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Assessment of Using UAV Photogrammetry Based DEM and Ground-Measurement Based DEM in Computer-Assisted Forest Road Design[1]

İnanç Taş*, M. Sait Kaska, Abdullah E. Akay

Bursa Technical University, Faculty of Forestry, 16310 Bursa, Turkiye

Abstract

Computer-assisted forest road design mainly relies on a high-resolution digital elevation model (DEM), which provides terrain data for supporting the analysis of road design features. The resolution and accuracy of the DEM in representing the terrain structures vary depending on the preferred dataset, which then reflects some of the essential road features such as alignment, road slope, and earthwork. In this study, three forest road sections were designed by using high-resolution DEMs generated from UAV photogrammetry data, GNSS-GPS data and Total Station data. NetCAD 7.6 software, developed in Turkey and mostly used in road design applications, was used to perform the road design while calculating horizontal profiles, vertical profiles, curves, cross sections, and earthwork. The DEM generation capabilities for three datasets were compared based on spatial resolution, data collection and data processing stage. Then, the differences between three road sections were evaluated by considering specified road features such as alignment properties, road slope, and earthwork. The results indicated that the UAV (Unmanned Aerial Vehicles) based DEM generation method provided the highest resolution (10 cm), followed by the Total Station (56 cm) and GNSS-GPS (61 cm) based methods. When comparing the time for data collection procedure, it took 14 minutes, 70 minutes, and 110 minutes for UAV data, GNSS-GPS data, and Total Station data, respectively. On the other hand, UAV based method falls into a disadvantageous situation in data processing stage, due to high data processing time (3 hours). However, GNSS-GPS and Total Station based methods work only with spatial point data, so they require less processing time of 15 minutes and 25 minutes, respectively. The results indicated that road lengths were 294.8, 272.4 and 282.1 m and the average road slopes were 3.41%, 3.39%, and 3.31% for the road sections designed by using UAV, GNSS-GPS, and Total Station based DEMs, respectively. The excavation and landfill volumes were 369.16 m^3 and 166.98 m^3, 285.86 m^3 and 201.83 m^3, and 433.17 m^3 and 183.95 m^3, respectively. The results indicated that UAV photogrammetry data generates high-resolution DEMs that can be effectively used to design forest roads.

Keywords: Digital elevation model, forest roads, GNSS-GPS, NetCAD, total station, UAV.

1. Introduction

A digital elevation model (DEM) data structure, typically in raster and grid formats, stores cells in square matrices on a two-dimensional plane and hold the value of average cell height. A cell on a geographic plane is defined by its row and column position within the matrix. DEMs have a broad range of applications because they are easy to use and calculations are more efficient (Martz and Garbrecht, 1992). They provide fundamental representations of the three-dimensional shape of the ground surface (Guth et al., 2021). DEMs are widely used in applications of remote sensing and geographic information systems (GIS) in various disciplines as they enable various calculations through their included height information.

DEMs can be produced in different qualities using various devices (Gülci et al., 2012). Today, it is possible to generate DEMs from photographs containing altitude information, especially with UAVs, and this has become quite widespread (Özemir and Uzar, 2016). Similarly, DEMs can be produced through ground-based measuring devices such as GNSS-GPS, Total Station, and terrestrial LiDAR sensors (Keim et al., 1999; Çelik et al., 2013; Gülci et al., 2012). In recent years, UAVs have started to replace traditional surveying methods in DEM production due to requiring less time and less labor (Polat and Uysal, 2015; Ciritcioğlu and Buğday, 2022). UAVs are also relatively more sensitive, cost effective, and quick systems compared to traditional airborne technologies (Fritz et al., 2013). Thus, there can be number of differences between the quality of DEMs produced with different devices depending on various factors such as the accuracy of the measurement, labor, and time.

Primitive methods for calculating the volume of three-dimensional objects can be difficult and time-

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*Corresponding Author: Tel: +90 224 3003430 E-mail: inanc.tas@btu.edu.tr
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consuming. Thanks to the development of GIS techniques and computer support, these types of studies can now be done with simple methods in short periods of time. By combining computer graphics, database management, and multiple environments, topology, geology, hydrography, and other applications can be supported through the 3D modeling and analysis features of GIS. These features allow for surface analysis such as slope, aspect, and relief maps, as well as profile extraction and determining the field of view. Generally, GIS and 3D modeling projects have proven themselves worldwide and have become an inevitable reality in terms of mapping technology (Rüstemov, 2014).

