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Assessment of the need for ground control points in aerial surveys for estimating the volume of stacked timber

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FOREST MANAGEMENT

ABSTRACT

Background: Our study aimed to investigate the feasibility of conducting aerial surveys without ground control points to estimate the volume of wood piles in planted areas. The data used in this study include both manual measurements (conventional method) and aerial imagery of 24 wood piles composed of *Eucalyptus* sp. The aerial surveys were conducted based on two flight plans: one performed at a flight height of 50 meters above the ground, with frontal and lateral overlaps of 70%, and other one conducted at a flight height of 80 meters above the ground, with frontal and lateral overlaps of 80%. Thirty-five ground control points (GCPs) were considered. Friedman and Nemenyi tests were applied to evaluate whether there were significant differences between the wood stockpile volume estimates obtained by the conventional method and those derived from the different surveys, with and without GCPs.

Results: The processing with the use of GCPs resulted in smaller RMSE values compared to those without GCPs. The volume estimates for each wood stockpile were similar, regardless of the presence or absence of GCPs. The Friedman test yielded a p-value of 0.3796, indicating that there is no evidence to suggest significant differences between the values obtained by different methods.

Conclusion: The use of control points did not significantly improve the accuracy of volume estimates for wood piles placed in the field. Under the analyzed conditions, a low-cost drone can be used to estimate the volume of wood piles in the field without the need for ground control points.

Key words: Woodpile measurement; remotely piloted aircraft; remote sensing.

HIGHLIGTHS

It is possible to obtain estimates of pile wood volumes using aerial surveys.
A correct flight plan should be considered for the survey.
A low-cost drone can be used to estimate the volume of wood piles.
There was no statistical difference between estimates considering the flight height of 50 m and 80 m.
Ground control points don't cause significant differences in estimates.

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INTRODUCTION

The Brazilian forest sector has made significant contributions to the country's development. It generated 260 billion Brazilian reals in gross revenue in 2022 (Indústria Brasileira de Árvores, 2023), with the industrial process consuming approximately 235.5 million cubic meters of wood. In the same year, planted forests covered nearly 10 million hectares. These substantial figures highlight the need for improvements in the wood supply chain, particularly in monitoring forest activities and measuring available wood.

Monitoring the amount of stacked wood in the field is crucial for calculating the size of the fleet required for wood transportation, distributing the workforce, and organizing activities in processing mills (such as charcoal or pulp production) within forest enterprises. Accurate quantification is also essential when negotiating wood transactions (Berendt et al., 2021) or making payments to service providers involved in harvesting and forest transportation (Miguel-Díez et al., 2023).

Typically, wood pile measurement in the field is conducted manually. The dimensions of each pile (length, width, and height) are measured with a tape, and the gross volume is calculated by multiplying these measurements (Kärhä et al., 2019). This process is slow, especially in large enterprises where the wood stock on-site may represent three months of mill demand, accounting for the time required to dry the wood (Zanúncio et al., 2017).

New technologies have been implemented to enhance the management of wood in the field. For example, methods such as laser scanning (Purfürst et al., 2023), photo-optical methods (Berendt et al., 2021; Kärhä et al., 2019), and aerial surveys (Heraki et al., 2022; Figueiredo et al., 2016) have been applied. Among these, aerial surveys have garnered interest due to their ability to provide data in difficult-to-access locations, accommodate different flight heights, optimize time, and reduce costs (Heraki et al., 2022). The estimation of object volumes on terrestrial surfaces using aerial imaging has been the subject of numerous studies (Ajayi and Ajulo, 2021; Carvalho et al., 2021; Deliry and Avdan, 2023; Filkin et al., 2022; Heraki et al., 2022; Maras and Nasery, 2023; Silva et al., 2016). Silva et al. (2016) indicate that volume estimation from digital elevation models derived from digital photogrammetry demonstrates both precision and reliability.

