

First results of a non-destructive LIDAR system for the characterization of tree crops as a support for the optimization of pesticide treatments

R. SANZ, J. LLORENS, M. RIBES, J. MASIP, J. ARNÓ, JM. VALLÉS, A.
ESCOLÀ, P. MASSANA, F. CAMP, J. PALACÍN, F. SOLANELLES, E. GIL,
S. PLANAS, L.VAL, JR. ROSELL

Corresponding authors: R. Sanz: rsanz@eagrof.udl.es ;

JR Rosell: jr.rosell@eagrof.udl.es

Department of Agro-forestry Engineering. University of Lleida. Av. Rovira Roure, 191
25198 LLEIDA, Spain

Summary

In order to measure the physical and structural characteristics of the plants, a detection system based on a *Time of Flight* laser scanner known as LIDAR (**L**ight **D**etection and **R**anging) has been developed. The LIDAR system is part of a research program to control and optimise the doses of pesticides applied to crops in order to reduce the environmental and economical impact of diseases control practices. The measurement system is presented, together with the first set of results corresponding to field tests carried out during the 2004 season, in fruit, citrus and vineyard orchards. Finally, the experimental results of the manually-made and LIDAR measurements were compared, to look for useful correlations for certain crop parameters such as tree volume and leaf area index, LAI. The obtained results will be used as support for the decision making related to the optimization of pesticide treatments for crop protection.

Key words: Orchards structural characteristics, Laser scanner, LIDAR, Plant protection products, Remote sensing.

1 Introduction

The measurement and structural characterization of plants can be carried out by means of several detection principles, such as image analysis techniques, stereoscopy photography, analysis of the light spectrum, infrared thermography, ultrasound sensors and light detection and ranging laser sensors. The last one has been applied to this study.

LIDAR (**L**ight **D**etection and **R**anging) is a remote sensing technique based on the measurement of the time a laser pulse takes between the sensor and a target. In recent years, the use of LIDAR sensors has been widely used for the measurement of environmental target parameters, in particular for forest and agricultural systems characterisation (Walklate *et al.* 2002; Tumbo *et al.*

2002; Wei and Salyani 2004). Usually, LIDAR for vegetation studies uses a near-infrared wavelength light, which reflects off leaves, branches and other elements of plants and comes back to the instrument, which determines the distance to each reflecting surface. Since 1994, the Department of Agroforestry Engineering of the University of Lleida and the Department of Agriculture of the autonomous Government of Catalonia, DARP, Spain, are developing a research line whose objective is the development of electronic systems to control and optimise the doses of pesticides applied to crops in order to reduce the environmental and economical impact of disease control practices in agriculture (Rosell *et al*, 1996; Escolà *et al*, 2002). The Spanish *Comisión Interministerial de Ciencia y Tecnología*, under Agreement No. AGL2002-04260-C04-02 has supported a research project (PULVEXACT) whose objective is to adjust and optimize the doses of plant protection products in tree crops –fruit trees, citrus and vineyard-. The University of Lleida and the DARP, together with the Polytechnic Universities of Catalonia and Valencia, are responsible of carrying out the research. The work is focused into two main directions: i) the development of a dose adjustment model and ii) the development of electronic systems to adjust the quantity of applied product according to the crop characteristics. Related with both previously exposed objectives, much effort has been addressed to the detection of the geometry and other structural parameters of plants –such as leaf area index (LAI)- by means of ultrasounds sensors and, more recently, terrestrial LIDAR scanners (Sanz *et al*. 2004). The present work describes the first results obtained by a low cost terrestrial LIDAR measurement system used for the measurement of structural characteristics of plants developed by the authors.

2 Methods

2.1 Detection system

The measurement system consists of a low-cost general purpose divergent laser scanner, or LIDAR, with a maximum scanning angle of 180° and a lateral resolution, which can be variably defined between 0,25° and 1°. The accuracy of measurement in a single shot is about ± 1 cm. Specific software has been developed to control the laser scanner and to collect, record and process the measurements obtained by the sensor. Although the used LIDAR is a two dimension (2D) laser scanner, the developed software makes it possible its use as a three dimension (3D) scanner, by moving the laser sensor along a transversal axis at a known velocity. The program allows converting the measurement data in several CAD compatible formats, which makes easier 3D modelling and processing of data. See more details in Sanz *et al*: 2004 and Rosell *et al*:2004. As a result, an electronic non-destructive measurement system for the detection of plants geometry and other characteristic parameters – such as Leaf Area Index and Leaf Area Density- by means of a terrestrial LIDAR scanner is available. Figures 1 and 2 show the LIDAR scheme and the system mounted on a tractor, respectively.

