

# Measurement of Tree Architecture by Close Range Photogrammetry for Use in Radar Backscatter Studies

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## ABSTRACT

Results from forest canopy radar scattering models proposed in the past years have demonstrated that the scattering coefficient depends not only on the quantity of biomass but also on the three-dimensional tree architecture (size, shape, and orientation of trunks, branches and foliage). For this reason an accurate forest database is needed for further validation and development of canopy radar scattering models. Unfortunately, acquisition of information about tree architecture is usually a difficult task. As a result, the different models developed are fed with simple geometric characteristics. This fact reduces the accuracy of the predictions. In this paper a new approach is addressed for measuring the main geometrical characteristics of trees in an accurate and economical way based on the use of close range photogrammetry. Two or more photographs of the trees are processed to retrieve meaningful parameters. The parameters being considered now are diameter at breast height (dbh), tree height, crown depth and size, length and orientation of the branches. Good agreement with direct measures was obtained.

**Keywords and phrases:** close range photogrammetry, tree architectural measures, SAR

## 1.0 INTRODUCTION

Synthetic Aperture Radars (SAR) have evolved into a powerful tool to monitor the earth's surface. The ability of microwaves to reflect into forest canopies, as well as the fact that radar can "see" through cloud and operate night and day has converted SAR into the prominent technique for monitoring forest canopies. However electromagnetic interaction with trees and forests is a complex mechanism whereby the three-dimensional architecture of trees plays a principal role. Several theoretical models have been developed to better understand radar backscatter from this kind of media (RICHARDS 90). Among all the models proposed in past years, those based on the radiative transfer (RT) theory (FUNG 94, ULABY 86) are the most widely used (KARAM 92, ULABY 90).

A common characteristic of all electromagnetic scattering models, regardless of the approximation they use, is that they need a realistic canopy description as input or as a way to verify their accuracy. Several approaches for describing forests have been proposed in the past years. For example in MARTENS 91 a stratified sampling method is presented in order to measure a walnut orchard. In LIN 99 fractal-based L-systems are employed to construct a realistic tree structure. More recently a physiological-based approach is used to feed various theoretical scattering models (CASTEL 01). The necessity for some kind of direct measures of tree architecture (tree height, diameter at breast height (dbh), branch size and orientation, etc.) is common to all the above

approaches. Unfortunately, this is a difficult, time-consuming and expensive task. This lack of accurate geometric data of forest canopies has retarded development and validation of different radar scattering models.

In this paper the use of digital close range photogrammetry is proposed to measure relevant tree parameters from an electromagnetic point of view. Photogrammetry is a technique to obtain information about the position, size and shape of an object by measuring pictures of that object instead of directly measuring the object (ATKINSON 96). Historically the most common application of photogrammetry has been the production of aerial maps. The introduction of digital techniques and the appearance of CCD cameras has extended the use of photogrammetry to multitude of fields. This paper shows how to measure a forest in an economical and accurate way by photogrammetry. We have chosen two chestnut-tree (*castanea sativa*) orchards to perform our experiment. Two or more photographs from each tree have been processed to retrieve its height, dbh, crown depth and insertion angle and size of primary branches.

In section 2 of the paper we present the basis of the close range photogrammetry. Section 3 describes briefly the two test sites. Finally, in section 4, the experimental results are shown and compared with direct measures from the trees.

## 2.0 BASIS OF CLOSE-RANGE PHOTOGRAMMETRY

The term close-range photogrammetry refers to a situation when the object being measured is placed less than about 100 meters from the camera station. In this section the theoretical basis of close-range photogrammetry is summarized. Only the situation when camera axes are convergent and images are obtained from all angles is considered.

### 2.1 Camera orientation

The first step to developing a mathematical model of the photogrammetric process is to define the camera orientation. To do this two coordinate systems are defined. The primary coordinate system (XYZ) is located arbitrarily in the object space. The secondary coordinate system (xyz) has its origin at the exposure center of the camera station and the xy plane is parallel to the plane of projection (film or CCD). The two coordinate systems are illustrated in Figure 1. This figure also shows the image formation process. A ray coming from point A passes through exposure center O and intercepts the image plane at a. The distance from O to the principal point (the point where optical axis intercepts image plane) is called principal distance and is denoted by c in the figure.

