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Comparison of Autonomous and Manual UAV Flights in Determining Forest Road Surface Deformations

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Abstract

The deterioration of the surface of forest roads is an important factor affecting the safe navigation of vehicles and traffic safety. In addition to traditional methods, automated methods are also used to determine the deterioration of the road surface. UAV systems, which are among the automated methods, are widely used to determine surface deformations with high accuracy. This study aimed to evaluate the advantages and disadvantages of two different flight modes of UAV, including autonomous flight and manual flight, in mapping road surface deformations. Within the scope of this study, the 50-meter section of the Type B forest road located in Kardüz Forest Management Chief (Düzce/Türkiye), was selected. For this study, first the pros and cons of the autonomous and manual flight data acquisition process were evaluated. Then, the photogrammetric data processing results were compared in terms of data size, with precision and accuracy. In addition, the deformation status on the surface within the selected road was determined using the average Z value differences obtained with two flight methods. The result of the study showed that, the number of images obtained from manual flights was 5.5 times higher than from autonomous flights and the flight time was taken four times longer. The average ground sampling distance of the orthophotos generated from two different light modes indicated that the manual flight mode provided seven times higher resolution than autonomous flight. Moreover, the results from the statistical tests for the two flight modes showed differences. When manual flights and autonomous flights are evaluated in terms of reducing the shadow effect, manual flights can be considered more advantageous. Furthermore, it was found that the dynamic mobility of erosion and accumulation on the road surface continued in time series in both flight methods.

Keywords: Forest road deformation, UAV autonomous flight, UAV manual flight, Türkiye.

1. Introduction

In the transportation of forest products, the deformation of forest road surface is an important factor affecting the safety of the hauling vehicles. Deformation rates are mainly affected by factors such as meteorological conditions, traffic payload, maintenance application, pavement structure and other similar factors over time (Tighe et al., 2003).

Traditional and automated methods are used to detect and measure the surface deformation of the forest roads while the traditional method has been mostly preferred (Ciobanu et al., 2012; Nasiri et al., 2012; Săceanu, 2013). However, since the traditional method is based on the experience of the evaluator, the results of the measurements may vary. In addition, due to the time consumption, the size of the measured data is limited, the workload is high and the safety of personnel during measurement is at risk. These are considered among the disadvantages of the method (Bogus, 2010).

In order to minimize errors and standardize the road surface research process, automated methods of storing, recording, and processing road surface data have been implemented (Attoh-Okineve and Adarkwa, 2013). Distortions in the automatic method can be detected with the help of equipment such as laser scanning systems, optical systems, and ultrasonic and laser point-based batch systems. Automated methods have taken place in the highway literature because they measure distortions more precisely and eliminate the disadvantages of the traditional method (Herr, 2001, 2009; Chang et al., 2005; Wang, 2005; Li et al., 2009; Wang et al., 2011; Huang et al., 2011; Tsai et al., 2013).

While using automated methods, the most critical stage in the evaluation process is the data collection process. Automated data collection technologies include creating road surface images by taking photos and videos or using different remote sensing sensors (non-contact) (laser, acoustic and infrared) to measure the cross-sectional and longitudinal profile of the road surface (McGhee, 2004).

Remote sensing methods can be an alternative method of mapping and monitoring road deformations. Advanced remote sensing techniques such as laser scanning and Unmanned Aerial Vehicles (UAVs) are

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widely used to achieve surface deformations with high accuracy (Eker et al., 2018). UAV based modern remote sensing techniques have recently allowed us to obtain accurate and high-resolution digital elevation models (DEM) and orthophoto mosaics (Yurtseven et al., 2016; Akgul et al. 2017; Akay et al. 2018; Turk et al., 2019a; Turk et al., 2019b). However, the quality of the data obtained with the UAV can be affected by the complexity of the target object, daylight conditions (in terms of brightness and shadow effect), sensor characteristics, overlap rates of images, spatial resolution (in terms of ground sampling distance and ground decoding distance) and flight altitude (above ground level, AGL) (Aydin et al., 2019). In this study, the pros and cons of two different flight modes of the UAV, autonomous flight and manual flight, were evaluated and compared in the mapping of road surface deformations.

