THE USE OF CAPTURED IMAGES BY REMOTELY PILOTED AIRCRAFT (RPA) IN MEASURING THE STACKED LOG VOLUME IN A STOCKYARD

Leonardo Heraki[1]*, Eduardo da Silva Lopes[2], Paulo Costa de Oliveira Filho[3]

[1*]Universidade Estadual do Centro-Oeste, Programa de Pós-graduação em Ciências Florestais, Irati, Paraná, Brasil - leonardoheraki@outlook.com
[2]Universidade Estadual do Centro-Oeste, Departamento de Engenharia Florestal, Irati, Paraná, Brasil - eslopes@unicentro.br
[3]Universidade Estadual do Centro-Oeste, Departamento de Engenharia Ambiental, Irati, Paraná, Brasil - paulocostafh@gmail.com

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Resumo

Uso de imagens obtidas por aeronave remotamente pilotada (ARP) na mensuração de madeira empilhada em pátio industrial. A quantificação de madeira em pátios industriais de forma rápida, precisa e com baixos custos é de grande importância para a gestão do estoque e a tomada de decisão. Neste trabalho foi realizada a mensuração do volume de toras de madeira empilhada em um pátio industrial a partir de imagens aéreas obtidas por uma câmera fotográfica instalada em aeronave remotamente pilotada (ARP). As aferições volumétricas da madeira empilhada foram testadas utilizando a técnica fotogramétrica *Structure from Motion-Multi View Stereo* (SfM-MVS) e comparadas com valores obtidos pelo método convencional de medição manual. As imagens aéreas foram obtidas em três alturas de voo: 60 m, 80 m e 100 m instalados 10 pontos de controle geodésicos para referenciar espacialmente os modelos digitais com uso de um receptor GNSS RTK. As imagens aéreas foram processadas com uso de *software* de fotogrametria digital resultando em modelos digitais de superfície (MDS) das unidades amostrais. Os resultados das estimativas volumétricas obtidos pela técnica fotogramétrica SfM-MVS quando comparadas ao método convencional apresentaram variações de 17,5; 14,9 e 8,3% para os voos realizados a 60 m, 80 m e 100 m de altura, respectivamente. De acordo com os testes estatísticos aplicados, as estimativas volumétricas realizadas com uso da técnica fotogramétrica SfM-MVS a partir de imagens nas alturas de voo estudadas não apresentaram diferenças significativas em relação ao método convencional de medição manual, indicando que a utilização de imagens aéreas obtidas por ARP pode ser uma opção viável para estimar o volume de madeira empilhada em pátio industrial.
Palavras-chave: Estoque de madeira, modelo digital de superfície, aerofotogrametria.

Abstract

Quantifying wood in industrial yards quickly, accurately and at low costs is of great importance for stock management and decision making. In this work, the volume of wood logs stacked in an industrial yard was quantified using aerial images with high spatial resolution obtained by remotely piloted aircraft (RPA). The volumetric measurements were tested using the Structure from Motion with Multi-View Stereo (SfM-MVS) photogrammetry technique and compared with values obtained through the conventional manual measurement method. The aerial images were taken at three different flight heights of 60 m, 80 m and 100 m installed at 10 ground control points using a GNSS RTK receptor. The aerial images were processed by digital photogrammetry software to generate digital surface models (DSM), which made it possible to obtain the volumetric measurements of the stacked wood. Thus, aerial images acquired at 60 m, 80 m and 100 m altitude presented variations of 17.50%, 14.93% and 8.31%, respectively. After the statistical tests applied to the results of volumetric estimates, the SfM-MVS photogrammetry did not show significant differences for the conventional measurement method, indicating that the use of aerial images acquired by RPA can be a viable option to estimate the stacked wood volume in an industrial yard.
Keywords: Wood stock, digital surface model, aerophotogrammetry.

