Bartın Orman Fakültesi Dergisi | Journal of Bartin Faculty of Forestry
2022, 24(3): 530-541 | DOI: 10.24011/barofd.1073229

Use of Unmanned Aerial Vehicles in Forest Road Projects

Mihrişah KINALI[1], Erhan ÇALIŞKAN[2*]

[1, 2*] Karadeniz Technical University, Faculty of Forestry, Department of Forest Engineering, 61080, Trabzon, Türkiye

Article History
Received: 15.02.2022
Accepted: 02.06.2022
Published: 15.12.2022

Research Article

Abstract − Road networks are accepted as a criterion showing the level of development of countries. Undoubtedly, the role of highways in facilitating human life is quite important. However, road routes involve high cost land surveying studies that can pass through areas with various land use types and cover.For forest road routes to be built in forest areas, points representing the land surface can be obtained by various measurement methods (remote sensing, photogrammetry and terrestrial measurement techniques). Depending on the land structure and cover, difficulties are encountered in the determination of spatial points with terrestrial measurement techniques. In this study, as an alternative to the terrestrial measurement technique, 341 m long forest road excavation and filling calculations were carried out with the help of Unmanned Aerial Vehicle (UAV) photogrammetry. Photo pairs taken from different heights (50 m, 75 m and 100 m) with real-time kinematics (RTK) GPS UAV were processed with Agisoft to produce a point cloud. The point cloud data obtained by digital photogrammetry and land measurement methods were carried out in NetCAD environment for the excavation and filling calculations for the same road route. Between the two methods, in the 50 m, 75 m and 100 m measurements of the UAV obtained by ground measurement; In the calculation of the UAV 50m measurement amount, 0.27% in the total excavation amount and 1.08% difference in the total filling amount, 2.51% in the total excavation amount and 5.22% in the total filling amount in the calculation of the UAV 75 m measurement amount, and the total difference in the UAV 100m measurement amount in the calculation of the UAV 50m measurement amount. A difference of 3.13% in the amount of excavation and 2.53% in the total amount of filling was determined. These results show that UAV photogrammetry is very effective in forest road projects and in calculating the amount of earthwork volume in mountainous terrain.

Keywords: *Forest road, UAV, photogrammetry, terrestrial measurement, earthwork volume*

İnsansız Hava Araçlarının Orman Yolu Projelerinde Kullanımı

[1, 2*] Karadeniz Teknik Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, 61080, Trabzon, Türkiye

Makale Tarihçesi
Gönderim: 15.02.2022
Kabul: 02.06.2022
Yayım: 15.12.2022

Araştırma Makalesi

Öz − Yol ağları, ülkelerin gelişmişlik düzeyini gösteren bir ölçüt olarak kabul edilmektedir. Hiç şüphesiz kara yollarının insan hayatını kolaylaştırmada rolü oldukça önemlidir. Bununla birlikte kara yolu güzergâhları çeşitli arazi kullanım tipi ve örtüsünün bulunduğu alanlardan geçebilen yüksek maliyetli arazi ölçme çalışmalarını içermektedir. Ormanlık alanlarda inşa edilecek orman yol güzergâhları için arazi yüzeyini temsil eden noktalar çeşitli ölçme yöntemleri (uzaktan algılama, fotogrametri ve yersel ölçüm teknikleri) ile elde edilebilmektedir. Arazi yapısına ve örtüsüne bağlı olarak yersel ölçme teknikleri ile konumsal noktaların tespitinde güçlüklerle karşılaşılmaktadır. Sık ormanlık alanlarda, arazi yüzeyinde konumsal nokta toplama işlemi maliyeti arttırmakta ve uzun zaman almaktadır. Bu çalışmada yersel ölçüm tekniğine bir alternatif olarak İnsansız Hava Aracı (İHA) fotogrametrisi yardımı ile yaklaşık 341 m uzunluğunda orman yolu kazı ve dolgu hesapları gerçekleştirilmiştir. Gerçek zamanlı kinematik (RTK) GPS'li İHA ile farklı yüksekliklerden (50 m, 75 m ve 100 m) çekilen fotoğraf çiftleri Agisoft ile işlenerek nokta bulutu üretilmiştir. Dijital fotogrametri ve arazi ölçüm yöntemleri ile elde edilen nokta bulutu verileri aynı yol güzergâhı için kazı ve dolgu hesabı NetCAD ortamında gerçekleştirilmiştir. İki yöntem arasında, yersel ölçüm ile elde edilen İHA 50 m, 75 m ve 100 m ölçümlerinde; İHA 50m ölçüm miktarının hesabında toplam kazı miktarında %0,27 ve toplam dolgu miktarında %1,08 fark, İHA 75m ölçüm miktarının hesabında toplam kazı miktarında %2,51 ve toplam dolgu miktarında %5,22 fark ile İHA 100m ölçüm miktarının hesabında toplam kazı miktarında %3,13 ve toplam dolgu miktarında %2,53 fark belirlenmiştir. Bu sonuçlar, İHA fotogrametrisinin dağlık arazide orman yolu projelerinde ve toprak hacmi miktarının hesaplanmasında oldukça etkili olduğunu göstermektedir.

Anahtar Kelimeler: *Orman yolu, İHA, fotogrametri, yersel ölçüm, toprak hacmi*

[1] mihrisah.kinali@gmail.com
[2] caliskan@ktu.edu.tr
* Corresponding Author/ Sorumlu Yazar: Erhan Çalışkan

1. Introduction

Forest roads are used for the transportation activities required for activities conducted in our forests such as tree cutting, haulage, afforestation, silvicultural interventions, firefighting and recreational activities (Çalışkan, 2013; Çalışkan, 2021).