Research involving wood pile measurements in stocking yards (Heraki et al., 2022; Figueiredo et al., 2016) has often utilized high-cost equipment to correct the coordinates of aerial images. However, the absence of ground control points can significantly reduce the costs of topographic surveys (Carbonneau and Dietrich, 2017) and enables the mapping of difficult-to-access areas using unmanned aerial vehicles (UAVs). On the other hand, imaging without field data from total stations or differential positioning systems can lead to errors in the final products after aerial image processing (Kalacska et al., 2020).

In this context, a range of scientific papers has evaluated the accuracy of digital elevation models with varying numbers of ground control points (James et al., 2017; Rangel et al., 2018; Carneiro et al., 2022; Pugh et al., 2021) and explored innovative methodologies for surveys that do not require field markers (Carbonneau and Dietrich, 2017; Cook and Dietze, 2019; Peppa et al., 2019). Although some studies have suggested the possibility of conducting surveys without ground control points (Maras and Nasery, 2023), this recommendation has not been extensively validated for quantifying wood stock in the field. Therefore, our study aims to investigate the feasibility of conducting aerial surveys without ground control points to estimate the volume of wood piles in planted areas.

MATERIAL AND METHODS

Data description

The study was conducted in a planted forest area owned by GELF Siderurgia S.A., located in the rural zone of the Itacambira municipality (16°51'49.41"S, 43°26'52.76"O) in the northern region of Minas Gerais State, Brazil (Figure 1). According to Köppen's climatic classification, the climate of the region is categorized as Aw (tropical with a dry season in winter) (Martins et al., 2018). The region has an annual average temperature of 23°C and an annual average precipitation of 912 mm between 2003 and 2023, based on data from the Brazilian National Institute of Meteorology (INMET). The local average altitude is 1,200 meters above sea level.

The data used in this study include measurements of 24 wood piles composed of Eucalyptus sp. logs. The measurements were conducted in November 2023 under stable atmospheric conditions, with minimal cloud cover and without strong winds. The terrain slope is less than 1%.

The logs were stacked immediately after harvesting along the border of two stands, separated by a road. The piles were organized based on the position of the logs along the length of the tree. Twelve piles were constructed with base logs (thick wood) and were placed inside the stands, while the other twelve piles were composed of top logs (fine wood) and were located near the road.

Conventional Measurement

The conventional measurement involved measuring the width, length, and height of each pile. All piles had a width of four meters due to the wood stacking pattern. The length of each pile was measured using a fiberglass tape, while the height of each pile was measured with a tape measure in a vertical position from the ground, with measurements taken at 2-meter intervals along the pile's length. The gross volume for each pile was calculated using Equation 1.

$$VPm = \sum_{i=1}^{n} \left[\frac{(H_i + H_{i+1}) * D}{2} \right] * \underline{C} \quad (1)$$

Where VPm é the gross volume for each pile measured manually (in stereo), $\underline{C}$ is the average width of logs (in meters), n is the number of observations, H_i is the pile height at place i (in meters), and D is the interval between height measures (in meters).

Aerial surveys

A low-cost unmanned aerial vehicle (UAV), the DJI Mini 2, was used to capture aerial images of the wood piles. The UAV was equipped with a GNSS (Global Navigation Satellite System) and a camera featuring a 12 MP effective resolution CMOS RGB sensor. Flight planning and execution were managed using the Drone Harmony app (Drone Harmony AG, 2024), which was installed on a Samsung Tab A tablet.

The aerial surveys were conducted based on two flight plans established from prior tests and results published in the literature (Figueiredo et al., 2016; Carvalho et al., 2021; Heraki et al., 2022). Aerial survey S50 was performed at a flight height of 50 meters above the ground, with frontal and lateral overlaps of 70%. Aerial survey S80 was conducted at a flight height of 80 meters above the ground, with frontal and lateral overlaps of 80%. In both cases, the camera was fixed with an inclination of 90º relative to the aircraft axis (nadir view), using a double grid pattern for imagery. The images were captured in JPG format with a resolution of 4000 x 2250 pixels.

