APPLICATIONS OF PHOTOGRAMMETRY FOR ANALYSIS OF FOREST PLANTATIONS. PRELIMINARY STUDY: ANALYSIS OF INDIVIDUAL TREES

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ABSTRACT:

This paper presents a method for using high detail volumetric information, captured with a land based photogrammetric survey, to obtain information from individual trees. Applying LIDAR analysis techniques it is possible to measure diameter at breast height, height at first branch (commercial height), basal area and volume of an individual tree. Given this information it is possible to calculate how much of that tree can be exploited as wood. The main objective is to develop a methodology for successfully surveying one individual tree, capturing every side of the stem a using high resolution digital camera and reference marks with GPS coordinates. The process is executed for several individuals of two species present in the metropolitan area in San José, Costa Rica, *Delonix regia* (Bojer) Raf. and *Tabebuia rosea* (Bertol.) DC., each one with different height, stem shape and crown area. Using a photogrammetry suite all the pictures are aligned, geo-referenced and a dense point cloud is generated with enough detail to perform the required measurements, as well as a solid tridimensional model for volume measurement. This research will open the way to develop a capture methodology with an airborne camera using close range UAVs. An airborne platform will make possible to capture every individual in a forest plantation, furthermore if the analysis techniques applied in this research are automated it will be possible to calculate with high precision the exploit potential of a forest plantation and improve its management.

1. INTRODUCTION

Traditionally manual instrumentation has been the main approach as a measurement method for individual trees in a forest plantation. These manual methods include meter tapes, diameter tapes, calipers and prisms to determine diameter. Telescopic bars, Blume-Leiss hypsometers, Haga altimeters, Suunto inclinometers to perform direct measurements of tree height. However, equipment cost, and lack of access and clearance required by these instruments have led to the research of new tools, many of them digital, to perform the same measurements.

Recently remote sensing systems have been on the spotlight of researchers interested in topics such as forest mass and growth. Especially photogrammetry has been applied in several studies with different strategies in order to calculate wood volume of an individual tree captured in photographs. For instance, (Dean, 2003) calculates the volume of an individual tree taking as a starting point a single photograph of the subject along with a calibrated reference framework. In this study volume data obtained from the photograph is multiplied by a specific taper factor for the stem.

Another remarkable example in photogrammetry applications is the study by (Larsen, n.d.), in which several photographs, taken from different positions around the subject, are processed to calculate a taper profile for the individual. In (Knyaz et al., n.d.), volume for a package of cut trees is estimated using 3D models from video camera stills and a custom made software for a wood-working facility.

Both species selected for this paper are part of the biodiversity present in the whereabouts of the National Center for Advanced Technologies (CeNAT), and this paper aims to test an applied method for individual tree measurement using photogrammetry techniques, that could be applied later on a forest plantation as a resource to determine forest growth.

1.1 PHOTOGRAMMETRY

Photogrammetry is a technique of image analysis that allows obtaining volumetric information from different photographs of the same target. By measuring differences in position and angle of each take it's possible to reconstruct the object in a digital 3D model and even characterize it through its dimensional properties. Along with the digital era and emergence of higher performance computers of the last decade, it's possible to perform a photogrammetric process of a large number of photographs, as well as production of digital models (Lerma-García, 2002). If a photogrammetric model is going to be used as a measuring tool for obtaining information from the target, calibration is mandatory, this can be achieved by including a calibrated reference framework along with the target captured. For this study several strategies for this framework were tested, being the most successful the placing of three reference markers in an equilateral triangle aligned to the geographic north with a single geographic coordinate for the first marker. This approach yielded a precision in measuring of 3 millimeters. (More detail of the reference framework will be discussed in section 2.5.1).