2. Material and Methods

2.1. Study Area

For this study, the 50-meter section of the secondary forest road located in the 50-meter section of the Type B forest road located in Kardüz Forest Management Chief (Düzce/Türkiye) was selected. The Kardüz Region is located in the Western Black Sea Region between 40° 39' and 40° 45' north latitudes and 30° 53' and 31° 01' east longitude (Figure 1). The total area of Kardüz FMC is 5045 ha, of which 3745 ha is forested, and 1300 ha is unforested areas. There is approximately 87 km of forest roads in Kardüz FMC. According to the Kardüz Plateau Meteorological Station, the average annual rainfall is 840 mm, the average temperature is 130C. The dominant tree species of the region are Eastern Beech (*Fagus orientalis Lipsky.*), Uludag Fir (*Abies nordmanniana subsp. bornmülleriana Mattf*) and Scotch Pine (*Pinus sylvestris L.*) (GDF, 2011). In the study, a 50 m section of the road was used for the measurement.

2.2. Obtaining Autonomous and Manual UAV Digital Images

During the data acquisition operations with UAV, the flight planning was carried out in three stages; evaluation of the flight plan in the field, implementing of ground control points (GCP) and obtaining images. DJI Mavic Pro model was used as the UAV platform. The DJI Mavic Pro model is in the category of ready-to-use UAV-1 with an integrated 12-megapixel resolution camera (Figure 2). Flights on the road surface were planned using UgCS flight planning software in an adaptation to the topography that allow images to be taken with a fixed 1.5 cm terrestrial resolution and flight speed 7 m/s (Figure 2). In this context, a flight plan was created at 50 m above ground level (AGL) with 70% front and side overlap. In addition, autonomous flights for 1.5 cm terrestrial resolution were carried out with manual flights for more detailed data acquisition on the road surface. These flights were made by remote control from an average height of 13 m above the ground. In

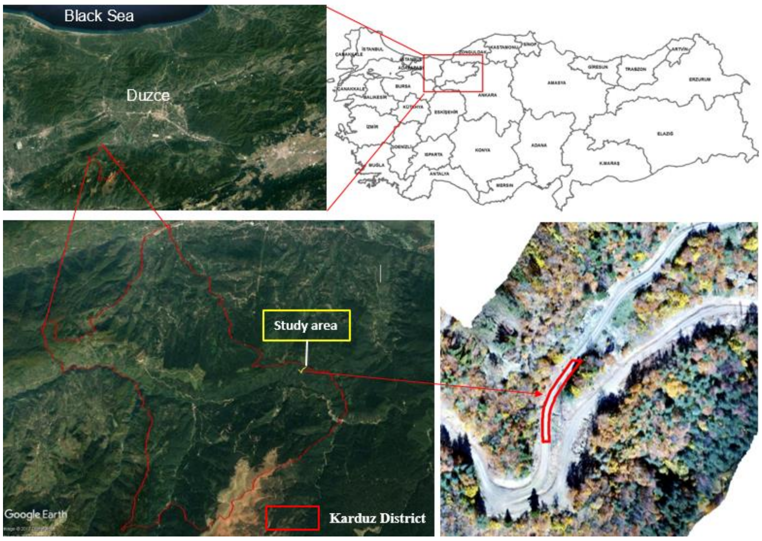

Figure 1. Study area and surroundings

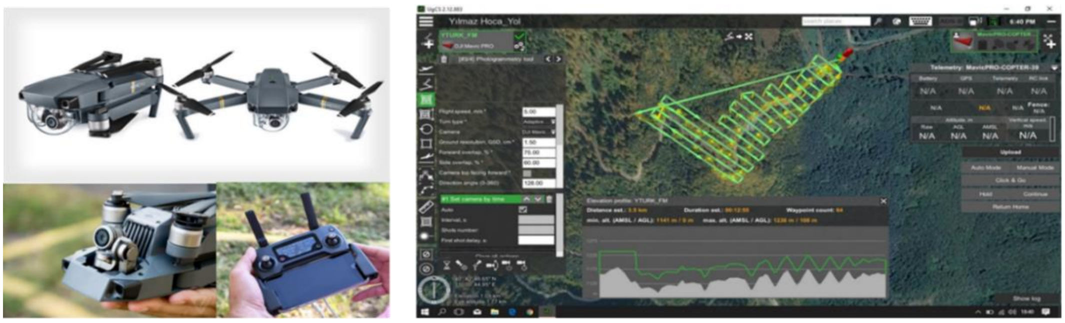

Figure 2. The DJI Mavic Pro model platform used and the prepared flight plan

Figure 3, images of autonomous and manual flights are given. UAV flights took place in April 2018, November 2018, March 2019, April 2019, May 2019 and June 2019, with a total of 6 flights. The study covers a time frame of about 14 months.