Earthworks in forest areas are a significant component of forest road construction. It entails considerable engineering work and specialized forest road construction equipment. It is critical to plan, schedule, and supervise excavation operations to achieve economically viable solutions. Excavation-fill works account for almost 80% of the cost of forest road construction in mountainous places (Stuckelberger et al., 2006; Contreras et al., 2012). In this scenario, calculating the excavation-filling volumes is critical for accurately exposing the road construction costs.

UAV technology is one of the most rapidly increasing fields of application, particularly in image processing. UAV photogrammetry is a type of measurement. Today, solutions in various disciplines have been developed using photogrammetric measurements obtained via UAV systems. UAVs can be used for various imaging, evaluation, and management tasks in natural resource management and forest settings. (Menteşoğlu and İnan, 2016; Akgül et al., 2016). It is used in a variety of studies, including those that follow forest fires and evaluate the post-fire spatial situation (Horcher and Visser, 2004), those that determine the deformation rate of roads (Zhang and Elaksher, 2012), those that determine the crown diameter and tree height , and those that determine the soil damage caused by excavation works (Zarco et al., 2014; Pierzchala, 2014). There are very few studies devoted to UAV systems on roads (Rathinam et al., 2008; Zhang and Elaksher, 2011; Siebert and Teizer, 2014; Vilarino et al., 2016). Gençerk (2016) sought to make excavation-fill estimates, monitor field studies, and determine their accuracy for application in engineering projects due to evaluating photographic overlay sets obtained by UAVs using photogrammetric methods. It is conducted with forest construction (e.g., excavation, filling, and road construction) and mapping works (Akgul et al., 2016; Buğday, 2018; Aktürk and Altunel, 2019; Yurtseven, 2019; Eker and Aydın, 2020; Zeybek and Şanlıoğlu, 2020).

Map production is required for project and survey stages and volume calculation work in transportation systems. When carried out using traditional methods, the mapping process is costly in terms of workforce and time. As a result, UAV systems, which are significantly less expensive to deploy than photogrammetric systems, provide an alternative for forest road projects and volume calculation work.

The feasibility of using UAV photogrammetry for forest road design and earthwork volume calculation was explored in this study by selecting a sample area within the forest area of the Çatak Forestry Operations Directorate, which is associated with the Trabzon Regional Directorate of Forestry.

2. Material and Method

2.1 Study area

In this study, sample road section was selected in Çatak Forest Enterprise Chief which is located in the border of Maçka Forest Enterprise Directorate in Trabzon Forestry Regional Directorate-Turkey. The study area is located between 40°41'38" - 40°49'59" north latitude and 39°19'35" - 39°31'44" " east longitude (Figure 1). The area was mountainous with size of approximately 13,529 hectares and an average elevation of 1600 m. The vegetation type is forest vegetation with *Picea orientalis* (L.) Link, *Abies nordmanniana* (Stev.) Spach subsp. *nordmanniana, Fagus orientalis Lipsky.* comprising the dominant tree species of vegetation.

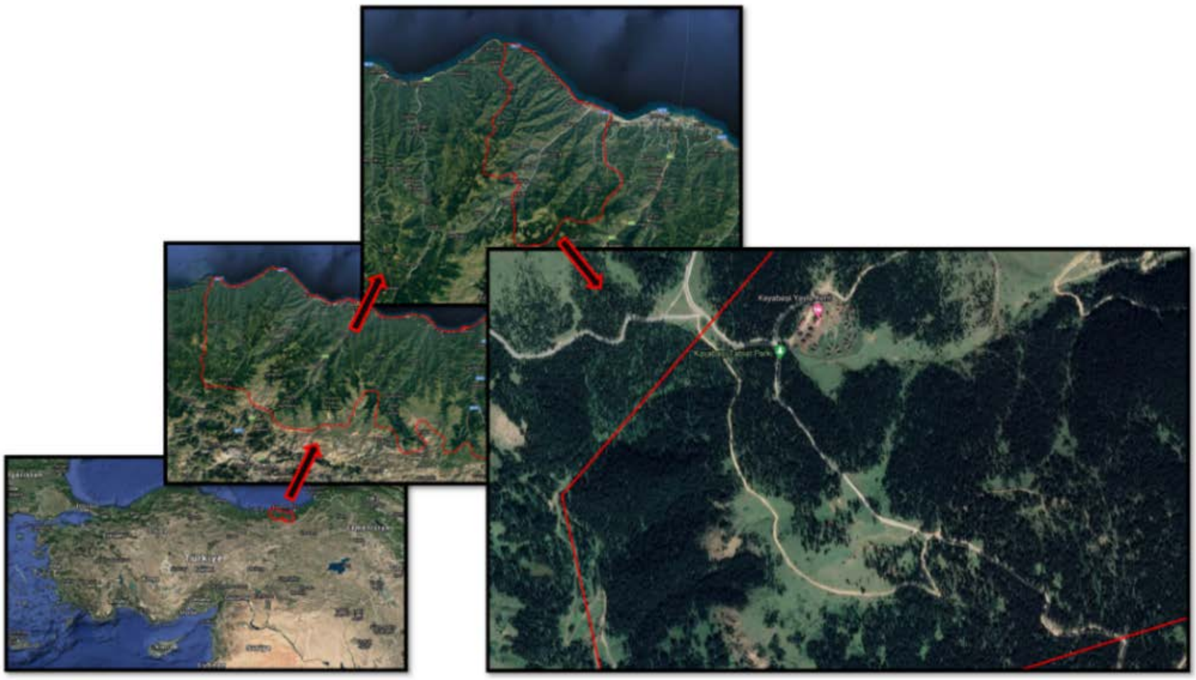

Figure 1. The study area

2.2. Measuring equipment

In this study, the 'CHC i73 CORS GNSS' measuring instrument to determine the locations of the ground control points, the 'Topcon QS Total Station' device with a reflective measurement accuracy of 1.5mm+2ppm a reflectorless measurement precision 2.0mm+2ppm, and the airborne method used to test the accuracy of the UAV photogrammetry method. The "DJI Phantom 4 RTK" drone was used in the photogrammetry method. DJI Phantom 4 RTK Drone' has a fully automatic and manual operation, a sensitivity of 0.01 meters horizontally and 0.015 meters vertically, and an integrated 20 Megapixel camera (URL 1, 2021) (Figure 2).