2. METHODS

2.1 Area of study

The research took place in the whereabouts of the Centro Nacional de Alta Tecnología, Franklin Chang Díaz facilities, in the city of San José, Pavas district, 9°57'01.30" North, 84°07'26.87" West, Costa Rica. According to (Ortíz, 2014), this location has use capacity IV (Agricultural with strong limitations) surrounded by urban use. Inside the facilities are permanent infrastructure and green areas with forest specimens as *Tabebuia rosea*, *Delonix regia*, *Spathodea campanulata* P. Beauv, *Eriobotrya japonica* (Thunb.) Lindl., *Parkinsonia aculeata* L. and several specimens of the arecaceaes family. According to the life zones proposed by Holdrigde in 1987 the location is part of a humid premountain forest (bh-P), with annual precipitation of 2000-4000 mm and biotemperature of 18-24 °C (Ortíz, 2014).

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2.2 Species selection

Given specimens density the facilities of CeNAT, three specimens of *D. regia* (malinche), as shown in Figure 1, and three specimens of *T. rosea* (roble sabana), Figure 2 where selected as subjects. Roble sabana's natural extent comprises Mexico, Central America (including Panama), Colombia and Venezuela. In Costa Rica it's distributed along the Pacific Slope, including regions of Guanacaste, Puntarenas, Puriscal, Valle Central and Zona Sur including Osa Península, from 0 to 1200 meters above sea level. A roble sabana can reach from 5 to 20 meters in height and from 25 to 75 centimeters in diameter. It's wood has several applications, from construction, tool crafting and paper industry (Sánchez and Cascante, 2008). A specimen of malinche, on the other hand, can be up to 20 meters high and around 50 centimeters wide (stem diameter), with a crown spread out in a horizontal pattern. This species is native of Madagascar, but can be found in tropical areas as ornamental. In Costa Rica, malinche specimens can be found in almost every urban area countrywide between 0 and 1200 meters above the sea level. Produces flowers from May to June and it's fruits remain attached to the tree for almost a year (Sánchez and Cascante, 2008).

Figure 1: D. regia specimens sampled.

Figure 2: T. rosea specimens sampled.

2.3 Measurement and variable estimation

2.3.1 Diameter at breast height (DBH) By means of a meter tape, tree circumference C was measured in centimeters, about 1.3 meters from the surface. Once C is taken the Equation 1 was applied to obtain

$$DBH = \frac{C}{\pi} \tag{1}$$

2.3.2 Height Commercial height was measured with a meter tape taking the distance between above the roots and below the first thick branch. In the scope of this paper this is considered as the commercial segment of the tree and the same criteria is applied to trim the digital model later on Section 2.5.3

2.3.3 Basal area Equation 2 was applied to obtain basal area:

$$G = DBH^2 * \frac{\pi}{4} \tag{2}$$

Where G = Basal area in m^2, DBH = Diameter at breast height in m.

2.3.4 Volume For the estimation of volume a simple cylindrical volume is calculated, taking the basal area as the base of the cylinder and commercial height as height of the cylinder. An additional taper factor is included in the equation to penalize volume in order to include shape deformation of the tree stem into the estimation. Equation 3 is the estimation of commercial volume of the tree, given in m^3.

$$Vc = G * Hc * Ff \tag{3}$$

Where Vc = Commercial volume in m^3, G = Basal Area in m^2, Hc = Estimated commercial height (height from above the roots to below the first thick branch) in m, Ff = Taper factor for the species, in both species the value taken was 0.45.

2.4 Photogrammetry process

2.5 Equipment and software

The photographs captured for this study where taken with a semi-professional digital camera model Canon EOS Rebel T2i with a Canon EFS 18-55mm Lens. Each photograph taken has 3456 pixels width per 5184 pixels height (pictures where taken in portrait to maximize subject data inside the frame). Agisoft Photoscan is the processing software used to align the pictures and generate the photogrammetric model. Photographs were previously calibrated using Agisoft Lens and the official manufacturer's specification for the camera en lens. Blender 2.73 was used to refine solid 3D models generated in Agisoft and exported in .OBJ format.