Ground control points

Thirty-five ground control points (GCPs) were marked with pulverized lime in the shape of a cross, with sufficient size to be visible in the aerial images. The points were distributed in three parallel lines along the wood stockpiles (Figure 2). Latitude, longitude, and altitude values were obtained at the central point of each GCP using a GNSS RTK system, model XMAP (X30 + X10 Pro). This system comprises two antennas: one fixed at a static location (base station) with known coordinates, and the other placed at the GCPs (rover). The horizontal and vertical precisions of the system were 5 mm and 6 mm, respectively.

Image processing

The image processing employed a photogrammetric approach that integrates Structure from Motion (SfM) and Multi-View Stereo (MVS) techniques for three-dimensional reconstruction from multiple images. This method yields low computational cost, high-resolution orthoimages, and digital elevation models (Eltner et al., 2015; Rangel et al., 2018; James et al., 2020; Dai et al., 2023). The processing was conducted using Agisoft Metashape software (Agisoft, 2019) installed on a computer with a 64-bit Windows 10 Home operating system, an Intel Core i7 2.90 GHz processor, 16 GB of RAM, and a 6 GB NVIDIA GeForce GTX 1660 SUPER GPU.

Four processes were conducted: aerial survey S50 without ground control points (S50s), aerial survey S50 with ground control points (S50c), aerial survey S80 without ground control points (S80s), and aerial survey S80 with ground control points (S80c).

The aerial images were imported into the software, and the spatial reference configuration was defined. The coordinate reference system was updated to the SIRGAS 2000 datum, zone 23S. Ground altitude was adjusted to account for the difference between the recorded flight altitude and the actual flight height. This adjustment was applied to the ground elevation for each of the four aerial surveys evaluated.

Additionally, image alignment was performed by identifying coincidental points between different photographs. Among the alignment parameters, accuracy was set to the highest level, with the image scale increased by a factor of four (doubling the scale on each side). Generic and reference pre-selection were utilized to reduce processing time. Advanced parameters were adjusted as follows: the key points limit was set to 40,000 units (the upper limit of feature points per image), and the tie points limit was set to 10,000 units (the upper limit of corresponding points per image).

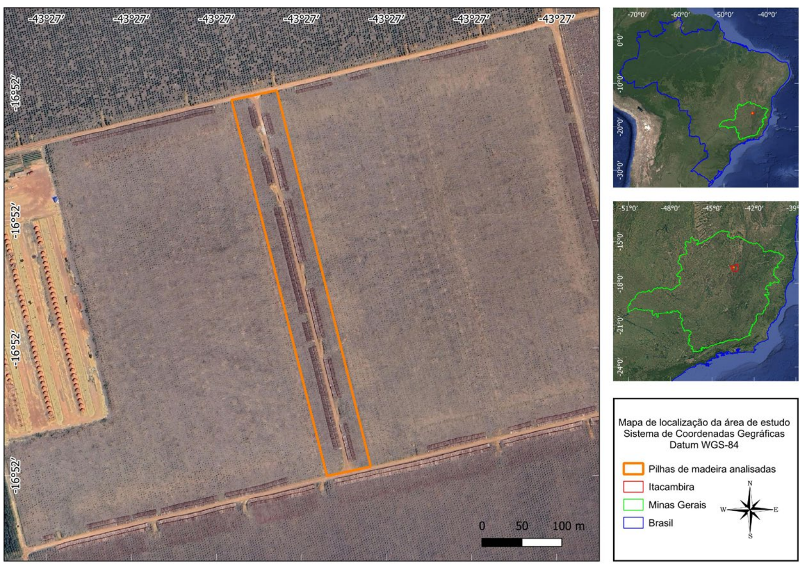

Figure 1: Location map of the study area.