Forest roads are constructed for various purposes of use in forestry. They provide access to forest areas to conduct forestry activities such as timber production, forest protection, afforestation, and forest management. Forest road design, taking into account of economic and environmental constraints, is quite complex task. The planning of the road network also involves social demands such as access to forest villages and recreation areas in Turkiye (Öztürk, 2009). The current studies on forest road design focus on challenging issues such as accurate measurement of earthwork volumes and determining the optimal routes. Road design software packages provide advanced features to the road engineers such as locating horizontal alignment and earthwork calculations based on high resolution DEMs. Some of the software used in designing forest roads are RoadEng, Lumberjack, and Platea. There is a similar road design software, NetCAD 7.6, widely used in road design studies in Turkiye. Forest road design is performed based on a contour map in NetCAD 7.6 which produces solutions for the needs of professionals from different disciplines in spatial data production, analysis and management. It offers the users the advantages of the CAD environment and the recognized structure of the GIS environment at the same time. These two spatial data formats, which complement each other in geographic data production processes, are supported by dynamic CAD & GIS integration. NetCAD 7.6 is constantly being developed in the focus of user needs and expectations with agile software development philosophy. It meets the digital data needs of user groups from different industries such as mapping, civil engineering, geology, roads, infrastructure and service.

In this study, an example of forest road design was constructed by using NetCAD 7.6 with UAV, GNSS-GPS, and Total Station generated DEMs. First, three different DEMs were produced using UAV and ground surveying devices. Then, road designs were made using NetCAD 7.6 with these DEMs. Forest roads were produced following similar routes as much as possible in the same study area. Finally, the constructed three different forest roads were evaluated.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Tuzaklı Forests located in the Osmangazi province of Bursa in Turkiye (Figure 1). The fieldwork was carried out in a relatively open stand with gentle slope. The dominant tree species is Black pine (Pinus nigra) and the average elevation and slope is about 750 m and 20%, respectively in the study area.

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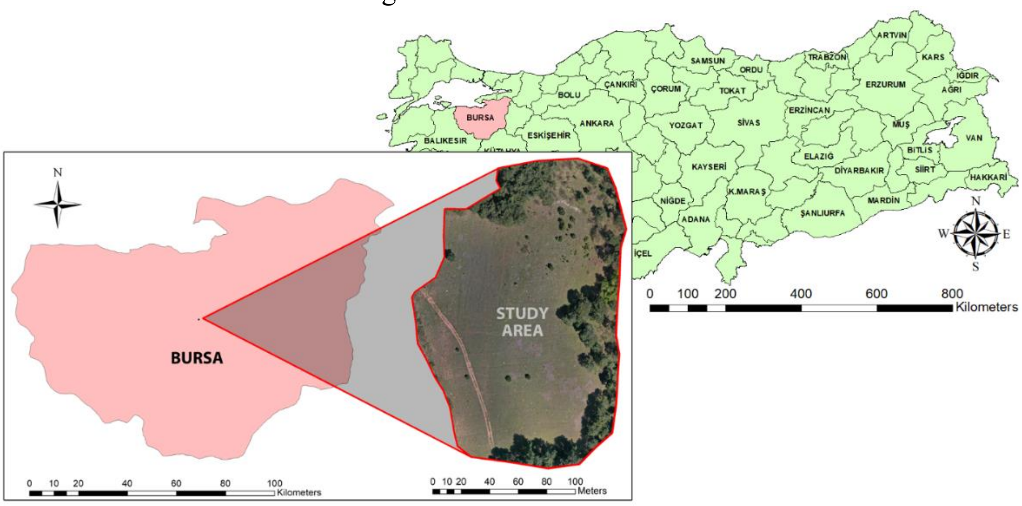

Figure 1. Study area

2.2. DEM Generation Methods

2.2.1. Generating DEM with UAV

DEM was produced using 3D data obtained by using a DJI Mavic 2 Pro (Table 1). A total of 67 aerial photographs were obtained by flying over the study area with a UAV. The Grid Mission option in the Pix4D application was used, with a flight altitude of 100 m, a flight area of 160x176m, and an overlap ratio of 80% (Figure 2).

Table 1. DJI Mavic 2 Pro technical specifications (URL -1)

Specifications	
Weight	650 gr-750 gr
Battery	3830 mAH LiPo
Size	31 cm-35 cm
GPS Mode	GPS Yes
Camera	4K
Max Speed	45 kmp-65 kmp
Flight Distance	8000 m
Flight Time	30-31 Minutes