2.5.1 Reference framework Agisoft Photoscan features a tool for generating reference markers, these markers are catalogued by the software and their patterns are automatically recognized during the alignment process, which make them very convenient for the application in this study. The reference framework is a square panel of 36 inches side with three markers located as the vertices of an equilateral triangle centered in the panel. Additionally a north arrow is located in the top-left corner of the panel, allowing the alignment of the panel with the geographic north. The distance from the center of each marker to each other is 53.4 centimeters with a error margin of 2 millimeters. The layout and final result are illustrated in Figure 3 and Figure 4 respectively.

2.5.2 Image capture The reference panel was placed next to each subject, avoiding shadows from the subject itself and ensuring the panel was aligned with the geographic north with assistance of a digital compass. The geographic coordinates of the first marker (Labeled A in Figure 3) were captured with assistance of a Global Positioning System (GPS) with an average collection error of 3 meters (the entire digital model is displaced by the GPS error, however the internal precision of the model is ruled by the error in the distance between the markers, around 3mm as stated before). Once the framework was in place and its coordinates taken, three pictures of the panel were taken, centering in frame each of the markers (A, B and C respectively) and ensuring the other two markers were clearly visible in the pictures. Next, a burst of pictures was captured starting at the reference framework and ending in a picture of the target framed and centered.
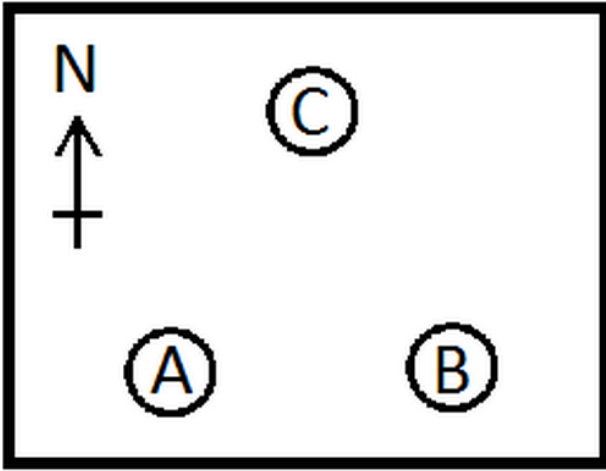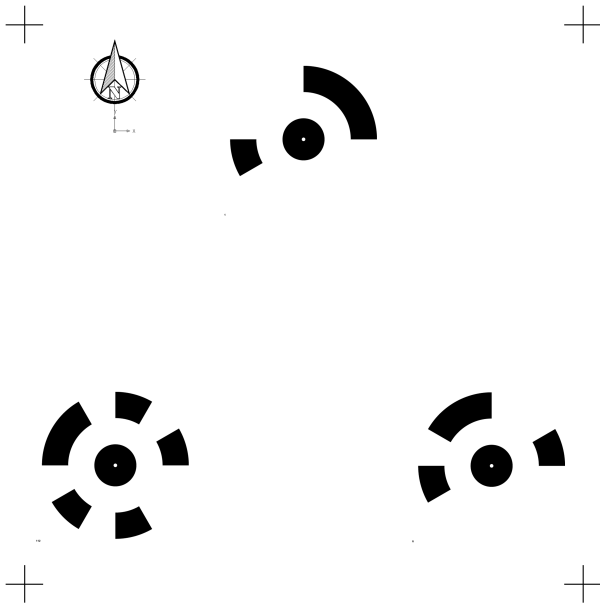
Figure 3: Layout of reference panel.

Figure 4: Reference panel final art.

These pictures would help later as tie shots between the reference framework and the target. Right after these preliminary steps, two bursts of shots were taken in a full circle around the subject covering every angle possible, the first burst captures the roots and stem, the second burst captures the stem and crown, both at an average distance of 5 meters away from the target. In total 100 to 135 pictures were taken for each subject, plus approximately 13 additional tie shots. In every case where the crown and stem didn't fit a single frame, a minimum 20% overlap between the lower and upper circle was guaranteed.