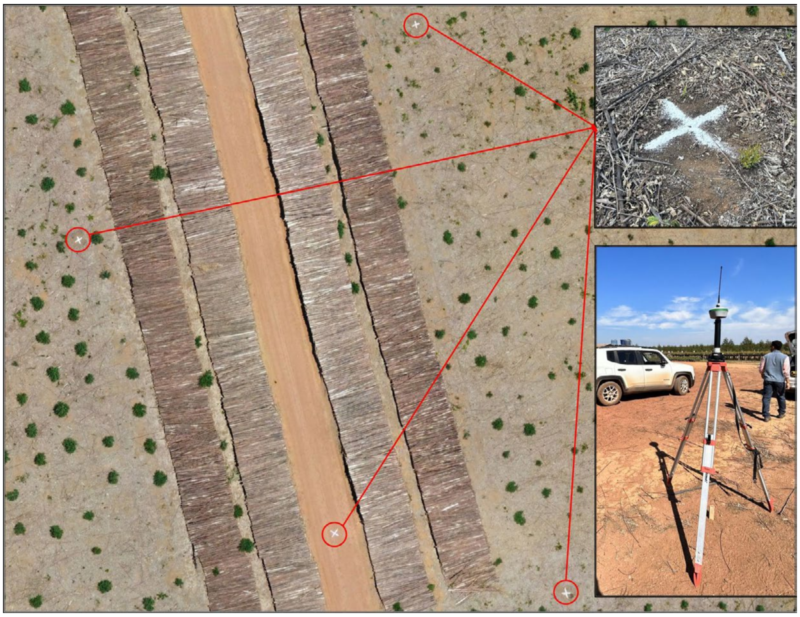

Figure 2: Identification of control points in the field and equipment used to obtain coordinates.

For cases where ground control points (GCPs) were used, the latitude, longitude, and altitude values from the GCPs were included in the processing, and the geolocation data from the UAV's GPS sensor were disabled. The GCPs were marked in the images at the corresponding locations defined in the field. The inclusion of GCPs followed the methodology described by Tinkham and Swayze (2021). The subsequent steps in the processing were the same for all cases, regardless of whether GCP data was used.

Camera parameters and sparse point clouds were optimized. The parameters considered included the focal length in pixels (f), the coordinates of the principal point (cx, cy), coefficients for affine transformation and inclination (b1, b2), radial distortion coefficients (k1, k2, k3, k4), and tangential distortion coefficients (p1, p2, p3, p4).

Next, the dense point cloud was generated using the Multi-View Stereo (MVS) algorithm, which considers depth data based on corresponding pixels in overlapping images (Denter et al., 2022; Deliry and Avdan, 2023). The reconstruction quality was set to ultra-high, and the depth filter parameter was configured as aggressive to reduce points with discrepant values (Deliry and Avdan, 2023).

Digital elevation models (DEMs) for each processing were generated by interpolating values from the dense point clouds, followed by the creation of orthomosaics. The DEMs were then used to estimate the volume of the wood stockpiles in the final step of the processing.

The volume of each wood stockpile (in stereo) was quantified using the software's measurement tool. A polygon was drawn around each pile based on the orthomosaics. The surface area of each stockpile was defined by interpolating altitude values along the borders of the polygons, utilizing the best-fit plane calculated by the software.

Evaluation of digital elevation models

The latitude, longitude, and altitude values were extracted from each digital elevation model (DEM) created in the various processing scenarios at the ground control points. These values were compared with those obtained using the GNSS RTK system. The accuracy of the vertical and horizontal positioning from the DEMs was assessed using the root-mean-square error (RMSE) Equation 2.

$$RMSE = \sqrt{\frac{\sum\left(\hat{Y}_i - Y_i\right)^2}{n}} \quad (2)$$

where Yi is the value for altitude obtained from GNSS RTK system at i-th ground control point, $\hat{Y}_i$ is the value of altitude obtained from digital elevation model for the i-th ground control point, and n is the total amount of ground points considered.