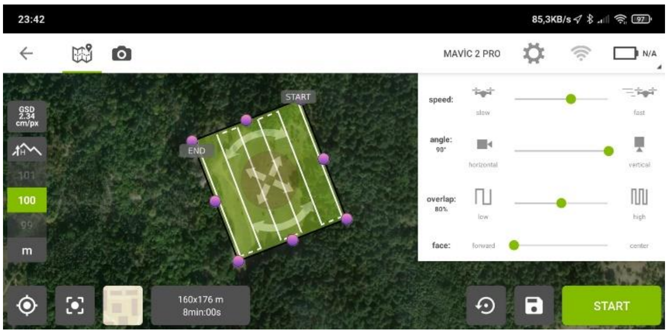

Figure 2. Pix4d flight settings

Seven control points were located in the study area and UTM coordinates were recorded by using GNSS-GPS. Then, office works were carried out using Agisoft Metashape 1.8.3 software with collected 67 photographs and 7 control points. By aligning the photographs, 36220 tie points were obtained (Figure 3) and then aerial photographs were positioned according to the control points.

After the spatial corrections were implemented on the images, a dense point cloud was generated using the "build dense cloud" process. These processes were carried out at a high-quality level, resulting in a total of 23,187,020 points. As the aim was to generate a digital terrain model (DTM) from the point cloud data, all objects above ground level had to be removed. Therefore, in this stage, the point cloud was classified and the points belonging to the ground were used to generate the DEM. An example of the classified point cloud is shown in Figure 4. Finally, the "build DEM" process was used to generate the DEM with a 10 cm pixel resolution.

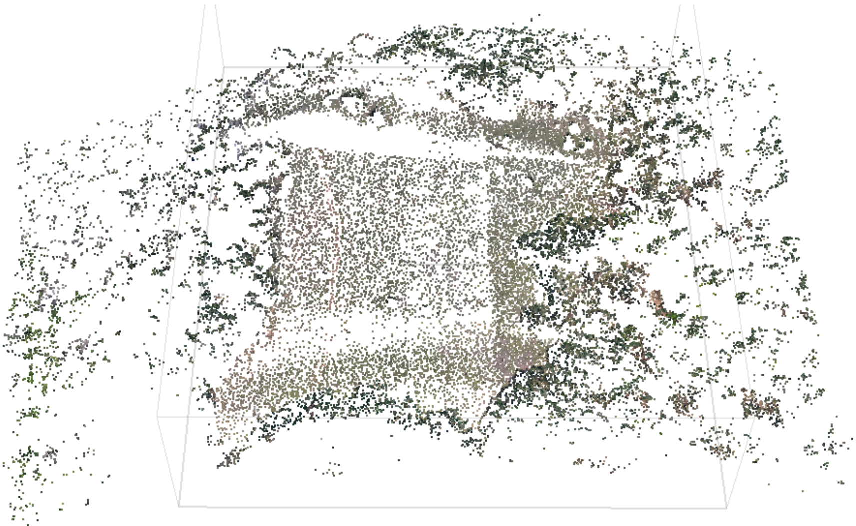

Figure 3. Tie points collected during UAV flight

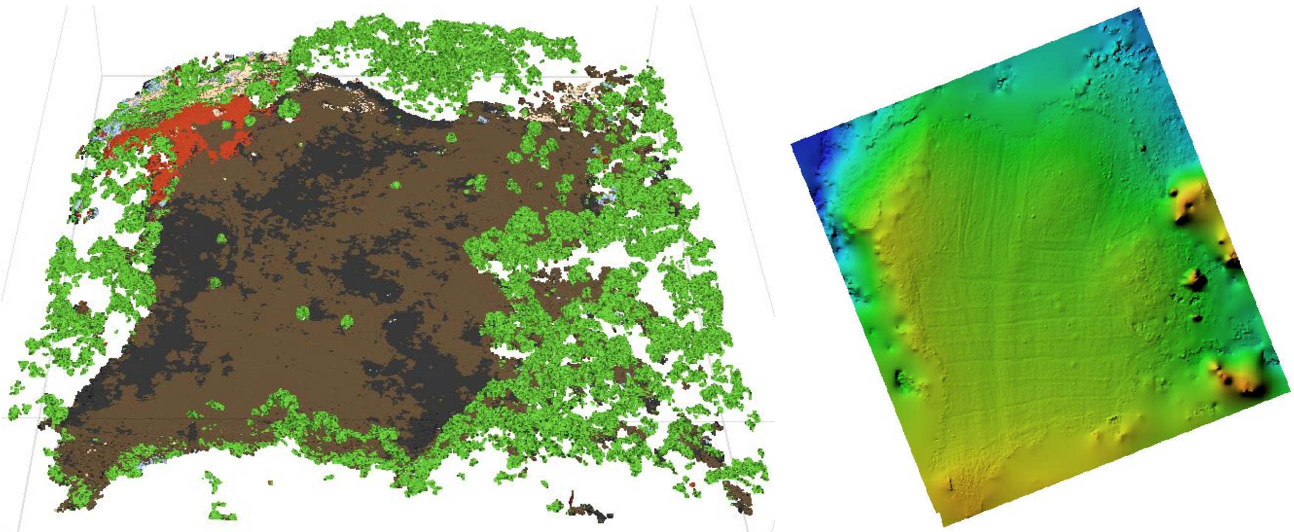

Figure 4. Classified point cloud (left) and digital elevation model (right)

