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Obtaining and mapping relevant characteristics of olive tree canopies using a multi-echo mobile terrestrial laser scanner (MTLS)

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Abstract

This paper describes an instrumental system developed to obtain geometric and structural parameters (phenotyping) of an olive orchard and the subsequent data process for the elaboration of raster maps of the parameters of interest. The system consists of a mobile terrestrial laser scanner (MTLS) based on a 2D LiDAR sensor and a RTK GPS, together with a data acquisition system consisting of a laptop computer. The olive orchard under study was an intensive plot of *Olea Europaea* cv. 'Arbequina' in Torres de Segre (Catalonia, Spain). The studied area was 1 ha and consisted of 16 rows that were scanned from both sides. The wide angular scan window of 270° allowed to simultaneously scan both sides of the olive tree rows while moving along each alley-way. Specific software has been developed to assign the corresponding UTM ETRS89 coordinates to each impact point and to extract various geometric parameters of interest for the agronomic management of olive orchards such as canopy height, width and volume. Additionally, data to build the digital terrain model (DTM) for the study area were also obtained. The maps built showed a clear spatial variability and confirmed the usefulness of MTLS for the measurement and mapping of relevant vegetative characteristics. This information can be used in the decision making process to decide whether a site-specific management under the framework of precision agriculture could be convenient. This research may be also useful to characterize other agricultural tree crops. Further research should be conducted in order to obtain information on canopy porosity, leaf area and leaf distribution and density taking.

Keywords: olive orchard, terrestrial laser scanner, LiDAR, mapping, precision agriculture/fructiculture

1 Introduction

LiDAR (Light Detection and Ranging) sensors are widely used to model any kind of object. The use of this measuring principle has been rapidly implemented in agriculture for many purposes. One of its applications is canopy characterization and it can be made in an airborne or ground-based manner. The latter can be performed by means of stationary 3D laser scanners or by means of mobile 2D scanners also referred mobile terrestrial laser/LiDAR scanners (MTLS). This last option has been reviewed (J R Rosell & Sanz, 2012) and specifically developed in several papers (Arnó et al., 2012; Palacín et al., 2007; J R Rosell et al., 2009; Joan R. Rosell et al., 2009). MTLS cover much smaller areas than airborne solutions but offer high-density measurements and accuracy (Sanz, Rosell, Llorens, Gil, & Planas, 2013). 2D MTLS are predominant due to their lower cost and the ease of moving them inside the crops in a continuous (non-stationary) way. Recently, new 2D LiDAR have appeared in the market characterized by smaller size, weight and cost, wider scanning windows (up to 360 degrees), more than a thousand measures per scan and longer ranges (Demski, Mikulski, & Koterak, 2013). These new sensors allow the implementation of MTLS systems to obtain high-density point clouds of orchards to better characterise canopies in terms of geometrical and structural parameters. This information is valuable to improve orchard management in the framework of Precision Agriculture.

The system presented in this communication consists of a mobile terrestrial laser/LiDAR scanner (MTLS) implemented with one of these last generation LiDAR sensors able to acquire high density point clouds of the orchard. Additionally, we present the procedure to extract information from point clouds and the creation of digital maps to present it in a friendly manner to farmers and advisors. Farmers could use this information to detect spatial variability in their orchards related to the crop growth and to locate problematic areas. Subsequently, this information can be used in the decision making process to consider the implementation of a variable rate approach in operations such as plant protection products dosage, irrigation scheduling, fertilization, pruning needs, among others.

2 Materials and methods

2.1 Olive orchard

The orchard scanned was an irrigated intensive olive orchard of *Olea Europaea* cv. 'Arbequina' for high quality oil production. The trees are mechanically harvested so tree height should be monitored and controlled. Row spacing is 4.2 m and tree spacing 2.2 m. A maximum-size tree is 3.75 m tall and 2 m wide. The orchard is located at Torres de Segre, Lleida, Catalonia, Spain (X=296850m, Y=4599700m, UTM 31N / ETRS89). The orchard is 2.5 ha although the scanned area was 1 ha and consisted of 16 rows of lengths ranging 125 m to 190 m. A view of the orchard is seen in Figure 1.