INTRODUCTION

In the last 10 years, the increasing use of remotely piloted aircraft (RPA) in the forest area has been remarkable, which has allowed the optimization of aerial imagery acquisition with significant improvements in spatial and temporal resolution (EUGENIO *et al*., 2020). Automatic detection of trees in planted and natural forest areas stands out among the various applications of this technology in this field (MOHAN *et al*., 2017; NEVALAINEN *et al*., 2017; HENTZ *et al*., 2018; EUGENIO *et al*., 2020), obtaining accurate information on tree parameters such as: height, volume, crown diameter, species identification, extension and growth.

The use of commercial software which uses algorithms for digital photogrammetric restitution and generation of 3D models generally presents a lower acquisition cost option compared to that based on laser scanning systems (KOCI *et al*., 2017). Miller *et al*. (2015) used the Structure from Motion with Multi-View Stereo (SfM-MVS) photogrammetric technique with a camera attached to an RPA to measure height, diameter and volume of individual trees by creating 3D models from high spatial resolution 2D images. The accuracy of the results proved to be comparable to those obtained by using Light Detection and Ranging (LIDAR), thereby demonstrating that the SfM-MVS technique has a lower cost and is an easier to handle alternative to LIDAR. Furthermore, Westoby *et al*. (2012) and Javernick *et al*. (2014) pointed out that the SfM-MVS technique is a low-cost alternative for acquiring high resolution 2D images to later construct 3D models with.

In view of this panorama, studying forest production from high spatial resolution images obtained by photographic cameras installed in RPA together with the use of the SfM-MVS technique presents itself as an alternative for forestry companies which seek to measure the volume of wood logs stacked in industrial yards with greater accuracy, providing greater assertiveness for remunerating services provided and forest products. It should also be noted that as only logs are measured instead of trees in a large and clean stockyard, there is a tendency for greater accuracy of measurements, as the background scene and ambient lighting in the surroundings seem to affect the accuracy of a 3D model built through SfM-MVS (MILLER *et al.*, 2015).

Normally the wood in forestry companies is commercialized after quantifying the volume of the logs stacked in the field, intermediate or industrial yards, and different measurement methods can be used. In the conventional method, the apparent volume (stereo) of the wood is determined using specific formulas, where the empty spaces between the logs are considered, and then the solid wood volume is estimated by applying a conversion factor. There is also the possibility of quantifying wood in mass units (tons) using weighing scales, with this method being performed in two weighings; the first is carried out with the transport vehicle loaded with wood to obtain the total gross weight; and then the second is performed later with the vehicle empty to obtain the tare weight of the vehicle, thus obtaining the net wood load by subtraction.

According to Acuna and Sosa (2018), it is necessary to implement new measurement procedures and technologies that provide volumetric estimates of wood logs with greater accuracy due to the high cost of wood, as inaccuracies in volumetric measurements can affect revenues and commercial contracts between service providers and forestry companies. Therefore, considering the information presented, the hypothesis established in this work was that the volumetric estimates by the Structure from Motion-Multi-View Stereo (SfM-MVS) photogrammetric technique does not differ from the conventional manual measurement method, allowing it to be used on a large scale by companies to quantify wood in industrial stockyards.

Thus, the objective of this work was to quantify the volume of wood logs stacked in an industrial yard from aerial images acquired by a photographic camera installed in RPA and to compare the results of volumetric estimates by the SfM-MVS photogrammetric technique in relation to the conventional manual measurement method.

MATERIAL AND METHODS

This study was carried out in an industrial wood stockyard of a forestry company located in the municipality of Mallet, state of Parana, Brazil, at the geographic coordinates 25°52'11" South Latitude and 50°48'52" West Longitude. The wood log stockyard had a total area of 5,500 m^2, with the wood coming from a *Pinus* stand to manufacture pallets.

Aerial images of the log stockyard were obtained using a FC6310 camera with a fixed focal length of 8.8 mm, a 1-inch (13.2 mm x 8.8 mm) CMOS sensor (Complementary Metal Oxide Semiconductor) and lens with f/2.8 aperture, being installed on a DJI® Phantom 4 Advanced aircraft, as shown in Figure 1(a). Images were recorded at 20 megapixels with three spectral bands (Red+Green+Blue).