2.2.2. Generating DEM with GNSS-GPS

A total of 1667 points were collected from the study area using Pentax G3100-R1 GNSS-GPS (Table 2) in mobile mode (Figure 5). The point acquisition interval was set as 2 m in the mobile mode. The collected points were then processed in ArcMAP 10.8 software. DEM production was provided by using “Topo to Raster” tool under ArcMAP 10.8. During the data production, the recommended pixel size of 61 cm was used in the study.

Table 2. Pentax G3100-R1 technical specifications (URL -2)

Model		G3100-R1	
Channel Configuration		136 channels (dual frequency) for GPS, GLONASS and SBAS	
Single Tracked	GPS	L1-C/A, L1-P(Y), L2-P(Y) and L2C	
	GLONASS	L1-C/A, L2-C/A	
Position accuracy		HORIZONTAL	VERTICAL
	Standalone	1.3 m	1.9 m
	SBAS	0.6 m	0.8 m
	DGPS	0.5 m	0.9 m
	SBAS	0.6 m	0.8 m
	DGPS	0.5 m	0.9 m
RTK Performance	Horizontal Accuracy	1 cm + 1 ppm	
	Vertical Accuracy	2 cm + 1 ppm	
	Average Time to Work	7 sec.	
	Availability	99.99%*1 (Baseline < 20km)	
Static Performance	Horizontal Accuracy	2 mm + 0.5 ppm	
	Vertical Accuracy	5 mm + 0.5 ppm	

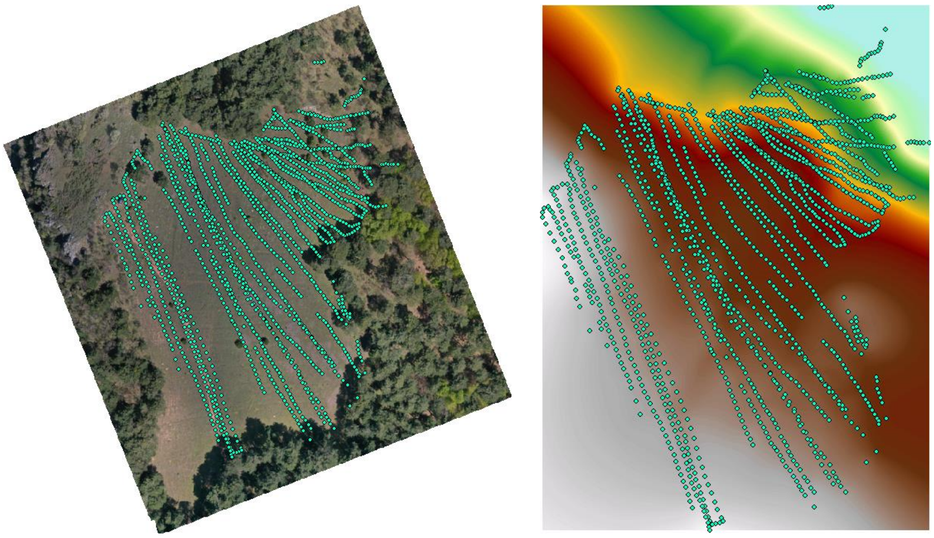

Figure 5. GNSS-GPS points (left) and GNSS-GPS based DEM (right)

2.2.3. Generating DEM with Total Station

DEMs were generated using Topcon Cygnus 2LS model Total Station (Table 3). Total Station was placed at a point close to the center of the study area. The location information of the point where the device was installed was measured with GNSS-GPS and entered into the device. Then, one person stood at certain points with a reflector at intervals of approximately five meters. The other person measured the coordinates by pointing the laser at the reflector. In this way, a total of 579 points were collected (Figure 6). The obtained data was transferred to the ArcMap 10.8 interface. Then, DEM production was provided with the "Topo to Raster" process. A recommended pixel size of 56 cm was used during the data production.

