Global Education Journal
Vol. 4, 1 (January-April, 2026), pp. 493-500
EISSN: 2986-6529, DOI: https://doi.org/10.59525/gej.1364

An Educational Study on the Impact of Ground Control Point (GCP) Quantity and Distribution on Orthophoto Geometric Accuracy in UAV Mapping

Randy M. Oswara[1], Devit Rahmawati[2]

[1,2] Muara Bungo University, Indonesia; randymo.lagdata@gmail.com

ARTICLE INFO

Keywords:

Educational Study, Ground Control Point, Quantity and Distribution, Orthophoto Geometric Accuracy, UAV Mapping.

Article history:

Received 2026-01-14
Revised 2026-02-18
Accepted 2026-03-24

ABSTRACT

The accuracy of orthophoto geometry from Unmanned Aerial Vehicle (UAV) mapping results is highly dependent on the quality of Ground Control Points (GCPs) as georeference references. This study aims to analyze the effect of the number and distribution pattern of GCPs on the accuracy of orthophoto geometry in the operational area of PT Sumber Cahaya Mineral, Jambi. The method used is an experiment by comparing three configuration scenarios: no GCPs, three GCPs, and four GCPs. Accuracy measurements use the Root Mean Square Error (RMSE), Circular Error 90% (CE90), and Linear Error 90% (LE90) indicators referred to in BIG Regulation No. 6 of 2018. The results of the analysis show that the use of three GCPs with optimal geometric distribution patterns produces the highest accuracy (RMSE 0.00965 m), compared to four GCPs (RMSE 0.01636 m). This finding confirms that increasing the number of GCPs does not always increase accuracy, but rather spatial distribution (distribution pattern) is the main key, as supported by the basic theory of land surveying and photogrammetry.

Corresponding Author:
Randy M. Oswara
Muara Bungo University, Indonesia; randymo.lagdata@gmail.com

1. INTRODUCTION

Geographic Information Systems (GIS) technology and photogrammetry have become the backbone in spatial information management in the mining sector. In this context, data accuracy is crucial. According to Wahyuningrum (2022), quality geospatial data must be able to represent the position of objects on the earth's surface with minimal errors according to the standard of map accuracy. Inaccuracies in data can lead to fatal errors in decision-making, especially in terms of volume estimation and mine planning.

The utilization of UAVs (drones) offers high efficiency in data acquisition, but has limitations in the accuracy of onboard GPS positioning. Therefore, the integration of the Ground Control Point (GCP) is an absolute requirement. Fundamentally, Walijatun Djoko (2003) explained that in soil measurement, the soil control point is the main reference framework that binds detailed measurements to a certain coordinate system. Without the existence of GCP, the map processed by drones would be distorted and would not have a strong legal basis for legal and technical purposes.

While important, the determination of the GCP amount is often a matter of debate. Excessive addition of the number of points can increase costs and operational time in the field. Research by Hidayat & Aji (2018) emphasizes the need to optimize the amount of GCP to be cost-effective while still meeting accuracy standards. In addition, Wahyudi & Yuwono (2020) showed that the distribution pattern of GCP has a more significant influence on orthophoto quality than just the number of dots. This study seeks to examine this phenomenon by examining the variation in the amount and distribution of GCP in the coal stockpile area at PT. Source of Mineral Light, Jambi.

To assess the success of GCP implementation, a standard accuracy test parameter is required. In Indonesia, technical references regarding this matter are regulated in the Geospatial Information Agency (BIG) Regulation Number 6 of 2018. This rule divides the precision of detailed maps into several classes (Classes 1, 2, and 3) based on horizontal and vertical accuracy values.

Table 1. Geometry Accuracy of RBI Maps

No	Scale	Interval contur (m)	Accuracy of RBI Map Class 1		Class 2		Class 3	
			Horizontal (CE90 in m)	Vertical (LE90 in m)	Horizontal (CE90 in m)	Vertical (LE90 in m)	Horizontal (CE90 in m)	Vertical (LE90 in m)
1	1:1000.000	400	200	200	300	300,00	500	500,00
2	1:500.000	200	100	100	150	150.00	250	250,00
3	1:250.000	100	50	50	75	75,00	125	125,00
4	1:100.000	40	20	20	30	30,00	50	50,00
5	1:50.000	20	10	10	15	15,00	25	25,00
6	1:25.000	10	5	5	7,5	7,50	12,5	12,50
7	1:10.000	4	2	2	3	3,00	5	5,00
8	1:5.000	2	1	1	1,5	1,50	2,5	2,50
9	1:2.500	1	0,5	0,5	0,75	0,75	1,25	1,25
10	1:1.000	0,4	0,2	0,2	0,3	0,30	0,5	0,50

(Source: BIG 2018)

This table displays horizontal (CE90) and vertical (LE90) accuracy standards for various map scales according to BIG Regulation No. 6 of 2018, which is the reference in this study.)

