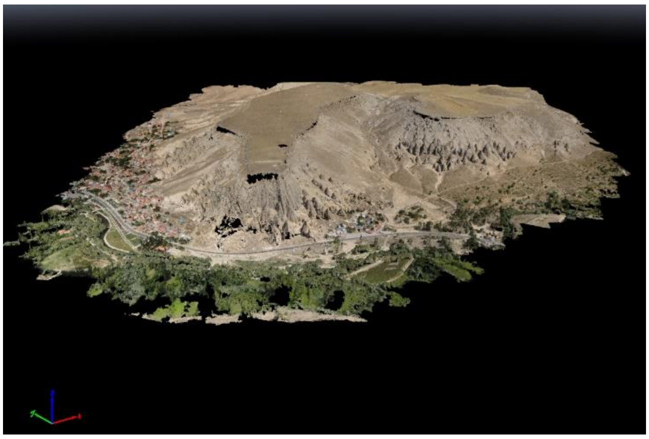

Figure 6. 3D model

3. Results

As a result of the block balancing made in the PIX4D mapper program, the mean square error was obtained as 19.6 cm. Position errors at the control points were obtained as mx= 1.46 cm, my=1.46 cm and mz= 3.0 cm. Thanks to the developments in photogrammetric software and hardware in recent years, photogrammetric relief and 3D modeling studies can be done faster, more precisely and more economically. Historical and cultural heritages constitute important values of human history. With today's technologies, it is important to carry out studies that will be the basis for documenting, protecting and relaying these values, both in terms of protecting these values and helping humanity to recognize them in virtual environments.

4. Conclusion

One of the most important values between the past and the future of a society is historical and cultural heritage. It is important for humanity to protect them and keep them alive. For this reason, it is considered as one of the most important responsibilities of humanity to protect these heritages and determine their current status, document them, record them and restore them in accordance with their original form. In this study, three-dimensional modeling studies of unmanned aerial vehicles data of Selime Cadet, which is located in the borders of Aksaray province and which is the largest cathedral of Cappadocia, were carried out.

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Author contributions

Adem Çolak: Conceptualization, Methodology, Software **Nusret Aktan:** Data curation, Writing-Original draft preparation, Software, Validation. **Hacı Murat Yılmaz:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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Accuracy of digital maps produced from UAV images in rural areas

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Abstract

Rural areas are areas that are surrounded by high mountains and are very rough and therefore transportation is insufficient. The measurement of these areas has also caused it to be time consuming and costly. With the development of technology, the rapid development of Unmanned Aerial Vehicles (UAV) technology has begun to be used not only in the military field, but also in the civilian fields. One of these areas was rural areas. In this study, the measurement of the mine field in the rural area was made by the UAV photogrammetry method and Digital Elevation Model (DEM) and Ortomosaic were produced. Accuracy analysis was carried out with the control points measured in the field on these produced maps. In this direction, it has been concluded that UAV technology can be used in rural areas.

1. Introduction

The environments where economic activities are based on the evaluation of natural resources, where face-to-face relations are relatively more common, where the rules of life are largely shaped according to traditions and customs, where technical and technological developments and economic, social and cultural developments take place more slowly and therefore with a delay are called rural areas. Obtaining 3D location data is difficult in terms of time and cost when it comes to rural areas, hard-to-reach areas and large areas in terms of surface area [1-3].

Traditional methods have been used to obtain 3D location data until today. However, these methods, especially in rural areas, have affected the accessibility of high mountains, which show significant changes in sudden changes in land heights, but have a negative impact on accessibility [4-5].

With the development of technology, the rapid development of Unmanned Aerial Vehicles (UAV) technology has begun to be used not only in military fields but also in various civilian fields. One of these areas was rural areas. Studies such as mapping rural areas, topographic mapping of the earth, monitoring and planning of mining operations, and determination of forestry and forest areas have begun to be carried out using UAV technologies [6-7].

With UAVs, which is a remote sensing technology, it is possible to obtain high resolution data in a short time with less labor and with comprehensive analysis. Images of a work area are taken by equipping UAVs with sensors suitable for the work to be done, and data processing can be done with many software [8-9].

The mapping of rural areas with the help of UAV technology is carried out with the UAV Photogrammetry method, which is considered a sub-science of photogrammetry. UAV photogrammetry is generally a photogrammetry process using photographs taken with a camera integrated into an aircraft [10-11].