The images were acquired on three different dates: 11/23/2019, 02/14/2020 and 05/04/2020, between 11:30 am and 12 pm, in order to reduce the presence of shaded areas in aerial photographs. Three daily flights were carried out, totaling nine flights, where the weather conditions indicated partially cloudy skies, with no occurrence of rain and winds with a speed of less than 3 km/h. The entire stock of wood logs was renewed in the interval between the data collection dates, and thus it was possible to obtain 10 samples in each period, totaling 30 samples.

Flight planning was performed using the Pix4D Capture application installed on a Smartphone with an IOS operating system in order to capture images at 60, 80 and 100 meters high. It was decided to perform double grid flight lines in the study with a camera angle of 65°, a lateral and longitudinal image overlap percentage of 80% for both situations. The images were obtained in JPG format with 4864 x 3648 pixels of horizontal and vertical resolution, respectively.

Next, 10 control points were installed during the data acquisition periods in order to spatially reference the digital models, and their respective geodetic coordinates were collected using GNSS RTK GEOMAX® Zennith 25 receivers, as illustrated in Figure 1(b). The base receiver was installed inside the log storage yard so that the control points obtained by the Rover receiver were at a maximum distance of 100 m between them. The targets used to identify the control points in the study area are shown in Figure 1(c).

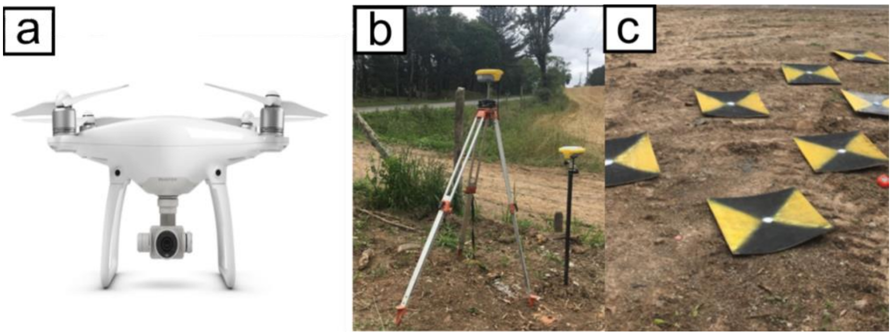


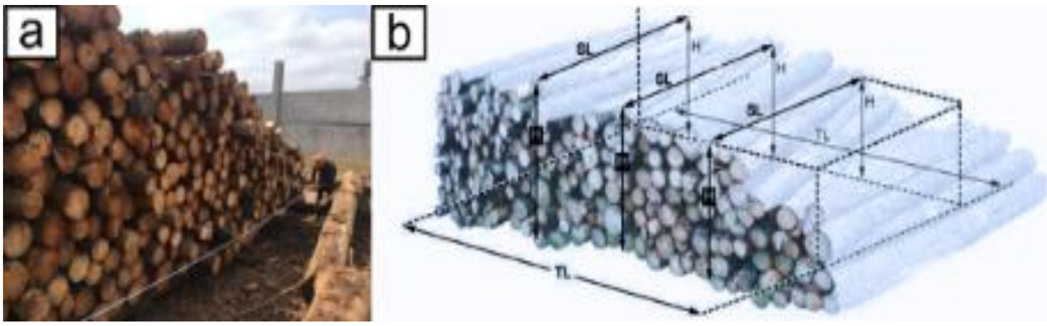
Figure 1. DJI® Phantom 4 Advanced RPA (a); GNSS RTK GEOMAX® Zennith 25 (b); and target for obtaining ground control points (c).
Figura 1. ARP DJI® Phantom 4 Advanced (a); GNSS RTK GEOMAX® Zennith 25 (b); e alvos para a obtenção dos pontos de controle (c).

The length, width and height of the stacks of wood logs were measured using a tape measure to determine the stacked wood volume by the conventional method (Figure 2a). The stacking height was measured at different points, since the stacking was not always uniform. Then, the apparent volume was obtained using the formula:

$$\mathrm{V(st)} = \mathrm{SH} \times \mathrm{SL} \times \mathrm{SW}$$

In which: H = Stack height; SL = Stack length; SW = Stack width.