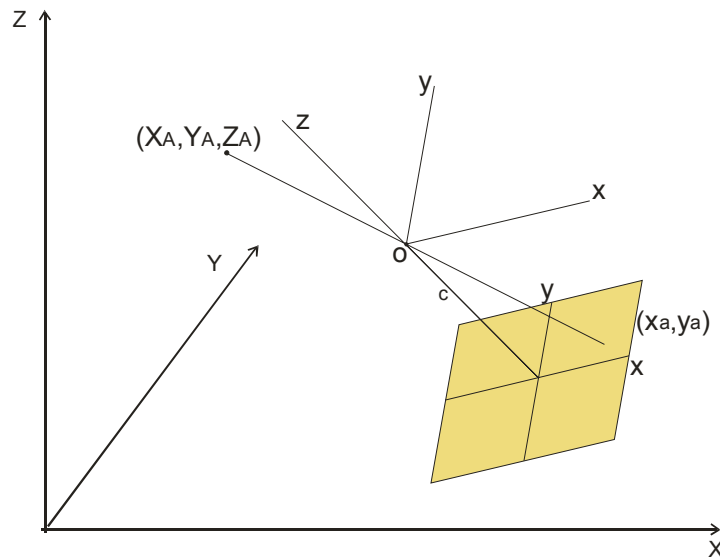


Figure 1: Coordinate systems and imaging process

Secondary axes are related to primary ones through three sequential rotations around each axis and a translation,

$$X_A = X_o - \mu R^t x_a \quad (1)$$

where  $\mathbf{X}_A$  and  $\mathbf{X}_O$  are the position vectors of A and O relative to the XYZ axes,  $\mathbf{R}$  is the rotation matrix (ATKINSON 96) and  $\mu$  is a scalar quantity. The rotation matrix accounts for rotations around the three principal axes. From this relation it is possible to obtain the *collinearity equations*, based on the fact that a, O and A lie on a line and which relate image coordinates to the rest of the parameters:

$$x_a = \frac{-c[r_{11}(X_o - X_A) + r_{12}(Y_o - Y_A) + r_{13}(Z_o - Z_A)]}{r_{31}(X_o - X_A) + r_{32}(Y_o - Y_A) + r_{33}(Z_o - Z_A)} \quad (2)$$

$$y_a = \frac{-c[r_{21}(X_o - X_A) + r_{22}(Y_o - Y_A) + r_{23}(Z_o - Z_A)]}{r_{31}(X_o - X_A) + r_{32}(Y_o - Y_A) + r_{33}(Z_o - Z_A)} \quad (3)$$

Collinearity equations may be corrected to account for non-ideal behaviour of the camera. First of all it is necessary to correct the principal point displacement introducing the principal point offset  $(x_o, y_o)$  so that the new image coordinates are  $x'_a = (x_a - x_o)$  and  $y'_a = (y_a - y_o)$ . Secondly, lens distortion must be corrected. Distortions can be grouped into *radial* and *decentering* distortion (see ATKINSON 96 and ASPRS 89 for more details) although only the former is usually taken into account because of the small value of the latter. Radial distortion is expressed in terms of polynomial series

$$\delta_r = K_1 r^3 + K_2 r^5 + K_3 r^7 + \dots \quad (4)$$

where  $\delta_r$  is the image radial displacement,  $r$  is the radial distance from the principal point and  $K_i$  are the radial distortion coefficients. Only the lower order terms in the series are relevant for most cameras.

These parameters, as well as the principal distance  $c$ , constitute the so called *calibration parameters* and must be determined before continuing with the photogrammetric process.

If  $c$ ,  $(x_o, y_o)$  and  $(X_A, Y_A, Z_A)$  are known then equations (1) and (2) will have six unknowns: rotation angles (that appear in the equation through the elements  $r_{ij}$  of the rotation matrix)  $\omega$ ,  $\phi$  and  $\kappa$  through the three principal axes and coordinates of the perspective center  $(X_O, Y_O, Z_O)$ . These parameters constitute the exterior orientation of the camera station and may be determined by a Least Square Estimation (LSE).

## 2.2 Intersection

If the elements of the exterior orientation of two cameras with exposure centers  $O_1$  and  $O_2$  are known, then it is possible to obtain the coordinates of point A from image coordinates of the homologue points  $a_1$  and  $a_2$ . In this case there are four equations and three unknowns, so a LSE is usually applied. This process is known as intersection and is graphically illustrated in figure 2.

