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Real-time approaches for characterization of fully and partially scanned canopies in groves

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ABSTRACT

Efficient information management in orchard characterization leads to more efficient agricultural processes. In this brief, a set of computational geometry methods are presented and evaluated for orchard characterization; in particular, for the estimation of canopy volume and shape in groves and orchards using a LiDAR (Light Detection And Ranging) sensor mounted on an agricultural service unit. The proposed approaches were evaluated and validated in the field, showing they are convergent in the estimation process and that they are able to estimate the crown volume for fully scanned canopies in real time; for partially observed tree crowns, accuracy decreases up to 30% (the worst case). The latter is the major contribution of this brief since it implies that the automated service unit does not need to cover all alleyways for an accurate modeling of the orchard, thus saving valuable resources.

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1. Introduction

In agriculture, knowledge of the characteristics of plants is essential to perform an efficient and effective management of crops. In recent years, the availability of affordable sensors and electronic systems capable of facilitating the performance of intensive measurements has gradually replaced traditional methods based on manual measurements. At present, there is hardly any relevant plant characteristic without an associated sensory system based on the use of electronics for its determination. As a result, (i) the accuracy of the measurements has drastically increased, (ii) data acquisition has been eased, lightened and, in many cases, automated, (iii) the traditional analysis of a reduced number of manually-collected data has given way to the processing of files with huge amounts of data resulting from the measurements provided by the sensors and (iv) decision making in crop management can be supported by information now available and impossible to have in the past. Among the characteristics of crops, geometry deserves special mention (canopy height, width and volume) as well as structural parameters (leaf area index, canopy porosity and permeability and wood structure) due to their great influence on the behavior of plants interacting with solar radiation, water and nutrients at their disposal (Lee and Ehsani, 2009) as well as on the knowledge and prediction of the vigor and quality of the produced crop (Arnó et al., 2013). These parameters also have a key role in assessing the efficiency and effectiveness of the main operations performed in the orchards, such as the application of inputs (fertilizers, irrigation and plant protection products against pests and diseases), pruning and harvesting (Sanz et al., 2011; Rosell and Sanz, 2012). Several studies have shown the existence of a relationship between the geometrical parameters of a crop and yield (Pascual et al., 2011).

Among the geometric parameters of plants, canopy volume has a special significance because it combines, in a single variable, the width, the height, the geometric shape and the structure of trees (Sanz et al., 2013). For this reason, its determination in a reliable, systematic and affordable way, both in cost and time, is a priority in the present and near future of Precision Agriculture/Fructiculture defined as the one that takes full advantage of the ICT (Information and Communications Technology) systems, geostatistics and decision making support systems.

Usually, precise measurement of the volume of a canopy requires of costly man-made measurements on the plants with the corresponding time and economical cost. However, several

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sensor-based approaches have been published in the scientific literature that deal with the problem of estimating the canopy volume. The most used techniques to determine the canopy volumes are based either on the use of electromagnetic radiation, mainly in the spectrum range from the ultraviolet to the infrared, including the visible, or on the use of ultrasonic waves. The most widespread systems in the first group are those based on the use of digital photography, photogrammetry, and stereoscopy techniques as well as LiDAR (Light Detection And Ranging) sensors (Rosell and Sanz, 2012). Indeed, the latter is increasingly being used in agricultural applications due to its high accuracy, reading speed rates and versatility. A LiDAR sensor estimates the distance apart of the object of interest, using – in some technologies – the Time of Flight (ToF) principle (Newnham et al., 2012). In practice most used LiDAR scanners perform sweeps in a plane (2D) or in the space (3D) by modifying the direction at which the laser beam is emitted. A very common configuration in agricultural research applications is what is known as mobile terrestrial laser scanner (MTLS), a 2D LiDAR sensor mounted on a vehicle moving along the alley-ways between rows of trees in an orchard in order to obtain the scanning of the entire crop in 3D, (Rosell-Polo et al., 2009; Rosell et al., 2009). This operation mode usually requires a high precision GNSS receiver to know the spatial coordinates of the LiDAR sensor at all times.

