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Assessing the Correlation between Camera Angle and the Accuracy of Elevation Measurements Derived from UAV-Photogrammetry

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ABSTRACT

Elevation measurement is essential for various applications, including construction engineering, monitoring land subsidence, maintaining infrastructure, etc. A conventional method for elevation measurement involves terrestrial surveying using a Total Station instrument. However, this method can be time-consuming and requires a considerable number of personnel. Unmanned Aerial Vehicle (UAV) photogrammetry method offers a more efficient solution for determining elevation. This method utilizes UAVs equipped with camera sensors to capture aerial photos. In this research, aerial photos were taken using three different camera angle configurations: nadir (90°), oblique (65°), and oblique (45°). The elevation points derived from the UAV photogrammetry data were compared with the elevation measured by the Total Station. The analysis showed that the nadir (90°) camera angle configuration had the lowest Root Mean Square Error (RMSE) at 0.0471 meters, followed by the oblique (65°) configuration with RMSE of 0.0508 meters, and the obliqu (45°) configuration with RMSE of 0.1399 meters. According to the t-test, the elevations derived using the UAV photogrammetry method were not significantly different from the elevations measured with the Total Station.

Keywords: *Elevation; UAV-Photogrammetry; Total station.*

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INTRODUCTION

Elevation measurement is essential for various applications, including construction engineering, monitoring land subsidence, maintaining infrastructure, etc. A conventional method for elevation measurement involves terrestrial surveying using a Total Station instrument. However, this method can be time-consuming and requires a considerable number of personnel [1], [2]. The unmanned Aerial Vehicle (UAV) photogrammetry (UAV-Photogrammetry) method offers a more efficient solution for determining elevation. This method utilizes UAVs equipped with camera sensors to capture aerial photographs. The use of camera sensor on UAVs enhances efficiency in cost and labor [3]. UAVs can be remotely controlled through automated flight planning that integrates with the Global Positioning System (GPS). Additionally, UAVs can operate accurately even when the GPS signal is lost. [4] [5].

The accuracy of elevation data derived from UAV-Photogrammetry method is influenced by several technical factors. One of the factors is the angle of the camera during aerial image capturing. The camera angle is essential for determining the quality and precision of the

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resulting aerial photos. Using an optimal image acquisition angle allows for more thorough imaging of ground surface objects, which enhances the quality of the elevation model. Therefore, selecting the appropriate image acquisition angle is a critical aspect of the mapping process in UAV-photogrammetry.

Several previous researchers have conducted studies on mapping various objects using the UAV-photogrammetry method with different camera angles. [6] Experimented to create a 3D model of the T06 building at UTM Malaysia using the UAV-Photogrammetry method. The experimental [6] results showed that an oblique camera angle of 45° was more accurate with an average RMSE value of 1.008 m, compared to a nadir camera angle (90°) which had an average RMSE value of 1.145 m. [7] Experimented to create a 3D model of an urban settlement in Al-Anbar Governorate, Iraq, using the UAV-Photogrammetry method. The experimental [7] results showed that an oblique camera angle of 70° with a transverse flight direction was more accurate than a nadir camera angle of 90° with an average RMSE value of 0.031 m. [8] experimented to create a 3D model of the topography of a hilly area using the UAV-Photogrammetry method. The experimental [8] results showed that the optimal camera angle range for generating a 3D model in a hilly area was between 22.5° and 33.75°. This research is focused on the influence of camera angle on aerial image acquisition on the accuracy of elevation data obtained using the UAV-Photogrammetry method on road objects.