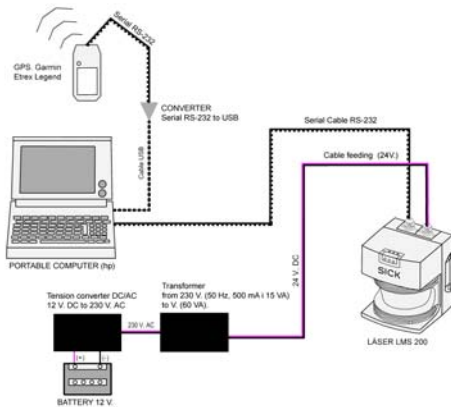


Figure 1. Scheme of the experimental LIDAR system for field measurements, with the main components.

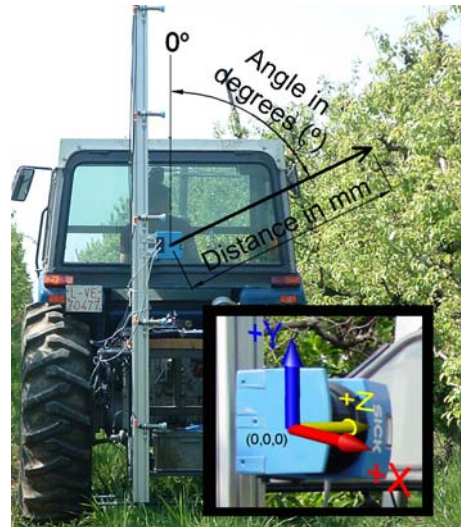


Figure 2. LIDAR system mounted on a tractor. the measurement data formats are also shown. Top: data in polar coordinates (distance and angle). Bottom: data in cartesian coordinates: x,y,z (z coordinate corresponds to tractor displacement axis).

2.2 Field measurements

The system has been applied to characterize some common Spanish tree crops. The analyzed species were pear trees (*Blanquilla* and *Conference*), apple trees (*Golden* and *Red Chief*), vineyard s (*Cabernet Sauvignon* and *Merlot*) and citrus (*Marisol*, *Oronules*, *Fortuna* and *Navelate*). Each field test consisted of several runs (measurements) with the LIDAR, on both sides of the row, as shown in figure 3, before and after the defoliation of the selected trees. In this way, the results of the LIDAR's measurements in both cases (trees with and without leaves) could be compared. As a result, 3D pictures of the crops could be built from the cloud of points obtained from the scanner measurements. The volume of trees (figure 4) and LAI were measured manually. For LAI measurements, trees were divided in several volumes, as shown in figure 5, and separately defoliated, in order to dispose of much information about the distribution of leaves in the trees, and to look for correlations with the LIDAR results. Once in the laboratory, the one side area of the leaves was measured.

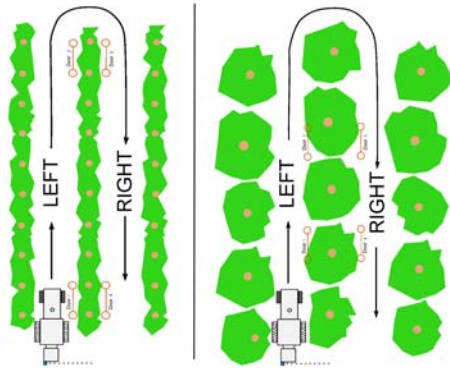


Figure 3. Trajectory of the LIDAR's measurement system on both sides of the tree rows. Left: fruit trees and vineyard orchards (almost continuous vegetation). Right: Citrus orchards and lonely trees (discontinuous vegetation).

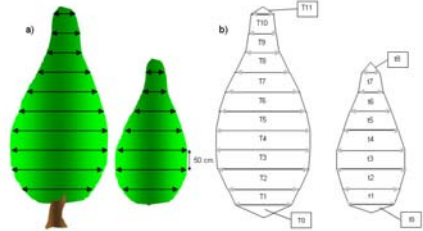


Figure 4. Segmentation of a tree in zones for the manual measurement of their volume.

