Potential of dense matching for DSM generation in tropical forests using UAV images

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Highlights: Reliable measures of the forest canopy can provide essential information for forest management. This work is a feasibility study of automatic generation of DSM in tropical forests, using dense image matching approaches, with UAV and aerial images of different resolutions.

Key words: *DSM, image matching, tropical forest.*

Introduction

Reliable measures of the forest canopy can provide essential information for climatic analysis, nutrient stocks, carbon cycle, forest management and other factors affecting the biosphere. Indirect methods for estimating forest parameters, such as using laser scanners or digital images, are a potential alternative to certain destructive and expensive direct methods. Automatic generation of DSM using correspondence of optical images has been exploited for many years and is a good alternative for LASER scanning because it can generate accurate 3D data with low-cost and light-weight systems. Digital cameras combined with unmanned aerial vehicle (UAV) platforms have been used in photogrammetric surveys, providing images with suitable quality and advantageous cost.

The most used matching methods are based on gray level, features, or global functions minimization. Feature-based methods produce sparse point samples [1]. Dense image matching methods can be based on area, pixel-wise, such as semi-global matching (SGM) [2], and can use multiple images. Research on image-based DSMs has been intensified due to the recent development of efficient matching algorithms and improvement in image quality [1, 3]. However, efforts are still being directed to the development of new techniques in order to reduce matching problems and edition steps. In addition, there is a lack in research on the use of image-based matching for DSM generation in tropical forests, which present a dense canopy formed by different trees species, varying in height and diameter. Determination of homologue points in the forest canopy is a complex task due to the multifaceted geometric shapes of the canopy, occlusions, shadows, movements, and structural similarities [4]. Variations in solar illumination and in viewing angles also limit image matching efficiency [5]. Also, UAV images are acquired in a more turbulent mode than aerial images. In addition, determination of ground control points in forest areas is a challenging task. Consequently, bundle adjustment of UAV forest images is more complex, influencing DSM quality. Most current works are carried out in boreal forest areas, which have different attributes and aspects than tropical forest.

In this context, the main aim of this work is to undertake a feasibility study of the automatic generation of DSM in a tropical forest area using dense image matching approaches, with UAV and aerial images of different resolutions. The commercial INPHO GmbH software MATCH-T DSM was used for the generation of two DSMs: with large format aerial images and with the UAV images. A third DSM was generated using in-house software and UAV data. Analysis and comparisons between the DSM were performed in order to verify the potential performance of the software combined with UAV images and middle resolution images in dense forest scenarios. The relevance of this feasibility study is to identify the main drawbacks found in DSM generation using image matching methods in tropical forest areas.

Material and methods

In Brazil, the Atlantic Forest has one of the highest levels of species and endemism rates in the world. However, almost 80% of the original forest has been decimated and the remaining areas are spread in small fragments, about which insufficient information is available. In this work, the study area is located in the fragment called Ponte Branca, which is part of a Federal Protected Reserve, named Estação Ecológica Mico Leão Preto (ESEC MLP), in Teodoro Sampaio, São Paulo State – Brazil.

The Geographic and Cartographic Institute (IGC) of São Paulo State has provided RGB aerial images covering the reserve area. The images were obtained in 2010 with an Ultracam-XP camera, with ground sample distance (GSD) of approximately 45 cm and 1310 x 17310 pixels. The exterior orientation parameters (EOP) of each image were also available. The focal length of the camera is 100.5 mm. The UAV image data set is composed of 67 images with two flight strips over the tropical forest and was acquired in 2014 with a hexacopter multi-rotor, mounted by Nuven.in and Sensormap Companies, using an RGB camera (Sony Next 7), and an on-board dual frequency GNSS receiver (Figure 1(a)).

Before starting the process of DSM generation, accurate Interior Orientation Parameters (IOP) and Exterior Orientation Parameters (EOP) of the images are required to achieve necessary quality in the DSM generation process. The IOP of the Ultracam-XP and EOP of each image were released by IGC. Regarding the UAV data, a calibration process of the camera was performed at the 3D calibration field of Unesp. Even though the coordinates of the camera perspective centres (PCs) were obtained directly with the dual frequency receiver, a refinement of these parameters was made using bundle adjustment, since the coordinates do not have the required accuracy to eliminate the total vertical parallax of each model. The coordinates of the PCs directly determined by GNSS was used as weighted constraints. Tie points were automatically measured by image matching. This process is highly influenced by the characteristics of the vegetation areas increasing the probability of false matches, demanding careful supervision by the operator. Ground Control Points (GCP) outside and inside the forest were used. However, the accuracy of the GCP inside the forest is highly affected by the forest canopy, which causes attenuations or signal blockage. The points inside the forest were considered as vertical control points in the bundle adjustment.