METHOD

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

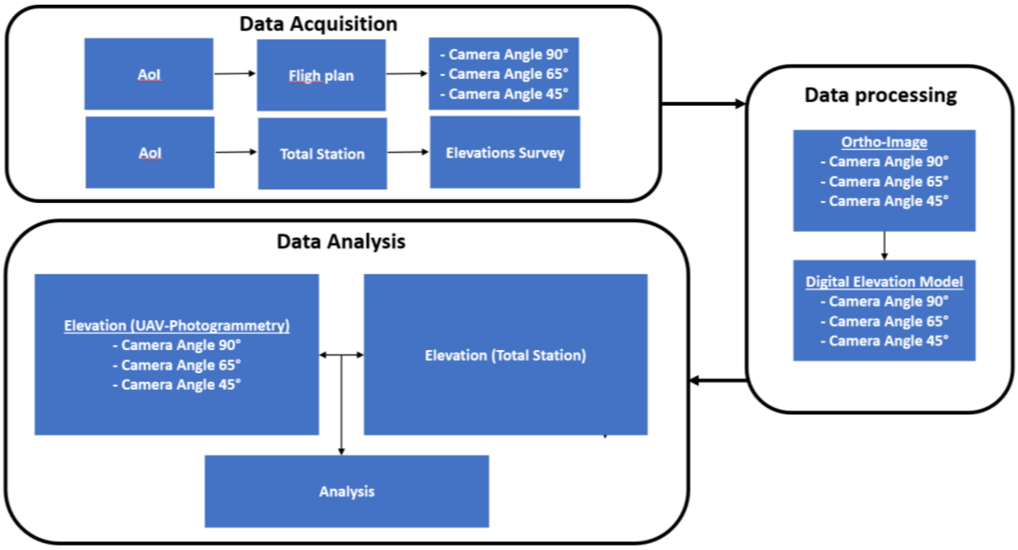

Figure 1. Research stages

The data collection process began with a flight path planning in the area of interest. Flight path planning is a crucial step to ensure that the acquired aerial imagery is of 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 research, the image acquisition process was carried out with three different camera angles, including 90°, 65°, and 45°. These angle variations aimed to evaluate the effect of data acquisition angle on the accuracy of the elevation model derived through UAV-Photogrammetry.

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Aerial photography was conducted automatically at an altitude of 25 meters above ground level. The flight followed a predetermined path, and the camera angles were pre-programmed into the UAV's navigation software. This photography session resulted in a series of overlapping partial aerial photographs. These partial images were then processed using photogrammetry software to create a complete aerial photo map (orthophoto) and a digital elevation model (DEM) map. Figure 2 shows the orthophoto map results from the data processing, highlighting three different camera angles: 90°, 65°, and 45°.