The orchard was scanned at two different moments during the season corresponding to two different development stages so that the canopy growth could be quantified and analysed. One scan was performed at the beginning of pit hardening (July 15th 2013) and the other was performed at the end of the season, after harvesting and before pruning (March 10th 2014).

2.2 Scanning system

The MTLS implements a UTM30-LX-EW (HOKUYO, Osaka, Japan), 2D, high speed (40 Hz), multi-echo (not used in this communication) LiDAR sensor. It is a 2D sensor, 30 m range and is based on the time-of-flight principle. The sensor provides the distance to the object impacted by the laser beam emitted at an angular resolution of 0.25°, making a total of 1081 measurement points for each complete 270° scan. The sensor gives the results of the measured distance in polar coordinates (angle and radial distance from the sensor) with respect to the coordinate system with origin in the sensor itself. The sensor, and hence the origin of

coordinates, is moved along the alleys of the plot boarded onto a vehicle at a height of 2 m above the ground. The absolute position of the LiDAR sensor is determined by an RTK GPS receiver placed above the sensor at a rate of 20 Hz. By displacing the LiDAR sensor along the different alley-ways of the orchard and geo-referencing its position with a RTK GPS receiver it is possible to georeference the obtained point cloud with centimeter accuracy. Displacement speed was set at about $4 \text{ km}\cdot\text{h}^{-1}$ resulting in a separation between scans (horizontal resolution) of approximately 2.7 cm. A general view of the MTLs is shown in Figure 1. The data generated by the receiver must be synchronously combined with the polar data points obtained by laser impacts. The acquisition system consisted of a laptop computer running a self-developed LabVIEW (National Instruments, Austin, USA) program. To obtain the georeferenced 3D point cloud, the polar coordinates of the points are transformed into UTM ETRS89 absolute coordinates.



Figure 1: Intensive olive orchard where the scanning system was tested (left). Mobile terrestrial laser scanner designed to scan orchards (right).

2.3 Data processing

The data was represented and colorized for visualization purposes using CloudCompare (EDF R&D Telecom ParisTech, 2014). A piece of software was specifically developed to process the data. It received input from a set of files, each containing polar coordinates of the points acquired during the displacement of the MTLs along the orchard alley.

2.3.1 Point classification

The position of the RTK GPS antenna in UTM ETRS89 coordinates was transferred to the LiDAR sensor and subsequently to the impact points according to their relative polar position to the sensor. Each single scan contained 1081 points, 540 of which were readings that corresponded to the right hand side of the LiDAR sensor while the remaining 540 corresponded to the left hand side. Those points impacted to the ground and to different rows. The developed program transferred the coordinates and classified the points into ground, left and right rows and other according to its position and distance to the sensor and stored them in different files. As the various alleys were processed, the points obtained from different sides belonging to the same row remained grouped in a single file.

Those points that were part of the ground and those located at a height less than 30 cm above the ground (trunks, weeds, etc.) were removed. A second filter to only consider those points located between 60 cm and 4 m from the LiDAR sensor was also applied. We empirically observed that the points of rows of trees adjacent to the LiDAR lied between these two limits. The points at a shorter distance were usually noise while those found further away corresponded to non-contiguous rows. All of them were discarded. Once we had the points in UTM ETRS89 coordinates stored in different file for each single row, there was a second step that processed each row separately.