Evaluation of volume estimates

The estimates of wood stockpile volumes obtained from each processing (S50c, S50s, S80c, and S80s) were evaluated by comparing them to the values calculated using the conventional method. The residual standard deviation (Equation 3), mean square error percentage (Equation 4), Spearman correlation (Equation 5), and Mean Bias Error (Equation 6) were calculated for this comparison.

$$S_{yx} = \sqrt{\frac{\sum\left(\hat{Y}_i - Y_i\right)^2}{n-1}} \quad (3)$$

$$RMSE(\%) = 100 * \frac{1}{\underline{Y}} \sqrt{\frac{\sum(\hat{Y}_i - Y_i)^2}{n}} \quad (4)$$

$$\rho = 1 - \frac{6\sum(d)^2}{n*(n^2-1)} \quad (5)$$

$$MBE = \frac{\sum(\hat{Y}_i - Y_i)}{n} \quad (6)$$

where $\hat{Y}_i$ is the estimated volume by aerial survey for the i-th wood stock pile, Y_i is the volume calculated considering the conventional method for the i-th wood stock pile, n is the total of observations, $\underline{Y}$ is the average for volume calculated by conventional method, and d is the difference in the ranks of each data pair.

The non-normality of the data was confirmed using the Shapiro-Wilk test at a 5% significance level. Non-parametric tests, specifically the Friedman and Nemenyi tests, were applied to evaluate whether there were significant differences between the wood stockpile volume estimates obtained by the conventional method and those derived from the different processing scenarios (S50s, S50c, S80s, and S80c). The tests were conducted using the R software, utilizing the friedmanTest and frdAllPairsNemenyiTest functions from the PMCMRplus package (Pohlert, 2023).

RESULTS

The volumes of wood stockpiles obtained by the conventional method ranged from 45.43 st to 845.90 st, with an average volume of 257.52 st and a median of 196.69 st. The average height of the piles ranged from 0.60 m to 1.33 m. The smallest pile had a length of 14.9 m, while the largest pile measured 145.0 m. Approximately 71% of the piles had a volume of less than 300 st (Figure 3).

The total time spent capturing images during the aerial surveys was 15 minutes for the S50 survey and 14 minutes for the S80 survey. The UAV covered distances of 3.5 km and 3.4 km for the S50 and S80 surveys, respectively. The number of images obtained for the S50 survey was 211, while for the S80 survey it was 192. On average, each ground control point was referenced by 13 images for the S50 survey and 24 images for the S80 survey.

The S50s processing produced a dense point cloud with nearly 7,373 points per square meter, while the S50c processing resulted in 6,251 points per square meter. The S80s processing generated a dense point cloud with 2,223 points per square meter, and the S80c processing produced one with 2,060 points per square meter. The spatial resolution of the digital elevation models obtained from each processing was 1.74 cm/pixel for both S50s and S50c, and 2.72 cm/pixel for both S80s and S80c. There was no variation in spatial resolution based on the use or non-use of ground control points.

The processing with the use of ground control points (GCPs) resulted in smaller RMSE values compared to those without GCPs (Table 1) for booth horizontal and vertical positioning. The RMSE values for the set of three-dimensional coordinates (longitude, latitude, and altitude) in the processing with GCPs were less than 3.5 cm, with the largest errors occurring in the Z coordinate (altitude). In contrast, the RMSE values for the processing without GCPs exceeded 20.1 m for the three-dimensional coordinates, with vertical positional errors reaching up to 20.0 m. The vertical positional error was close to zero meters for the processing using GCPs, while it was 20.0 m and 25.0 m for the S80s and S80c processing, respectively.