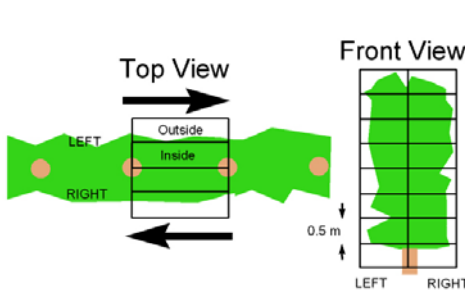


Figure 5 a). Top and front views of the distribution of the defoliation boxes in the case of fruit trees.

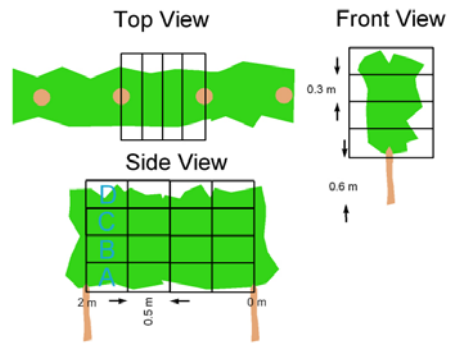


Figure 5 b). Top, front and side views of the distribution of the defoliation boxes in the case of fruit vineyard.

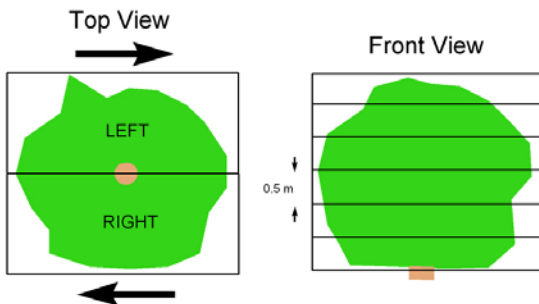


Figure 5 c). Top and front views of the distribution of the defoliation boxes in the case of citrus trees.

At present, a considerable computational and experimental effort is being made in order to extract the volume, the leaf area density, the LAI and other structural parameters from the obtained 3D data of plants, so that they can be valuable information for the optimization of pesticide treatments. In this way, from the 3D digital model of trees obtained from the LIDAR system, an algorithm for the digitally determination of the volume of a plant was implemented. Although the numerical values of the tree volume determined by this method differ from the manually measured ones, it has been found that they are related. The possible relationship between plant volume and LAI has also been investigated.

3.Results and discussion

The results of the first set of field measurements in pear trees, apple trees, citrus and vineyard crops, developed during the first half of 2004 have been very satisfactory, as 3D digitalized pictures of the crops, which contain a large amount of plant information, have been obtained. Figures 6,7,8, and 9 show some examples of the obtained images, taken with a digital camera (left) and with the LIDAR scanner (right), respectively.



Figure 6. Pear Trees.

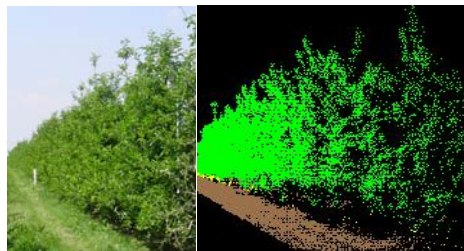


Figure 7. Apple Trees.

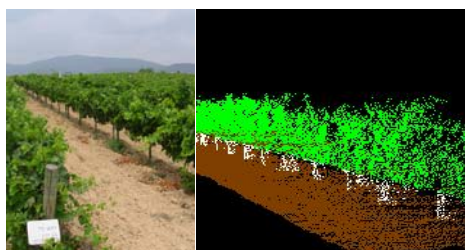


Figure 8. Vineyards.



Figure 9. Citrus Trees.

Finally, the experimental results of the manually-made and LIDAR measurements were compared, to look for useful correlations for certain crop parameters such as tree volume and leaf area index, LAI.

As far as plant volume is concerned, manually and LIDAR measurements are not coincident but there exists a straightforward relationship between both values, as is shown, as an example, in figure 10 for a *Blanquilla* pear orchard. The differences come from the uncertainty that is inherent with the concept of the volume of a tree and the method for its calculation (manually, by means of computer graphical methods...): what is understood as tree volume?