Firstly, a DSM of the entire fragment was generated with the Ultracam-XP imagery using MATCH-T DSM software. Then, two DSM of a smaller area were generated with the UAV images, one with MATCH-T DSM and the other one using the software developed in-house. MATCH-T DSM performs the correspondence in the image space using rectified image pairs, which are selected for each 3D point based on the viewing angle and matching unit. Feature-based matching (FBM) is applied as a first step to establish the basis for the next levels. Then, area-based matching and least squares refinement are performed. The high-density surface model is computed using an adaptation of the semi-global matching (SGM) method. Finally, all matching results are fused in the object space to calculate the final 3D coordinates [6]. The in-house algorithm uses a multi-image matching approach performed in the object space and it was implemented with the Vertical Line Locus (VLL) technique. The correlation coefficient was used to calculate a similarity measure. The VLL performs a geometric constraint in the search space during the image matching process, starting from the object to the image space [7]. Assuming that the EOP of each image and the approximate heights of the area are known, the planimetric position (X and Y) of a point P on the surface is selected. Maximum and minimum values are established ($Zmax = Z_0 + \Delta Zmax$ and $Zmin = Z_0 + \Delta Zmin$) to bound the search range for each vertical line search; also, a dZ increment is defined; Z_0 is the approximate height of the point. The photogrammetric coordinates of the point (x_f, y_f) are calculated for each image in which this point appear, using the collinearity equations; the windows are defined taking these image coordinates as the center; the correlation coefficient is calculated between all possible image pairs. The process above is repeated until the largest height value $Zmax$ has been achieved. The height Zi, in the search range, having the highest similarity value between the windows, is assumed to be the estimated height of point P. Unlike MATCH-T DSM, the matching calculation is performed in the object space in the implemented algorithm, and the best matches directly indicate the 3D positions. The projection of the X, Y, Z coordinates leads to sub pixel coordinates within the images, and intensity interpolation is performed for the similarity calculation. Each point (X, Y) of a window defined in the object space is projected in all possible images, and the intensity values are assigned to these points, creating rectified templates centred on (X, Y) for each image. In order to reduce problems of scale and variations in viewing angle, an on-the-fly rectification procedure of the correlation windows is applied.This process is important to reduce the effects of perspective distortion and relative rotation between the planes of the images.

Experiments and results

The bundle adjustment was performed for the UAV images using as observations PC coordinates, 2 GCP and 356 tie points and 4 checkpoints. Table 1 presents the Root Mean Square Errors (RMSEs) in the GCPs and in the checkpoint coordinates obtained from the bundle adjustment. The altitude component presented RMSE around of 60 cm, which is close to the quality of the GNSS accuracy obtained in the forest clearings.

Table 1: RMSE obtained from GCPs and checkpoints in object and image spaces.

Coordinate	GCP	Checkpoint
	RMSE(m)	RMSE (m)
E	0.0047	-
N	0.104	-
h	0.044	0.668
	(pixel)	(pixel)
Image x	0.485	0.659
Image y	0.3003	0.224

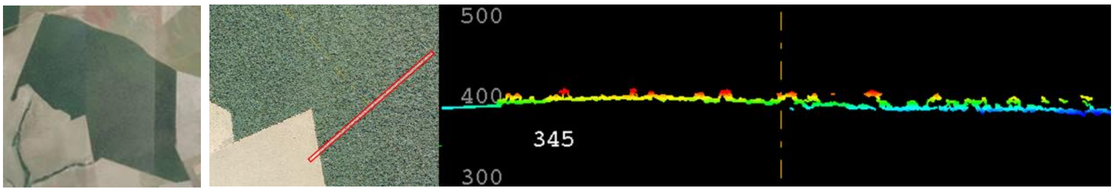
Figure 1(a) shows the hexacopter used to acquire the forest images. In (b) a UAV image sample is presented. Figures 1 (c) and (d) illustrate the characteristics inside the forest and the problems for GCP measurements.

The DSM with Ultracam-XP data set was generated using four images. Figure 2 shows a mosaic of the aerial images. The DSM of the entire Ponte Branca fragment was generated in the MATCH-T DSM software. Figure 2

(a) shows the Ponte Branca fragment and Figure 2 (b) presents a cross section extracted from the DSM. It can be seen that it is possible to observe the variations in canopy height with this DSM. This characteristic is important for several investigations, such as the classification of successional forest stage.