Table 2. Geometry Accuracy Requirements for RBI Maps by Class

Precision	**Class 1**	**Class 2**	**Class 3**
Horizontal	0.2 mm x number of scales	0.3 mm x number of scales	0.5 mm x number of scales
Vertical	0.5 x contour interval	1.5 x 1st class accuracy	2.5 x Class 1 accuracy

According to the regulation, the horizontal accuracy test uses the Circular Error parameter 90% (CE90), which is defined as the radius of the circle that contains 90% of the test points, while the vertical accuracy test uses a Linear Error of 90% (LE90). Although in theory Walijatun Djoko (2003) stated that the more control points will increase the determination of the measurement network, in the practice of UAV photogrammetry there is variability in the results. Research by Wahyudi & Yuwono (2020) shows that the spatial distribution factor (distribution pattern) of GCP is often more dominant in influencing the quality of orthophotos than just the number of dots. An even distribution around the perimeter of the area prevents a bow-tie effect or distortion in the central area that is far from control. In addition, Hidayat & Aji (2018) highlight the aspect of operational efficiency where there is a diminishing return in the increase in the number of GCPs.

2. METHODS

This study uses a quantitative method with an experimental approach. The research location is in the stockpile area of PT Sumber Cahaya Mineral, Jambi. The stages of the research include: 1) Flight Mission Design: Using the DJI Mavic Air 2S UAV at an altitude of ±100 meters with a 70% overlap to minimize missed areas considering vegetation cover.

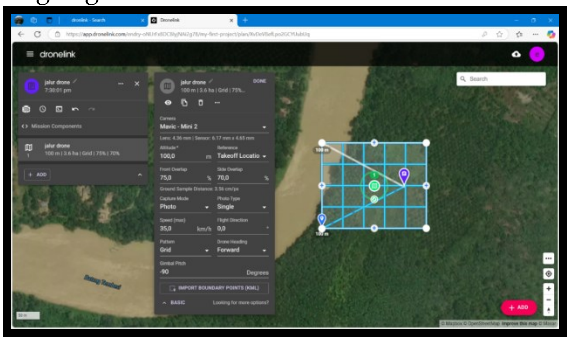

Image 1. Flight Plan Path
(Source: Data Processing)

2) GCP measurement**:** The control point is installed and measured using Geodetic GPS with high accuracy. The variations of the tested scenarios were: 1) Scenario A: No GCP; 2) Scenario B: 3 GCPs (with a triangle pattern); 3) Scenario C: 4 GCP (with 1 point rectangle/incremental pattern).

Table 2. Field GCP Coordinates

Label	Easting	Northing	Altitude
GCP_1	279334,592	9800501,473	35,075
GCP_2	279308,921	9800523,236	36,459
GCP_3	279339,975	9800532,191	34,956
GCP_4	279324,046	9800517,484	36,749

3) Data Processing: Images are processed using Agisoft Metashape through the stages of align photo, dense cloud, mesh, and texturing. Georeferencing is done by entering GCP coordinates in each scenario

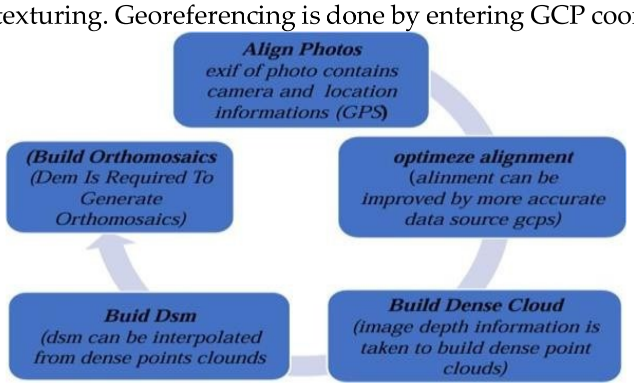

Image 1. Data processing flow in agishof
(Prayogo et al., 2020)

4) Accuracy Test: Calculates RMSE (Root Mean Square Error) to compare the coordinates of the processed product with the field coordinates. RMSE values are converted to CE90 (horizontal) and LE90 (vertical) referring to the National standard (BIG No. 6 of 2018).