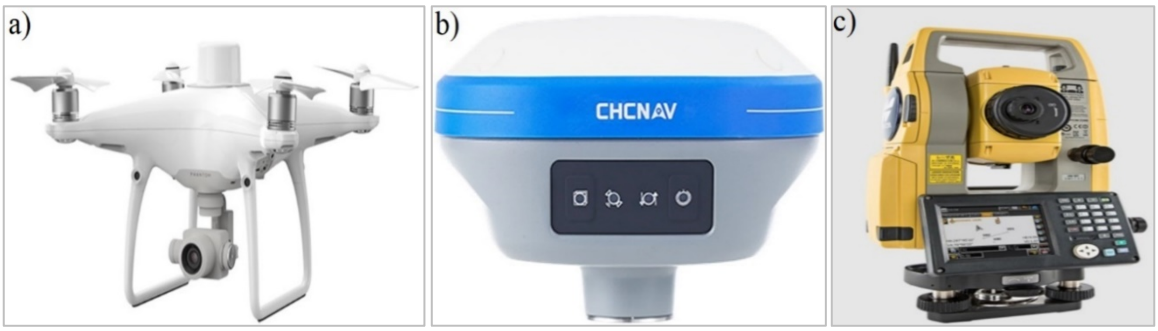

Figure 2. Measurement equipment used in the study: a) UAV; b) CORS; c) Total Station.

This entire processing and analysis works were conducted on a PC with the following configuration: 3.70 GHz Intel(R) Core(TM) i7-6500U, 16.00 GB RAM, and CPU 2.59 GHz.

2.3. Method

2.3.1. Flight planning and data set collection

It was carried out using the UAV under conditions consistent with available meteorological data (wind speed, rain, sun angle of incidence, and air temperature). The weather was clear and sunny during the first flight, with an air temperature of 21°C and a wind speed of 2 m/s. The second flight was cloudy but clear, with an air temperature of 18 °C and a wind speed of 3-4 m/s. The weather was cloudy but clear during the third flight, with an air temperature of 20°C and a wind speed of 2-3 m/s. The study region was carried from 50 m, 75 m, and 100 m altitudes using the DJI Phantom 4 RTK Drone equipment. For the UAV flight, the camera shooting angle was determined to be 90°. The photo overlay rates were determined to be 70% transverse and 80% longitudinal for each flight height (Figure 3).

Figure 3. Flight planning screen.

To ensure that the images obtained by the unmanned aerial vehicle can be used as a map following some orientation and calculation processes, they must be coordinated with a suitable and homogeneous distribution and a sufficient number of ground control points when preparing the business region's flight plans.

It was determined that 11 ground control points would stabilize the UAV images. The data gathered during the GNSS measurements were made using the CORS method in conjunction with the TKGM TUSAGA-AKTF (Turkey National Fixed GNSS Network Active) system. Ground control point data were measured with Satlab GNSS receiver at 3 degrees in ITRF 96 datum. The data of the points purchased in the field were opened in Satlab GNSS Office software, saved with ncz extension, and transferred to the Netcad program. Ground control points were transformed from ITRF96 3 degrees to WGS84 6 degrees in the application above. The photographic coordinate system and the ground control point data are aligned by transforming this system.The land structure and distribution of plants were considered during the application process carried out in the study area. The highly forested land and problematic areas have harmed the terrestrial measurement process. Following the polygon determinations, the terrestrial measurement process with the Total Station equipment was carried out as frequently as possible, taking into account the forest's thorny regions and tree placements. The terrestrial measurement method was used to collect 260 points on land.

2.3.2. Photogrammetric data processing

The photographs carried out with the UAV tool were obtained for photogrammetric evaluation. All photogrammetric operations in this study were carried out using Agisoft Metashape Professional software, which employs Structure-from-Motion (SfM)-based photogrammetric approaches and is widely regarded as a low-cost photogrammetric software. This technique allows the extraction of information such as the photogrammetric point cloud, camera position and orientation information, and parameters from the overlay images.

When using Agisoft Metashape software to process images, the photographs taken by the UAV are uploaded to the software and corrected. At this stage, the photographs are rectified, and the camera positions and orientations for each image are calculated using the Metashape software, resulting in the creation of a point cloud model.

While the accuracy level of image orientation was set to medium, the quality settings were selected to high in the production of other depth maps and dense point cloud production stages. During this process, it was determined that the selected features were identical for each flight, and dense point clouds were produced. In the resulting point cloud, classification parameters were determined. Due to the dense nature of the point cloud data representing the land surface, point density reduction was used to create triangle models and contour lines. When point data representing the land surface were reviewed separately from the road project area for each elevation, it was determined that points not connected to the surface were outside the land surface. These duplicate data, which we refer to as noise points, must be removed to depict the land surface's reality accurately. Cloud Compare software was used to extract the noise points that were found. The computer was fed point cloud data representing the land surface obtained from photographs taken at 50 m, 75 m, and 100 m altitudes.

