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Structure characterization on Mediterranean forest stand using terrestrial laser scanning

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Abstract

The definition of the structural parameters of forest stands and its vertical and horizontal continuity is relevant for a number of environmental applications, such as carbon dynamics studies, sustainable forest management, ecological studies, and fire risk mitigation and management.

Obtaining detailed information on tree structures and canopy variables requires extensive and time- consuming field campaigns. Recently, proximal sensing techniques as Terrestrial Laser Scanning (TLS) have been used for forest monitoring studies and have demonstrated their potential to overcome the limitations of conventional ground-based forest inventory techniques. However, accuracy and applicability of TLS techniques for canopy characterization of broadleaf evergreen forests still require further investigation. In particular, a proper separation between points representing woody material, leaves and small branches is fundamental for the estimation of tree attributes and crown characterization.

In this work, we developed and tested an automatic procedure based on the DBSCAN point density algorithm to accurately separate points derived from terrestrial Lidar measurements at plot level. The objective was to identify volume of woody material, tree density, and canopy cover of a forest stand.

The study was conducted in an area located in southeastern Sardinia (Italy) covered by evergreen forests dominated by holm oaks, with different types of understorey (sparse and dense). Destructive and non-destructive measurements were carried out within three circular plots of 20 m, 25 m and 30 m diameter, respectively. TLS data were collected in field by multiple scans of the three plots. 3D point clouds were processed to isolate trees, soil and understorey. The point clouds were then transformed into voxel clouds (cubic volumes) that were used as input to classify woody and non-woody components by applying both DBSCAN point density clustering algorithms and principal component analysis.

The results show that the proposed method enables the correct identification of crown, trunk, and main branches through an automatic procedure that requires the setting of only a few parameters. Moreover, the procedure does not need excessive computing power and takes only a few minutes to complete the process. Our approach represents a step forward in improving the procedure for measuring forest structure from three-dimensional point clouds. However, further studies are needed to test the capabilities of this method in forest stands characterized by higher and denser understorey and with different tree species (e.g. mixed forests).

1. Introduction

Information on forest canopy structure and reconstruction of tree geometry is required at a wide range of spatial scales for several environmental applications such as carbon dynamic and ecological studies, ecological and forest management, ecosystem productivity model, forest fuel studies and fire risk management.

In particular, an accurate description of fuel is crucial for fire hazard mitigation planning by predicting potential fire behaviour and effects of fuel treatment. Obtaining landscape-level fuel maps, allows the description of the parameters needed to interpret the fire behaviour models, increasingly used to support fire management processes. A correct characterization and classification of fuel needs accurate estimates of vegetation structure and crown attributes. However, many fuel characteristics are often operationally hard to be measured requiring manual field measurements and cutting.

Because to obtain detailed information on forest stand and canopy variables estimation, extensive, difficult and laborious field campaigns are required, remote and proximal sensing techniques for forest monitoring have become popular in recent decades. Specifically, Terrestrial Laser Scanner (TLS) has demonstrated its potentials to overcome the limitations of the conventional ground-based forest inventory techniques. TLS is a LiDAR system from which detailed 3D information called point clouds can be collected. Using a laser beam, TLS provide a high-resolution 3D view on vegetation structure right down to branch and leaf scales, making it superior to data obtained through traditional field work. Using the intensity of the returned laser pulses, TLS can be used to estimate the water content and photosynthetic capacity of the vegetation. TLS allows accurate estimation of traditional structural metrics used in forest monitoring and management, such as basal area per hectare, tree height, and diameter at breast height-DBH, and also offers a non-destructive approach to estimate quantify canopy and stem volume with high accuracy, thus allowing estimation of AGB parameters with reduced uncertainties, as well as development and improvement of reliable allometric equations.

Although several studies highlight the effectiveness of TLS in describing forest parameters, the accuracy and applicability of TLS techniques for canopy characterization of broadleaf evergreen forests needs further investigations. In particular, estimation of tree attributes such as canopy density, crown bulk density, branch size distribution, etc., in evergreen plants presupposes a correct separation between points representing shrubs, woody material, leaves and small branches. Separation of photosynthetically active material (leaves) from non-photosynthetically active material (wood) is particularly challenging in the case of non-deciduous broadleaf trees, which are characterized by complex crown architecture and where measurements must be performed under foliage conditions.

In a previous work (Ferrara et al., 2018) we proposed an approach based on the point density algorithm DBSCAN for wood-leaf separation from terrestrial LIDAR point clouds of single trees. The TLS data set collected in field by multiple scanning on single trees were partitioned in cubic volumes (voxels) that were used as input to generate clusters through DBSCAN. The most highly populated cluster, due to continuous bark shape versus chaotic leaf distribution, represented wood voxels. So that process led to the identification of wood and non-wood voxels.

In this work we applied the previous DBSCAN based approach at plot level in order to evaluate performance of the proposed procedure in estimating woody material volumes, tree density and canopy cover in holm oak forest stand.