2.3.2 Canopy height calculation

The first point of each row was taken as a reference. From there, for each point belonging to that row, the horizontal distance between to the reference point was calculated. All points of the row were classified into groups according to the distance to the reference point. The first group contained those points which were found between 0 and 10 cm from the reference point. The second group contained those points between 10 cm and 20 cm, and so on. When the points were already grouped, each set was analysed and then the point with maximum Z coordinate was selected, the distance to the ground was computed and it was stored as the maximum canopy height of the group. Then, there was a second process with each set of 10 contiguous groups along the row, with a total actual distance of 1 m. For each set, the centroid in UTM ETRS89 coordinates was determined as well as the average of the 10 maximum heights and the standard deviation. This way, information on the canopy was obtained every 1 m along all rows.

2.3.3 Canopy width calculation

For each of the previously mentioned vertical slices of 10 cm along the rows, points were again grouped every 10 cm in the vertical plane containing them in rectangular prisms of 10 x 10 x 300 cm along the cross section of the canopy all over the orchard. For each of those prisms, the horizontal distance from the furthest left point to the furthest right point was calculated meaning the canopy width at that height. Averaging all the widths in a single vertical slice provided us with the average width every 10 cm along the rows. Again, these values were averaged in order to have an average canopy width every 1 m along the rows.

2.3.4 Canopy volume calculation

Adding every single (10 x 10 x canopy width) volume in the rows resulted in the total canopy volume of the orchard. Volumes were again grouped in 1 m – long row sections in order to map them.

2.3.5 Maps generation

The variographic analysis and mapping of canopy heights, widths and volumes was performed using ArcGIS 10.2 together with the extension Geostatistical Analyst. The interpolation was performed with ordinary kriging or Gaussian process regression according to the semivariogram models fitted in each case. The model selection criterion was minimizing the root mean square errors (RMSE).

Raster maps were built for each parameter to represent their spatial variability in the two scanning dates. Furthermore, difference raster maps were generated in order to analyse the growth of the orchard in terms height, width and canopy volume between those dates.

2.3.6 Digital terrain model

To generate a digital terrain model (DTM) of the orchard, the data were processed as follows: when an alley was processed, the points located at a height less than 15 cm above the ground were considered part of the ground and stored in a separate file. This file was processed dividing the ground in 20x20cm tiles. Then, the average height of each tile was calculated. Those points of each tile having a height above 15 cm were eliminated. This processing served to eliminate points which probably would belong to grass, only keeping the points that make up the DTM.

3 Results and discussion

After transferring the sensor UTM ETRS89 coordinates to each of the obtained points, the result is a high density point cloud of the orchard. The number of 1st echoes received in the whole orchard is about 87,000,000 while 2nd echoes are about 8,500,000. The point density in the scanned area is higher than 8,000 points·m⁻². Part of the point cloud of the orchard is shown in Figure 2.