## 2.3 Methodology

In summary, to obtain three coordinates of a point from two or more photographs it is necessary to use a camera with known calibration parameters. These parameters can be obtained from the manufacturer or from a calibration process. Secondly it is necessary to determine the orientation of each camera station. Then homologue points must be identified and its photocoordinates must be measured. Finally  $(X, Y, Z)$  coordinates are obtained by a Least Square Estimation considering orientation parameters as constants and photocoordinates as measures, the point coordinates being the parameters to be estimated.

In our case, an average of six photographs for each tree were processed in order to obtain three coordinates for each point. Once these coordinates are calculated, measures of distances and angles are easily obtained. Processing was carried out by a photogrammetric software.

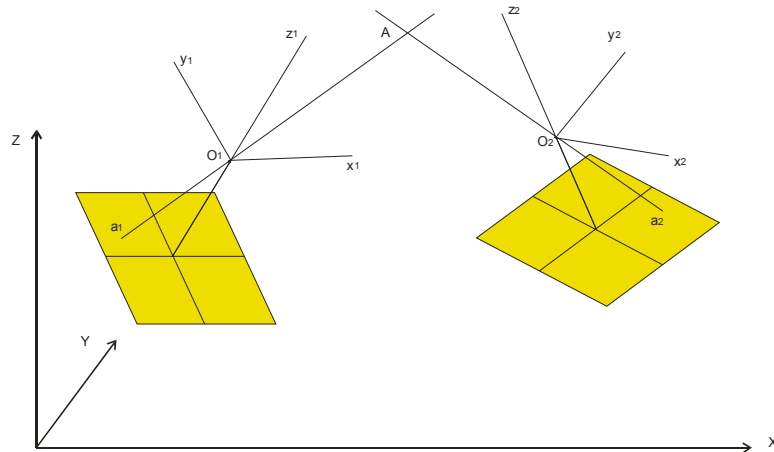


Figure 2: Intersection

### 3.0 DESCRIPTION OF TEST SITES

Chestnut trees (*castanea sativa*) are considered a native species in the Iberian Peninsula and are widely distributed over all the Spanish provinces. Two test sites have been selected to carry out our experiment: a small orchard located at the Forestry and Environmental Research Center of Lourizán and an orchard in the village of Pontecaldelas. Both of them are in the province of Pontevedra (Galicia, Spain) at a distance of approximately 20 km apart (see figure 3).

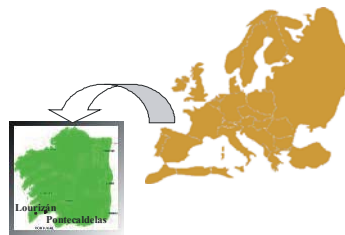


Figure 3: Location of two test sites.

	Lourizán	Pontecaldelas
Area (ha)	1	1
Number of trees	35	47
Density(trees/m <sup>2</sup> )	0.35	0.47
Row Space (m)	5	5
Column Space (m)	5	5
Tree age (years)	6	7
Mean Height (cm)	530	536

