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Analysis of UAV-Photogrammetry for the Spatiotemporal Monitoring of Pavement Elevation in a Rural Road

Helik Susilo[1], Martince N Bani[2], Muhammad Tri Aditya[3], Dyah A.R Cupasindy[4], Fuji Asema[5]
[1-5] Departement of Civil Engineering, Politeknik Negeri Malang and susilohelik@polinema.ac.id

ABSTRACT

Unmanned Aerial Vehicle (UAV) photogrammetry has gained significant popularity across various industries due to its versatility in a wide range of applications. In the field of surveying, UAV photogrammetry offers a faster and more cost-effective solution compared to surveying conventional methods such as leveling instruments or total stations. In rural areas, the pavement of village access roads is vulnerable to deterioration, particularly in the form of settlement caused by repeated loads from transport vehicles. Therefore, monitoring pavement settlement is essential to ensure safety and facilitate timely maintenance planning. Mostly, pavement settlement measurements are conducted using conventional surveying methods. This study aims to explore the potential of UAV-photogrammetry in monitoring pavement elevation in rural areas and to assess its accuracy compared to conventional surveying methods. Aerial data acquisition was conducted in two separate epochs: Epoch I on December 18, 2024, and Epoch II on April 23, 2025. These multitemporal aerial surveys produced a series of overlapping aerial photos. Within the study area, point markers were installed as reference points for elevation measurements on the generated Digital Elevation Model (DEM). The elevation change from Epoch I to Epoch II ranged from 0.00 to 0.029 meters. However, this change cannot be directly interpreted as pavement deformation or settlement. This limitation arises because the root mean square error (RMSE) values of the elevation data obtained from UAV photogrammetry and total station measurements range from 0.048 to 0.098 meters.

Keywords: *Elevation, Pavement, Deformation, UAV-Photogrammetry, Rural Road.*

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have become increasingly popular across numerous industries for a wide range of applications [1]. Specifically for mapping, UAVs offer a faster and more affordable approach. They can also fly closer to targets, capturing images with detail down to the centimeter level [2]. Furthermore, UAVs enable rapid data collection over extensive areas. These aircraft can be piloted remotely or follow pre-programmed flight paths guided by navigation software that linked to GPS and even continue operating without a GPS signal [3] [4].

The pavement of village access roads facilitates transportation of farmers' harvests from agricultural area to sales points. The pavement of village access roads is susceptible to deterioration in the form of settlement due to the load from transport vehicles. Consequently, monitoring this pavement settlement is essential for ensuring safety and planning repairs. Conventional methods for measuring road pavement settlement typically involve leveling instruments or total stations; however, these require significant time and personnel resources [5]. Therefore, innovation in road pavement settlement measurement methods is needed to enhance speed and efficiency. One potential alternative is the utilization of UAV-Photogrammetry for elevation measurement. This measurement method has proven effective in topographic mapping because of its accuracy in open areas, significant productivity, and rapid data acquisition process.

Several researchers have explored the application of the UAV-Photogrammetry method to measure land surface subsidence. [5] Experimented to investigate land surface subsidence resulting from underground mining activities using the UAV-Photogrammetry method. The findings of that investigation revealed that measuring land surface subsidence with the UAV-Photogrammetry method can detect subsidence with an accuracy of ±5 cm. [6] Performed a study on the measurement of land surface subsidence using the UAV-Photogrammetry method. The results of that research indicated that measuring land surface subsidence with the UAV-Photogrammetry method can detect subsidence with an accuracy of ±3.33 cm.

[7] Conducted a study by simulating land surface subsidence measurements in an urban area using the multi-temporal UAV-Photogrammetry method. The simulation results indicated that land subsidence measurement using the UAV-Photogrammetry method at a flight altitude of 150 m can detect subsidence with an accuracy of ±11 cm, at a flight altitude of 100 m can detect subsidence with an accuracy of ±10 cm, and at a flight altitude of 80 m can detect subsidence with an accuracy of ±5 cm. [8] Performed an experiment monitoring land surface subsidence resulting from open-pit mining activities using the multi-temporal UAV-Photogrammetry method. The findings of that experiment revealed that land surface subsidence measurements using the temporal UAV-Photogrammetry method have a standard deviation of 0.13–0.19 m. This study aims is to explore the potential of UAV-photogrammetry technology in monitoring pavement elevation in rural areas and assess its accuracy and reliability compared to conventional surveying methods.