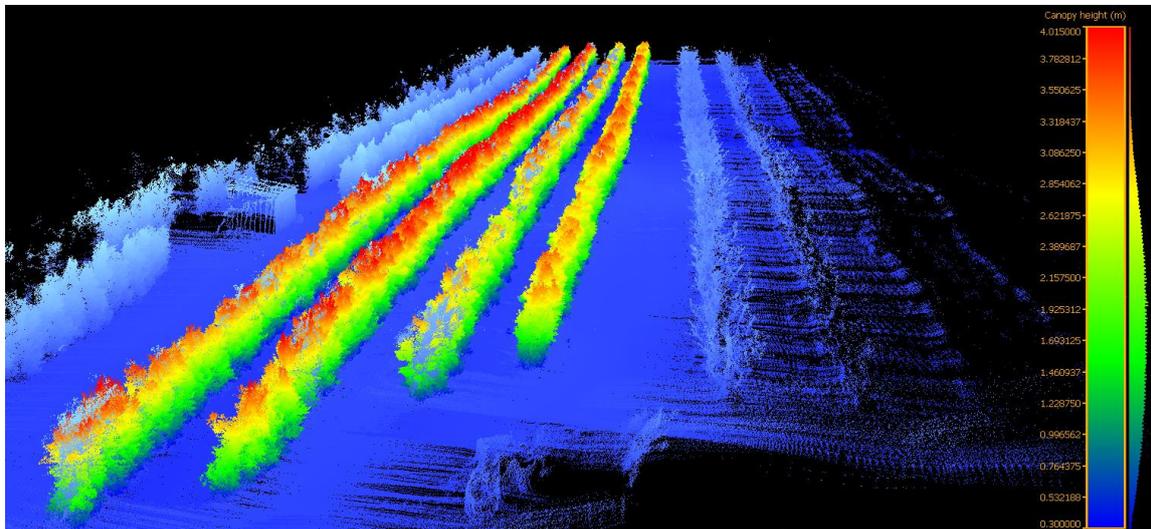


Figure 2: High density point cloud of part of the scanned olive orchard. Blue points are non-processed 1st echoes. The first 4 row are represented in a colour scale according to canopy height.

3.1.1 Canopy height

After processing the point cloud to extract height information along the rows, we obtain the maps shown in Figure 3. Areas with shorter and taller trees are highlighted but differences are not very important. The reason is that the farmer is controlling this parameter in order to use an over-the-row mechanical harvesting machine at the end of the season.



Figure 3: Canopy height raster maps for 1 m – long row sections.

3.1.2 Canopy width

Canopy width maps for the 2 scanning dates are shown in Figure 4. As it can be seen, width variability is important and differences can be greater than 100%. As expected, areas with

narrower canopies tend to coincide with shorter trees. However the spatial distribution is not exactly the same and differences get bigger along the season.

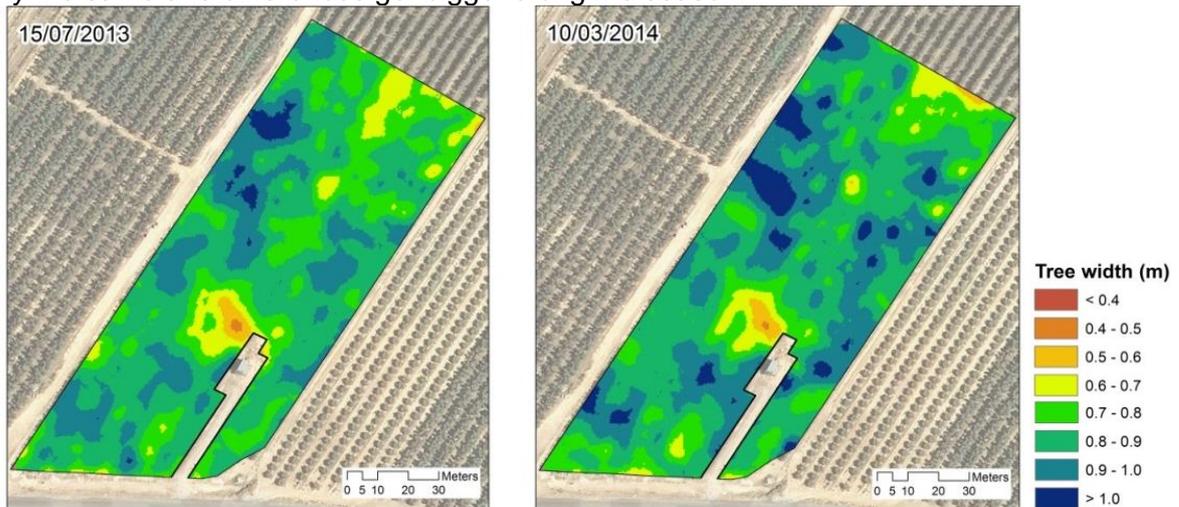


Figure 4: Canopy width raster maps for 1 m – long row sections.

3.1.3 Canopy volume

The canopy volume maps are shown in Figure 5. They are somehow a combination of height and width information but spatial variability patterns are much more similar to canopy width maps rather than to height maps, probably as a consequence of controlling tree height.

