Automatic detection of dominated vegetation under canopy using Airborne Laser Scanning data

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Abstract

In this paper we explore the potential of Airborne Laser Scanning to measure the understorey vegetation in variously composed Alpine forests, proposing an innovative method of laser scanning data processing to automatically determine the spatial distribution of the dominated layer. To this aim, a complete processing chain was developed, starting with the point cloud as input data and ending with derived three dimensional parameters for each single tree. First, the dominant trees are detected by means of a mathematical morphology approach. Afterwards, the laser points belonging to the single crowns are clustered and crown shapes are delineated. To enhance the quality of the calculated crown parameters (area, base height, volume), a statistical analysis of the height frequency distribution is performed which allows the re-filtration of the low vegetation (border or under-canopy vegetation). The extracted data, integrated in a GIS environment in order to create a database for the forestry sector, integrate the information on the vertical structure of the forest. A field survey campaign in some mountainous geo-referenced plots was performed in coniferous and mixed forests characterized by mono-storey and multistorey canopies. The results highlighted interesting performances of the re-filtering method as far as the automatic detection of the dominated vegetation in both forest typologies are concerned.

Keywords: LiDAR, Forestry, Tree extraction, Cluster analysis, Vertical structure, Understorey

1. Introduction

Monitoring of the forestry ecosystem is a current topic in the wooded resources sustainability debate. To characterize the vegetation from an ecological state and biomass content point of view, a detailed knowledge of the vertical structure is needed. In actual fact, the vertical structure of forest plays an important role in determining microclimatic conditions, the availability of niche space, habitat quality, the distribution of fuels and subsequent fire risk (Hill, 2007). Moreover, even if the majority of the above ground biomass is stocked in the dominant layer, information on the understorey layer can be essential to determine the carbon content of an ecosystem and is very important for forestry inventories (Patenaude et al., 2005).
There are numerous case studies involving airborne laser scanning for the extraction of forest parameters at tree level (Andersen et al., 2001; Pyysalo and Hyyppä, H., 2002; Morsdorf et al., 2003; Hyyppä et al, 2004; Pitkänen et al, 2004; Weinacker et al., 2004, Tiede et al., 2005; Barilotti et al., 2007a). In these studies, the attention has been focused on assessing the dominant vegetation layer while, recently, a trend toward the undercover has been noticed (Zimble et al., 2003; Hyde et al., 2005; Maltamo, 2005; Barilotti et al., 2007b; Hill, 2007; Wang et al., 2007). Forests belonging to the alpine and boreal latitudes can have simple mono-storey structures or more complicated bi-storey or multistorey structures. In forests characterized by a heterogeneous vertical structure, photogrammetry and, in general, remote sensing techniques can have some limits concerning their capacity to furnish information on single trees. This is particularly true when understorey vegetation has no direct access to light and grow underneath a relatively close canopy (bi-storey forests). The structure in which the dominated vegetation

can have free access to light, even if it does not occupy the upper canopy (co-dominant layer) is relatively simpler. In this case, the laser scanning technique can be useful in order to distinguish single trees and, consequently, classify the stand structure.

In Maier et al. (2006) for instance, the authors developed an automatic approach for assessing and quantifying forest structure using landscape metrics on height class patches of the normalized crown model (nCM). Previously, Zimble demonstrated that differences between mono-storey and multistorey vertical structural classes could be detected with 97% of accuracy by analysing LiDAR-derived tree height variance. However, a common limit highlighted in these studies is that where the dominant trees form a dense and closed canopy it is not possible to distinguish the smaller trees and, consequently, the different forest structures. This is probably due to the fact that these approaches are essentially based on the LiDAR-extracted Crown Height Models. Consequently, the morphology of the canopy is the main source of information used. Maltamo et al. (2005) developed a histogram threshold method to calculate the distribution of LiDAR canopy height returns. The method (HistMod) was applied to the height distribution of laser points in order to classify them as uni or bi-modal distribution. In such a way they separated different forestry storeys. The results showed that multi-layered stand can be recognised and quantified using quantiles of laser scanner height distribution data. In this work, the analysis is carried out by using a plot-level approach.

It is clear that the method used and the plot compositions are not the only factors affecting the accuracy of the forestry parameters to be estimated. Goodwin et al. (2006) for instance investigated the effect of a number of intrinsic LiDAR survey specification by comparing the results from three different platform altitudes (up to 3000 meters), two different scan angles at flight altitude of 1000 m, and three footprint sizes (0.2, 0.4, and 0.6 m). The authors found that higher platform altitudes record a lower proportion of first/last return combinations, with the direct effect of reducing the number of laser points available for Digital Elevation Models and, subsequently, for forestry structure assessment.