This point cloud is georeferenced and enhanced for accuracy by adding ground control points. Triangular models and orthophoto maps were produced based on the point cloud.

2.3.3. Forest road planning

A current map is required with the triangle model and contour curves required for the road project's construction using the point data obtained by terrestrial measurement and aerial photogrammetry methods. It was carried out utilizing Netcad software, which is currently being used for map development and road project construction.

When using Agisoft Metashape software to process images, the photographs taken by the UAV are uploaded to the software and corrected. At this stage, the photographs are rectified, and the camera positions and orientations for each image are calculated using the Metashape software, resulting in the creation of a point cloud model. During this process, it was determined that the selected features were identical for each flight, and dense point clouds were produced. In the resulting point cloud, classification parameters were determined. The Netpro module's "Platform Editor" command was used to initiate red elevation definitions, road definitions, and slope definitions. A 3 m right- and left-hand road width and a 2% overturn slope were defined to ensure water flow on the road. For the road slopes to be formed, 1 m horizontally and vertically, 1 m excavation width and 25 cm height are defined. The cross-sections were drawn at 10-meter intervals along the road project's 0.00 m to +341.17 m length, using the standard red elevation on the land surfaces obtained at 50m, 75m, and 100m intervals by terrestrial measurement and UAV after they enter into the program, with the same longitudinal section, cross-section, and road platform values.

The forest road project was carried out using terrestrial measurement and aerial photogrammetry methods to determine the land surfaces without determining the red elevation that will reference any adequate slope range. The excavation and fill volumes obtained with the forest road project were then calculated and compared using UAV data and terrestrial data.

3. Result and Discussion

The study's conclusions on the usability of the UAV in forest road projects were analyzed and debated. Ground control locations were made uniformly throughout all flight zones. Table 1 contains numerical data for the forest area's ground control points and ellipsoidal height values.

Table 1
Ground control points

Point No	**Y**	**X**	**Z**
P.1	538988.550	4521581.740	1983.220
P.2	539026.070	4521532.450	1984.780

Table 1
Ground control points (continues)

Point No	Y	X	Z
P.3	538923.792	4521561.487	1979.811
P.4	538882.780	4521551.672	1978.593
P.5	538847.548	4521551.095	1975.698
P.6	538819.918	4521560.864	1969.345
P.7	538808.696	4521594.608	1967.092
P.8	538812.515	4521617.403	1968.419
P.9	538809.631	4521639.307	1966.115
P.10	538800.145	4521701.202	1949.886
P.11	538773.443	4521638.534	1953.108

Throughout the terrestrial measurement process, points were acquired as frequently as feasible, considering thorny regions and tree placements in the forest. On land, using the terrestrial measurement method, 260 points were gathered (Figure 4).

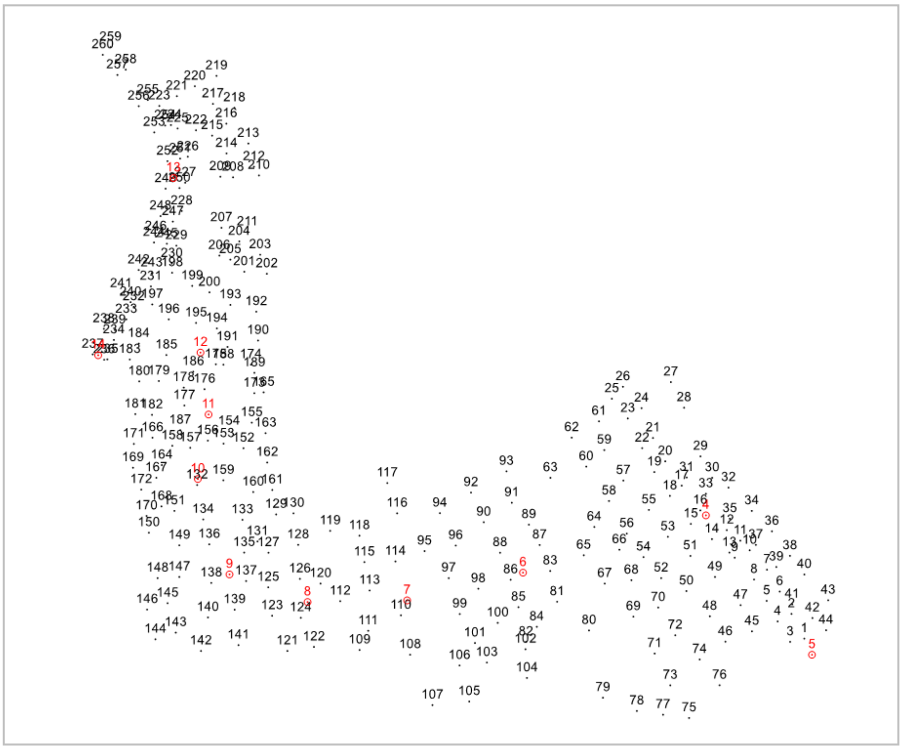

Figure 4. Polygon and point data obtained by the terrestrial method

Aerial image acquisition in the study area is 50 m, 75 m, and 100 m for each flight. Flight parameters with UAV are given in Table 2.

Table 2
Flight planning parameters

Flight altitude (m)	Forward overlap (%)	Side overlap (%)	Surface area (m²)	Number of Photos	Flight time
50	80	70	82181	552	29 min. 39 sec.
75	80	70	82181	302	13 min. 56 sec.
100	80	70	82181	200	11 min. 50 sec.

