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Improving Survey Time Efficiency and Embankment Volume Measurement Using Photogrammetry

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ABSTRACT

This study aims to analyze the effect of photogrammetry methods on the efficiency of implementation time and the accuracy of embankment volume calculations in the Yogyakarta–Bawen Toll Road Construction Project Package 1 (Section 1). The research method was carried out by collecting data using drones with a combination of nadir and oblique image capture, calibrated with Ground Control Points (GCP) to generate a Digital Surface Model (DSM). The embankment volume obtained from photogrammetry was then compared with conventional measurements using a Total Station as a reference control. The results showed that the use of photogrammetry significantly reduced the survey execution time while maintaining a relatively small volume deviation compared to terrestrial methods. Therefore, photogrammetry can be considered an effective alternative for contour data acquisition in embankment volume estimation.

Keywords: photogrammetry, project duration, embankment volume, drone, Yogyakarta-Bawen toll road.

INTRODUCTION

In the related toll road project, there are works being carried out, namely main road works and road structure works. The main road works cover the section from STA 68+610 to STA 76+300, which requires a measurement survey to ensure that the volume of embankment is in accordance with the plan. In the Yogyakarta-Bawen Toll Road Construction Project Package 1 (Section 1), the measurement survey work still uses the terrestrial method with a Total Station (TS). The measurement time with a Total Station (TS) depends on the area size, terrain conditions, number of measurement points, and the required level of accuracy. In this case, it took about 1 week due to several factors. Factors such as hilly terrain, bad weather, the large number of measurement points, and heavy equipment activity in the field can slow down the process. In addition, pressure from a tight project schedule can also be an obstacle. All of these factors affect the efficiency of measurements in the field.

Previous studies have shown the application of photogrammetry methods used for measuring, observing, or recording objects with digital cameras to produce images with interrelated points [1]. According to [2], one of the applications of photogrammetry in civil engineering is to determine the volume of a pile. Research by [3] entitled Three-Dimensional Modeling aims to determine the differences in the use of Total Station (TS), Terrestrial Laser Scanner (TLS), and Drone tools in three-dimensional modeling. The results of the study show that the use of drones with the addition of Ground Control Points (GCP) produces better accuracy because it has a wide range, fast data collection time, and lower equipment costs. Research by [4] compared the results of Building Information Modeling (BIM) against as-built data using Lidar and drones and found significant differences between the actual concrete volume and the BIM model. In line with this, research by [5] shows that taking nadir aerial photographs produces orthophotos with a higher level of accuracy than oblique photographs.

Research by [6] also reinforces these findings with results showing that the use of GCPs increases measurement accuracy compared to without GCPs. Research by [7] shows that the more GCPs are used, the higher the accuracy of the volume produced. Furthermore, [8] found the accuracy value of the Independent Check Point (ICP) at the nadir position to be 0.05 cm (x), 0.09 cm (y), and 0.12 cm (z). In the mining sector, international research by [9] and [10] highlights the role of autonomous drones in improving safety and monitoring rock mass behavior in underground mining areas.

Given the time constraints in conducting measurement surveys, alternative methods such as aerial photo-based photogrammetry can be considered. Previous studies have shown that photogrammetry can be an effective option for measurement surveys. Applying photogrammetry methods can help monitor work, time, and costs more efficiently than terrestrial measurements [3]. In addition to time efficiency, this method can also support work monitoring activities, cost control, and data integration into the Building Information Modeling (BIM) system. However, photogrammetry has not been fully utilized in this project, especially in the application of Building Information Modeling (BIM). Therefore, it is important to conduct further research on the application of photogrammetry in this project. Based on these conditions, this study was conducted to determine the time required for data collection using the photogrammetry method, analyze the volume of deposits based on variations in angles of 40°, 55°, 70°, and 90°, and compare the volume and time efficiency results between the photogrammetry method and the terrestrial method. The results of this study are expected to contribute to the development of science in the field of photogrammetry, as well as broaden the understanding of the use of drones, which are not only used for photography and mapping to support infrastructure development projects.