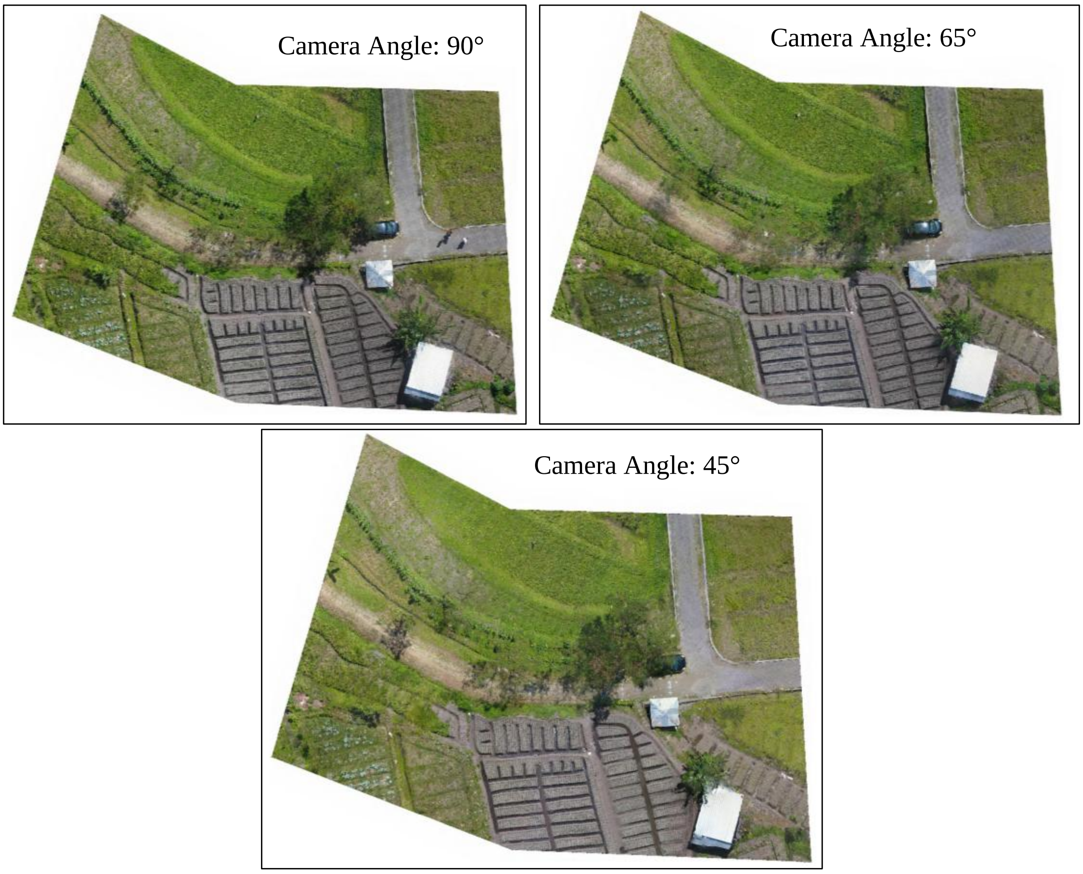

Figure 2. Orthopoto Maps

In the area of interest, point markers were installed to serve as location markers for elevation measurements. A total of nine marker points were distributed across the area of interest. These markers functioned as ground points used in the validation process of elevation data derived from the UAV-Photogrammetry method and total station measurement. Figure 3 shows the positions of the point markers.

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Figure 3. Elevation Marker

The elevation at the marker points shown in Figure 3 was measured using a total station. This measurement was carried out to obtain elevation data used as a reference for comparison against the elevation derived from the UAV-Photogrammetry method. Table 1 shows the elevation data at the marker points measured using a total station.

Table 1. Elevation From Total Station

Marker Point	Elevation (meter)
1	788,830
2	788,838
3	788,791
4	789,379
5	789,354
6	789,362
7	789,695
8	789,668
9	789,659

The results of the orthophoto map in Figure 2 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.

