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Analysis of the Influence of Flight Altitude on the Accuracy of Elevation Derived from UAV-Photogrammetry

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ABSTRACT

Precise elevation data are essential for tasks such as construction planning, subsidence assessment, and infrastructure maintenance. Traditional ground-based surveying with Total Stations is known for its accuracy, but it requires considerable time and labor. In contrast, UAV-Photogrammetry provides a faster approach by deriving elevation information from aerial images captured by camera equipped unmanned aircraft. In this research, aerial data were acquired at flight heights of 25 m, 35 m, and 45 m above ground level (AGL), and the resulting elevation estimates were validated against measurements obtained using a Total Station. The analysis indicated that the 25 m AGL flight produced the most accurate results, yielding Root Mean Square Error (RMSE) of 0.0313 m, followed by 35 m AGL with RMSE of 0.0539 m and 45 m AGL with RMSE of 0.1118 m. Furthermore, t-test analysis confirmed that there was no statistically significant difference between elevation values derived from UAV-Photogrammetry and those measured using the Total Station.

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1. INTRODUCTION

Unmanned aerial vehicles (UAVs) are now extensively utilized in many sectors because of their widespread availability and efficient performance (Kokamägi et al., 2020). Within mapping and surveying applications, UAVs represent a faster and more economical option compared to traditional techniques. Their low-altitude flight capability allows for the capture of very high-resolution images with spatial accuracy at the centimeter scale (Eisenbeiß, 2009). Additionally, UAV systems enable rapid acquisition of data across broad areas. These platforms may be controlled remotely or programmed to follow predetermined flight paths through Global Navigation Satellite System (GNSS) supported software, and certain UAV configurations are able to operate in conditions where GNSS coverage is weak (Burdziakowski, 2018) (Burdziakowski, 2017).

The accuracy of elevation data obtained through UAV-Photogrammetry is highly influenced by the flight altitude at which the data is collected (Kršák et al., 2016). Generally, flying at a lower altitude result in higher resolution data with greater detail, but may also lead to increased processing time and costs (Aasen et al., 2018). On the other hand, flying at a higher altitude can cover larger areas more quickly but may sacrifice some level of detail and accuracy. Finding the optimal balance between flight altitude and desired level of accuracy is essential for maximizing the benefits of UAV-Photogrammetry in various industries such as construction planning, subsidence assessment, and infrastructure maintenance. Additionally, factors such as weather conditions, lighting, and the type of terrain being surveyed also play a role in determining the most suitable flight altitude. It is important for UAV operators to consider these variables and carefully plan their missions to achieve the best possible results. By effectively balancing these considerations, users can ensure that they are obtaining accurate and precise elevation data for their specific needs.

Numerous studies have investigated the use of UAV-Photogrammetry for mapping different types of objects at varying flight altitudes. Ab Aziz et al. (2021) conducted a study to generate a three-dimensional model of the Sultan Salahuddin Abdul Aziz Mosque in Shah Alam, Malaysia, using UAV-Photogrammetry. Their findings indicated that a flight height of 170 m produced the highest accuracy, with a Root Mean Square Error (RMSE) of 0.123 m when compared with other tested altitudes. Syafuan et al. (2021) examined UAV-Photogrammetry for 3D modeling in both flat and hilly terrains at UPNM, Malaysia. The results revealed notable differences in accuracy between terrain types: in flat areas, the optimal flight altitude was 60 m, achieving a mean variance of 0.86 m, while in hilly regions, the best performance was obtained at a 100 m altitude with a mean variance of 0.43 m. Chen et al. (2023) developed a 3D model of the Blessington Bridge in Ireland and reported that the highest accuracy was achieved at the lowest tested altitude of 10 m, using a 90% image overlap. This research is focused on the influence of flight altitude on aerial image acquisition on the accuracy of elevation data obtained using the UAV-Photogrammetry method on road pavement objects.

2. RESEARCH METHODS

This study was conducted through three primary stages: data collection, data processing, and data analysis. The overall workflow of the research is presented in Figure 1.