Data collection and volume calculations were only carried out on the main road embankment work at STA. 74+800 to STA 76+300 of the Yogyakarta-Bawen Toll Road Construction Project Package 1 (Section 1). The three-dimensional embankment volume was calculated using MC100, noting that the channel was not included in the existing embankment volume. To minimize errors in calculations, the software *Autodesk* was used. This study uses standard camera settings with a DJI Mavic 2 Pro drone and a GNSS GRX2 GPS for collecting *Ground Control Point* (GCP) coordinate data. Aerial photography was conducted using the *oblique* method at angles of 40^0, 50^0, and 70^0, as well as the nadir method at an angle of $40^{0.}$

RESEARCH METHODS

The research began with collecting relevant literature, then preparing secondary data in the form of MC00 calculations and tools and materials for collecting primary data in the form of aerial photographs and GCP coordinates. The data obtained was processed using Agisoft software for photogrammetry and Civil 3D for volume calculations. Next, the accuracy of the calculations was verified, and the final stage involved drawing conclusions based on the analysis results. The research was conducted quantitatively and was tangible in nature, aiming to determine the accuracy level of the volume of deposits using the photogrammetry method compared to the MC100 results. The research was conducted in the even semester, from March to July 2025. The research was analyzed using primary data in the form of aerial photographs taken by a DJI Mavic 2 Pro drone and GCP coordinates using GPS GNSS GRX2 RTk method, and secondary data in the form of MC100 calculation results in DWG format from the project.

The data collection stage included determining the location in the embankment area of STA 74+629–STA 76+300 of the Yogyakarta–Bawen Toll Road Project, which was chosen because it was easily accessible and had complete MC100 data. The flight path was designed using the DJI Pilot application with the oblique method at an altitude of 90 m, side overlap of 60%, frontal overlap of 80%, and camera angles of 40^0, 55^0, and 90^0. Ground Control Points (GCPs) were distributed according to field conditions to connect the photo data to the global coordinate system covering the road shoulder and embankment slopes [11]. After installing 1x1 m GCP markings, aerial photography was carried out using a DJI Mavic 2 Pro drone according to the planned flight path. Next, the GCP coordinates were measured using SOKKIA GRX-2 Geodetic GPS with the RTK method to obtain high-accuracy position data. The aerial photo data was processed using Agisoft Metashape through the stages of photo alignment, GCP coordinate input, point cloud creation, ground area classification, *Digital Terrain Model* (DTM) formation, and creation of 25 cm interval contours. The contour results were saved in DXF format for processing in Autodesk Civil 3D to use the volume dashboard feature. The photogrammetric volume values were then compared with the MC100 results to assess the accuracy of the method used.

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RESULT AND DISCUSSION

Result

From the field data collection activities at STA 74+800 to STA 76+300, several variables were obtained, including two types of photos, namely oblique photos and upright photos with varying camera angles. Oblique photos are photos taken with the camera axis forming an angle to the earth's surface [12]. For oblique photos, 371 photos were produced, and for vertical photos, 216 photos were produced, as shown in Table 1.

Table 1 Summary of types, angle variations, number of photos

Photo Type	Angle Variation	Number of Photos
Crooked	40	371
Crooked	55	371
Crooked	70p	371
Upright	90	216

Source: Field data collection

The following are the results of processing and analyzing the volume data of the research object based on the photogrammetric method.

Camera Shooting Angle Variations

Figure 1 Camera angle type 40°

Figure 2 Camera angle type 55°

Figure 3 Camera angle type 70°

Figure 4 Camera angle type 90°

GCP Coordination

Based on coordinate measurements at STA 74+800 to STA 76+300 using GNSS. According to [13], compared to conventional terrestrial measurements, the use of GNSS has several advantages, such as not being dependent on time and weather, being more efficient in terms of time, energy, and cost, and having GNSS satellites with a sufficiently high orbital altitude. The RTK geodetic method obtained the coordinates of the GCP points in the format presented in Table 2.

Table 1 GCP Coordinates

GCP Name	Easting	Northing	Elevation
106	9144162.5492	425201.5096**GCP Name**	132.7052
123	9144228.4570	425036.4356	130.4265
131	9144286.6063	424893.1980	127.8061
148	9144314.3894	424713.4837	127.3061
162	9144335.5888	424642.2881	127.2068
173	9144422.1373	424542.6426	126.3856
183	9144467.0680	424312.8949	132.8534

Contours

From the processing of aerial photographs, the contours of each configuration are obtained as shown in Figures 5, 6, 7, and 8.