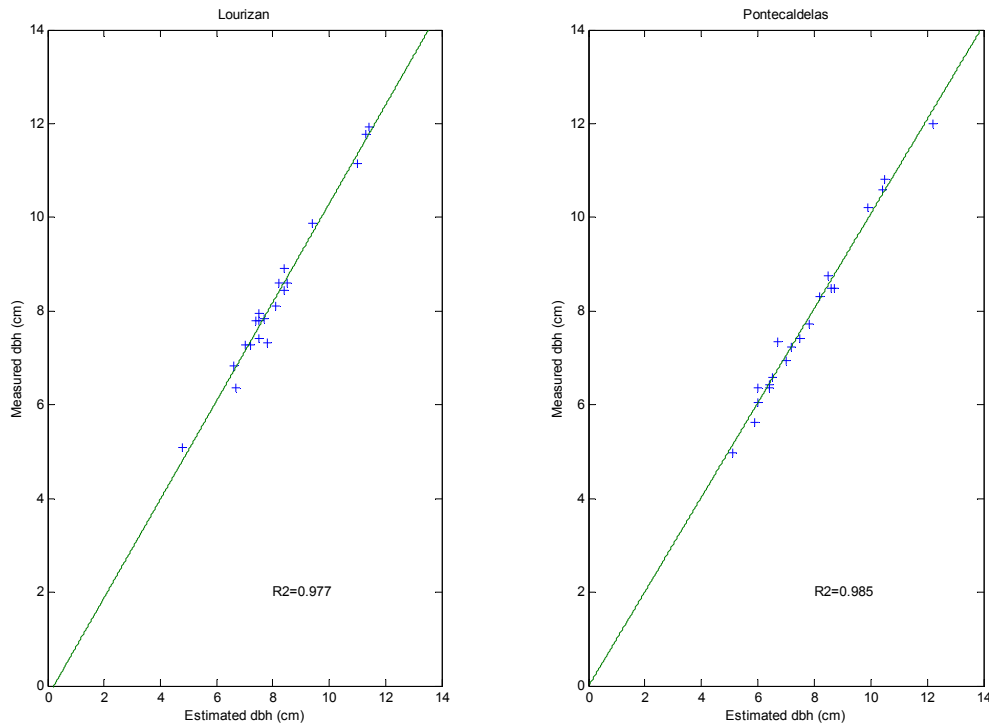
Table 1: Orchard parameters

The trees in Lourizán orchard were six years old at the time of the measuring campaign (April 20-21, 2002). It is an experimental plantation. Trees are positioned in rows with 5 m between each tree. The trees in Pontecaldelas were seven years old when they were photographed (April 24-25, 2002). It is a small orchard of about 1 ha sown inside the reforestation programs. The position of the trees is similar to Lourizán orchard and also 5 m apart.

Both orchards present a flat topography. A total of 20 trees from each orchard were selected and photographed. In table 1 the principal parameters of each orchard are summarized.

#### 4.0 RESULTS

A total of 40 trees (20 from each orchard) were randomly selected and photographed in order to extract their geometric parameters. A total of 261 digital photographs (2240×1680 pixels) were taken and processed with a photogrammetric software. The dbh of the trees were measured manually to validate results from photogrammetric process. This validation is illustrated in figure 3. An excellent agreement between direct measures and derived ones was observed. A correlation coefficient of 0.977 was obtained in the Lourizán orchard whereas the correlation coefficient in Pontecaldelas orchard was 0.985.



*Figure 3: Accuracy of photogrammetric-derived data of Lourizán orchard (left) and Pontecaldelas orchard (right)*

After showing the accuracy of data obtained from the photogrammetric process, it is possible to obtain other parameters such as tree height, branch orientation, branch length and diameter and insertion height of the branches. These parameters describe completely orchard architecture.

Insertion angle, diameter and length were estimated for each branch. Figure 4 shows the distribution of the insertion angle of branches in Pontecaldelas orchard. A total of 105 branches were sampled and measured from their photographs. Angles were measured from the vertical direction. A branch pointing in the trunk direction (straight up) would have an insertion angle of 0, horizontally 90 and straight down 180. We only consider zenith angle (from vertical) as the azimuthal angle can be assumed uniformly distributed.

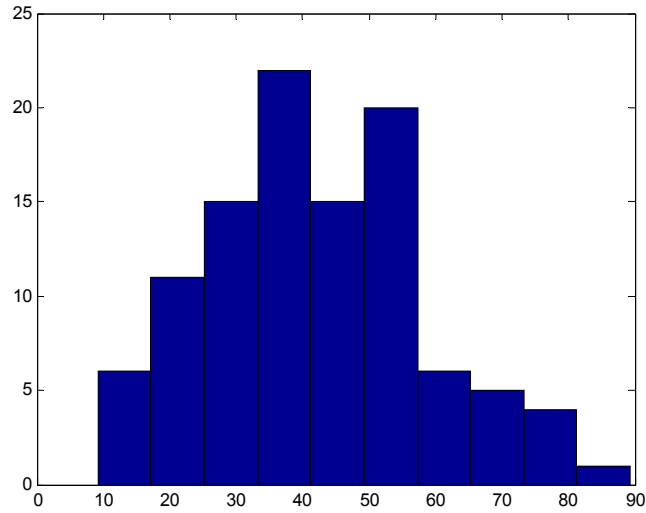


Figure 4: Insertion angle of Pontecaldelas trees (n=105)

Figure 5 shows the distribution of branch length and branch diameter of the trees in Pontecaldelas orchard. Chestnut trees are composed of a few primary branches, long and thick, from which appear the rest of the branches, shorter and thinner. This morphological characteristic can be seen in figure 5.