Figure 3. Images of manual flight (left) and autonomous flight (right) in the study area

Before starting UAV flights, 16 ground control points (GCP) were placed on the road surface, which will be clearly seen in the images. The X, Y and Z coordinates of each GCP painted with red spray paint on the road surface were measured SATLAB SL600 with 6G RTK GNSS receiver with 1-2 cm error horizontally and vertically (Figure 4). After completing GCPs measurements on the ground, flights were carried out.

Figure 4. Image in the image taken by GCP and UAV taken by Cors-GPS

Within the scope of post-flight office work, the obtained images by the UAV were processed and high resolution and accurate point cloud, DEM and orthophoto images were produced using Agisoft Metashape Professional Version 1.5.2 software (Figure 5). The software was run on Windows 10 64-bit Operating System. While the accuracy level of the image orientation process was set to medium, other depth maps were generated, the quality settings were selected as high in the dense cloud production stages. Later, GCPs were defined in image optimization. The outputs from the photogrammetric analysis were dense point cloud data in "las" format and DEM and orthomosaics in "tiff" format. Then, in order to ensure spatial consistency in the analyses, all DEM and orthomosaics were resampled to the same size by using a vector data representing the study area in "shp" format.

2.3. Comparison of Autonomous and Manual UAV Flight Data

For this study, data obtained from two different UAV flight modes, autonomous and manual, were used to determine road surface deformations with photogrammetric analysis. All autonomous flights were operated at standard flight altitudes, speeds and overlap rates using the same flight plans. Manual flights were carried out in a non-standard manner under the control of the operator who controlled the UAV with remote control over the road surface. The period covered by autonomous and manual flights was between 10.04.2018 and 26.06.2019 and corresponded to six flights. Each autonomous and manual flight was carried out on the same date, and all flights were operated on a manual flight following autonomous flight. Autonomous and manual flight data comes with advantages and disadvantages, starting with the data acquisition process, followed by photogrammetric processing. Thus, the data from both flight modes were compared in terms of resolution, precision, accuracy, and data size.

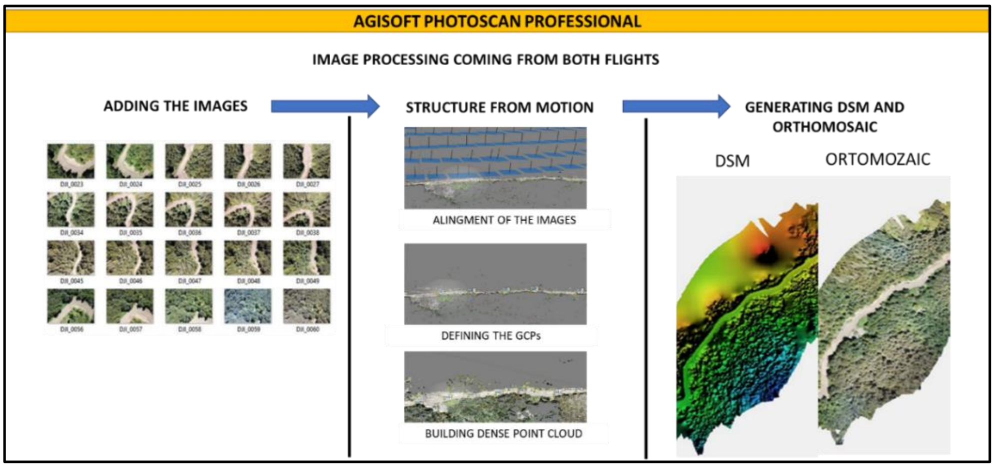

Figure 5. Image processing steps in Agisoft Photscan Professional version 1.5.2.