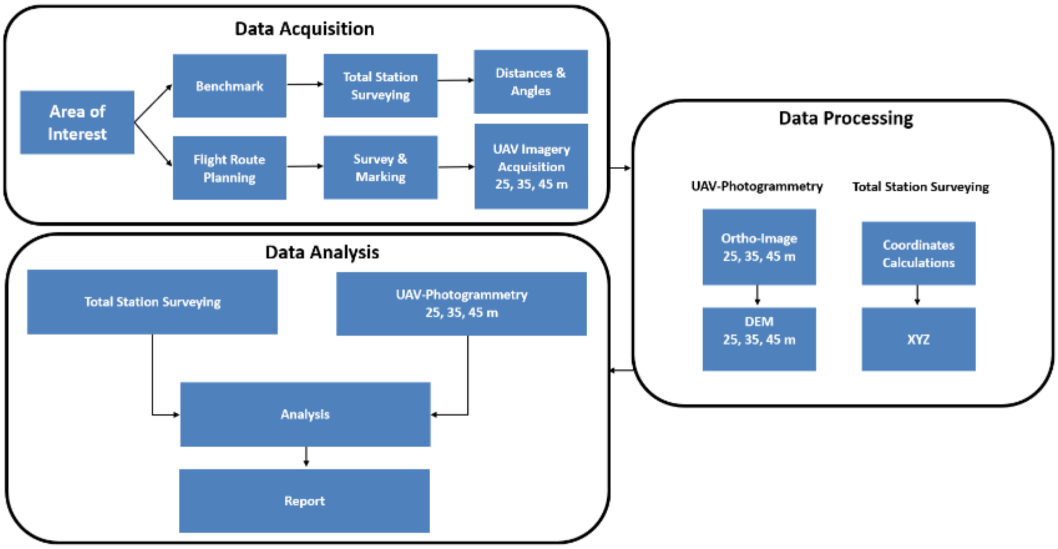


Figure 1. Research Stages

This research utilized a UAV platform and a Total Station as the main tools for collecting data. A DJI Phantom 4 was deployed for aerial image acquisition, while elevation reference measurements were obtained using a Sokkia IM-57 Total Station. The instruments used in this research are shown in Figure 2.

Figure 2. UAV and Total Station.

Data acquisition began with the planning of flight routes across the selected study area. This step is essential to ensure the collection of high quality aerial images that meet the geometric criteria required for accurate mapping. Flight paths were tailored to the specific conditions of the study area, allowing clear definition of the survey coverage and image capture limits. Aerial photographs were collected at three different flight altitudes to evaluate how altitude influences the accuracy of the resulting elevation data. The image acquisition parameters applied in this study are summarized in Table 1.

Table 1. *Aerial Photo Data Collection Parameters.*

	Parameters	
1	Flight Altitude (Above Ground Level)	25 m, 35 m, 45 m
2	Ground Sample Distance	1 cm/px, 1.2 cm/px, 1,8 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 UAV navigation software was set up using the image acquisition parameters summarized in Table 1. With these configurations, the UAV performed automated flights at heights of 25 m, 35 m, and 45 m above ground level to collect aerial images. The use of multiple flight altitudes aimed to examine their effect on the accuracy of elevation models generated through UAV-Photogrammetry. The acquired images were then processed with photogrammetric software to generate orthophoto products. The orthophotos produced from each flight altitude are shown in Figure 3.