2. METHODS

This research was conducted through three main stages: data collection, data processing, and data analysis. The research stage workflow is illustrated in Figure 1.

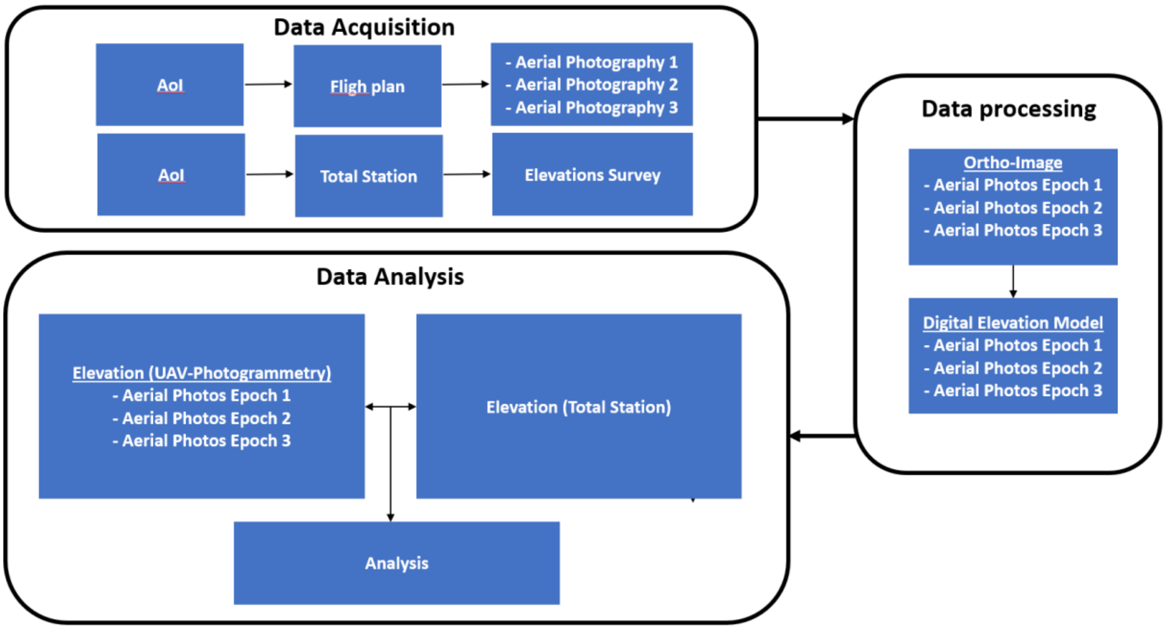


Figure 1. Research Stages

This research uses UAV and total station equipment as the primary instruments for data acquisition. The UAV platform used is DJI Phantom 4, and the total station used is the Sokkia IM 52. The equipment used in this study is shown in Figure 2.

Figure 2. UAV and Total Station

The data collection process began with flight path planning in the area of interest. Flight path planning is a crucial step to ensure that the acquired aerial imagery has high quality and meets the geometric requirements of mapping. The flight path was designed based on the characteristics of the area of interest, enabling accurate determination of the shape and size of the image acquisition area. In this study, the acquisition of elevation data using UAV-photogrammetry was conducted across two time epochs. Data acquisition two times in different epochs aimed to detect subsidence on the pavement road. Table 1 shows aerial photo data collection parameters.