The manual measurement scheme is shown in Figure 2(b).



Adapted from SDC (2016).

Figure 2. Manual measurement with tape measure (a); manual measurement scheme with tape measure (b).
Figura 2. Aferição manual com fita métrica (a); esquema de aferição manual com fita métrica (b).

The Agisoft Metashape™ Professional version 1.6.2 software program was used to process the images. The sequence of activities started by adding aerial photographs to the program, selecting the UTM coordinate system with Datum in SIRGAS 2000 and inserting the geographic coordinates of the 10 control points installed in the study area. Then, the image alignment was performed to match the features in the images, selecting the high accuracy option. The SfM digital stereoscopy algorithms identified the keypoints in the images in this step, thus generating a descriptor for each identified keypoint, with such descriptors being known as keypoint descriptors (WESTOBY *et al*. 2012). According to the same authors, it is a mechanism for extracting homologous points between the different scenes. The program has a bundle adjustment algorithm which resolves the position and orientation of each image and internal calibration parameters of the camera from the selection of keypoints, resulting in a sparse three-dimensional point cloud (FERRER-GONZÁLEZ *et al*., 2020). Thus, the models were referenced to the coordinate system and scaled, and the control points were manually identified in the images. In the next step, the high quality option was selected to densify the point cloud. At this stage, the MVS algorithms used to densify the sparse three-dimensional point cloud identified the features in the images from their correlation, then interpolation was performed by creating a dense point cloud with three-dimensional coordinates (SILVA *et al*. 2015). A three-dimensional mesh (Mesh) was subsequently constructed to improve the visual aspect of the model, performed the texturing of the 3D digital model (generating texture) and the construction of the tiled model.

After generating the 3D digital model, all parts of the model that should not have the estimated volume were manually extracted, and then there could be a failure in the representation of the sample unit due to the lack of information in the 3D model reconstruction. Thus, the flaw was corrected to estimate the volume of the wood piles using the ‘‘close holes’’ function to interpolate the surface between the closest points, resulting in the solid 3D mesh model, as illustrated in Figure 3.

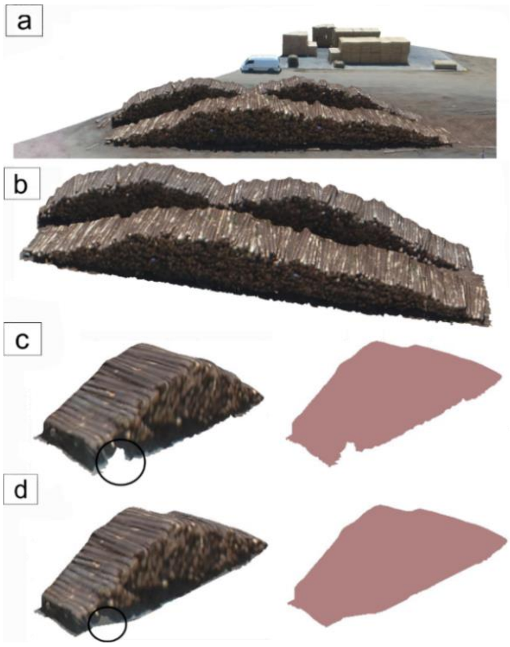


Figure 3. DSM of sample units in which: (a) Step prior to removing objects not involved in volumetric measurement; (b) Sample units of the volumetric measurement; (c) Example of digital model failure; and (d) Interpolation of the digital model surface by the “close holes” function.

Figura 3. MDS das unidades amostrais em que: Etapa anterior à remoção dos objetos sem interesse em quantificar os dados volumétricos (a); Unidades amostrais para quantificar os dados volumétricos (b); Exemplo de falha do modelo digital (c); e Interpolação da superfície do modelo digital pela função *close holes* (d).

After interpolating the surface of the sampling units (which considered the empty spaces between the stacked wood logs in the same way as the conventional method of manual measurement), the volumetric data of the samples were obtained by the SfM-MVS photogrammetric technique applying the Measure Area and Volume function of the software program.