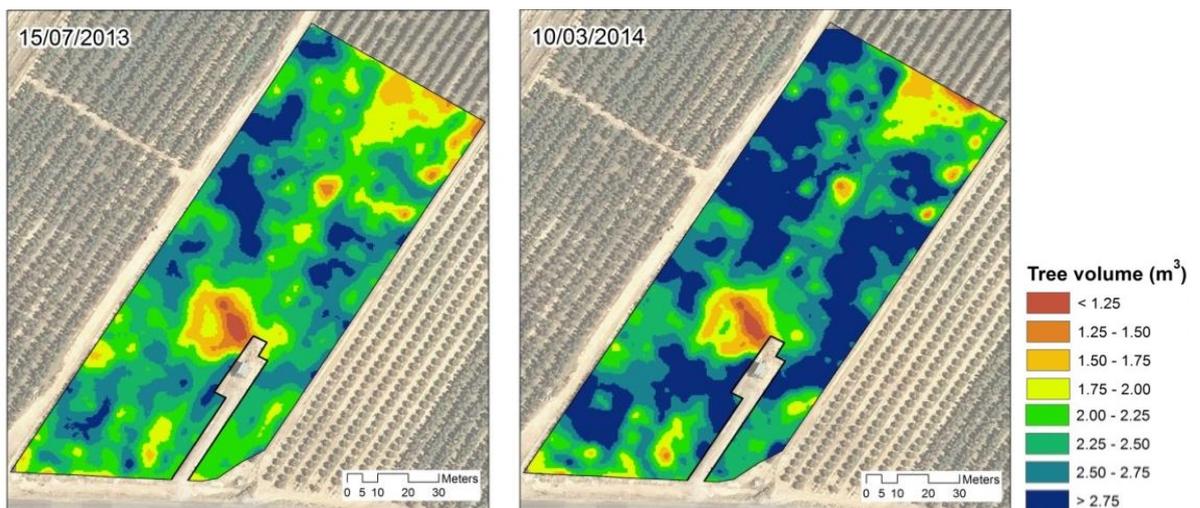


Figure 5: Canopy volume raster maps for 1 m – long row sections.

As it can be seen, scanning the orchard with MTLs provides information on the spatial distribution of geometrical parameters of the canopy across the orchard and on the existence of variability within it. This information and its presentation to the farmer and advisor can be very useful as it is related to the status of the tree (vigor, water status, fertilization, pest infestation, etc.) as well as to possible changes in the physical and chemical properties of the soil.

Although this system is not providing the farmer with diagnosis of possible problems in his/her orchard, the analysis of the variability and its distribution patterns advises the grower where to start searching for possible causes. Additionally, providing the farmer with variability maps could help him/her better decide whether to implement site-specific management strategies related to crop protection, irrigation, fertilizing and other operations.

3.1.4 Canopy growth

A powerful tool in map-based precision agriculture is the combination of different maps. Figure 6 shows raster map differences highlighting the growth of each analysed parameter between the two scanning dates. All the maps clearly show that growth is not uniform in this plot and it will have to be scouted to find the reasons and the best strategy to manage it.