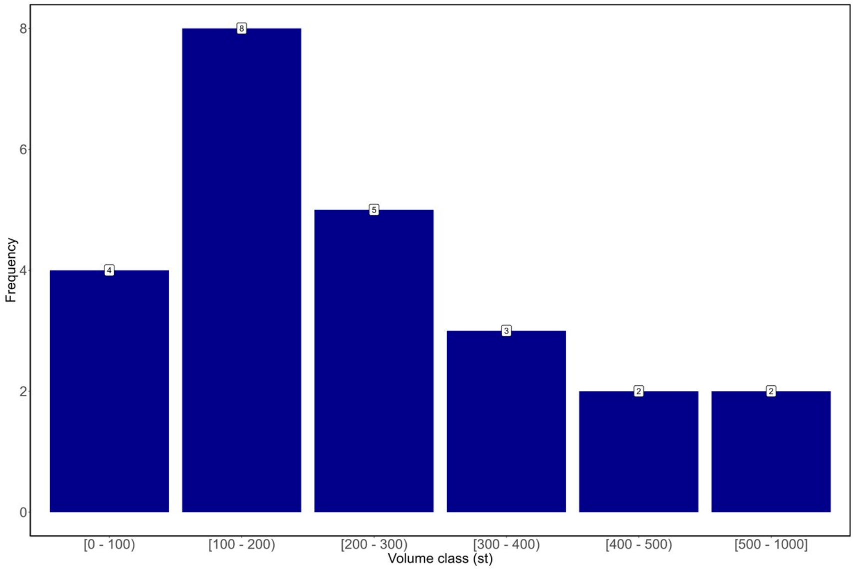

Figure 3: Distribution of wood stacks piles by volume class.

The S50c and S80c processing resulted in lower values of residual standard deviation and mean square error as a percentage (Table 2). They also showed higher correlation values between the estimated and calculated values (from the conventional method). All correlations were statistically significant (α = 5%), with p-values below 10^-6. The total volume estimated from the different aerial surveys exceeded the value calculated using the conventional method. The MBE values were equals to 2.36 st, 9.68 st, 4.34 st, and 7.22 st for S50s, S50c, S80s and S80c, respectively. The use of GCPs led to a higher overestimation in both cases. Despite this, the volume estimates for each wood stockpile were similar, regardless of the presence or absence of GCPs (Figure 4).

Table 1: Accuracy of horizontal and vertical positioning of locations related to control points for each processing.

Proc.	RMSE					$Error_z$		
	X (m)	Y (m)	Z (m)	XY (m)	XYZ (m)	Min. (m)	Aver. (m)	Max. (m)
S50s	1,74	1,02	25,20	2,02	25,28	24,23	25,19	26,59
S50c	0,01	0,01	0,02	0,02	0,03	-0,03	0,00	0,06
S80s	2,16	1,07	20,02	2,41	20,17	18,61	20,01	20,88
S80c	0,00	0,00	0,03	0,00	0,03	-0,06	-0,00	0,05

Table 2: Descriptive analysis of woodpile volume estimates for conventional methods (VPm) and for the three different aerial survey methods (S50s, S50c, S80s and S80c).

Proc.	Sum (st)	Avg (st)	Min (st)	Max (st)	Std (st)	S_{yx}	RMSE	Corr.
VPm	6.180,51	196,70	45,43	845,89	202,31	-	-	-
S50s	6.237,09	199,48	57,43	802,17	191,49	34,74	13,21%	98,43%
S50c	6.412,87	198,25	52,67	826,51	201,79	26,42	10,04%	98,87%
S80s	6.284,69	200,54	51,54	816,12	196,86	32,58	12,38%	98,52%
S80c	6.353,83	201,35	51,23	827,76	200,20	25,06	9,52%	98,87%