2. Materials and methods

The study was carried out in an area located in South-East Sardinia, Italy. The area was covered by evergreen forests dominated by holm oaks with associated species consisting of Arbutus unedo, Erica arborea, etc. Destructive and non-destructive measurements were done inside three circular plots of 20 m, 25 m and 30 m diameter, respectively. Data sets were collected in field by multiple scanning of the three plots using a Leica HDS6100 laser scanner in super high-resolution mode, it means 3.1 x 3.1mm point spacing at 10 m range. The TLS data set collected in field were processed as reported in figure 1 with the purpose of isolating trees from understorey and separating wood from foliage. The whole process was carried out by algorithms in the opensource R platform.

The first step of the process is the discretization of the point cloud, going from scattered points to voxels ordered in a grid. A voxel is a cubic element, that we choose of 2 cm edge, that contains n points. This step allows to reduce the amount of data in the further computation and also to reduce the noise characteristic of laser scanner acquisition.

The second step is to classify voxels as ground or above ground biomass. Ground voxels will be useful to determinate the height in each point of the plot, needed for example in DBH determination, but are not useful in the following process to determinate wood, leaf and understorey biomass.

Third step; with respect to the single tree approach which used DBSCAN cluster algorithm, in this case the identification of wood voxel clusters was made by applying the principal component analysis and setting a minimum threshold of number of voxels per cluster.

3. Results and Discussion

Due to significant advances in technology and refinement of analysis methods over the past decade, several approaches have been proposed to separate leaf and wood points in a TLS point cloud. These separation methods can be divided into: 1) methods based on the geometric characteristics of point clouds; 2) methods based on the radiometric characteristics of point clouds; 3) methods with machine learning algorithms. Most of the methods developed focus on the geometric attributes of the point clouds.

The results obtained show that the separation method which uses density-based spatial clustering of application with noise (DBSCAN) algorithm proposed, allows the discrimination of the woody groups from the foliar ones and consequently to correctly identify foliage, trunk and main branches at plot level. It is a fully automated procedure that requires the choice and setting of few parameters in order to work properly. Unlike other developed methods, it does not require excessive computational power and takes only a few minutes to complete a good classification. Not being bound to the use of a specific instrument and requiring open source software, it can easily be replicated and applied to any point cloud.

The approach used represents a further step in the improvement of the measurement procedure of the forest structure from clouds of 3D points, in particular as regards the estimation of the woody material, the density of the trees and the projection area of the foliage, especially when the underlying layer is dominated by a not high herbaceous vegetation.

However, further studies are needed to assess the ability of this method in forest stands characterized by high and dense understorey and with different species of trees.

4. References:

Ferrara R, Virdis SGP, Ventura A, Ghisu T, Duce P, Pellizzaro G (2018) An automated approach for wood-leaf separation from terrestrial LIDAR point clouds using the density based clustering algorithm DBSCAN. AGR FOREST METEOROL 262:434-444. https://doi.org/10.1016/j.agrformet.2018.04.008

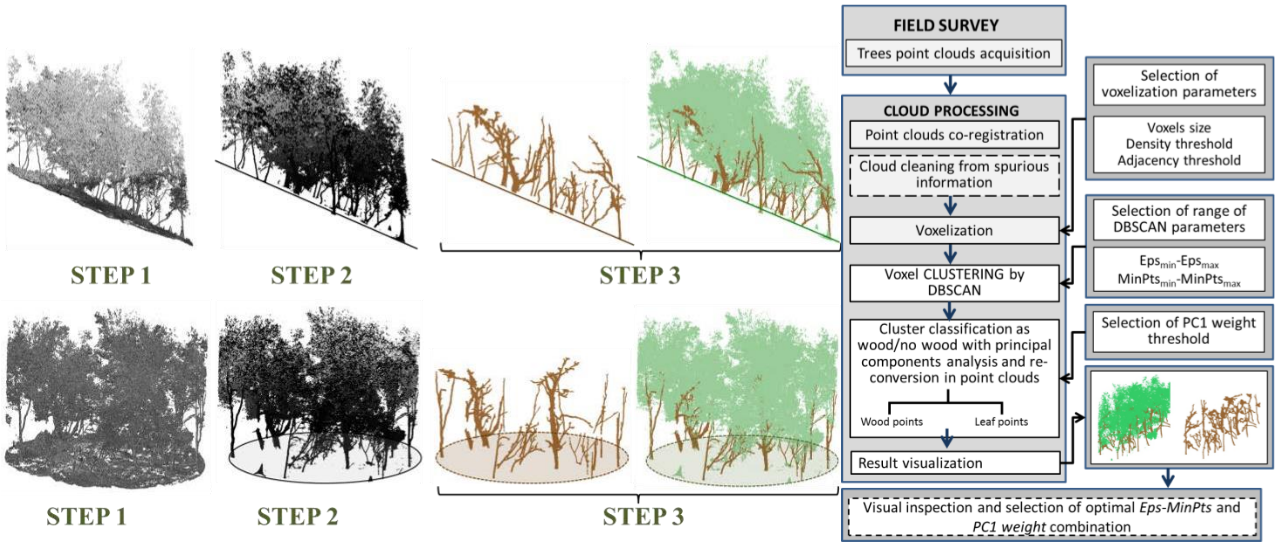

Figure 1. Scheme of proposed approach at plot level for wood separation (a) and an example of qualitative final segmentation results from the elaboration of the plot scans (b)