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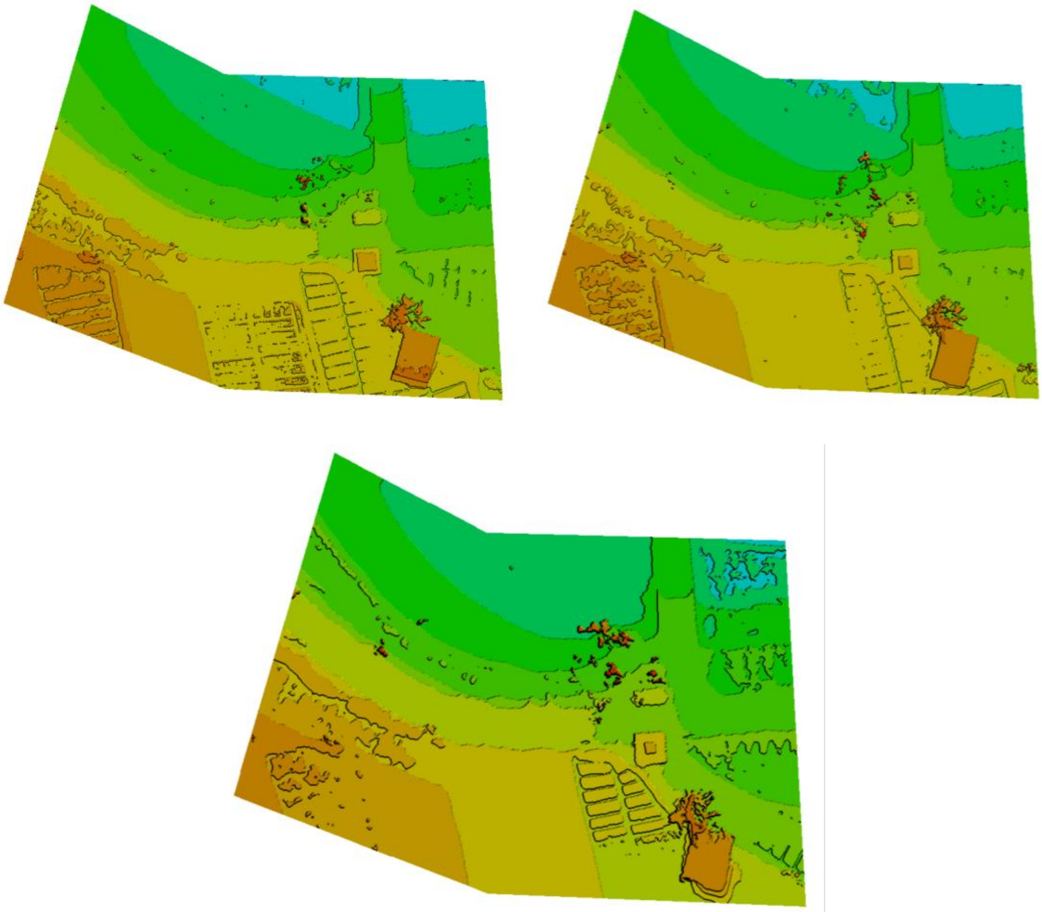

Figure 4. Digital Elevation Model Maps

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. The elevation values taken from the DEM map were compared with the elevation data from total station measurement to evaluate the accuracy of the elevation model derived from the UAV-Photogrammetry method.

RESULTS AND DISCUSSION

A. 90° (Nadir) Camera-Based Elevation Analysis

Elevation derived from the UAV-Photogrammetry method with a camera angle of 90° has been carried out at marker points spread across the area of interest. The elevation results are compared with elevation data obtained from a total station. Elevation from the total station was used as a reference because this method is considered to be higher accurate. A comparison of elevation values between both methods was carried out to evaluate the accuracy of the elevation model derived from the UAV-Photogrammetry. The comparison results are shown in Table 2.

Table 2. The elevation deviation between UAV-Photogrammetry (90°) and Total Station

Marker Point	UAV-Photogrammetry (meter)	Total Station (meter)	Deviation (meter)
1	788,823	788,830	-0,007
2	788,814	788,838	-0,024
3	788,763	788,791	-0,028

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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

According to Table 2, the difference in elevation between the measurements using the UAV-Photogrammetry method and the total station ranges from 0.002 to 0.028 meters. This range indicates that the elevation modeling derived from the UAV photogrammetry using a camera angle of 90°, demonstrate a considerable level of accuracy.

B. 65° (Oblique) Camera-Based Elevation Analysis

Elevation derived from the UAV-Photogrammetry method with a camera angle of 65° has been carried out at marker points spread across the area of interest. The elevation results are compared with elevation data obtained from a total station. Elevation from the total station was used as a reference because this method is considered to be higher accurate. A comparison of elevation values between both methods was carried out to evaluate the accuracy of the elevation model derived from the UAV-Photogrammetry. The comparison results are shown in Table 3.