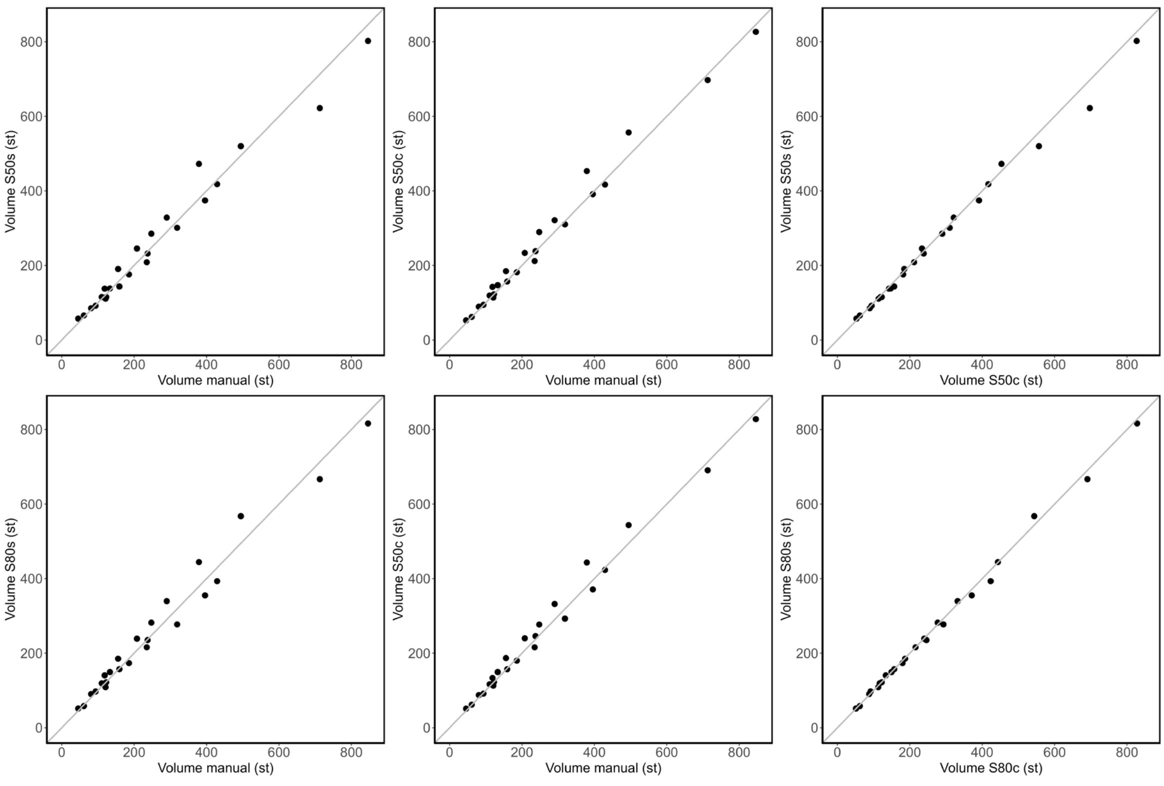

Figure 4: Relationship between the volumes obtained considering the conventional method (manual) and the different processing with and without the use of GCPs.

The Friedman test yielded a p-value of 0.3796, indicating that the null hypothesis cannot be rejected. In other words, there is no evidence to suggest significant differences between the values obtained by different methods. The results of the Nemenyi test (Table 3) provide a detailed comparison between the different pairs of results.

DISCUSSION

Santana et al. (2021) also observed a reduction in the number of photos as flight height increased. However, the small difference observed in this study may be attributed to varying values of frontal and lateral overlap. The time required for acquiring the photographs was similar across all surveys, and this did not pose an impediment to using either of the flights.

There was a reduction in the density of point clouds for the two aerial surveys (S50 and S80) when ground control points were included in the image processing. However, this reduction was minimal and did not affect subsequent products. A decrease in point cloud density with increasing flight height was also observed by Figueiredo et al. (2016). Densely populated point clouds enable better data interpolation during three-dimensional model generation, resulting in higher accuracy for volume estimates of the object of interest (Ajayi and Ajulo, 2021).

The horizontal positional errors when using GCPs align with those reported in the literature. Tomaštík et al. (2017) found RMSE values ranging from 0.037 m to 0.114 m for horizontal accuracy, depending on the number of ground control points used. Quoc Long et al. (2020) considered RMSE values below 5.0 cm as indicative of reliable digital elevation models. Rangel et al. (2018) noted that, in general, horizontal accuracy is better than vertical accuracy when unmanned aerial vehicles are used for mapping, as was observed in our study.

Kalacska et al. (2020) noted that mapping without ground control points (GCPs) requires the use of equipment such as RTK or PPK systems onboard to achieve high accuracy in terms of horizontal and vertical positioning. Although vertical positional errors were observed in cases without GCPs (S50s and S80s), it is possible to note a trend of overestimation for all analyzed points, considering the minimum and maximum values (Table 1). This suggests that the entire digital elevation model was systematically altered, with approximately equal changes across all locations where control points were considered. Therefore, there is no indication of deformation on the analyzed surface that could result in errors in volumetric estimates.