Next, four treatments were tested to evaluate the results of volumetric measurements, as described below:

- SfM (60 m): measurement of the wood log stacks by the SfM-MVS technique with 3D Digital Models generated by aerial images captured at 60 m height;
- SfM (80 m): measurement of wood log stacks using the SfM-MVS technique with 3D Digital Models generated by aerial images captured at 80 m height;
- SfM (100 m): measurement of wood log stacks using the SfM-MVS technique with 3D Digital Models generated by aerial images captured at 100 m height; and
- Manual measurement: Measurement of wood log stacks by the conventional method.

The data obtained were analyzed using a completely randomized design (CRD) with three treatments (60, 80 and 100 m high) and a control, with 30 replications. Means were compared by the Dunnett’s test at the 5% probability level. The homogeneity of variances was verified by the Bartlett’s test, and the normality of the data by the Kolgomorov-Smirnov test, with the ASSISTAT 7.7 program being used to perform the statistical analyzes.

RESULTS

The DSMs generated from the aerial images had a resolution of 1.84 cm/pixel, 1.85 cm/pixel and 1.97 cm/pixel for flights performed at 60 m height in different periods. The resolution for flights performed at 80 m height was 2.24; 2.48 and 2.59 cm/pixel, while flights performed at 100 m height had a resolution of 3.07; 3.09

and 3.2 cm/pixel. The DSM generated from aerial images and processed in digital photogrammetry software is shown in Figure 4, where the warmest colors represent the highest altitudes.

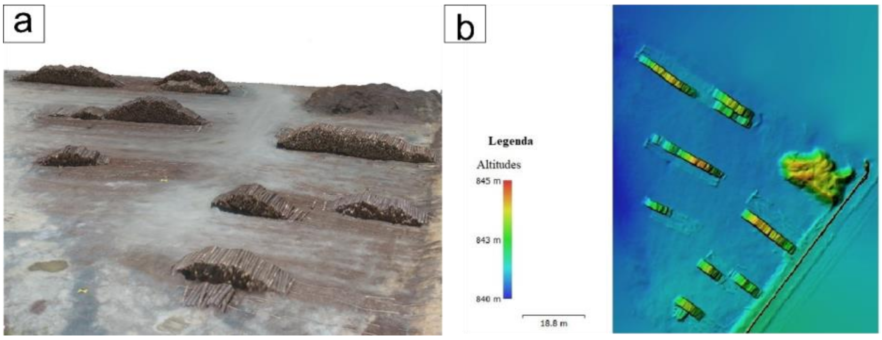


Figure 4. DSM of the study area in which: Tiled model (a); and color scale planialtimetric data (b).
Figura 4. MDS da área de estudo em que: *Tiled Model* (a)*;* e informações planialtimétricas em escala de cores (b).

The estimated total mean square error (RMSE) referring to the three-dimensional coordinates of the images collected in the study area with the installation of control points and without the control points are represented in Figure 5.