Table 1. *Aerial Photo Data Collection Parameters.*

	Parameters	
1	Flight Altitude	24 m
2	Ground Sample Distance	1 cm / px
3	Front Lap	80 %
4	Side Lap	75 %
5	Flight Speed	3 m/s
6	Gimbal Angle	-90
7	Flight Direction	-156

The aerial photography parameters detailed in Table 1 were inputted into the UAV's navigation software. Subsequently, the UAV executed automated flights based on these parameters, as outlined in Table 1. Aerial photography data acquisition was conducted on two distinct epochs: December 18, 2024; and April 23, 2025. This multitemporal aerial photography session yielded a series of overlapping partial aerial photos. These partial images were subsequently processed using photogrammetry software to generate a comprehensive orthophoto. The resulting orthophoto map in the three distinct epochs is shown in Figure 3.

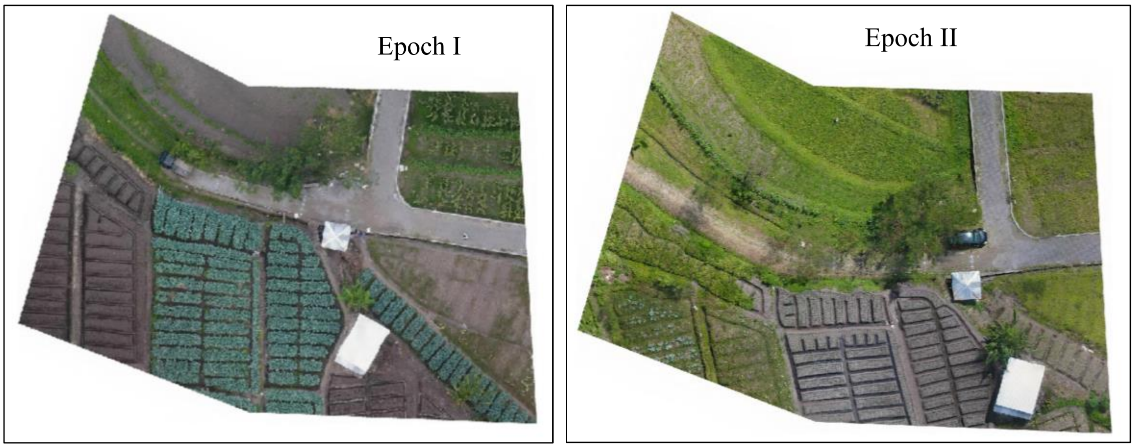


Figure 3. Orthopoto Maps

In the area of interest, point markers were installed to conduct elevation measurements on the DEM maps. These markers functioned as elevation measurement points on each DEM map generated from different time epochs, ensuring their position remained consistent with the measurement points. Figure 3 shows the positions of the point markers.

Figure 4. Elevation Marker.

The results of the orthophoto map in Figure 2 were converted into a Digital Elevation Model (DEM) map. A DEM map is a representation of a digital elevation model that makes it possible to measure the elevation of marker points on the surface in raster/grid format. Figure 4 shows the DEM map.

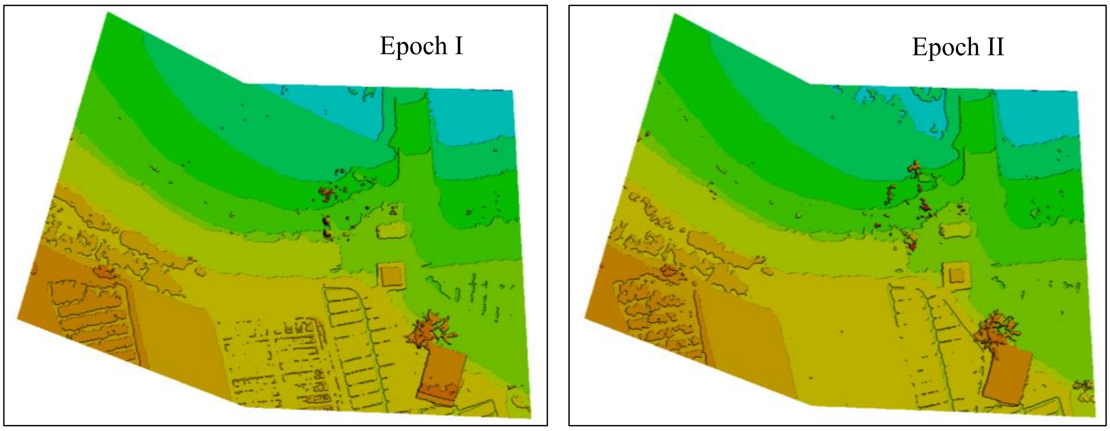


Figure 4. Digital Elevation Model Maps.