2.4. Determination of road surface Z values differences

In the study, deformations on the road surface were examined by using the change in Z values in two flight methods. Here, the study area digitized in the GIS environment is the use of all pixels that enter the polygon of the road surface, the presence of vegetation in the areas close to the edge ditches, due to works carried out in the area, there is production material left in these parts or rock fragments coming from the outside in some way, except for the usual deformation processes of the road, and these were not used in the scope of this study (Figure 6). The study area free from external factors is determined as 188.74 m2. In order to accurately analyse the usual deformations, points were marked on the road surface at certain intervals near the middle line of the road surface, then to these points with a radius of 50 cm, circle-shaped zones (buffers) with a radius of 50 cm were defined at these points. The aim here is to use the Z values of the pixels remaining within these selected zones and whose usual deformation is not affected by external influences. These points defined on the road surface are shown in Figure 7.

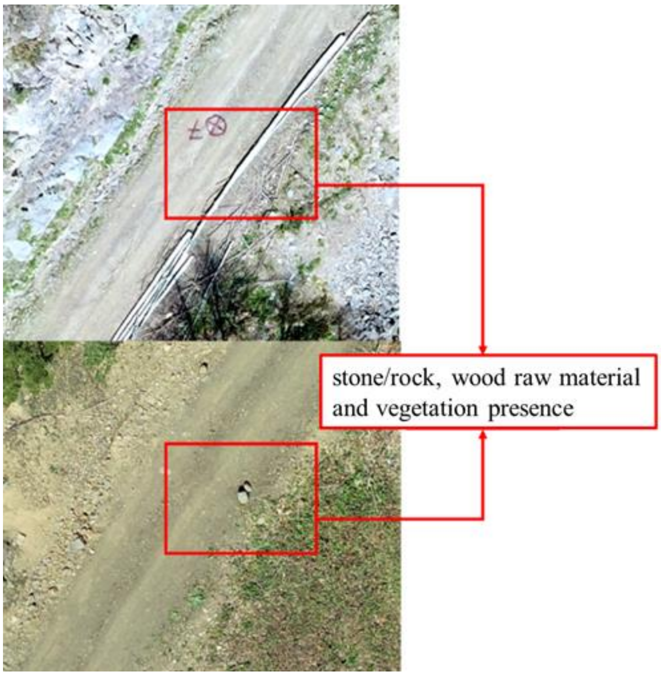

Figure 6. External factors (presence of vegetation, stones/rocks and repair waste)

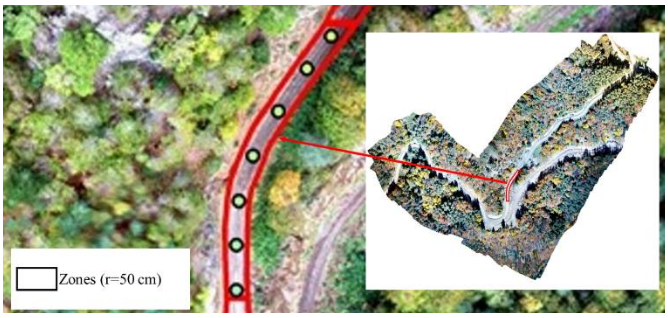

Figure 7. Circular zones with a radius of 50 cm defined on the road surface

The deformations within the designated zones were determined using the average Z values of all pixels in the zone. Zonal Statistics Tool within ArcGIS Spatial Analyst Toolbox was used to estimate the Value. Then, the average Z values obtained from the first flight image (on April 10th, 2018) were subtracted from the average Z values obtained from the other flight images. Defining zones and calculating the average Z value of each zone rather than using a single pixel prevents errors that may occur due to flight height, image quality, or shadow effect, and mislead the model the results. Deformations were compared by producing scatter plots by using the differences in the average Z values of the zones in the road surface of the study area.

2.5. Statistical Analysis

A statistical test was used to determine whether there is any difference between autonomous and manual flight data. A paired-samples t-test was used for the statistical test to determine whether the differences between the values were significant. The test was used to determine whether the mean difference between the two observations was zero. In a paired sample t-test, each subject or entity is measured twice, resulting in pairs of observations. The typical applications of the paired sample t-test include case-control studies or repeated-measures designs (Ozdamar, 2002).