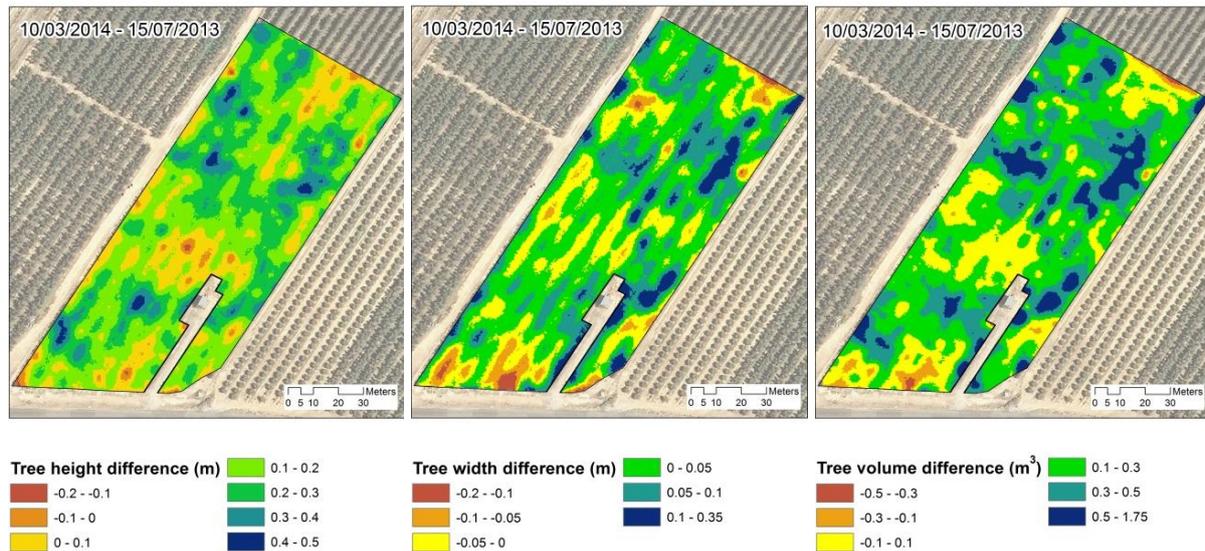


Figure 6: Difference raster maps of canopy height (left), width (centre) and volume (right) highlighting canopy growth of each specific parameter between two dates.

3.1.5 Digital terrain model

Additionally, a sub product of the MTLs is the DTM. When properly georeferenced with a centimetre-accuracy RTK GPS, laser impacts on the ground can be processed to obtain the DTM. In our study, Figure 7 shows a representation of the 33,185,142 impacts on the ground obtained in the scanned plot in a colour scale ranging from 184.56 m to 187.84 m above sea level. That is more than 3,000 points·m⁻². The DTM can provide the farmer with an additional layer with information on possible water and nutrient movements caused by the relief and microrelief of the plot. As shown, there is a difference of more than 3 m from the highest to the lowest point. Next analysis would be overlaying the DTM to the rest of the maps to discover possible correlations.

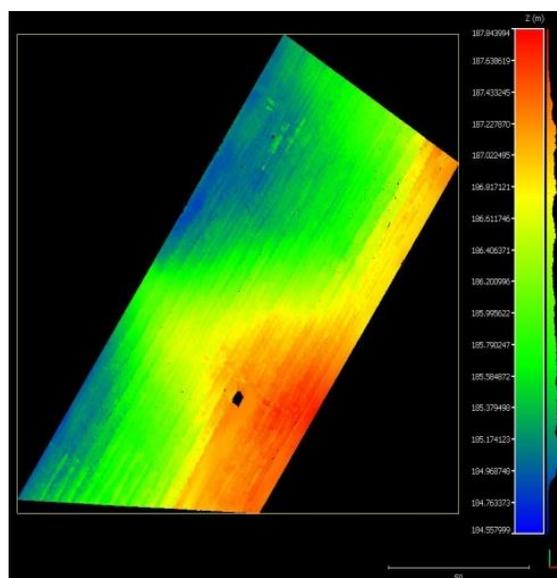


Figure 7: Impacts on the ground ready to generate the digital terrain model of the plot.

4 Conclusions

The developed mobile terrestrial laser scanner allows the acquisition of high density point clouds. The developed algorithms to analyze and map the canopy height, width and volume have been proven to be able to extract information from the canopy in a 10-cm- and 1-m-resolution basis.

However, further research is to be done regarding the extraction of other geometrical and structural parameters of the canopy taking advantage of the multi-echo capabilities of the sensor.

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6 References

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