The DEM map in Figure 4 is a digital representation of the earth's surface in the form of a grid containing elevation value information. This map is used to obtain elevation values at previously determined marker points.

3. RESULTS AND DISCUSSION

3.1 Elevation Analysis Across The Initial Temporal Baseline (Epoch I)

Elevation data for Epoch I acquired through UAV-photogrammetry were collected at marker points distributed across the study area and are presented in Table 2. Simultaneously, the elevation of these same marker points was measured using a total station to provide a comparative baseline. This Epoch I elevation data will serve as the reference to assess pavement subsidence in the area of interest.

Table 2. The Elevation of Marker Point in Epoch I

Marker Point	Elevation (UAV-Photogrammetry)	Elevation (Total Station)	Deviation
1	788,821	788,829	-0,008
2	788,808	788,822	-0,014
3	788,766	788,772	-0,006
4	789,353	789,401	-0,048
5	789,349	789,400	-0,051
6	789,329	789,353	-0,024
ex7	789,684	789,646	0,038
8	789,683	789,646	0,037
9	789,690	789,640	0,050
Average			0,031
RMS			0,098

According to Table 2, the elevation derived from the UAV-photogrammetry method shows a difference ranging from 0.008 to 0.050 m compared to the elevations obtained from the total station. The average elevation difference between the two methods is 0.003 meters, with a Root Mean Square Error (RMSE) of 0.098 m. The graphical representation of the elevation differences between UAV-photogrammetry and total station data can be seen in Figure 5.

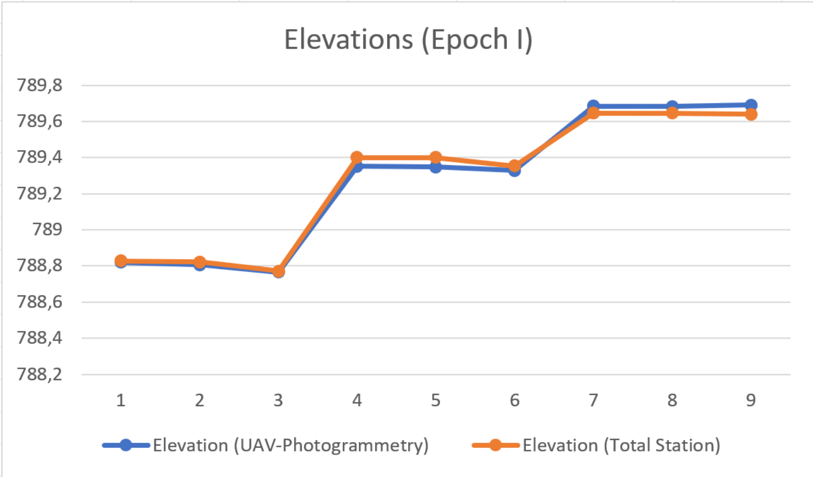


Figure 5. Elevation Differences Between UAV-Photogrammetry And Total Station Epoch I.

The initial surface conditions are represented by the elevation in Table 2. This detailed dataset serves as the reference for quantifying any vertical pavement displacement observed in subsequent measurements.