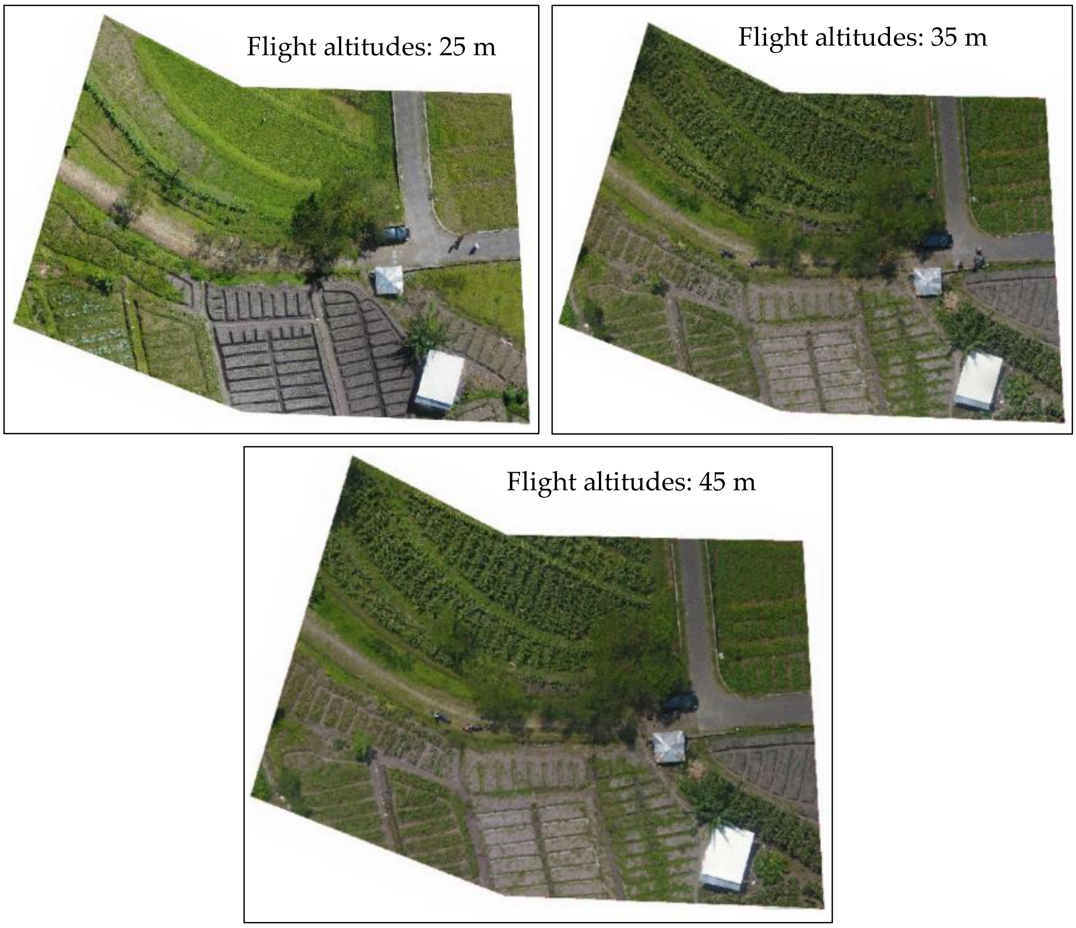


Figure 3. Orthopoto Maps.

To extract elevation from the Digital Elevation Model (DEM), point markers were placed within the area of interest. These markers served as fixed elevation sampling points on each DEM generated from the different flight altitudes, ensuring consistency in the measurement locations across all datasets. The positions of the point markers are shown in Figure 3.

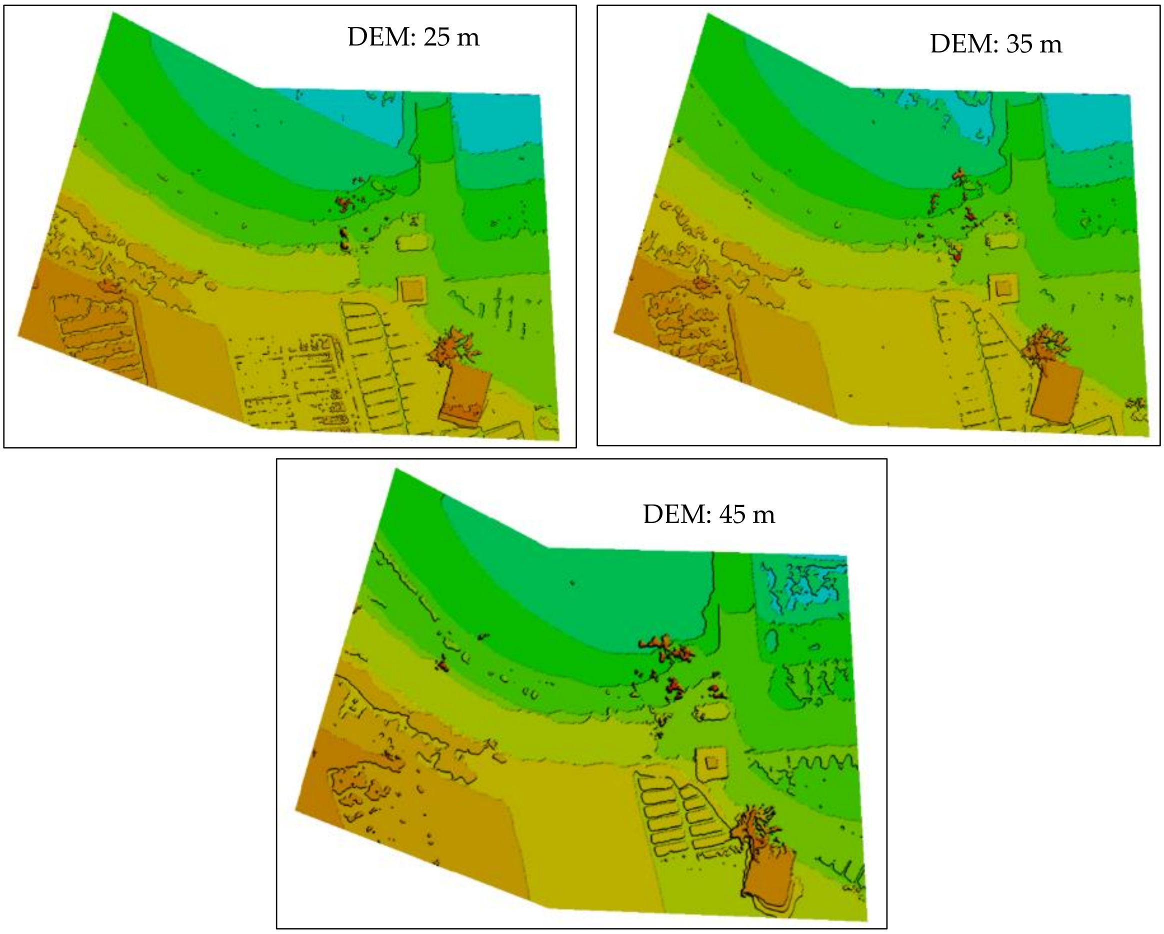
Figure 3: Elevation Marker.