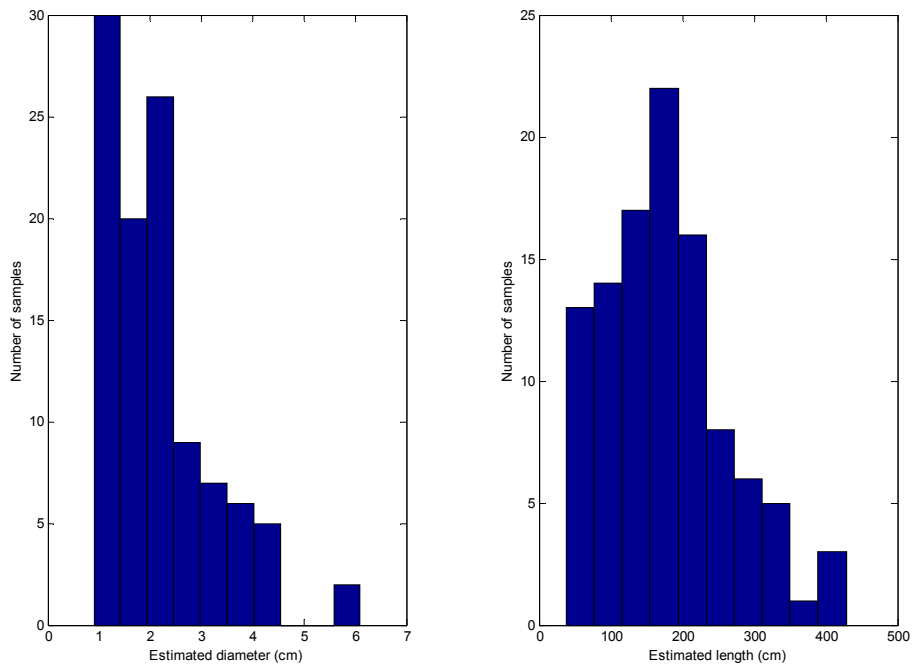


Figure 5: Distribution of branch diameter (left) and branch length (right) in Pontecaldelas orchard

Finally, in figure 6 a 3D reconstruction of the trunk and a few branches is shown. Trunks and branches are modelled as cylinders whose orientation can be obtained through the photogrammetric process. Figure 6 shows only a few branches and the trunk of tree number 5 in Lourizán orchard.

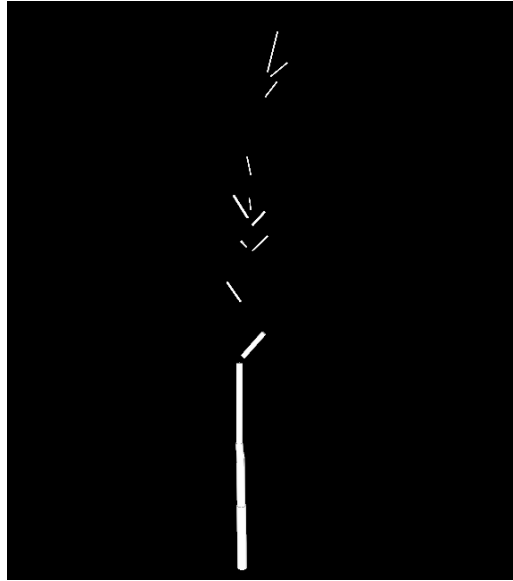


Figure 6: 3D reconstruction of tree 5 in Lourizán orchard (only the direction of the trunk and a few branches is shown).

## 5.0 CONCLUSIONS AND FUTURE WORK

In this paper we have shown how to use photogrammetric techniques to obtain tree architectural measures in an economical and simple way. It is possible to estimate principal parameters of the trees which affect radar backscatter and which are not taken into account in forest inventories such as branch inclination. Therefore digital close-range photogrammetry can be a useful tool to obtain forest databases of forests in the framework of radar remote sensing studies.

Photogrammetric techniques reduce the time of field-work (images of 40 trees were taken by one person in four days) and it is possible to measure parameters which at the time of the measuring campaign were not necessarily required.

Once a database with the principal parameters is obtained, a statistical processing of data is needed in order to obtain density and distribution functions. RT models use as input parameters these functions so this database can be used to validate inversion algorithms or sensibility studies. Such a statistical process is now being carried out.

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