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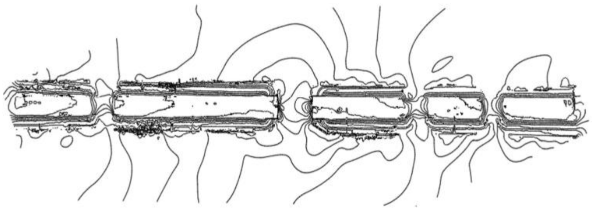

Figure 5 Camera angle type 40°

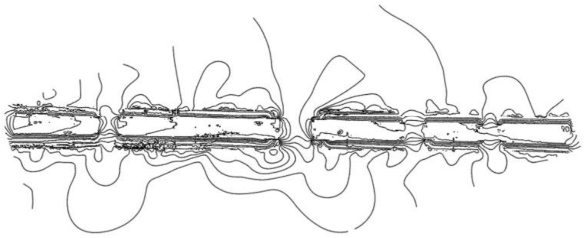

Figure 5 Camera angle type 55°

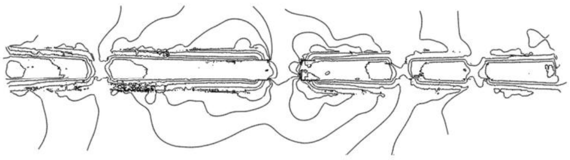

Figure 6 Camera angle type 70°

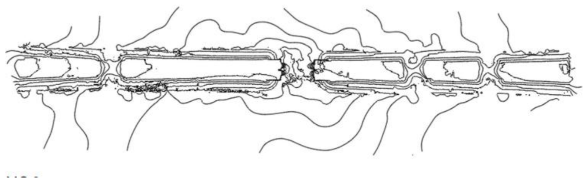

Figure 7. Camera angle type 90°

Survey Implementation Time

[14] stated that the flight planning process with the help of applications such as Pix4Dcapture or DroneDeploy takes less than an hour, depending on the size of the area and the topographical conditions encountered. Comparison of Photogrammetric Survey and Terrestrial Survey Implementation Times in the research area STA 74+800 to STA 76+300, as shown in the following table:

Table 2 Measurement survey implementation time

No.	Stages of Activity	Photographers	Terrestrial
1.	Tool preparation	30 minute	30 minute
2.	GCP Placement	60 minute	0 minute
3.	Measurement process	15 minute	480 minute
4.	Data processing	120 minute	60 minute
Total		225 minute	570 minute

Source: Field data collection results

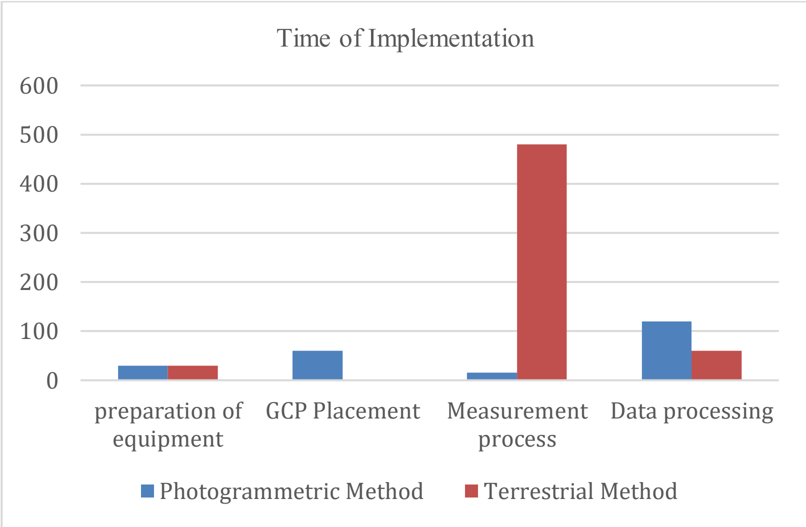

Figure 8 Implementation Time Graph Source: Data processing results

Volume of Fill

Various methods and techniques have been developed to accurately calculate the volume of work [15] Using the volume dashboard feature in Civil 3D, the volume of fill in the study area from STAp 74+800 to STA 76+300 is as follows:

Table 3 Volume of Photogrammetry Results

Photo Type	Angle Variation	Photogrammetry Volume Backpile (m^3)
Crooked	40	427708,06
Crooked	55	355350,19
Crooked	70	400932,24
Upright	90	441069,81

Source: Data processing results

The data above was then compared with terrestrial data to determine the difference and accuracy level, as shown in the following table:

Table 5. Volume of backpile

Photo type	Angle Variation	Photogrammetry Volume Backpile (m^3)	Difference (m^3)	Difference (%)	Deviation Absolute (%)
		b	c = a - b	d = (b/a) - 100	e = d/a
Crooked	40	427708,06	-70774,28	19,83%	0,00034%
Crooked	55	355350,19	1583,59	-0,44%	0,00028%
Crooked	70	400932,24	-43998,46	12,33%	0,00031%
Upright	90	441069,81	-84136,03	23,57%	0,00035%

Source: Data processing results

Note: The above data is compared with the measurement results using a Total Station with a value of 356,933.78 m^3.