After examining the images obtained by the UAV at various altitude , it was determined that the flight speed of the UAV did not affect the image. It has been determined that the number of photographs and flight length increase in direct proportion to the proximity to the ground in flights at various altitudes done in the same flight region. Considering the number of photographs, it has been determined that the more photographs included in the point cloud data obtained via the intensive image matching approach, the more detail obtained in the resulting point cloud. Point data with a very high density can be produced from images obtained by UAVs. The topography can be examined and interpreted immediately using these point clouds.

After balancing with Agisoft Metashape software, a dense point cloud was produced. Instead of manually collecting points in this dense forest environment, the generated point cloud data was examined using the point cloud classification method to colorize the points belonging to the ground and the points belonging to natural and artificial items. After photo-matching, a colored point cloud was produced by marking the ground control points on the photographs obtained throughout the flights (Figure 5).

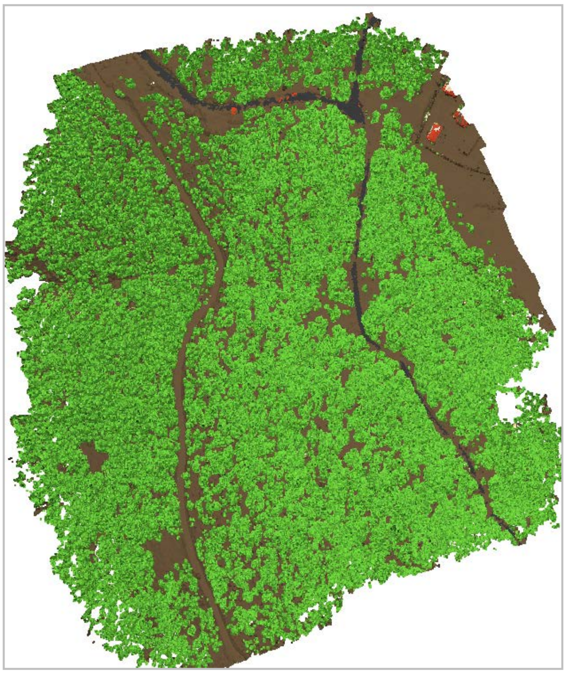

Figure 5. Classified point cloud view

It has been determined that there are no visible deviations in the details of the surface and wooded area in the point cloud generated using the dense image matching method with photographs taken from a height of 50 meters and that the point production of the areas representing the forest ground surface is more healthy. Simultaneously, it has been established that tree classification in the point cloud classification process is more healthy. Using the point frequency in the post-classification point data representing the ground surface, it was determined that the maximum number of points were deleted during the noise point cluster determination. Taking into account the density of the point data and the spatial formation of the points during the process of reducing the point frequency to once every two meters after the noise data was eliminated, it was determined that the result obtained at 75 m height contained more point data after the point data. After reducing the point frequency, it was determined that no pits or bumps formed as a process of broken triangles, broken curves, or an incorrect value for the point elevation in the triangle model creation of the resulting data.

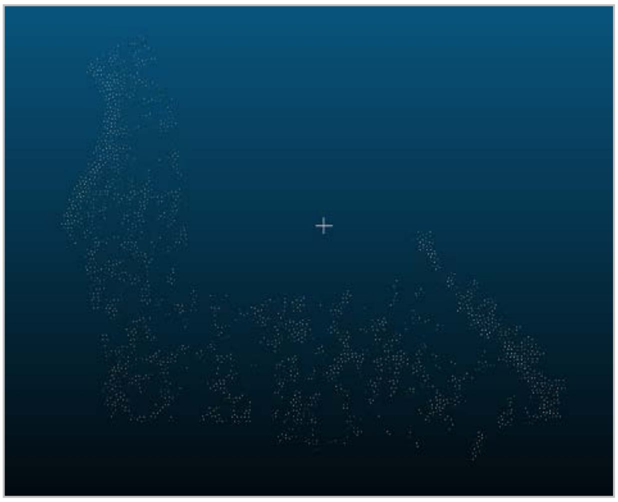

Figure 6. Reduced point data

Because the point cloud data representing the land surface is highly dense to the development of triangular models and contour lines, a point density reduction was used to reduce the point density to a value of 2 m. This process resulted in the acquisition of 2932 points representing the land surface, 3037 points representing the land surface, 3037 points from a height of 75 m, and 2865 points from a height of 100 m for the forest road project's implementation, and distinct recording processes were carried (Figure 6).

The NetCad-NetPro module was used to determine the excavation-filling ratios that will emerge by considering the design criteria in the computer environment. After drawing the details of the land in the interface of the program, the triangle model was produced by using the point data of the land, and the proximity criterion was defined as 50 m in the process of creating the contour lines and the production of the triangle model was carried out. This process was carried out separately for the point data obtained by terrestrial measurement and aerial photogrammetry. In this way, the land surface of each measurement was formed (Figure 7). The geometric features of the forest road are given in Table 3.

Table 3
Cross-section parameter

Cut slope	1:1
Fil slope	2:3
Ditch slope	3:1
Road width	10 m
Road bed width	5 m
Lane slope	8%-6%