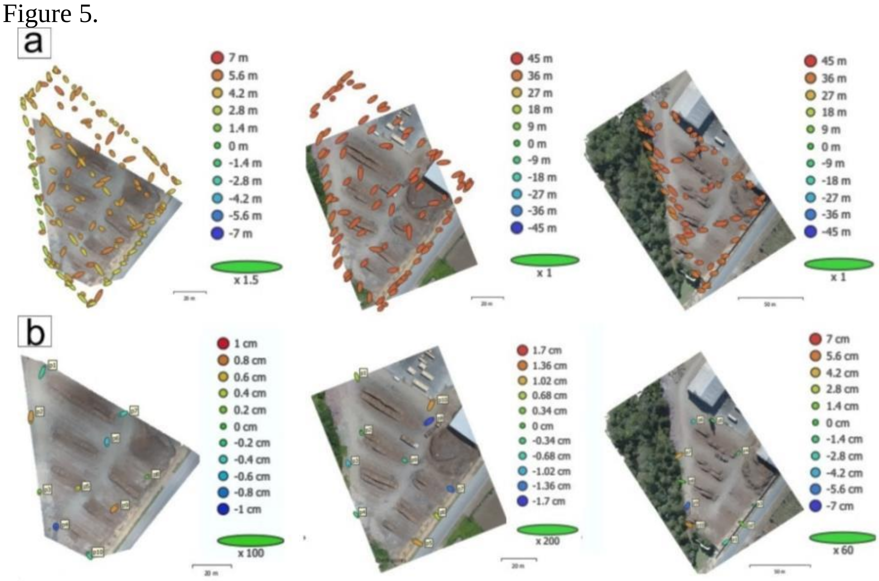


Figure 5. Altimetric errors represented by elipse color and the planimetric errors represented by elipse expansion (a) without ground control points and (b) with ground control points.
Figura 5. Erros altimétricos representados pela cor da elipse e os erros planimétricos representados pela expansão da elipse sem pontos de controle (a) e com pontos de controle (b).

The use of the control points installed in the first data collection resulted in a total estimated RMSE of 2.0 cm for the three-dimensional coordinates represented in the images; the RMSE in the second collection was 2.8 cm; and 7.2 cm in the third. It is important to emphasize that without the control points installed in the first, second and third collection, a total RMSE estimated for the three-dimensional coordinates represented in the images resulted in 5.2 m; 39.9 m; and 38.6 m, respectively. The flight plan configuration with a lateral and longitudinal overlap percentage of 80% for both cases resulted in at least nine images for each correspondence point identified in the sample units.

The results of volumetric measurements by the SfM-MVS photogrammetry technique with images captured at three different flight heights (60, 80 and 100 m) and manually by the conventional method for the 30 samples of wood log stacks are shown in Figure 6.

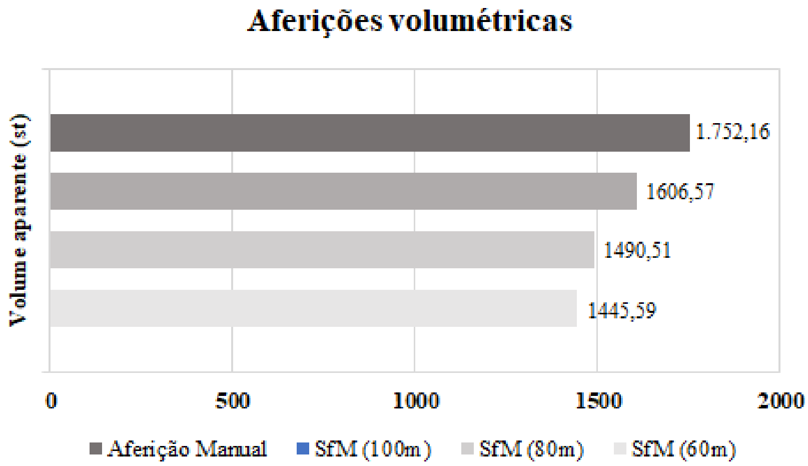


Figure 6. Volumetric measurements of wood stacks manually and from different flight heights.
Figura 6. Aferições volumétricas das pilhas de madeira manualmente e á partir das diferentes alturas de voo.

The wood stacks measured by the conventional method presented greater volume in relation to the estimates made using the SfM-MVS technique. The volumetric measurements using images obtained at 60, 80 and 100 m height showed variations in relation to the conventional method of 8.31%, 14.93% and 17.50%, respectively. The treatment variances were homogeneous (Bartlett's test) and the data showed normal distribution by the Kolmogorov-Smirnov test. The average stacked wood log volumes did not show statistical differences by Dunnet's test at 5% probability using the SfM-MVS technique from aerial images collected at 60, 80 and 100 m height compared to the conventional method.

DISCUSSION

The digital models of the sampling units did not show areas with exaggerated deformations or shading considering the time of flights performed between 11:30 a.m. and 12:00 p.m. with a camera angle of 65° and a percentage of 80% for the lateral and longitudinal coverage. They presented nine images for each correspondence point in the point cloud of the study area, thus allowing to quantify the volume of the wood log stacks by the SfM-MVS photogrammetric technique. Iglhaut *et al*. (2019) raised important practical considerations for collecting aerial images which made it possible to extract data by the SfM-MVS photogrammetric technique, such as the flight schedule being close to solar noon and the oblique view camera angle which reduced shaded areas and occlusions. The lateral and longitudinal overlap percentage of 80% or more resulted in an increase in the matching capacity of the scenes, with at least four images being recommended for each matching point identified in the point cloud.