3. Results and Discussion

3.1 Findings on Autonomous and Manual Flights

The aspect of the road is southwest, the average width of the road is 4 m and longitudinal slope is 9%. The lowest elevation extracted from the DEM of the road generated using UAV images was 1168 m, and the highest elevation was 1174 m. A comparison of the advantages and disadvantages of autonomous and manual flights of the UAVs in road deformation studies was first evaluated within the scope of data acquisition processes. In this context, due to the realisation of flight planning in autonomous flights, the same standards can be applied in data acquisition in applications that require time series such as deformation monitoring studies with UAV. However, there are some points to be considered during the flight planning stage.

In manual flights, the platform does not require flight planning as the operator controls it. In autonomous flights, front and side overlap ratios are determined at the planning stage. Depending on the topography adaptive flight opportunity and the desired ground sampling distance, it can be performed at a specific flight height. In this study, the flight height was 50 m from the ground, and the ground sampling distance corresponds to an average of 1.5 cm. However, it can be seen in Table 1 that the flight altitude values vary between 65.50 m and 70.10 m for autonomous flight mode.

Table 1. Findings of autonomous and manual UAV flights

Date	Image numbers		Flight height (m)		Ground sample distance (cm/pixel)		GCP Location error (Total RMSE; Root Mean Square Error) (cm)	
	Autonomous	Manual	Autonomous	Manual	Autonomous	Manual	Autonomous	Manual
10.04.2018	26	135	65.50	14.60	2.02	0.34	5.59	2.79
01.11.2018	24	110	67.90	9.40	2.03	0.29	2.89	1.83
26.03.2019	25	152	68.00	8.29	2.10	0.26	2.90	2.70
25.04.2019	24	162	67.50	11.40	2.08	0.25	2.49	0.87
23.05.2019	25	138	70.10	15.30	2.16	0.30	2.42	1.41
26.06.2019	25	130	67.80	18.60	2.22	0.28	2.21	0.66
Average	25	138	67.80	12.93	2.10	0.29	3.08	1.71

In addition, the average ground sampling distance values obtained from autonomous mode were 2.1 cm/pixel. While flight altitude values were relatively close to each other in autonomous flights, they varied between 8.29 m and 18.60 m in manual flights. It is considered that these differences might be due to planning and implementation and external factors.

When comparing the two methods regarding the number of images obtained, a significant increase in the number of images taken is observed due to the decrease in flight altitude. Since data acquisition is carried out using the same sensor, the difference in the number of images could not be a reason. The average number of images acquired from the autonomous flights was 25, while the average number of images obtained from manual flights was 138. Accordingly, the number of images taken from manual flights is 5.5 times higher than from autonomous flights. When considering the limitations of computer hardware for data storage and photogrammetric processing, the manual flight modes are a disadvantage. In addition, standard overlap rates cannot be achieved in manual flight modes due to the lack of a standard flight plan. It requires an experienced operator of the UAV to minimize this effect. However, the ground sample distance increased due to the decreased flight altitude in manual flight mode. In other words, the resolution of the pixels allows more detail on the ground (Figure 8).

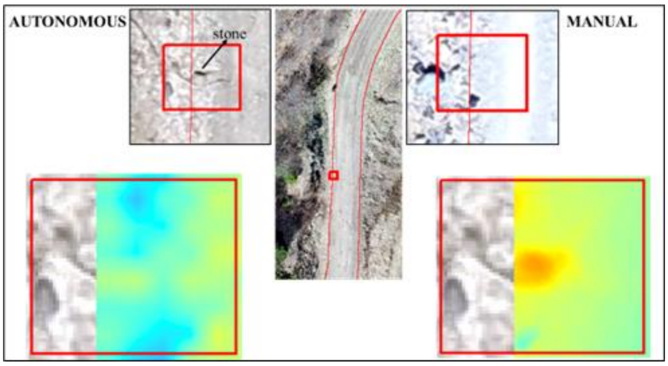

Figure 8. A stone falling over the road surface

When Figure 8 is examined, the rock falling on the road surface in the manual flight image, used to generate DEM, can be observed more prominently. However, the generated DEM from autonomous flight images was less precise. When Figure 9 is examined, the image quality and blurriness in the image details are caused by the flight altitude observed more in autonomous flights. However, data acquisition of the study area with manual flight requires more time than with autonomous flight. Autonomous flights averaged 1.5 minutes, while manual flights could only take 6 minutes in the area corresponding to the road surface. The autonomous flight lasted 4 times less.