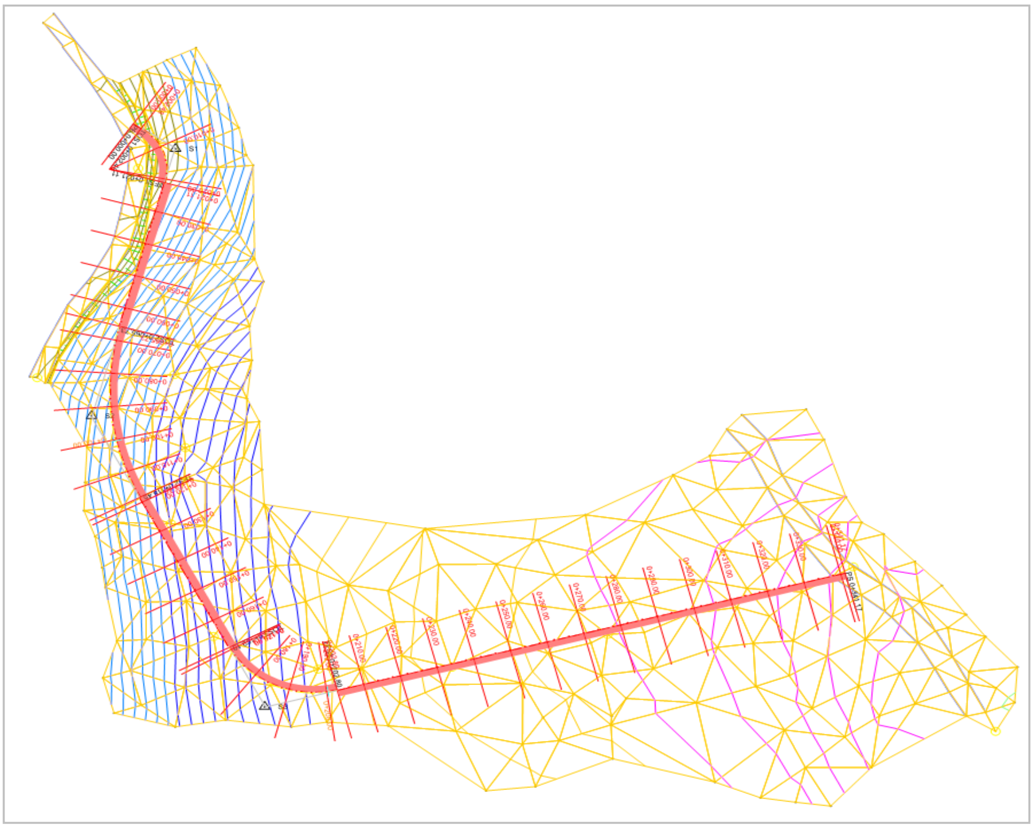

Figure 7. The land surface was created with a triangular model and forest road route

The forest road is 341.17 meters long and has a slope of 6-8 percent. The proposed road is a forest road of category B. The road's width is planned to be 5 meters. The road trench width was determined to be 1 m and the trench depth to be 0.30 m. Cross-sections were taken every 10 meters, and at the curve head, middle, and endpoints after the road route was determined as points and the route drawn. By calculating the total length of the road, a longitudinal profile was generated (Figure 8, Figure 9).