The total mean squared error (RMSE) estimated in the three-dimensional coordinates of the images was minimized in this study by installing 10 geodetic control points. In the same vein, Mesas-Carrascosa *et al*. (2016) tested different parameters which influence data collection with RPA, in which the authors found that installing control points resulted in reduced positional errors compared to photogrammetric processing. Santana *et al*. (2021) tested the influence of the quantity and distribution of control points used in the georeferencing of images obtained by RPA (among other variables), and found that the photogrammetric processing carried out with the installation of 10 control points in an area of 20,000 m² showed greater positional accuracy regardless of flight height.

According to Mesas-Carracosa *et al*. (2016), a lower flight height tends to contribute to increase the spatial resolution of the images. In this sense, Figueiredo *et al*. (2016) tested some digital surface models generated from images obtained by an RGB camera installed in a DJI PHANTOM 3 RPA which had a camera with a 1/2.3-inch CMOS sensor with 12 effective megapixels in order to generate volumetric estimates of logs stored in the timber industry. The spatial resolution of the model in their study was 2.16 cm for a flight at 50 m height. Despite obtaining images at a lower flight height, the spatial resolution of the DSM was lower when compared to the present study at a flight height of 60 m, which presented a DSM with a spatial resolution of 1.84 cm when generated from aerial images. This result is possibly related to the greater capacity of the DJI® PHANTOM 4 Advanced still camera, which has a one-inch CMOS sensor and records images at 20 megapixels.

According to Dandois and Ellis (2013), measurements using 3D models with high spatial resolution have enabled developing methods which use photogrammetric computer vision algorithms. In the study developed by Gomez *et al*. (2019), the SfM-MVS photogrammetric technique was used to calculate the volume of tree trunks for the timber industry in Indonesia. The authors highlighted that the photogrammetric method was considered appropriate, allowing to detect variations in the shapes of the trunk of the sampled trees, unlike the conventional measurement method which overestimated the volumetric quantification by 20 to 40%, having an important effect on the economic projection.

The volumetric measurements of the stacked wood logs using the SfM-MVS photogrammetric technique in the DSM generated from aerial images at flight heights of 100, 80 and 60 m in this work resulted in differences of 8.31; 14.93; and 17.50% in relation to the manual method, respectively. Such differences were not significant, indicating the feasibility of using the SfM-MVS technique to volumetrically quantify logs stacked in an industrial stockyard. In the same direction, in studies on the use of unmanned aerial vehicles (UAV) in measuring wood in the field, Oliveira Sobrinho *et al*. (2018) quantified the stereo volume of stacks with variations of 2.42 and 4.26% in relation to the conventional method. The authors also considered that the stereo volume estimates of stacked wood presented low variability in relation to the factory volume. The use of unmanned aircraft to obtain data in the forest area can generally present advantages over conventional methods due to the possibility of flying over places with restricted access by land, the possibility of obtaining data at different flying heights, time optimization and cost reduction.

CONCLUSIONS

- The use of aerial photographs obtained by a camera installed in a remotely piloted aircraft (RPA) combined with digital photogrammetric processing software used to generate 3D digital models enabled satisfactorily performing volumetric estimates of wood logs stacked in industrial stockyard.
- The volumetric estimates performed using the SfM-MVS photogrammetric technique from images obtained from flight heights of 60, 80 and 100 m did not show significant differences in relation to the conventional manual measurement method, indicating that the collection methodology and aerial image processing obtained by RPA enables estimating the volume of wood logs stacked in an industrial stockyard with the same level of accuracy in relation to the conventional manual measurement method.
- The volumetric estimates of the wood logs by the SfM-MVS photogrammetric technique obtaining the images collected with a flight height of 100 m showed the smallest variation when compared to the conventional measurement method.

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