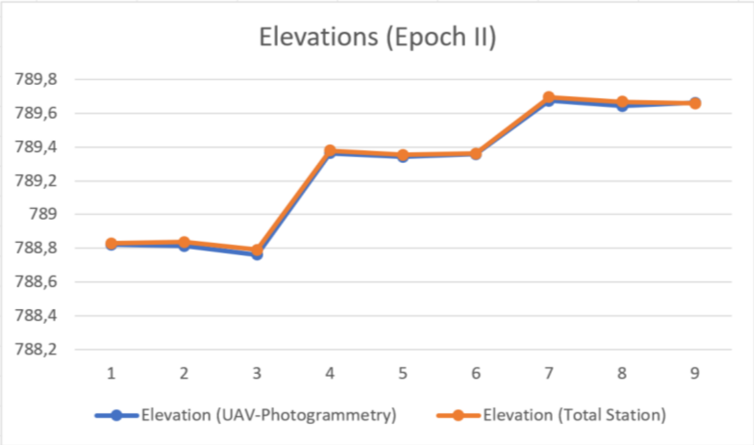
3.2 Elevation Analysis Across Second DEM (Epoch II)

Elevation data for Epoch II acquired through UAV-photogrammetry were collected at the same marker points as in Epoch I, presented in Table 2. Simultaneously, the elevation of these same marker points was measured using a total station. This Epoch II elevation data was used as the second surface to determine if any elevation decrease (subsidence) occurred on the pavement.

Table 3. The Elevation of Marker Point in Epoch II

Marker Point	Elevation (UAV-Photogrammetry)	Elevation (Total Station)	Deviation
1	788,823	788,830	-0,007
2	788,814	788,838	-0,024
3	788,763	788,791	-0,028
4	789,363	789,379	-0,016
5	789,343	789,354	-0,011
6	789,358	789,362	-0,004
7	789,675	789,695	-0,020
8	789,644	789,668	-0,024
9	789,661	789,659	0,002
Average			0,015
RMS			0,048

According to Table 3, the elevation derived from the UAV-photogrammetry method shows a difference ranging from 0.002 to 0.028 m compared to the elevations obtained from the total station. The average elevation difference between the two methods is 0.015 m, with a Root Mean Square Error (RMSE) of 0.048 m. The graphical representation of the elevation differences between UAV-photogrammetry and total station data can be seen in Figure 6.



Gambar 6. Elevation Differences Between UAV-Photogrammetry and Total Station Epoch II.

Representing the second temporal measurement, the elevation data in Table 3 were derived from aerial photogrammetry conducted during Epoch II. This dataset will be directly compared with the elevation data from Epoch I to analyze and quantify any vertical movement or subsidence of the road pavement over the intervening period.

3.3 Multi Temporal Elevation Change Analysis (Epochs I and II)

The elevation data obtained from the UAV-Photogrammetry method across Epoch I and Epoch II will be compared to identify any pavement elevation subsidence. The elevation data from Epoch I will serve as the baseline. The elevation values for Epoch I and Epoch II are presented in Table 5.

Table 4. The Elevation of Epoch I, Epoch II and Epoch III

Marker Point	Epoch I	Epoch II	Change
1	788,821	788,823	0,00
2	788,808	788,814	0,01
3	788,766	788,763	0,00
4	789,353	789,363	0,01
5	789,349	789,343	-0,01
6	789,329	789,358	0,03
7	789,684	789,675	-0,01
8	789,683	789,644	-0,04
9	789,69	789,661	-0,029

Based on Table 4, the elevation change from Epoch I to Epoch II ranges from 0.00 to 0.029 meters. This change is illustrated in the graph shown in Figure 7.

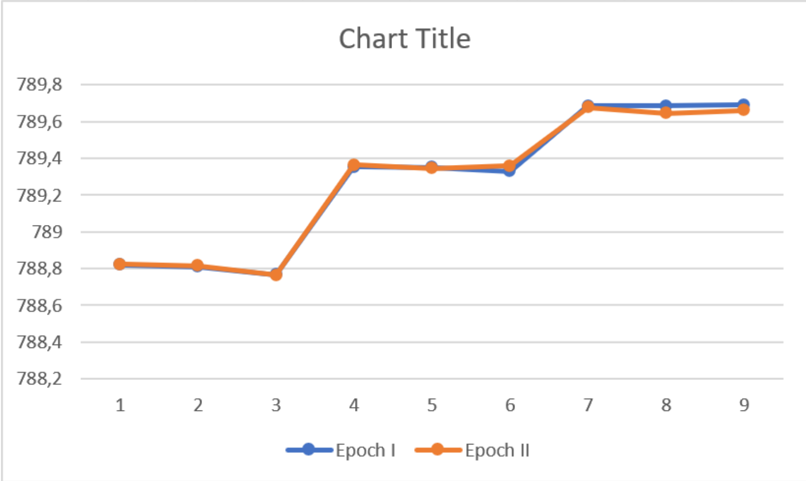


Figure 6. Elevation Differences Between UAV-Photogrammetry Epoch I and Epoch II.