While providing more flexibility with UAVs compared to traditional data collection methods, less time is spent in the working area and also provides significant cost advantages. In addition, thanks to the Global Navigation Satellite Systems (GNSS) integrated into the new type of UAVs, the latitude, longitude and height information of the pictures taken are among the advantages of this system. In addition, the presence of a GNSS module and the ability to take pictures automatically with these UAVs contribute to a significant reduction in distortion (translation, rotation and offset). Moreover, the data obtained by UAVs with their low altitude flight capability and advanced technical imaging systems contain significantly higher resolution and much more detailed information compared to the data obtained from satellite images and manned aircraft [12-15].

There are many open source and commercial software that works integrated with UAV photogrammetry. Many of these software is based on Structure from motion (SfM) proprietary algorithms. SfM is a photogrammetric imaging technique used to predict 3D structures from arrays of two-dimensional (2D) images. In the SfM method, 3D structures are created from a series of overlapping frames. SfM in a short time; It has had a transformative impact on geoscience research, providing extraordinarily fast, cost-effective and easy 3D measurements [16-19]. The reason for this is that the SfM technique also offers the possibility of integrating photographs taken from different shooting platforms, both terrestrial and aerial, if certain working methods are followed. The main difference between traditional stereoscopic photogrammetry and the SfM method is that the calculations required to obtain the precise position of a point in 3D space are fully automated and precise positioning of the cameras is not required [20-23].

In a study by Lee & Choi [16], 89 photos were obtained by flying autonomously for 30 minutes at 100 m altitude using a rotary wing UAV (DJI Phantom 2 Vision). A digital surface model Digital Elevation Model (DEM) was created by processing the collected data. Comparison of the X, Y, Z coordinates of the five ground control points (GCP) measured by the Differential Global Navigation Satellite Systems with those determined by UAV photogrammetry shows that there is a mean square error of about 10 cm. At the end of this study, they reported that rotary vane UAV photogrammetry can be effectively used as a technology that can replace or complement existing topographic measurement equipment in open pit mines [24-26].

Doğruluk et al. [24] examined the performance analyzes of filtering methods from DEM production in rural areas. Collecting control points with field measurements for absolute accuracy assessment of filtering results contributed significantly to the results of the study. In addition, it was emphasized that the use of high-resolution optical images of the study area would be meaningful in terms of allowing different methods to be used in accuracy analysis [27].

Akgul et al. [25] carried out DEM production of forest areas with UAV photogrammetry. It has been emphasized that UAVs are an important tool that will contribute to high-precision studies for forestry studies, since more sensitive data such as Lidar data of forest areas are not yet available or widespread [28-30].

In this study, UAV Photogrammetry of the open mining area, which is one of the rural areas, produced DEM and orthomosaic maps and the accuracy of these maps was examined.

2. Material and Method

A rural area belonging to the province of Burdur, shown in Figure 1, was chosen as the study area. The reason for choosing this region is that it is a rural area far from the city center, difficult to reach and not easily accessible.