The processing with ground control points (GCPs) improved the statistics of the residual standard error, root mean square error (RMSE), and correlation when comparing the volumes calculated by the manual method and the volumes calculated by aerial imaging. However, the inclusion of GCPs resulted in an increase in the total volume estimates for both aerial surveys, which worsened the values of mean bias error, making them deviate further from the values calculated using the conventional method. Despite this, the statistical tests applied indicate that there are no significant differences between the estimates obtained with and without GCPs.

There were no significant differences between the estimates obtained from the aerial surveys and those calculated using the conventional method. These results are consistent with findings by Heraki et al. (2022). Ajayi and Ajulo (2021) suggest that volume estimates for objects on surfaces obtained from aerial imagery processing can be more precise than those derived from conventional methods. This improvement is attributed to the dense point cloud, which allows for more accurate interpolation compared to measuring only a few points along the object. Berendt et al. (2021) also noted that measuring wood stockpiles using digital photographs can generate a larger number of reference points, which are used to define the contours of logs more precisely, potentially resulting in estimates that are closer to the actual values.

The results demonstrate that the use of ground control points (GCPs) is not necessary for accurately estimating the volume of wood stockpiles in field conditions. This finding is particularly significant for reducing both costs and time associated with measuring wood piles. This result is consistent with the findings of Ajayi et al. (2023), where all evaluated software produced more precise volume estimates when GCPs were not used in aerial image processing.

James et al. (2017) noted that the use of convergent and high-quality images helps reduce the need for ground control points. These factors were present in our study and may have influenced the results. It is important to consider that the aerial surveys were conducted using a double grid pattern, which requires more time for data collection and may reduce operational efficiency, especially when evaluating wood piles on a large scale.

Another important aspect is related to the conditions of the site where the wood piles were placed. In this case, the terrain did not exhibit significant variations in elevation. Filkin et al. (2022) indicated that low-cost equipment can yield accurate volume estimates for objects situated in flat areas without the use of ground control points (GCPs). The authors observed errors of approximately 5% in the absence of GCPs.

Table 3: Results of Nemenyi test comparing processing with and without ground control points for two aerial surveys.

	VPm	S50s	S50c	S80s	S80c
VPm		0,99$^{n.s}$	0,31$^{n.s}$	1,00$^{n.s}$	1,00$^{n.s}$
S50s	0,99$^{n.s}$		0,31$^{n.s}$	0,99$^{n.s}$	0,92$^{n.s}$
S50c	0,31$^{n.s}$	0,31$^{n.s}$		0,99$^{n.s}$	0,81$^{n.s}$
S80s	1,00$^{n.s}$	0,99$^{n.s}$	0,99$^{n.s}$		1,00$^{n.s}$
S80c	1,00$^{n.s}$	0,92$^{n.s}$	0,81$^{n.s}$	1,00$^{n.s}$	

It can be concluded that, for the studied case, the use of high-cost equipment was not necessary to estimate the volume of wood stockpiles under field conditions. While this result is promising from a financial perspective, further and more rigorous studies are needed. It is important to evaluate volumetric estimates for wood piles under varying conditions, including different organizational setups, terrain slopes, and wood origins, among other factors.

CONCLUSIONS

The use of control points did not significantly improve the accuracy of volume estimates for wood piles placed in the field. Under the analyzed conditions, a low-cost drone can be used to estimate the volume of wood piles in the field without the need for ground control points.

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AUTHORSHIP CONTRIBUTION

Project Idea: CAAJ

Funding: CAAJ; RSRMC

Database: CAAJ; RSRMC

Processing: CAAJ; RSRMC

Analysis: CAAJ; RSRMC

Writing: CAAJ; RSRMC

Review: CAAJ; RSRMC

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