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Discussion

Survey Implementation Time

Survey implementation time is one of the important factors in determining the efficiency of the measurement method used in construction projects. Based on the comparison table of activity stages between the photogrammetric and terrestrial methods, it can be seen that each method has advantages and limitations in terms of time, both in the field and in the data processing stage. In the equipment preparation stage, both methods have the same duration of approximately 30 minutes. This shows that both photogrammetric and terrestrial methods require a similar amount of time to prepare the survey equipment. The placement of GCP (Ground Control Point) is only required in the photogrammetric method. The time required is around 1 hour, depending on the area size and the number of GCPs used. Meanwhile, the terrestrial method does not require GCPs, so it can proceed directly to the measurement stage. The measurement process in the field is the stage with the most striking difference in time. The photogrammetric method only requires 15–30 minutes to take aerial photographs of the entire surveyed area. In contrast, the terrestrial method requires up to a full day because it involves measuring each point manually. Photogrammetric data processing takes about 2 hours, as it involves digital processes such as photo alignment, contour creation, and volume calculation. Meanwhile, data processing from the terrestrial method only takes about 1 hour, because the collected data is in the form of coordinate points that can be processed numerically.

Estimated Volume of Deposits

The use of photogrammetry in measuring the volume of deposits provides varying results depending on the type of photo (upright/oblique) and camera angle configuration. Based on a comparison of the volume of deposits using the terrestrial method and the photogrammetry method, it can be seen that the camera angle affects the accuracy of the volume data. The following are the measurement results based on these variations: Oblique photos with an angle of 55° provided the most accurate results, with a volume of 355,350.19 m³ compared to the terrestrial volume of 356,933.78 m³, resulting in a difference of only 1,583.59 m³ and an accuracy rate of 99.56%. as well as the smallest absolute deviation of 0.00028%. The 40° oblique photo type produced a volume of 427,708.06 m³, with a negative difference of -70,774.28 m³ from the terrestrial result. This resulted in an accuracy of 119.83% and an absolute deviation of 0.00034%. These results indicate an overestimation of volume by the photogrammetric method at this angle. The inclined photo type with an angle of 70° showed an accuracy of 112.33% with a difference of -43,998.46 m³. This means that a larger angle of inclination does not always increase accuracy; in fact, in this case, it causes a significant overestimation. The upright photo type (90°) actually provided the highest volume result of all configurations, namely 441,069.81 m³. The difference reached -84,136.03 m³ with an accuracy of 123.57% and an absolute deviation of 0.00035%, which also showed the largest overestimation of this method. In general, although the absolute deviation in percentage appears very small (below 0.001%), the volume difference in m³ units remains significant for the scale of construction projects.

Comparison of Terrestrial and Photogrammetric Methods

In the study area from STA 74+800 to STA 76+300, photogrammetric surveying took 225 minutes, while terrestrial surveying took 570 minutes. The project construction involved survey work at STA 67+500 to STA 76+300, resulting in an efficiency level of 12.5% / 87.5%. In the research area from STA 74+800 to STA 76+300, the results of volume measurements using photogrammetry were 355,350.19 m³ or an accuracy rate of 99.56% compared to terrestrial measurements. The project construction involved survey work at STA 67+500 to STA 76+300, resulting in an accuracy level for this work of = 99.556%.

CONCLUSION

Based on the comparison between photogrammetric and terrestrial methods in measuring the volume of deposits and the efficiency of survey implementation, it can be concluded that the photogrammetric method is more efficient in the field. The survey time required is only about 15 minutes, which is much shorter than the terrestrial method, which requires a full day. The results of measuring the volume of embankments using the photogrammetric method reached 355,350.19 m^3 with an accuracy rate of 99.56% compared to the terrestrial method. Overall, the photogrammetric method provides survey time efficiency of up to 87.5% with a volume accuracy rate of 99.56%, making it an effective alternative for measuring the volume of embankments. Based on the research results, the photogrammetric method is recommended for use in measuring the volume of embankments in other areas of the Yogyakarta–Bawen Toll Road Construction Project Package 1 (Section 1). However, in this study, the determination of GCP coordinates still uses the RTK method, which has a relatively high potential for error. Therefore, it is recommended that future research and measurements use the *static* method to obtain more accurate coordinate data.

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