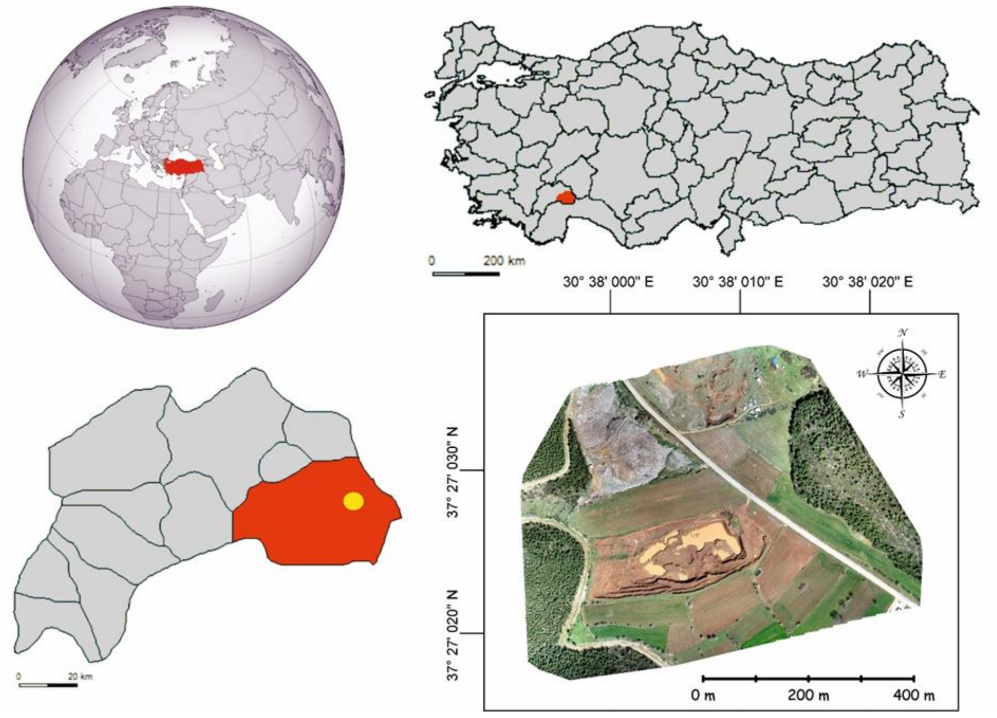


Figure 1. Location map of the study area where the rural area is located

2.1. Data collecting

In this section, 30 control points (CP) points were established in the rural area. At these CP, 18 were used as GCP and 12 as checkpoints (ChP). These points were measured with the Topcon GR5 Global Navigation Satellite Systems (GNSS) rover in the ITRF96 datum system (Figure 2).

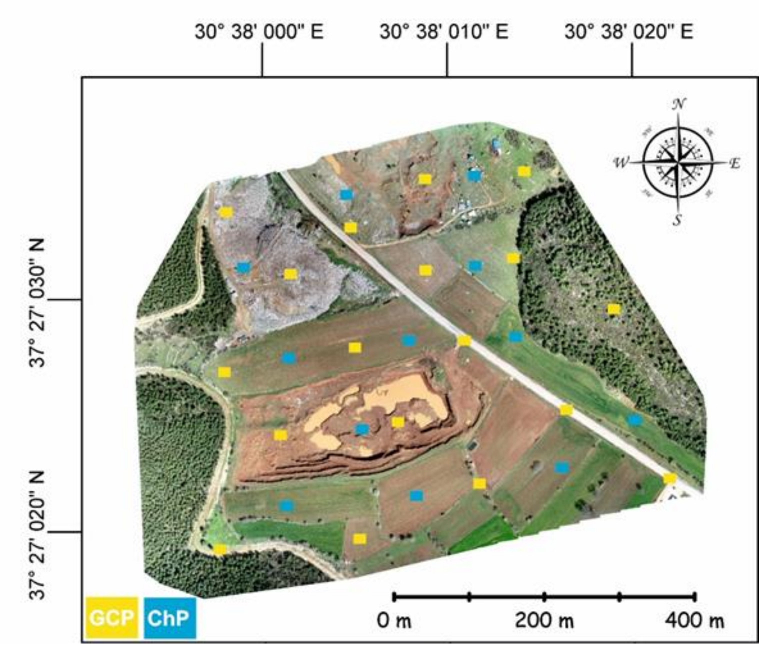


Figure 2. Distribution of GCP and ChP to study area

Phantom 3 PRO brand UAV and integrated ground control systems were used as a flying carrier platform for generating DEM data and taking high-sensitivity images (Figure 3). The photographs were obtained from different angles and overlapped from a height of 30 m. In Table 1, the technical specifications of the UAV are given.