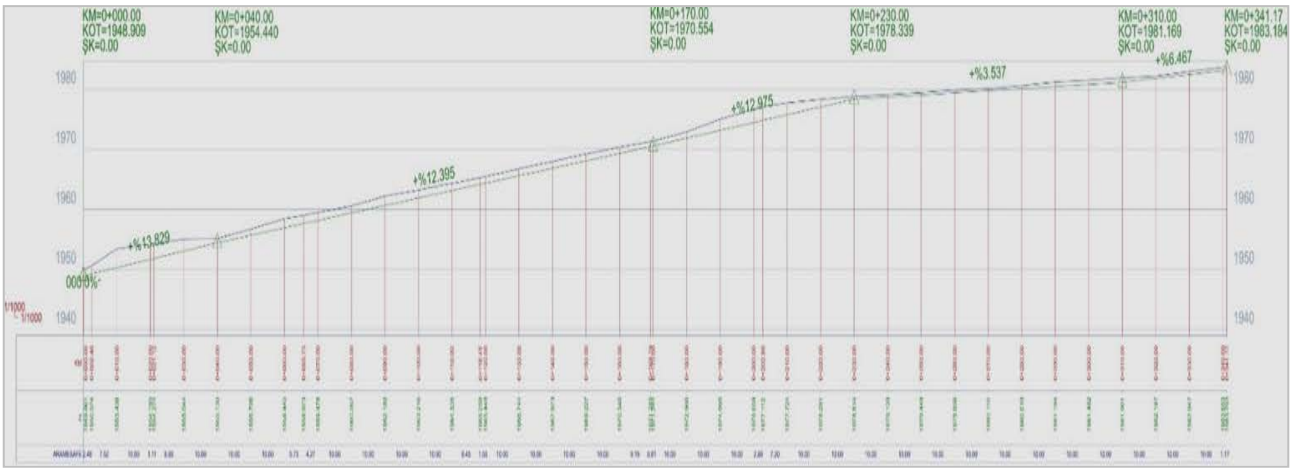

Figure 8. Longitudinal profile creation

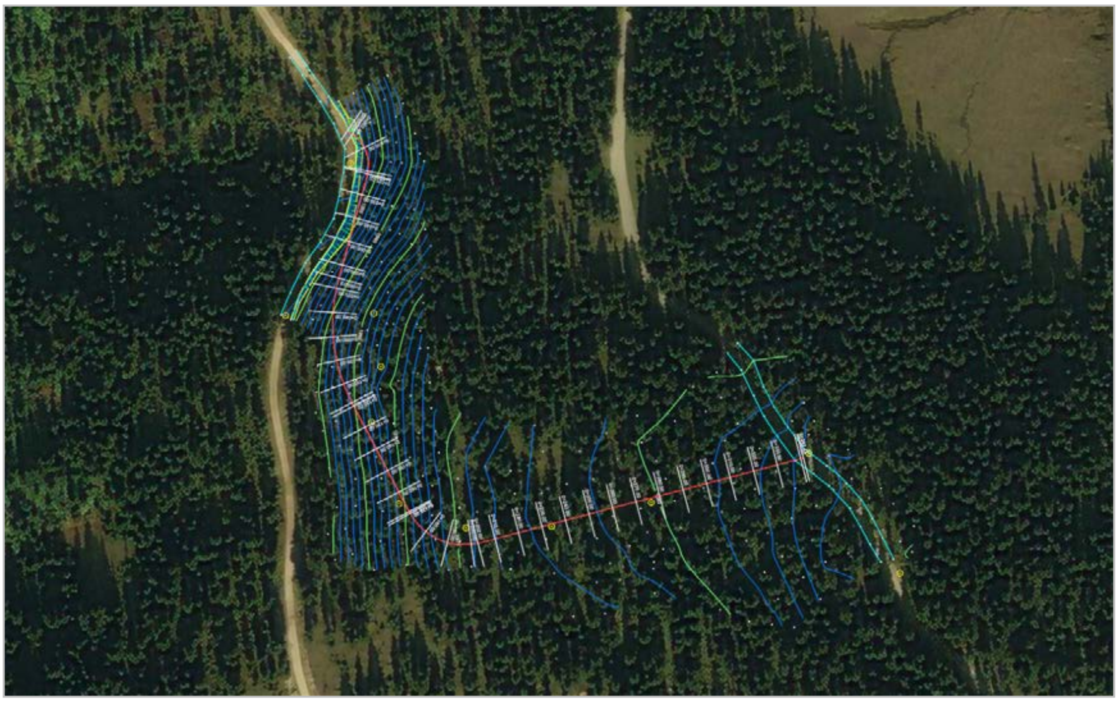

Figure 9. Cross-section drawing over the route

Cut and fill volumes for the study region were calculated and compared using UAV data and data obtained terrestrial. After the forest road design work is done in a drawing, the prices can be determined based on the road construction machines selected and the area's soil and ground characteristics. The primary factor in determining expenses is the volume of excavated dirt. Four different study were conducted in total, and the earthwork volume comparison is provided in Table 4.

Table 4
Earthwork volume comparison

Measurement Method	**Fill Volume (m^3)**	**Cut Volume (m^3)**	**Total Volume (m^3)**
Terrestrial	594,410	847,506	+ 259,097
UAV (50 m)	588,078	849,746	+ 261,668
UAV (75 m)	625,435	868,808	+ 243,373
UAV (100 m)	579,129	874,014	+ 294,885

On the land surface process, it has been observed that the level disparities between the start and endpoints of a road project are the same. Due to the result that the cross-sections produced for this project indicate the land surface, special attention was paid to the red elevations, and it was determined that similar red elevation drawings were created with the reference surface. While the terrestrial measurement method determined 594,410 m^3 of filling and 847,506 m^3 of the excavation area, the method done with result data of 50 m height determined 588,078 m3 of filling 849,746 m3 of the excavation area. When the soil quantities were compared, it was discovered that the data from the terrestrial method and the UAV's (50m) height were more similar.

Contreras et al., (2012) employed a LIDAR-based high-resolution digital elevation model, which has a higher point density than UAV systems, to precisely determine the excavation-fill volume. The volumes of three dirt piles were compared in a highway study area, and it was discovered that the variances were between 8% and 16%. (Siebert and Teizer, 2014). The difference in excavation volume was found to be 0.998 percent, and the difference in fill volume was found to be 0.997 percent in a study carried out on flat land for a highway project (Erdoğan, 2016). Another study found that the difference in excavation volume was 11.3 percent and the difference in fill volume was -1.1 percent in an area with undulating terrain (Tercan, 2017). Akgül et al., (2018) compared digital terrain model (DTM) data acquired via UAV to DTM data acquired via GNSS (Global Navigation Satellite System) in the excavation-fill calculation. Buğday (2018) conducted a study to determine the use of unmanned aerial vehicles (UAVs) and geographic information systems (GIS) technologies in the design of forest road construction. As a result, he found that the excavation volume was 81804.4 m^3, and the fill volume was 74.2 m^3. In another study, it was observed that there was a difference of 3.2 percent in the cut volume and 3.5 percent in the fill volume for a mountainous roadway project (Fidancı and Karabörk, 2019). Our study is similar to recent excavation and fills volume calculations utilizing UAVs and terrestrial methods.

Given the land surface's height structure and the difficulties of gaining land to places where a forest road project is planned, it has been recognized that terrestrial measurement methods may be inefficient. It would be prudent to choose the terrestrial method based on the application area's accessibility and just on accuracy and sensitivity criteria. Given that the length of time spent on the land can directly affect the cost, conducting the application process with the UAV will be more effective.

4. Conclusion

This study aimed to determine the use of data obtained from UAV images in forest areas for forest road projects. In this direction, the data produced by the terrestrial method and the UAV were compared in terms of soil volume and height. A forest road project with a length of 341.17 meters and a width of 6 meters was developed in the desired working area of a forested structure. Between the two methods using the land structure identification method, a difference of 0.27 % in the total excavation amount and 1% in the total filling amount was determined in the calculation of the UAV's 50 m measurement amount, in the UAV's 50 m, 75 m, and 100 m measurements concerning the ground measurement. Following that, a difference of 2.51% in total excavation and 5.22 % in the total filling was determined when calculating the UAV 75 m measurement amount, and a difference of 3.13 % in total excavation and 2.53 % in the total filling was determined when calculating the UAV 100 m measurement amount.

When comparing road project results based on the land surface, it was determined that the UAV's 50-meter flight data is more convenient and accurately portrays the actual surface.

The production of digital terrain models on forest road routes with topographically mountainous terrain and 3D point cloud data with high accuracy and precision and the much more precise calculation of excavation and filling amounts have formed an essential foundation for future studies using UAVs photogrammetry. It is demonstrated that UAV photogrammetry can be used efficiently in hilly forest road construction in terms of time, cost savings, accuracy, and visuality.