Table 3. Topcon Cygnus 2LS technical specifications (URL -3)

Specifications	
Magnification	30x
Image	Erect
Field of View	1°30'
Resolving power	3.0"
Minimum focus distance	1.3 m
Measuring range - Reflectorless	200 m
Measuring range - Prism	2,000m (Single Prism)
Accuracy - Reflectorless	(3+2 ppm x D) mm
Accuracy - Prism	(2+2 ppm x D) mm
Measuring time (Fine) - Reflectorless	1.1 s
Measuring time (Fine) - Prism	1.1 s

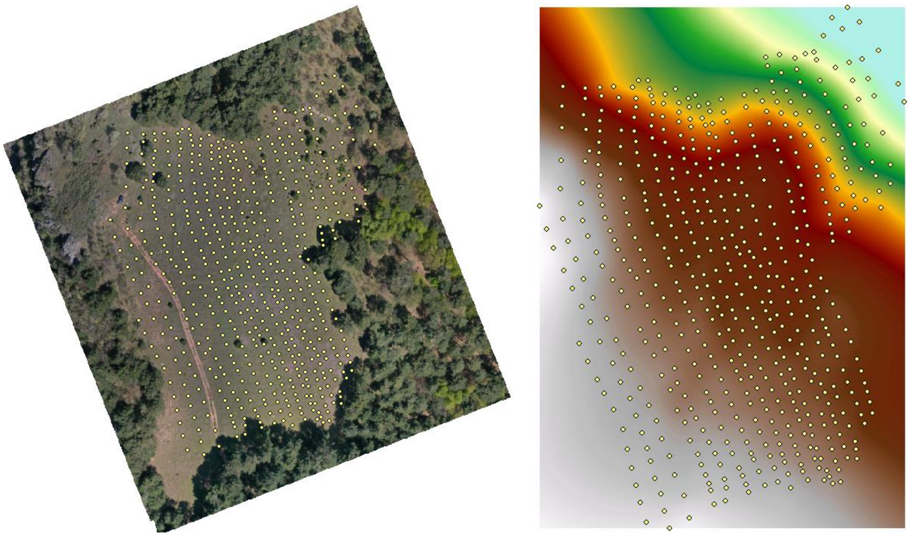

Figure 6. Total Station points (left) and Total Station based DEM (right)

2.4. Forest Road Planning

The digital elevation models (DEMs) generated with three different methods in the study were used to design a road in the NetCAD 7.6. The program requires triangulated models for volume calculations, so triangulated models were obtained from the produced DEMs. Then, contour lines were obtained to determine the route of the road. The contour lines were generated with a 0.5 m height interval.

After the contour lines were generated, the preliminary road alignment was located on the terrain by using 25-meter and 15-meter circles determined based on stepping out (divider) method for given average grade. In the next step, the route was determined and the horizontal and vertical curves were placed. These operations were performed by using the route editor. The same route was attempted to be used for each method in the operations. Curves of equivalent sizes were attempted to be used at similar points in all methods. In some points, these values have varied due to terrain structure and angles.

In the next stage, the cross-section editor was used to enable the identification of excavation and filling areas by taking cross-sections of the terrain and road platform. An example cross-section is shown in Figure 7. Cross-sections were distributed at certain intervals along the roadway. The volumes were measured using cross-section areas and the distances between cross-sections and then volumes were transferred to the volume table.

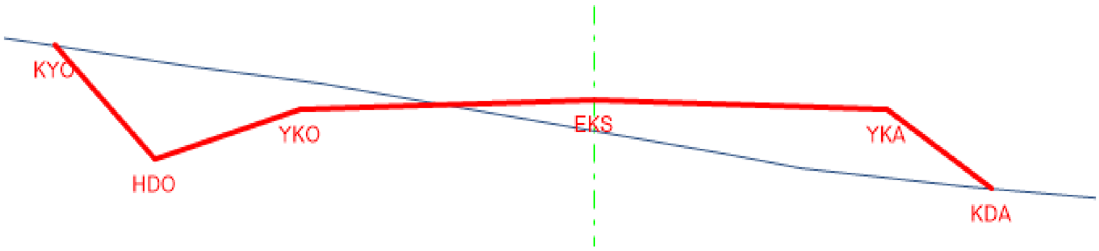

Figure 7. Cross section example

After generating cross-sections, the road's horizontal profile and vertical curves can be defined using the profile drawing tool. In the next stage of the study, volumes were obtained and material distribution was determined. In this stage, volume information was obtained by filling in the volume table with the information obtained from the cross-sections. An example of horizontal profile and vertical curve is shown in Figure 8. Finally, a material profile was generated by using Bruckner tool based on the volume values. The relationships between the storage and borrow points determined for the material to be transported or stored can be seen. An example material profile is shown in Figure 9.