2.5.3 Processing and model generation Before processing the data set, the geographic system must be assigned to the reference frame. First the coordinates for marker A are translated to CRTM 05 Coordinate Reference System (CRS), the official for Costa Rica, this CRS has the additional benefit that the coordinates are expressed in meters and the projection is planar, simplifying the equations required to calculate coordinates for markers B and C. Having A as the origin of the local coordinate system, and the segment AB perpendicular to the north axis, and taking

P as the geographic location of A expressed in meters, where P_x is the longitude and P_y is the latitude, the geographic coordinates of A, B and C can be calculated by equations 4, 5 and 6 respectively:

$$A = (P_x, P_y) \tag{4}$$

$$B = (L_{ab} + P_x, P_y) \tag{5}$$

$$C = (\cos(\alpha)L_{ac} + P_x, \sin(\alpha)L_{ac} + P_y) \tag{6}$$

$$\alpha = \arccos(\frac{(L_{ac}^2) + (L_{ab}^2) - (L_{bc}^2)}{2L_{ac}L_{ab}}) \tag{7}$$

Where L_{ab} is the length of segment AB, L_{bc} is the length of segment BC and L_{ac} is the length of segment AC.

Once the coordinates for the reference framework are ready, the dataset is calibrated with Agisoft Lens and then included in an Agisoft Photoscan project in three different chunks. The first chunk is comprised by the tie shots, the markers are recognized automatically by the software, if any of the markers is not identified correctly, it can be assigned manually by the user. Next the entire subset is calibrated with the coordinates of the markers, allowing the whole model to scale accordingly to real world dimensions. In this part of the process it's possible to verify the model precision. The second and third chunks correspond to the lower and upper rings of shots around the subject, note that if the subject fits entirely in frame, the upper ring is not required to reconstruct the model. During the alignment process the software searches visual patterns shared by any two or more pictures inside a chunk and, based on differences in distance and size between patterns, each shot is aligned in a spatial reference frame that is, at the same time, aligned with the coordinates of the reference markers previously identified. The final alignment step is to merge the chunks into one single dataset. This strategy (three separate chunks merged afterwards) reduces noise during the alignment process and improves precision. At this point a sparse point cloud is generated by the software and every picture used in the process has already a spatial reference in a georeferenced tridimensional space. With the pictures aligned the software can generate a dense point cloud that increases detail drastically, this point cloud is already a viable model for analysis. The dense point cloud can be manually trimmed, removing noise and unused data from the model (only the section of the stem between above the roots and below the first thick branch is considered for the volume estimation). Afterwards a solid 3D model is generated that can be exported to a 3D design software, like Blender, for refinement (and imported back to Agisoft seamlessly).

2.5.4 Measurement and variable estimation From the refined model is possible to measure distance by means of the scale tool available in Agisoft Photoscan. Diameter in the model is calculated, by means of the scale tool, using an average between two perpendicular diameters in the bottom side and two perpendicular diameters in the top side of the refined solid model. Volume, on the other hand, is calculated using the volume and area tool, also available in the software, over the refined model. Both tools deliver results in the scale given to the spatial reference for the project, in this case meters and cubic meters, respectively.

3. RESULTS

3.1 Precision analysis

The distance between the reference markers reported by the model is taken as input to verify the error of the model. Table 1 summarizes distances for each marker to each other and maximum distance error.

Tree	B-C(m)	A-C(m)	A-B(m)	Error(mm)
M1	0.534168	0.533175	0.534883	0.883
R1	0.533987	0.533391	0.534850	0.850
R2	0.534000	0.533289	0.534937	0.937
M2	0.532387	0.533776	0.536048	2.048
M3	0.532387	0.533776	0.536048	2.048
R3	0.533653	0.533600	0.534974	0.974

Table 1: Model distance from each marker to each other expressed in meters and maximum distance error expressed in millimeters.