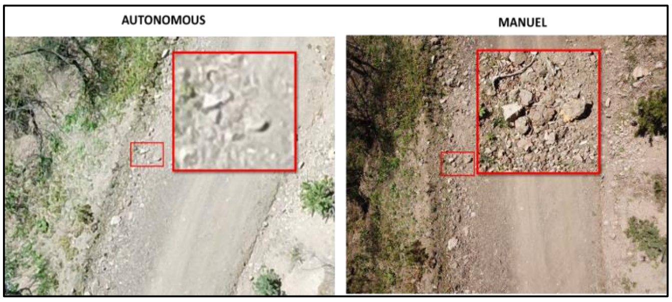

Figure 9. Distinguishability in details based on resolution in images from autonomous and manual flights

In this study, the average ground sampling distance of orthophotos produced from images taken by autonomous flight was 2.1 cm, while the average ground sampling distance of images taken from manual flights was 0.29 cm. Accordingly, manual flights provided 7 times higher resolution (Table 1). When manual flights and autonomous flights are evaluated in terms of reducing the shadow effect, manual flights can be considered as more advantageous. When Figure 10 is examined, it can be observed that shadows have less effect in the model produced from manual flight data.

The statistical test showed a significant difference for each feature. There was a difference between the two flight methods in terms of the number of images ($t=-15.330$, $p=0.000$), flight height ($t=32.401$, $p=0.000$), ground sample distance ($t=48.307$, $p=0.000$), and total RMSE error ($t=3.893$, $p=0.011$).

Hrůza et al. (2016) have demonstrated the possibilities of detecting and monitoring the wearing course of forest roads using UAVs. The study revealed that deformation detection is possible with 2 cm RMSE (Average Root Mean Square Error) by using UAV data. Our finding is similar to recent studies with 3.08 cm RMSE from autonomous mode and 1.71 cm RMSE from manual mode. Thus, it can be used to detect and monitor the deformation.