A Total Station was used to measure the elevations at the marker locations, as illustrated in Figure 3. These measurements served as reference elevation data for comparison with the elevations derived from the UAV-Photogrammetry method. The elevation values obtained using the Total Station at each marker position are presented in Table 1.

Table 1. *Elevation From Total Station*

Marker	**Elevasi**
1	788,813
2	788,854
3	788,778
4	789,688
5	789,691
6	789,646

A DEM was generated from the orthophoto map shown in Figure 2. The DEM represents surface elevations in a raster (grid) format, enabling the extraction of elevation values at the predefined marker points. The resulting DEM is presented in Figure 4.



Gambar 4: Digital Elevation Model Maps.

The Digital Elevation Model (DEM) shown in Figure 4 represents the Earth's surface as a grid of elevation values. This DEM was used to extract elevation data at the predefined marker points. The extracted elevations were subsequently compared with the Total Station measurements to evaluate the accuracy of the elevation model generated using the UAV-Photogrammetry method.

3. RESULT AND DISCUSSION

3.1 Elevation Analysis Based on 25 Meter AGL Flight Altitude

Table 2 presents the elevation values extracted at predefined marker locations using UAV-Photogrammetry at a flight altitude of 25 m above ground level (AGL). These elevations were compared with elevation measurements obtained from a Total Station, which served as the reference standard. This comparison was conducted to evaluate the accuracy of the elevation model derived from UAV-Photogrammetry. The detailed results of this assessment are summarized in Table 2.

Table 2. The elevation deviation between UAV-Photogrammetry and Total Station

Marker Points	UAV-Photogrammetry (Meter)	Total Station (Meter)	Deviation (Meter)
1	788,806	788,813	-0,007
2	788,83	788,854	-0,024
3	788,75	788,778	-0,028
4	789,668	789,688	-0,020
5	789,699	789,691	0,008
6	789,648	789,646	0,002

As shown in Table 2, the elevation differences between the UAV-Photogrammetry results and the Total Station measurements range from 0.002 to 0.028 m. These small discrepancies indicate that the elevation model generated from UAV-Photogrammetry at a flight altitude of 25 m achieves a high level of accuracy.

3.2 Elevation Analysis Based on 35 AGL Meter Flight Altitude

Table 3 presents the elevation values extracted at predefined marker locations using UAV-Photogrammetry at a flight altitude of 35 m above ground level (AGL). These elevations were compared with elevation measurements obtained from a Total Station, which served as the reference standard. This comparison was conducted to evaluate the accuracy of the elevation model derived from UAV-Photogrammetry. The detailed results of this assessment are summarized in Table 3.

Table 3. *The elevation deviation between UAV-Photogrammetry and Total Station*

Marker Points	UAV-Photogrammetry (Meter)	Total Station (Meter)	Deviation (Meter)
1	788,817	788,813	0,004
2	788,798	788,854	-0,056
3	788,751	788,778	-0,027
4	789,711	789,688	0,023
5	789,691	789,691	0,000
6	789,69	789,646	0,044

Based on the results presented in Table 3, the elevation differences between UAV-Photogrammetry and Total Station measurements range from 0.000 to 0.056 m. This range indicates that the elevation model produced from UAV-Photogrammetry at a flight altitude of 35 m exhibits an accuracy level comparable to that obtained at the 25 m flight altitude.