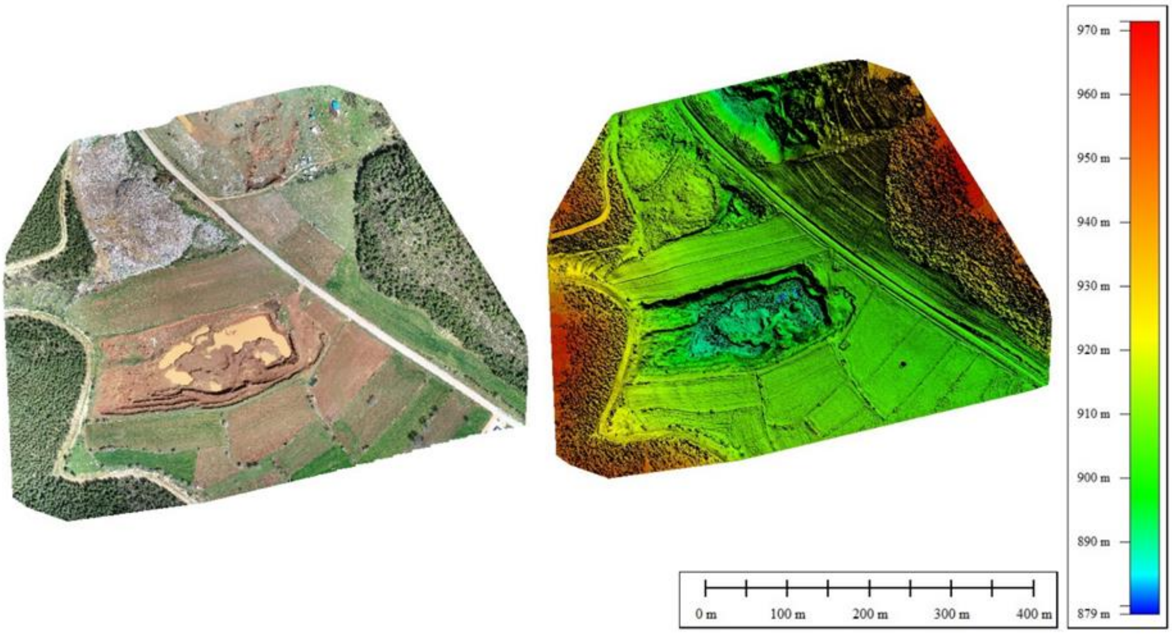
Figure 3. Phantom 3 Pro UAV

Table 1. Phantom 3 Pro UAV

Features	Value
weight	
Maximum Takeoff Speed	5 m/s
Minimum Takeoff Speed	3 m/s
Maximum Speed	16 m/s
Maximum Tilt Angle	35°
Satellite Positioning Systems	GNSS/GLONASS
Sensor size	1/2.3”
Lens	20 mm

2.2. Data Processing

Agisoft Metashape software was used for photogrammetric evaluation. First, the GCP points measured in the field were transferred to the software and the photographs were marked. Then, 3D modeling was done in Agisoft Metashape software. As a result of the study, orthomosaic map and DEM map of the study area were produced (Figure 4).



(a) (b)

Figure 4. a) Orthomosaic map of the study area, **b)** DEM map of the study area

2.3. Accuracy Assessment

18 GCP and 12 ChP were homogeneously established in the study area. The coordinates of these points were measured by GNSS rover. These coordinates are accepted as reference coordinates. Square mean error equations were used in the accuracy analysis. The accuracy of the photogrammetric project was calculated using control points not used in georeferencing [19-20-21]. In this context, orthomosaic and DEM control points were defined and their coordinates were compared with the GNSS coordinates examined, and $RMSE_x$, $RMSE_y$, $RMSE_z$ horizontal accuracy measures were obtained as defined in the equations given below:

$$V_{x,y,z_i} = X, Y, Z_{ChP_i} - X, Y, Z_{GNSS_i} \quad (1)$$

$$RMSE_{x,y,z} = \pm\sqrt{\frac{[VV]}{n-1}} \quad (2)$$

Table 2. Error-values and RMSE of ChPs

ChP	VxVx	VyVy	VzVz
1	8.10	11.50	15.20
2	3.60	4.80	14.50
3	9.30	12.80	21.00
4	8.70	9.20	19.00
5	8.60	9.80	18.70
6	6.90	5.80	16.40
7	11.60	8.70	21.80
8	7.90	11.80	17.80
9	8.00	5.20	11.80
10	11.80	4.80	23.80
11	13.10	14.70	5.70
12	4.20	7.80	8.70
RMSE	3.04	3.12	4.20

In line with these data, the mean position errors in the x, y and z coordinates of the digital map produced using the UAV photogrammetry technique were found to be ±3.04, ±3.12, and ±4.20 cm, respectively.

3. Discussion and Conclusion

This study showed that this is readily possible with UAV photogrammetry technology in rural areas. UAVs can be used without problems on such terrain. UAVs allow practical, very fast, accurate, and cost-effective measurements in difficult and impassable terrain conditions. The 3D model was created in a short time. It provides a highly practical solution for monitoring mining area progress, identifying discrepancies, making good decisions for the future, and planning in light of those decisions. Examining the accuracy of the output products produced at the same time indicates that they can be used within the scope of the study.

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Conflicts of interest

The authors declare no conflicts of interest.

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