3. FINDINGS AND DISCUSSION

Analysis of Horizontal and Vertical Geometric Precision

The results of photogrammetry data processing showed that the variation in the number of Ground Control Points (GCP) had a significant impact on the accuracy of orthophoto geometry and Digital Elevation Model (DEM). Quantitative evaluation was carried out by comparing horizontal and vertical Root Mean Square Error (RMSE) values of the three scenarios.

Table 3. Accuracy Test Results (RMSE)

Skenario	GCP Amount	RMSE Horizontal (m)	RMSE Vertical (m)	Remarks
A	0 (Without GCP)	> 6,000	> 6,000	Not Suitable for Use
B	3 GCP	0,00965	0,010	The Most Accurate
C	4 GCP	0,01636	0,017	Accurate

In detail, the results of the rigor test show that:

- **Scenario Without GCP:** Results in a very large deviation with an RMSE value exceeding 6 meters. This confirms that mapping UAVs without ground control points does not have a strong georeference base, so the data is not feasible for mining technical purposes.
- **GCP Scenario 3:** Record the best accuracy performance. The value of horizontal RMSE (RMSEr) was recorded at 0.00965 m and the vertical RMSE (RMSEz) was 0.010 m. This value meets the class 1 standard for 1:1000 scale maps.
- **Scenario 4 GCP:** Actually experienced a decrease in performance compared to 3 GCPs. The RMSEr value was recorded at 0.01636 m and the RMSEz was 0.017 m.

Although both scenarios with GCP (3 and 4 points) have met the accuracy standards of 1:1000 scale maps Class 1 according to BIG Regulation No. 6 of 2018, the data proves that the increase in the number of control points is not linear with increased accuracy. The 3 GCP configuration proved to be more geometrically precise.

Table 4. CE 90 test for accuracy of 1:1000 Scale Maps

Precision	Test Results CE 90 (In M)	Accuracy of the 1:1000 scale map		
		Class 1 (In M)	Class 2 (In M)	Class 3 (In M)
Horizontal	0.01636	0.2	0.3	0.5

Table 1. LE90 test for 1:1000 Scale Map accuracy

Precision	Test Results	Accuracy of the 1:1000 scale map		
		Class 1 (In M)	Class 2 (In M)	Class 3 (In M)
Vertical	0.01695	0.2	0.3	0.5

Visual Analysis of DEM Incisions and Topographic Profiles

Qualitative analysis through visualization of 3D models and cross-sectional profiles was carried out to validate the suitability of the model with field conditions.

Orthophoto and DEM Visualization:

- **No GCP:** The difference in surface quality between models without GCP is evident and is distorted.

Figure 3. No gcp
(Source: Data Processing)

Figure 4. Dem without gcp
(Source: Data Processing)

- **With 3 GCP & 4 GCP:** Featuring a smoother and more continuous surface.

Image 2. With 3 GCPs
(Source: Data Processing)

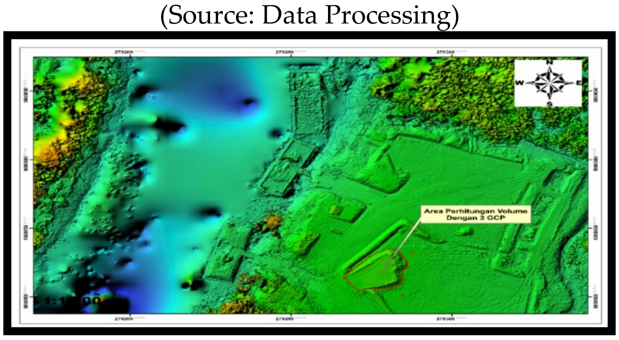

Figure 6. Dem with 3 gcp
(Source: Data Processing)

Figure 7. With 4 GCPs
(Source: Data Processing)

Figure 8. Dem with 4 GCPs
(Source: Data Processing)

Elevation profile analysis on two tracks showed that the processed 3 GCP profile lines had a very high match with the ground surface reference. Although the 4 GCP profile also shows a near-actual shape, there is little variation or irregularity (noise) that causes the vertical difference to be slightly larger than that of the 3 GCP profile.