Acknowledgement

This study was produced from a master’s thesis prepared by Mihrişah KINALI and supervised by Prof. Dr. Erhan ÇALIŞKAN for the Institute of Natural and Applied Science, Karadeniz Technical University, Turkey. The authors declare that they have no conflict of interest.

References

Akgül, M., Yurtseven, H., Demir, M., Akay, A. E., Gülci, S. and Öztürk, T. (2016). Usage opportunities of generating digital elevation model with unmanned aerial vehicles on forestry. *Journal of the Faculty of Forestry Istanbul University*, 66(1), 104-118.

Akgül, M., Yurtseven, H., Gulci, S. and Akay, A. E. (2018). Evaluation of UAV-and GNSS-Based DEMs for Earthwork Volume. *Arabian Journal for Science and Engineering*, 43(4):1893-1909.

Akturk, E. and Altunel, A. O. (2019). Accuracy assessment of a low-cost UAV derived digital elevation model (DEM) in a highly broken and vegetated terrain. *Measurement*, 136, 382-386.

Buğday, E. (2018). Capabilities of using UAVs in forest road construction activities. *European Journal of Forest Engineering,* 4(2), 56-62.

Contreras, M., Aracena, P. and Chung, W. (2012). Improving accuracy in earthwork volume estimation for proposed forest roads using a high-resolution digital elevation model. *Croatian Journal of Forest Engineering*, 33(1), 125–142.

Çalışkan, E. (2013). Planning of forest road network and analysis in mountainous area, *Life Science Journal*, 10(2), 2456-2465.

Çalıskan, E. and Sevim, Y. (2021). Forest road detection using deep learning models. *Geocarto Iınternatıonal,* https://doi.org/10.1080/10106049.2021.1926555

Eker. R. and Aydın, A. (2020). The use of Unmanned Aerial Vehicle (UAV) for tracking stock movements in forest enterprise depots. *European Journal of Forest Engineering,* 6(2), 68-77.

Erdoğan, A. (2016**)**. Şeritvari Haritaların İnsansız Hava Araçları ile Üretimi. Yüksek Lisans Tezi, Selçuk Üniversitesi, Fen Bilimleri Enstitüsü. Konya,48s.

Fidancı, Y. and Karabörk, H. (2019). Use of Unmanned Aerial Vehicles in highway projects in forest areas. *GUFBED,* 9(3), 473-485.

Gençerk, E. Y. (2016). İnsansız Hava Aracı Fotogrametrisi Uygulaması ile İnşaat Projesi İmalat Durumunun Araştırılması. *Yüksek Lisans Tezi*, İstanbul Teknik Üniversitesi, Fen Bilimleri Enstitüsü, Geomatik Mühendisliği Anabilim Dalı, İstanbul, 127 s.

Horcher, A. and Visser, R. J. (2004). Unmanned aerial vehicles: applications for natural resource management and monitoring. Council on Forest Engineering Proceedings 2004. Machines and People, The Interface.

Menteşoğlu, B. E. ve İnan, M. (2016). İnsansız Hava Araçlarının (İHA) Ormancılık Uygulamalarında Kullanımı. 6. Uzaktan Algılama ve CBS Sempozyumu, 5-7 Ekim 2016, Adana.

Pierzchała, M., Talbot, B. and Astrup, R. (2014). Estimating soil displacement from timber extraction trails in steep terrain: application of an unmanned aircraft for 3D modelling. *Forests, 5*, 6, 1212-1223.

Rathinam, S., Kim, Z.W. and Sengupta, R. (2008). Vision-based monitoring of locally linear structures using an unmanned aerial vehicle. *First Journal of Infrastructure Systems,* 14 1, 52-63.

Siebert, S. and Teizer, J. (2014). Mobile 3D mapping for surve-ying earthwork projects using an Unmanned Aerial Vehicle (UAV) System. Automation in Construction, 41, 1-14.

Stuckelberger, J. A., Heinimann, H. R. and Burlet, E. C. (2006). Modelling spatial variability in the life-cycle costs of low-volume forest roads. *European Journal of Forest Research*, 125(5): 377–390.

Tercan, E. (2017). Evaluation of Digital Terrain Model Obtained with Unmanned Aerial Vehicle in Roadway Projects: Bucak-Kocaaliler Roadway Example. *The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University,* 8(2), 172-183

URL 1 (2021). https://www.dji.com/phantom-4-rtk (26.11.2021).

Vilariño, L. D., Jorge, G. H., Sánchez, M. J., Bueno, M. and Arias, P. (2016). Determining the limits of unmanned aerial photogrammetry for the evaluation of road runoff. *Measurement,* 85, 132-141.

Yurtseven, H. (2019). Comparison of GNSS-, TLS-and different altitude UAV-generated datasets on the basis of spatial differences. ISPRS International Journal of Geo-Information, 8(4), 175.

Zarco-Tejadaa, P. J., Diaz-Varelaa. R., Angileria C. and Loudjania, V. P. (2014). Tree height quantification using very high resolution imagery acquired from an unmanned aerial vehicle (UAV) and automatic 3D photo-reconstruction methods. *European Journal of Agronomy* 55, 89-99.

Zeybek, M. and Şanlıoğlu, İ. (2020). Investigation of landslide detection using radial basis functions: a case study of the Taşkent landslide, Turkey. *Environmental Monitoring and Assessment,* 192(4), 1-19.

Zhang, C. and Elaksher, A. (2012). An Unmanned Aerial Vehicle based ımaging system for 3D measurement of unpaved road surface distresses, *Computer-Aided Civil Infrastructure Engineering*, 27(2), 118-129.