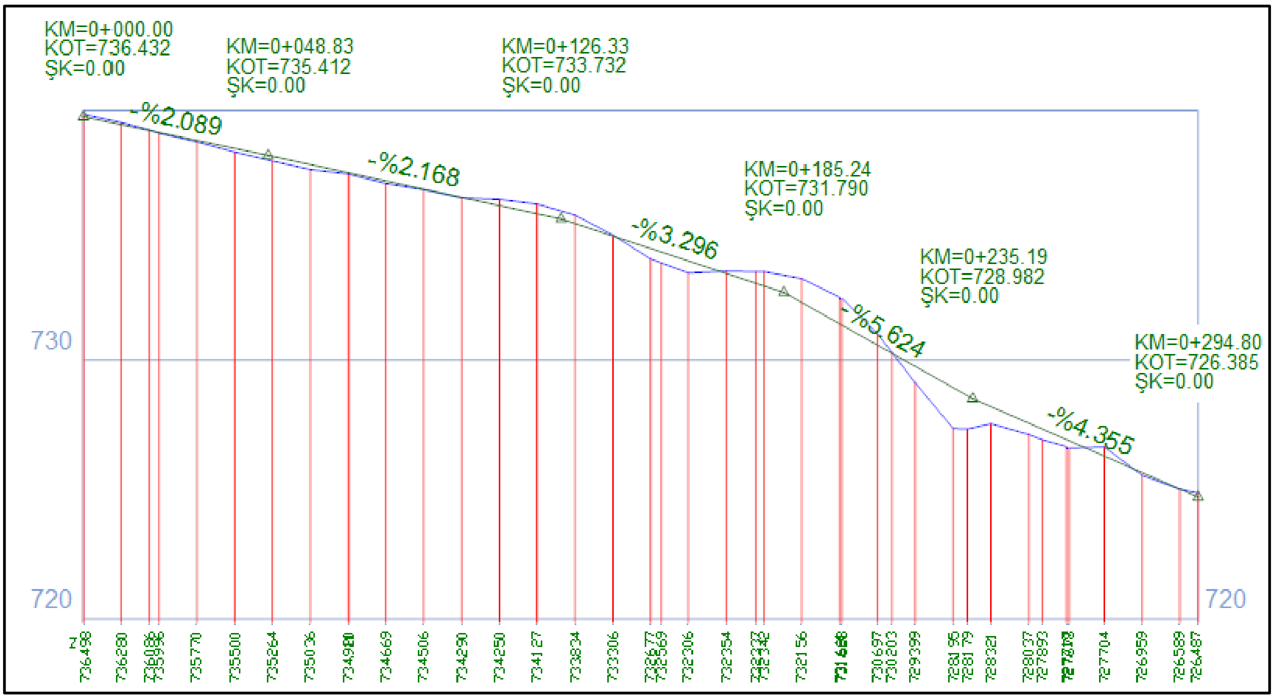

Figure 8. Horizontal profile and vertical curve definitions

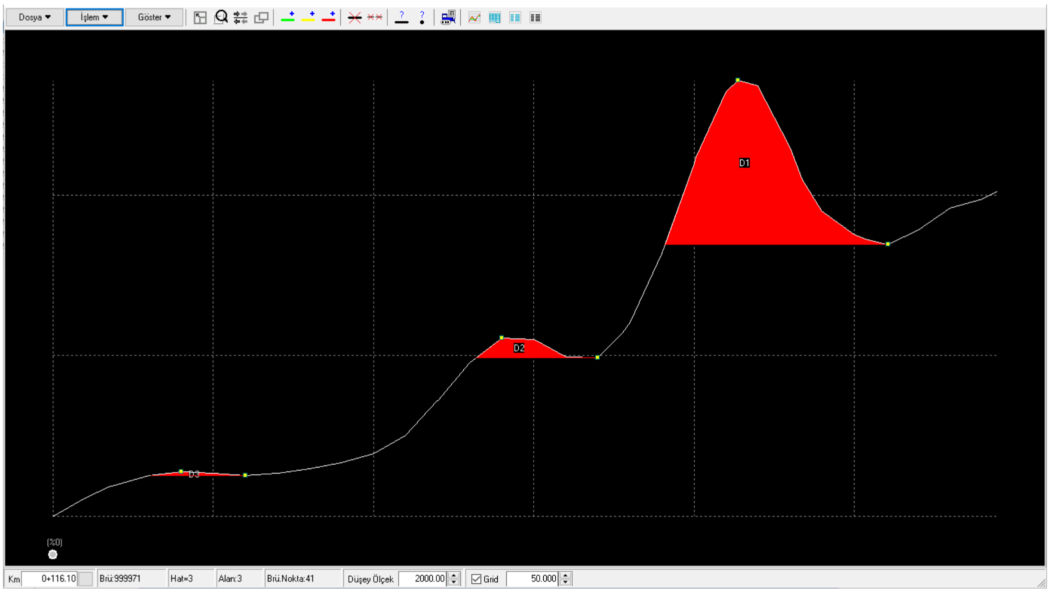

Figure 9. Material profile

3. Results and Discussion

The results indicated that DEMs generated from UAV images has a pixel resolution of 10 cm, while it was 61 cm and 56 cm for the DEMs generated from GNSS-GPS and Total Station methods, respectively. Therefore, UAV data provides the highest resolution. Figure 10 shows the triangulated models and contour lines generated from the digital elevation models produced by the UAV, GNSS-GPS, and Total Station methods, respectively. In a similar study conducted by Akay and Çiğdem (2022), effectiveness of UAV-based data for 3D mapping of open-pit mines in forest areas was evaluated and results compared with other map production methods including CORS RTK and Total Station. They also reported that DEM generated based on UAV data has a higher resolution (9.2 cm) than the ground-based measurements methods.

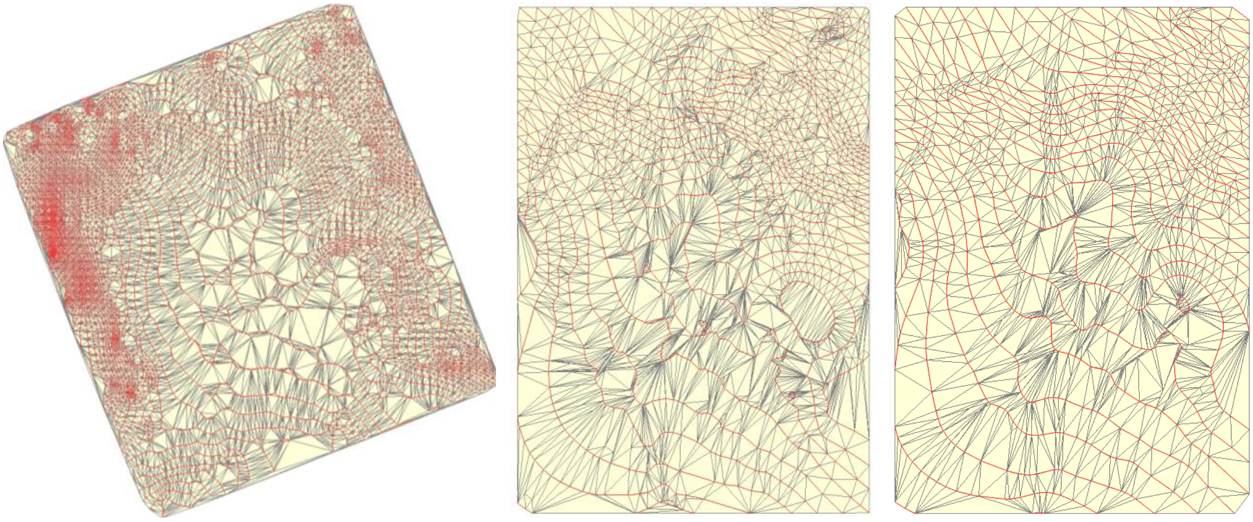

Figure 10. Triangular model and contour lines produced by UAV (left), GNSS-GPS (middle), and Total Station method (right)

Regarding processing time, the UAV requires the least amount of time and labor in field data collection, taking only 14 minutes. GNSS-GPS, which can be used by a single person, comes in second place with 70 minutes. The device that requires the longest time and labor is Total Station, which took 110 minutes. However, in the office stages, this situation is somewhat reversed. Processing and transferring images obtained by UAV took longer than other methods. Data preparation and processing took approximately 3 hours, the computers performance. In other methods, however, since point data is used, it does not require high processing capacity, which makes this situation advantageous. GNSS-GPS and Total Station use only point data, and their data production processes are completed in 15 and 25 minutes, respectively. Akgul et al. (2018) conducted a study where the capabilities of two data collection systems (UAV and GNSS-GPS) were compared for DEM generation. They also noted that even though field data collection with UAV could be completed quickly, data processing takes much time due to massive data size compared to the GNSS-GPS method.

When considering road planning with NetCAD 7.6, TIN models were obtained using DEMs based on UAV, GNSS-GPS, and Total Station. The quality and accuracy of the TIN models depend on the DEM data. Therefore, the TIN model obtained from the UAV DEM data, which has the highest resolution, represents the terrain better. The other models also show similar characteristics. As suggested by the previous studies, producing high-resolution digital elevation models is critical for the accuracy of computer-based forest road design applications using NetCAD software (Melemez et al., 2015).