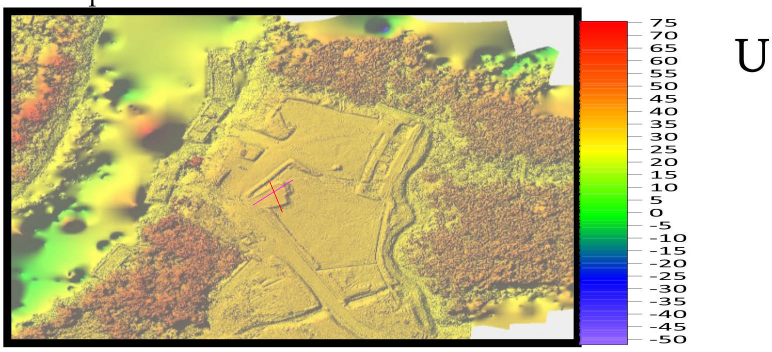

Figure 9. Dem incision
(Source: Data Processing)

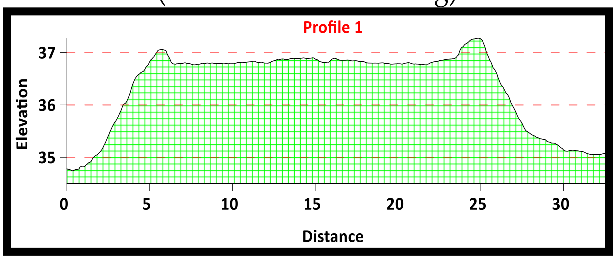

Image 30. Profile 1
(Source: Data Processing)

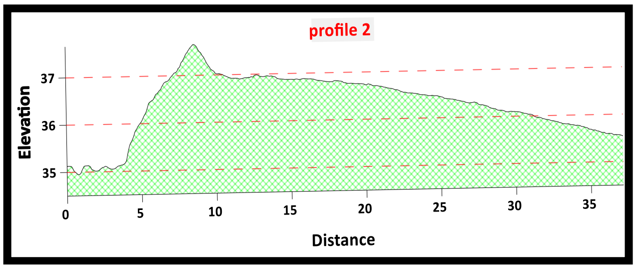

Figure 11. Profile 2
(Source: Data Processing)

Based on the results of the data analysis, several key points can be discussed as follows:

This research validates the basic theory of photogrammetry which states that GCP is an absolute geometric "anchor". Without GCP, drone onboard GPS data with limited accuracy is not capable of producing dimensionally correct models. The impact is very visible in the estimation of material volume. The results of the calculation show a drastic difference in volume:

Table 6. Comparison of Volume Estimation Results

Skenario	**Volume (m^3)**	**Remarks**
No GCP	358,278	Underestimate hampir 50%
3 GCP	716,674	Most Reliable
4 GCP	723,926	Andal

Mapping without GCP has the potential to significantly harm a company's operations due to a huge underestimation of volume.

The finding that the configuration of 3 GCPs is more accurate than 4 GCPs is at the heart of this discussion. This phenomenon supports the statement of Wahyudi & Yuwono (2020) that the quality of orthophotos is more influenced by spatial distribution (distribution patterns) than just the number of dots. The triangular pattern formed from 3 GCPs provides optimal geometric strength for the bundle adjustment process in this study area. The addition of the 4th point, which may be less strategically positioned or has a slight measurement error, actually introduces noise into the calculation system, thus reducing the overall accuracy.

Practically, these results are in line with the principle of operational efficiency according to Hidayat & Aji (2018). Given that the use of 3 GCPs has met the 1:1000 scale detailed map accuracy standards of Class 1 and provides reliable volume results (the volume difference between 3 GCPs and 4 GCPs is only about 7 m^3), no additional costs and manpower are required for the installation of the 4th GCP.

4. CONCLUSION

Based on data analysis and discussions synchronized with soil measurement theory and previous research, it is concluded that: 1) Ground Control Point (GCP) implementation is an absolute requirement to produce geometrically accurate orthophotos. Mapping of UAVs without GCP results in unacceptable positioning errors for mining purposes (RMSE > 6 m) and volume underestimates of up to 50%. 2) A larger amount of GCP does not guarantee higher accuracy. The configuration of 3 GCPs proved to be more accurate (RMSE 0.00965 m) than 4 GCPs (RMSE 0.01636 m). 3) The use of 3 GCPs with optimal distribution patterns has met the accuracy standards of 1:1000 scale maps Class 1 (CE90 and LE90 < 0.2 m). 4) Good geometric accuracy has a significant impact on the reliability of material volume estimation. Mapping with GCP (3 or 4 points) results in much more reliable volume estimation than mapping without GCP.

REFERENCES

Arafat, R., & Yunaf, A. S. (2021). Analisis Perubahan Penggunaan Lahan Dan Kerapatan Vegetasi Di Kawasan Pertambangan Rantau Pandan Kabupaten Bungo Provinsi Jambi. *Jurnal Geografi*, 2(September).

Badan Informasi Geospasial (BIG). (2018). *Peraturan Kepala Badan Informasi Geospasial Nomor 6 Tahun 2018 tentang Pedoman Teknis Ketelitian Peta Rinci*.