As appreciated, error for distances measured in the model is close to 3mm in every subject, yielding a general model precision of less than 3mm for distance measurements. Note that the meter tape used to measure distance of markers directly on the reference panel has an uncertainty of 1mm and for trees M1, R1, R2 and R3 error in distance is actually under instrument uncertainty.

3.2 Diameter and volume comparison

Table 2 demonstrates that the diameter captured in the field has several discrepancies towards diameter captured using the software tool. Both measurements assume the tree is cylindrical, however the capacity to measure average diameters might increase the confidence of this variable when captured with from the photogrammetric model.

Tree	Common Name	Manual DBH(m)	Digital DBH(m)
M1	malinche	0.6175	0.5487
R1	roble sabana	0.6239	0.7225
R2	roble sabana	0.5523	0.7305
M2	malinche	0.5698	0.5983
M3	malinche	0.7624	0.7230
R3	roble sabana	0.5952	0.6622

Table 2: Diameter comparison between manual method and photogrammetric (digital) approach.

Regarding volume, Table 3 demonstrates that volume calculated using the equations proposed in Section 2.3 present a solid tendency to underestimate volume of the subject when compared to the results of volume calculated using the refined solid 3D model inside of Agisoft Photoscan.

Tree	Manual Volume(m^3)	Digital Volume(m^3)
M1	0.3414	0.4015
R1	0.9171	0.8214
R2	0.2875	0.5681
M2	0.3060	0.7774
M3	0.4108	0.5192
R3	0.2504	0.4007

Table 3: Volume comparison between manual and digital methods.

4. CONCLUSIONS

According to the precision and final results analysis, it is possible to conclude the following statements:

1. Results from the manual method include uncertainty inherent to several assumptions about the shape of the tree, this assumptions render impossible to establish a direct numerical error to the estimation, in contrast the photogrammetric approach takes into consideration the entire volume of the analysed tree section and applies an arithmetic approach to calculate volume, yielding a direct numerical error derivable from the original precision of the model.
2. As a direct consequence of the last statement, the photogrammetric approach for volume measurement is more precise than the manual approach exposed in this study.
3. It is possible to measure diameter of the exploitable section of the tree with higher precision, when using photogrammetric analysis in contrast to the manual method studied.
4. The manual method and proposed equations present a solid tendency to underestimate volume of the tree segment as calculated by the tool provided by the photogrammetric suite. Higher precision and removal of underestimation could represent a direct positive impact on profit for the owner of a forest plantation.
5. The photogrammetric method proposed presents potential new features that are not possible using the manual method. For instance:

   - The technique could impact on a cost reduction for a plantation owner, as less technicians would be necessary to capture data on the field (one for the photogrammetric approach in contrast to minimum 3 for the manual approach).
   - The technique could allow a more precise analysis of the exploitable wood of standing trees, it would be possible to measure wood volume of thick branches and other features of the tree that are neglected due to difficulties of measurement of standing trees.
   - It could be feasible to calculate actual saw logs directly from standing trees, optimizing benefit ratio of the plantation, using only the photogrammetric suite and a 3D design tool as blender.

5. RECOMMENDATIONS AND LIMITATIONS

Given the scope of this study, is not possible to determine if results will remain for a higher scale, it is recommended that the experiment developed in this paper is reproduced with a higher sample, using different wood exploitable species in actual forest plantations. As well it is recommended to repeat the experiment with other manual methods used to estimate exploitable wood in a forest plantation.

The data capture approach proposed for generating and calibrating the photogrammetric model was refined empirically, reinforced by the official documentation provided by the software manufacturer, an experiment focused in precision improvement for photogrammetric models using the same tools and conditions as this paper could enrich the results of this study and it's derivatives, if any.

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