The lengths of designed road using DEMs from UAV, GNSS-GPS, and Total Station were found to be 294.8, 272.4, and 282.1 meters, respectively. The average road slopes were 3.41%, 3.39%, and 3.31%, respectively. Figure 11 shows the preliminary alignment (black), road alignment (blue), and curve location (red) stages produced by using the 3D data of the UAV, GNSS-GPS, and Total Station methods.

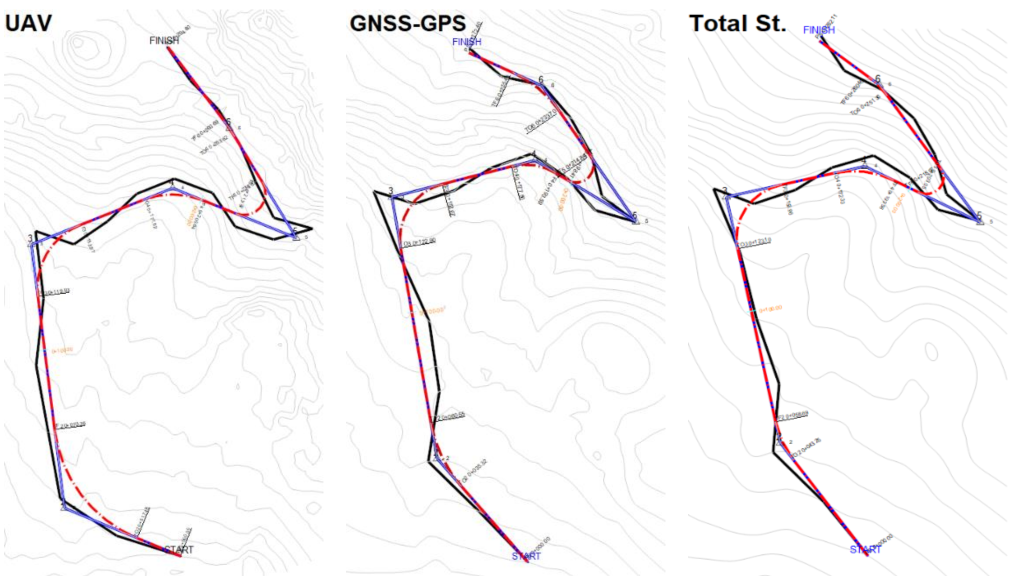

Figure 11. Preliminary alignment, road alignment and curve location determined by UAV (left), GNSS-GPS (middle), and Total Station (right) methods

According to the earthwork volume information, excavation and filling volumes using DEMs generated from UAV, GNSS-GPS, and Total Station were 369.16 m^3 and 166.98 m^3, 285.86 m^3 and 201.83 m^3, and 433.17 m^3 and 183.95 m^3, respectively. When the difference between the cut and fill volumes were compared within three methods, it was found that Total Station method showed the highest material change, followed by UAV and GNSS-GPS methods. The differences in road alignment for each method have affected by both the distance and slope as well as the excavation and embankment volumes.

4. Conclusion

Due to the accuracy of UAV data, which reflects the terrain more realistically and has higher data quality, it provides more accurate results in the study. Considering the labor and time consumption in the data processing stages, UAV is still leading. On the other hand, there is a disadvantage of data processing stage which requires strong and fast computer processors due to high data production time of UAV data. However, if there are PCs with sufficient power, this situation becomes no longer an issue. Thus, it can be concluded that UAVs can become indispensable when data processing is provided in a shorter time.

Compared to using UAVs, GNSS-GPS and Total Station require more manpower and time in generating DEMs. Especially when using Total Station, two people are needed to operate the equipment and certain conditions such as ensuring reflection from the reflector and aiming at the reflector significantly affect the work time. In addition, if the device is not on a level, measurements cannot be taken, resulting in significant time losses. Therefore, compared to the other two methods, using Total Station for measurements becomes more disadvantageous. GNSS-GPS, on the other hand, can be considered advantageous compared to Total Station as it only requires walking around the area during data collection. However, network issues and terrain irregularities can make working with GNSS-GPS more difficult. Having points in the wrong places due to weak GPS and network signals in certain areas is another significant issue. Therefore, in studies using GNSS-GPS, measurements taken in areas where GPS and network signals are strong will be more efficient.

Road planning processes with NetCAD 7.6 provide many advantages compared to traditional methods. In addition to obtaining all the information about the planned road, it is significantly faster than traditional methods. Furthermore, even if mistakes are made, correction processes can be completed in shorter periods of time, which provides an advantage. Planning that would take days with traditional road design methods can be completed in significantly shorter time using NetCAD 7.6. Moreover, the high accuracy, measurement and calculation precision using computer-assisted method provides more realistic results, compared to traditional methods.

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