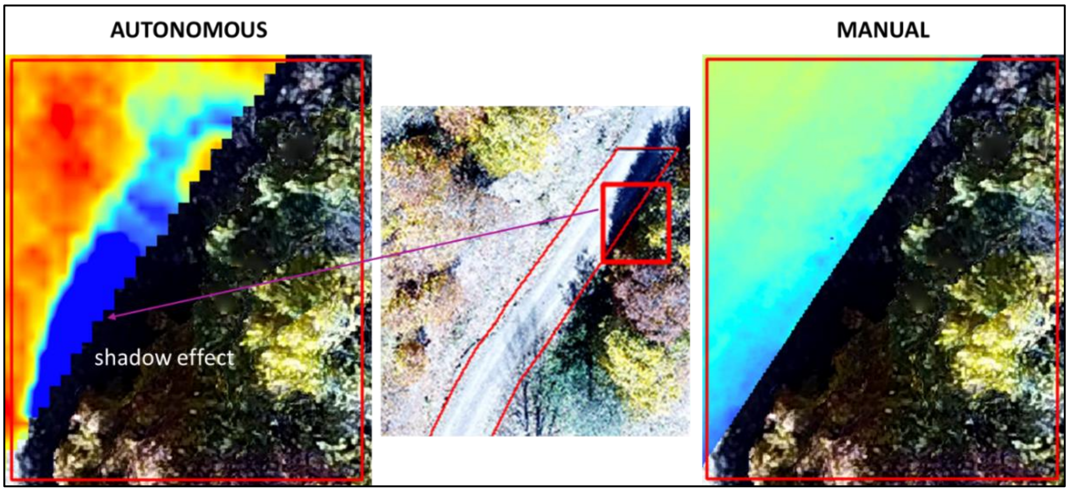

Figure 10. Comparison of autonomous and manual flights in terms of shadow effect

3.2 Findings for the Determination of Road Surface Deformations (Differences in Z Values)

In determining road surface deformations within the scope of the study, the method of comparing the average Z values differences of the pixels in the zones defined at certain intervals were used. The aim here is to prevent misleading effects such as the presence of vegetation (branch-leaf and living cover) in the side ditches of the road, the debris left on the road as a result of road repairs and works, and the coming of rock/stone pieces on the road other than the usual deformation processes of the road. In this method, the average Z values in the zones were compared by using scatter graphs from both flight methods. Table 2 shows the average Z values for the road surface of the flight data given. The graph obtained from these separate operations for autonomous and manual flight data is given in Figure 11.

Table 2. Autonomous and Manual flight data differs from the average Z

Flight DEM differences	Autonomous (m)	Manual (m)
April 2018- November 2018	0.10	0.01
April 2018- March 2019	0.03	0.04
April 2018- April2019	0.12	-0.01
April 2018- May 2019	0.12	-0.24
April 2018- June 2019	0.04	-0.69

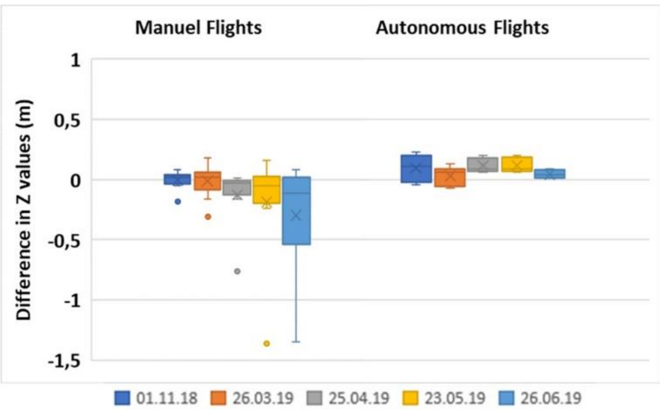

Figure 11. Deformations derived from the average Z-value differences of manual and autonomous flights

When the graph given in Table 2 and Figure 11 are examined, it can be determined that the amount of erosion and accumulation on the road surface varies over the 14 months (April 2018-June 2019). Its dynamic mobility continues in the time series. The result also indicated that the increase in Z differences in manual flights as time progresses gives good results in predicting deformations better. Recent studies stated that the amount of erosion and accumulation of the road surface differed temporally (Akgul et al., 2017; Akay et al., 2018). Akay et al. (2018) examined the deterioration of the road surface with a terrestrial laser scanner for one year (in three-month periods). Akay et al. (2018) examined the deterioration of the road surface successfully with a terrestrial laser scanner for one year (in three-month periods). As in our study, the dynamic mobility of periodic erosion and accumulation amounts continues. In the study, in order to eliminate the unusual effects effectively in road surface deformations, it was ensured that the results were obtained in a more stable way by using the method presented here. Here, the change indicated as deformation is the difference in the average Z values of the pixels. The t-value was calculated as 1.967 from the dependent two-sample t-test that was performed to determine whether there is a difference between the mean Z differences data obtained from the two flight methods. There was no significant difference between mean Z differences ($p=0.121$). It is thought that this is due to the dynamic mobility of the road surface deformation.

4. Conclusions

In the study, the advantages and disadvantages of autonomous and manual flights were compared to determine the road surface deformation with the UAV. According to the results, it was concluded that both autonomous and manual UAV flights could be used to map road surface deformations. However, manual flights can be carried out for a more detailed analysis of short-road lengths (i.e., meter-scale) and small-scale studies, regardless of other disadvantages. On the other hand, the image quality and blurriness in the images taken depending on the flight altitude of the autonomous flight are observed more. However, performing data acquisition with manual flight for the study area can be considered a disadvantage due to more image acquisition time, data storage, and computer hardware constraints in photogrammetric processing. In addition, more (4 times) time is needed in the manual method. Nevertheless, for the long road section, this ratio could dramatically increase. It was also concluded that with these methods, it would be better to obtain data every 3 or 6 months instead of monthly.

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