The elevation change shown in Figure 6 cannot be directly interpreted as a deformation or settlement of the pavement. This is because, based on Table 2 and Table 3, the RMS values of elevation obtained from UAV photogrammetry range between 0.048 and 0.098 meters. Therefore, it can be concluded that in this case, pavement settlement measurements using UAV photogrammetry can only detect changes greater than 0.048 meters.

CONCLUSION

Pavement elevation monitoring can be conducted using UAV photogrammetry. In this case study, a comparison between elevation data obtained from UAV photogrammetry and total station measurements revealed RMSE values ranging from 0.048 to 0.098 meters. The elevation change derived from UAV photogrammetry between Epoch I and Epoch II ranged from 0.00 to 0.029 meters. However, this change cannot be directly interpreted as pavement deformation or settlement. This limitation exists because the RMSE values of the elevation data exceed the observed elevation change, indicating that the variation may fall within the measurement error margin.

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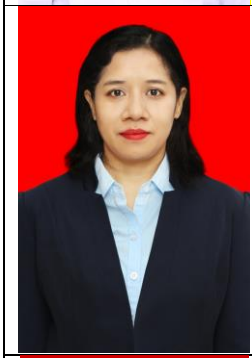
BIOGRAPHIES OF AUTHORS

	Helik Susilo completed his undergraduate studies in Geodetic and Geomatic Engineering at Institut Teknologi Nasional Malang in 2014, and continued his master's degree in Geomatic Engineering at Universitas Gadjah Mada in 2018. Her research interests focus on surveying and mapping. He can be contacted via email at susilohelik@polinema.ac.id
	Martince Novianti Bani earned her Bachelor's degree in Geodesy Engineering from Institut Teknologi Nasional Malang in 2010. She later pursued advanced studies and completed her Master's degree in Geodesy and Geomatics Engineering at Institut Teknologi Bandung in 2018, specializing in photogrammetry. Her academic and research interest include photogrametric and UAV-based mapping. She can be contacted via email at novianti_mb@polinema.ac.id.
	Muhammad Tri Aditya Graduated with a Bachelor's degree in Mining Engineering, Adhi Tama Institute of Technology Surabaya (ITATS) in 2018 and a Master's degree in Mining Engineering, Veteran National Development University Yogyakarta (UPNVYK) in 2021. Currently, the author teaches at the Civil Engineering Department, D3 Mining Technology Study Program, Malang State Polytechnic. He teaches courses in Basic Geology, Mining Drainage Engineering, Fluid Mechanics, Mineral Processing, and Metallurgy. He is active as an independent consultant for rock mining and writes scientific journal articles and books related to Post-mining Planning for Wetland Systems, Basic Geology, etc. email: muhammadtri@polinema.ac.id
	Dyah Ayu Rahmawati Cupasindy completed her undergraduate studies in Civil Infrastructure Engineering at Institut Teknologi Sepuluh Nopember in 2018, and continued her Master's degree in Civil Engineering with a specialization in Geotechnical Engineering at Institut Teknologi Sepuluh Nopember in 2020. Her research interests focus on soil improvement, foundation engineering, and slope stability using numerical modeling. She can be contacted via email at dyahayu.rahmawati@polinema.ac.id
	**Fuji Asema,** I completed my undergraduate studies in Civil Engineering at Universitas Negeri Padang, graduating in 2018, and continued my Master's degree in Civil Engineering at Universitas Andalas in 2020. My area of expertise is geotechnical engineering, with a strong research interest in liquefaction, foundation design, and soil properties. I can be contacted via email at fuji.asema@polinema.ac.id