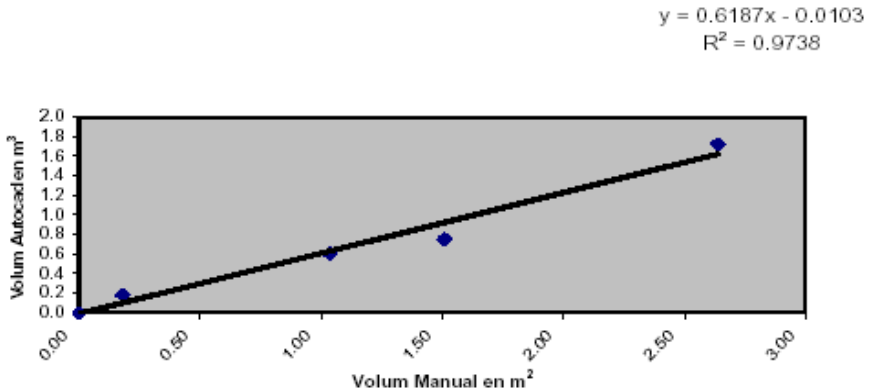


Figure 10. Manually versus LIDAR measured volume of *Blanquilla* pear trees.

On the other hand, two methods for the determination of LAI are being developed. The first one is based on the actual relationship between the LIDAR measured plant volume and its respective total foliate area (from which LAI can be obtained). As is shown in figure 11, there exists a straightforward relationship between both values.

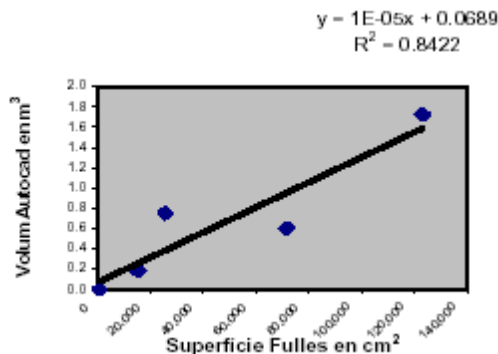


Figure 11. Total foliate tree area versus LIDAR measured volume of *Blanquilla* pear trees.

The second method is based on Beer's law, according to which the transmission of a beam of light across a plant is attenuated exponentially: $I(r) = I_0 \exp(-\alpha r)$, where I_0 and $I(r)$ are the original and the final (after a distance r) beam intensity, respectively, and α is an extinction coefficient related to the leaf area density and orientation. By this procedure the leaf area density (LAD) distribution along a plant is expected to be obtained, and so, the leaf area index. Figure 12 shows preliminary results for a fruit orchard.

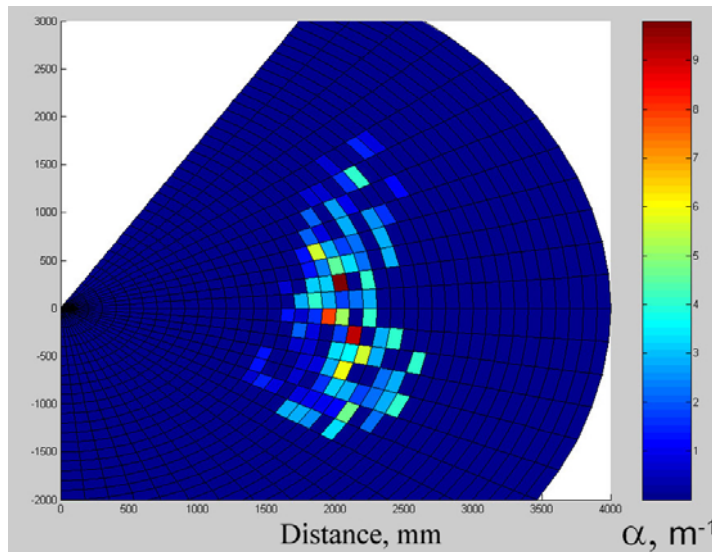


Figure 11. Mean distribution of the α factor (which is closely connected with the leaf area density) for a Blanquilla pear orchard, deduced from LIDAR measurements.

4. Conclusions

The developed LIDAR-based measurement system is proving to be a valuable tool for the remote measurement of the physical and structural characteristics of the plants, such as tree volume and leaf area density and index. The obtained results will be used as support for the decision making related to the optimization of pesticide treatments for crop protection. Moreover, the developed system is expected to be of great interest, in general, for precision agriculture practices, in the two basic methods of implementing site-specific management for the variable-rate application of crop production inputs: *map-based* and *sensor-based*.

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