In this context Pforte et al. (2012) show a LiDAR system combined with a monocular vision system used to estimate the plum tree canopy cover, using a LiDAR sensor mounted on a tractor. The machinery drives through the alleys while the LiDAR, strategically located above the canopies, acquires the range information. One of the main drawbacks of the system is the height of the trees: they cannot be taller than the tractor, as it is presented in Pforte et al. (2012). In Keightley and Bawden (2010) a LiDAR sensor mounted on a ground tripod is used for 3D volumetric modeling of a grapevine. The system does not consider position errors (as mentioned in Auat Cheein and Guivant (2014)) and the validation was performed under laboratory conditions. In Bucksch and Fleck (2009), Raumonen et al. (2013) a ground fixed LiDAR sensor is used to 3D model the tree skeletons, based on a graph splitting procedure to extract branches from the cloud of points. Although the system efficiently extracts the skeleton patterns from several trees, it does not offer a real time solution and its robustness to leaves density is not provided in the research. In the same line, Cote et al. (2009), explores and tests the use of LiDAR scanners in tree modeling. In addition, Moorthy et al. (2007) used a 3D LiDAR to measure structural and biophysical information of individual trees. Although a consistent statistical analysis is presented regarding the estimation of leaf area (unlike Beland et al. (2011) and Hosoi and Omasa (2006)), no information is provided regarding the geometric determination of the treetop. Fieber et al. (2013) used a LiDAR to classify ground, trees and oranges using only the reflected waveforms from the LiDAR, avoiding the need of using geometric information. Although efficient, the proposal was not tested for real time implementations but for batch processing only. In addition, no information is provided regarding shapes or sizes of the agricultural features. In Walklate et al. (2002) a LiDAR sensor and a GPS receiver are mounted on a same chassis for 3D reconstruction of orchards. No information is provided regarding the geometric processing. Instead, the research is focused on using the 3D information for spray management. The performance of the previous methods relies on the precision of the GPS (see Auat Cheein and Guivant, 2014). Méndez et al. (2014, 2013) used a LiDAR for skeleton reconstruction of a grove and for vegetative measures. On the other hand, Jaeger-Hansen et al. (2012) uses a similar hardware and provides a first estimate of the treetop surface using ellipses and minimum square fitting techniques. In addition, in Rosell et al. (2009), a first study in 3D orchard reconstruction is presented, in which a LiDAR and a differential GPS are used for mapping the environment. Although based on manual fitting techniques, the authors provided a first approach for groves characterization.

The huge amount of data generated by electronic measuring systems such as MTLS makes it a must the development of both (i) hardware fast enough and with enough storage capacity, as well as (ii) efficient software capable of processing such large data sets, in many cases being able to process them as quickly as possible to allow for real time crop management applications. With regards to MTLS, the results obtained from the measurements are point clouds (though georeferenced using GNSS receiver) which, in the case of an entire row or orchard, can contain tens of millions of points, each one with information on their geographical coordinates and, in some cases, additional information such as reflectance and color. In the presence of such huge amount of information it is essential to perform the extraction of the parameters of interest, such as the volume of plants, by means of automated algorithms with low computational time cost. An alternative to lighten the volume of data to be measured and processed and thus facilitate real-time operation consists of measuring the tree rows from one side only. In this way, the monitoring of the entire tree crop can be done with half the time by passing the MTLS measuring system along alternated rows. Arnó et al. (2013) showed the advantages of scanning a vineyard from only one side of the rows when estimating the LAI with an MTLS. Additionally, it was also concluded that, in the N–S oriented vineyards analyzed, the estimation of LAI was to a great extent independent of which side of the row was scanned (Arnó et al., 2015). In the specific case of the determination of the volume of the crowns, it must be verified that the results obtained by measuring alternated rows are sufficiently accurate and reliable before giving this proposal as valid.

In the field of Precision Agriculture/Fructiculture, the acquired information should be reliable for agricultural purposes constrained to minimize available resources. The latter is the main issue faced in this work: the characterization of orchards when are partially and fully scanned by a LiDAR. We propose and evaluate the performance of several methodologies developed for this aim.

In this work we implement four methodologies based on LiDAR readings for characterization of canopies: a convex hull approach, a segmented convex hull approach, a cylinder based approach and an occupancy grid approach. Such methodologies use the advantages of computational geometry to obtain an estimate of the canopy volume, considering that the canopy's true volume is unknown. The methodologies, based only on LiDAR range readings (thus no attenuation of the beam is considered) are evaluated, compared among each other and validated with real data. Taking into consideration that one of the challenges is to reduce the resources consumption of the service unit, the canopy characterization procedures are also applied when canopies are partially scanned, thus avoiding the need of visiting all the alley-ways in the grove. The four computational methodologies shown in this work provide the geometry associated with the canopy, which can be used later for spray management and other operations performed in the orchards.

2. Materials and methods

In this work, four computational approaches are presented for canopy characterization of orchards and groves: (i) a convex hull approach, (ii) a segmented convex hull approach, (iii) a cylinder-based modeling of canopies and (iv) a 3D occupancy grid approach (Hosoi and Omasa, 2006). The four methods are first evaluated using a known template and then they are tested in the field. For

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