3.3 Elevation Analysis Based on 44 AGL Meter Flight Altitude

Table 4 presents the elevation values extracted at predefined marker locations using UAV-Photogrammetry at a flight altitude of 35 m above ground level (AGL). These elevations were compared with elevation measurements obtained from a Total Station, which served as the reference standard. This comparison was conducted to evaluate the accuracy of the elevation model derived from UAV-Photogrammetry. The detailed results of this assessment are summarized in Table 4.

Table 4. The elevation deviation between UAV-Photogrammetry and Total Station

Marker Points	UAV-Photogrammetry (Meter)	Total Station (Meter)	Deviation (Meter)
1	788,893	788,813	0,080
2	788,881	788,854	0,027
3	788,844	788,778	0,066
7	789,722	789,688	0,034
8	789,714	789,691	0,023
9	789,733	789,646	0,087

As presented in Table 3, the elevation differences between the UAV-Photogrammetry results and the Total Station measurements range from 0.023 to 0.087 m. These larger discrepancies indicate that the elevation model generated from UAV-Photogrammetry at a flight altitude of 45 m exhibits lower accuracy compared to the models produced at flight altitudes of 25 m and 35 m.

3.4 Comparative Analysis

The accuracy of the elevation data derived from UAV-Photogrammetry was evaluated using the Root Mean Square Error (RMSE). RMSE measures the average magnitude of error by computing the square root of the mean squared differences between elevations obtained from UAV-Photogrammetry and corresponding measurements acquired using a Total Station, which serves as the reference standard. The mathematical expression used to calculate RMSE is provided in Equation (1), and the resulting RMSE values are summarized in Table 5.

$$RMS_E = \sqrt{\frac{\Sigma(M_{UAV-Photogrammetry} - M_{Total\ Station})^2}{N-1}} \qquad (1)$$

Where:

$M_{UAV-Photogrammetry}$: Elevation derived from UAV-Photogrammetry
$M_{Total\ Station}$: Elevation from Total station
N : Number of sample

Table 5. *Root Mean Square Error*

No	High Altitude	RMS
1	25	0,0313
2	35	0,0539
3	45	0,1118

As presented in Table 5, the RMSE values of elevation estimates obtained from UAV-Photogrammetry range from 0.0313 to 0.112 m. The smallest RMSE 0.0313 m was observed at a flight altitude of 25 m, followed by 35 m with an RMSE of 0.0539 m, while the largest error was recorded at a flight altitude of 45 m, with an RMSE of 0.1118 m.

To statistically evaluate the differences between elevation values derived from UAV-Photogrammetry and those measured using a Total Station, a t-test was performed. This test was applied to determine whether the observed elevation differences were statistically significant. A one-sample t-test was conducted on the elevation differences, based on the following hypotheses:

Ho = There is no significant difference between the elevation of the UAV-Photogrammetry method and the total station

H1 = There is a significant difference between the elevation of the UAV-Photogrammetry method and the total station.

The results of the t-test statistical estimation can be seen in Table 6 below,

Table 7. *t-test result*

High Altitude	**t test**	**Critical t values**	**Decision**
25	0,017883	2,77645	Accepted
35	0,003167	2,77645	Accepted
45	0,083423	2,77645	Accepted

As shown in Table 6, the results of the t-test indicate that the calculated t value is lower than the critical t value, leading to acceptance of the null hypothesis (H_0). The elevation data therefore show no statistically significant difference between measurements obtained using UAV-Photogrammetry and those collected with the Total Station. This outcome indicates that the elevation values derived from both methods are statistically comparable.

4. CONCLUSION

This study demonstrates that UAV-Photogrammetry is a reliable method for obtaining elevation data at varying flight altitudes. Comparison with Total Station measurements shows that the lowest flight altitude 25 m provides the highest elevation accuracy, as indicated by the smallest RMSE value, while accuracy decreases as flight altitude increases. Despite these variations in error magnitude, statistical analysis using a t-test confirms that there are no significant differences between elevation values derived from UAV-Photogrammetry and those obtained from the Total Station. These findings indicate that UAV photogrammetry can produce elevation measurements that are statistically comparable to conventional ground-based surveying methods.

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