Firmansyah, I., Yuwono, & Budisusanto, Y. (2023). Analisis Perbandingan Volume Metode Penampang Rata-Rata, Composite Volume, Dan Prismpoidal Untuk Jalan Berkelok. *M*(1), 29–40.

Hidayat, R., & Aji, P. B. (2018). Optimasi Jumlah Ground Control Point (GCP) Pada Pemrosesan Fotogrametri untuk Pembuatan Peta Rinci. *Jurnal Teknik Sipil dan Perencanaan*, 20(2), 118-126.

Heriyanto, Wijaya, R., & Putra, G. A. (2019). Managemen Pemetaan Sistem Informasi Geografis Distribusi Lahan Terbuka Pasca Bencana Gempa Bumi Kab. Padang Pariaman. *Seminar Nasional Teknologi Informasi, Komunikasi Dan Industri (SNTIKI)*, November, 314–319.

Lillesand, T. M., Kiefer, R. W., & Chipman, J. W. (2015). *Remote Sensing and Image Interpretation* (7th ed.). Wiley.

Oktavia, M., Rianto, D. J., Novratrilova, L., Heriyanto, H., & Aswana, A. (2024). Fungsi Penggunaan Add Placemark Dan Add Polygon Dalam Pembuatan Peta Situasi Menggunakan Google Earth Pro. *Madaniya*, 5(1), 252–263.

Oswara, R. M., Fathira, R. L., Permana, I. S., Renjani, M. S., Heriyanto, D., & Wijaya, S. (2025). AL-INAYAH 3. *6*(1), 968–972.

Prasetyo, Y. S., et al. (2021). Analisis Ketelitian Penggunaan Titik Kontrol Tanah (GCP) dari Pengolahan Data RTK-NTRIP pada Pemetaan Skala Besar. *Majalah Ilmiah Globe*, 23(1), 27-34.

Prayogo, I. P. H., Manoppo, F. J., Lefrandt, L. I. R., & Dasar, P. (2020). Pemanfaatan Teknologi Unmanned Aerial Vehicle (Uav) Quadcopter Dalam Pemetaan Digital (Fotogrametri) Menggunakan Kerangka Ground Control Point (Gcp). *10*(1).

Seandy, R., Pradana, N., Riani, D., Silitonga, S. P., Teknik, F., & Raya, U. P. (2023). Pembuatan Digital Elevation Model Universitas Palangka Raya Menggunakan Drone Dan GPS Geodetik. *1*(1), 33–40.

Suprapti, N. M. S., & Sukanadi, I. N. (2019). Evaluasi Akurasi Horizontal Dan Vertikal Pada Pemetaan Drone dengan Variasi Jumlah Titik Kontrol Tanah (GCP). *Jurnal Geomatika Planasara*, 3(2), 85-94.

Syafique, M., Luwyk, H., & Usup, D. (N.D.). Perbandingan Volume Overburden Removal Menggunakan Foto Udara Dji Phantom 4 Dan Hasil Survey Total Station Trimble C5 Pada Pit Cap Pt . Insani Baraperkasa. 84–88.

Wahyudi, D., & Yuwono, B. D. (2020). Pengaruh Jumlah dan Sebaran Ground Control Point (GCP) terhadap Akurasi Ortofoto Hasil Pemetaan Drone. *Jurnal Geodesi Undip*, 9(4), 1-10.

Wahyudi, D. P., Riyanto, A., Studi, P., Sipil, T., Teknik, F., & Surakarta, U. M. (2023). Akurasi Perhitungan 3D Volume Galian Proyek Pembangunan Jalan. *6*.

Wahyuningrum. (2022). *Dasar Dasar Teknik Geospasial*. (Rifqi Risnadyatul Hudha. Futri F. Wijayanti (Ed.)).

Walijatun Djoko. (2003). *Dasar Dasar Pengukuran Tanah*. (endra s (ed.); ketujuh). pt. gelora aksara pratama.

Widodo, S., Farida, A., Maysyurah, A., & Widianto, A. (2023). Pemanfaatan Teknologi Drone Dalam Pemetaan Digital (Fotogrametri) Menggunakan Kerangka Ground Control Point (GCP) di Daerah Irigasi Waibu Distrik Salawati Tengah.

Wulan, S., Auningsih, N., Rohmaeni, D., Megasukma, Y., & Zahar, W. (2021). Pemodelan Stockpile Menggunakan Metode Fotogrametri Dengan Wahana Uav (Unmanned Aerial Vehicle) Di PT Triaryani. *9*, 141–149.