(a) (b) (c) (d)

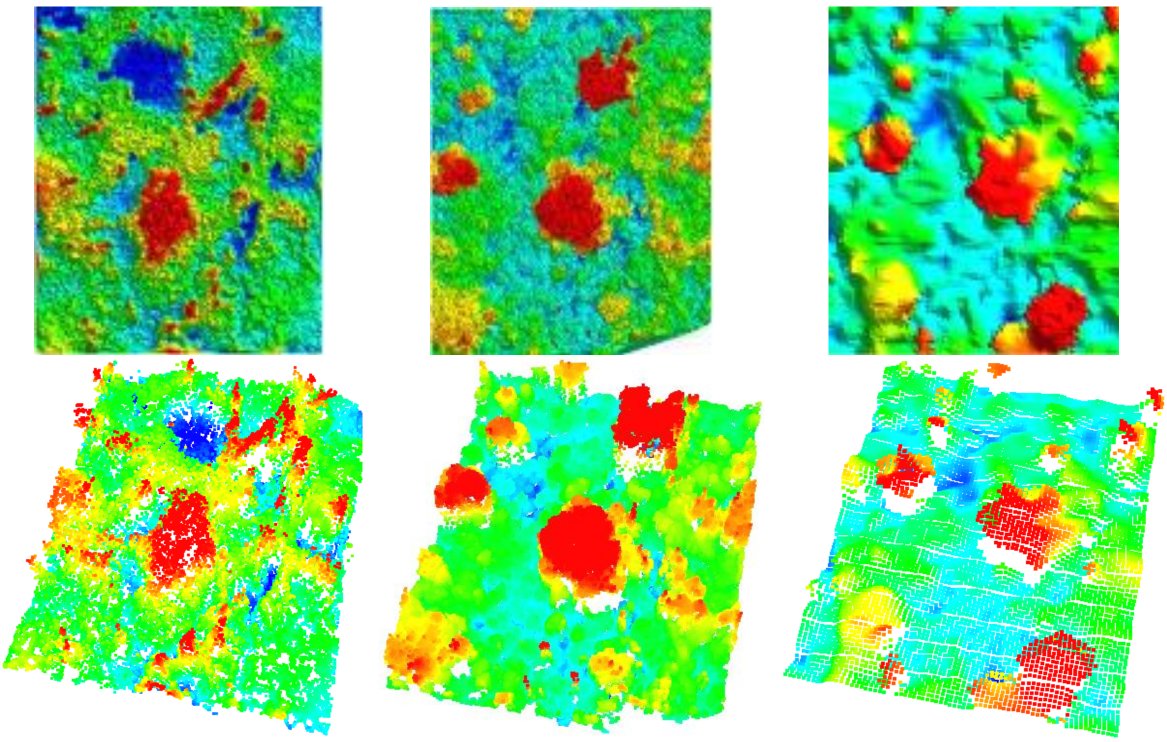
Figure 1: (a) Hexacopter used to acquire the images; (b) UAV image sample; (c) control point collection inside the forest and (d) characteristics inside the forest.



(a) (b)

Figure 2: (a) Mosaic from Ponte Branca area; (b) cross section extracted from the Ultracam-XP DSM.

A block with six images was used for the experiments with the UAV dataset and the DSMs were generated over an area of 80 m x 100 m. Figure 3 shows the DSMs generated from (a) the software developed in-house using correspondence in the object space and UAV images, (b) software MATCH-T DSM and UAV images and (c) software MATCH-T DSM and Ultracam-XP images. Visual analysis of DSMs (a) and (b) indicates that it was possible to recover the shape of several tree crowns in a large scale, which is important for several forest applications. MATCH-T DSM shows more dense and detailed information. It is worthy of note that DSMs (a) and (b) have some differences with respect to DSM (c), which is probably due to the difference in the epochs of image acquisition as well as different resolutions of the images used.



(a) (b) (c)

Figure 3: DSMs generated using (a) the implemented method and UAV images; (b) MATCH-T DSM and UAV images (c) MATCH-T DSM and Ultracam-XP.

Table 2 shows the minimum and maximum height values for each DSM. These values are similar to the minimum and maximum height values of the tie points.

Table 2: DSM minimum and maximum height values.

DSM	Min	Max
UltracamXP MATCH-T	409.45	435.24
UAV MATCH-T	392.61	438.4
UAV VLL	395.27	436.7

Conclusions

A feasibility study of the automatic generation of DSM in tropical forest areas, using dense image matching applied to small-format UAV images and large-format aerial images was described. The objective was to investigate the use of new generation matching algorithms to generate DSM in dense forest areas.

The visual analysis of the results confirms that dense correspondence methods have the potential to generate suitable DSMs in complex areas, such as tropical forest. The DSM generated by software developed in-house provided more spurious points than the DSM of the MATCH-T, but was found to be promising given some improvements. The results also showed that the DSM of tropical forest areas can be derived from images acquired with a relatively stable platform, such as aerial images, and from images acquired with a less stable UAV platform. The tree DSM generated indicated to be suitable to perform different analyzes, such as the study of the successional stage of the forest, tree species identification and tree density calculation. UAV DSMs present high information density because of the high resolution of the images. Quantitative analysis of the DSMs could not be performed due to lack of reliable reference data.

For future studies, new study areas and different software will be considered. Also, the results will be compared with laser data and checkpoints. Challenging areas for the matching image process, such as homogeneous areas, occlusions and shadows, deserve more studies. In addition, the implementation of filtering methods to reduce spurious points must be put in place in the software under development.

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