Table 3. The elevation deviation between UAV-Photogrammetry (65°) and Total Station

Marker Point	UAV-Photogrammetry (meter)	Total Station (meter)	Deviation (meter)
1	788,853	788,830	0,023
2	788,84	788,838	0,002
3	788,801	788,791	0,010
4	789,392	789,379	0,013
5	789,362	789,354	0,008
6	789,381	789,362	0,019
7	789,711	789,695	0,016
8	789,691	789,668	0,023
9	789,69	789,659	0,031

According to the data shown in Table 3, the difference in elevation between the measurements using the UAV-Photogrammetry method and the total station ranges from 0.002 to 0.031 meters. This difference range shows that the elevation modeling derived from the UAV-Photogrammetry with a 65° camera angle have a level that is not much different from the 65° camera angle.

C. 45° (Oblique) Camera-Based Elevation Analysis

Elevation derived from the UAV-Photogrammetry method with a camera angle of 45° has been carried out at marker points spread across the area of interest. The elevation results are compared with elevation data obtained from a total station. Elevation from the total station was used as a reference because this method is considered to be higher accurate. A comparison of elevation values between both methods was carried out to evaluate the accuracy of the elevation model derived from the UAV-Photogrammetry. The comparison results are shown in Table 4.

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Table 4. The elevation deviation between UAV-Photogrammetry (45°) and Total Station

Marker Point	UAV-Photogrammetry (meter)	Total Station (meter)	Deviation (meter)
1	788,893	788,830	0,063
2	788,881	788,838	0,043
3	788,844	788,791	0,053
4	789,404	789,379	0,025
5	789,375	789,354	0,021
6	789,407	789,362	0,045
7	789,722	789,695	0,027
8	789,714	789,668	0,046
9	789,733	789,659	0,074

According to the data shown in Table 3, the difference in elevation between the measurements using the UAV-Photogrammetry method and the total station ranges from 0.021 to 0.074 meters. This difference range shows that the results of elevation modeling derived from UAV-Photogrammetry with a camera angle of 45° have a lower level of accuracy than those with camera angles of 65° and 65°.

D. Comparative Analysis

Analysis of elevation accuracy derived from UAV-Photogrammetry using Root Mean Square Error (RMSE). RMSE is the square root of the average of the difference squares from elevation derived from UAV-Photogrammetry with the results of direct measurements using a total station whose accuracy is considered higher. Equation 1 is the basic formula used to obtain RMSE. The results of the RMSE calculation are shown in Table 5.

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

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	Camera Angle	RMS
1	90°	0,0471
2	65°	0,0508
3	45°	0,1399

According to Table 5 shown that the elevation RMSE derived from the UAV-Photogrammetry method ranged from 0.0471 to 0.0508 m. The lowest RMSE of 0.0471 m was achieved with a 90° camera angle, followed by the 65° camera angle with an RMSE of 0.0508 m, and the 45° camera angle exhibited the highest RMSE at 0.1399 m.

The difference in elevation between the UAV-Photogrammetry method and total station was statistically tested using the t-test. The t-test is used to determine whether there is a significant difference in elevation between the UAV-Photogrammetry method and the total station data. The statistical test was carried out simply using a one-sample t-test for volume differences,

with the following hypothesis:
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

Camera Angle	t test	Critical t values	Decision
90°	-0,029	2,36462	Accepted
65°	0,031	2,36462	Accepted
45°	0,086	2,36462	Accepted

According to Table 6. the results of the t-test, if the calculated t is smaller than the t table then the Ho value is accepted. The data in Table 6 shows that the calculated t value is smaller than the t table in elevation, from these results it states that there is no significant difference between the elevation of the UAV-Photogrammetry method and the total station. This means the elevations are statistically similar.

CONCLUSION

Elevation measurements can be done using the UAV-Photogrammetry method at various camera angles. A comparison of the elevation data derived from UAV photogrammetry and total station measurements revealed the following Root Mean Square Error (RMSE) values: 0.0471 m for a 90° camera angle, 0.0508 m for a 65° camera angle, and 0.1399 m for a 45° camera angle. The results of the t-test statistical test showed no significant difference between elevation derived from the UAV-Photogrammetry method at different camera angles and those from the total station, which means both measurement types produce statistically similar results.

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