The work reported in this paper makes use of multipulse LiDAR data acquired in leaf-on conditions in two different study sites. The method implemented for the understorey detection is based on firstly identifying the single trees and crowns belonging to the dominant storey. A subsequent algorithm makes it possible to automatically determine a local threshold value for filtering the clustered crowns and, at the same time, classifying the understorey point cloud. Field data is surveyed and used ad hoc for this study, both in mono-storey and in bi-storey forestry plots, enabling the method setting and the verification of the results obtained.

2.1 Study area

Two different study areas located in some mountainous sectors of the Friuli Venezia Giulia Region (N-E Italy) were investigated in this paper. The first area (MB) is essentially characterized by spruce, and spruce-fir, with a sparse presence of beech (Figure 1). As far as the vertical structure is concerned, the area is a managed mono-storey forest (zone marked as A2 in the image), without the presence of vegetation under the canopy. Significant for the aim of this study is the extensive presence of growing vegetation along the border line between forest and adjacent open stand (zone A1 in the image).

The second area (BA) is a bi-storey forest in which the higher level is dominated by black pine with a population density of about 530 trees/hectar (Figure 2). The dominant layer has a homogeneous stand structure and the canopy is relatively closed. The lower level is characterized by a natural regeneration of different species: hop hornbeam, pubescent oak, flowering ash. In this area different population densities are to be found with the result that two different sub-zones can be distinguished within this forest: one with dense homogeneous low vegetation (B1) and the other with more sparse vegetation (B2).

Figure 1: MB area, characterized by a mono-storey spruce forest. The average of crown base height is about 7-8 meters inside the forest (A2). The area shows the presence of border vegetation (A1).

Figure 2: BA area, characterized by bi-storey black pine forest with different low vegetation population density. In the B1 part the understorey vegetation has a regular pattern while in B2 it is irregular (patched).

Within these areas some sub-zones of interest have been located and geo-referenced using topographic total station and GPS. This has allowed the precise and accurate determination of the coordinates of 6 circular plots (transects), with radius ranging between 12 and 25 meters. The general forestry characteristics of these plots are reported in Table 1.

Table 1 – Summary of the geo-referenced forestry plot characteristics in the MB forestry area.

Plot ID	**trees /ha**	**Area (m^2)**	**Management type**	**Age**	**Composition**	**Structure**
MBA	619	450	stand	mature	mixed	mono-storey
MBB	1525	450	stand	juvenile	spruce	mono-storey
MBC	575	450	stand	juvenile	spruce	mono-storey
MBD	463	2000	stand	mature	spruce	mono-storey
BAA	536	2000	stand	mature	black pine	bi-storey
BAB	510	450	stand	mature	black pine	bi-storey

As far as the BA forestry area is concerned, the low vegetation was detected at area-level using GPS, enabling the detection of the small broad-leaved clumps of trees. In particular, two types of undercover were surveyed: regular pattern and patched.

The principal characteristics of the LiDAR datasets are reported in Table 2. As shown in the table, the datasets were surveyed in leaf-on condition. This must be taken into consideration, especially in the cases of beech forests because the presence of foliage decreases the capacity of the laser beam to penetrate the canopy and detect the intermediate strata (Barilotti et al. 2006).

Table 2 – Summary of the laser data characteristics for each forestry transect.

Plot_ID	Period of survey	N° of echoes	Local point density
MBA	June	Multiple	6 pt/m^2
MBB	June	Multiple	7 pt/m^2
MBC	June	Multiple	8 pt/m^2
MBD	June	Multiple	10 pt/m^2
BAA	June	Multiple	5 pt/m^2
BAA	June	Multiple	6 pt/m^2

The datasets were detected using a multiple pulse laser scanner (Optech ALTM 3100) that increases the capacity to sample the intermediate layers of the vegetation if compared to the First & Last instrument. The flight altitude was about 1000 m above ground and the laser beam divergence was 0.2 mrad for both campaigns.

3. Method

A complete processing chain was developed, starting with raw laser points as input data and ending with derived tree parameters for each single tree of the dominant layer. The procedure is composed of a series of elaborations and transformations that can be schematically related to the following methodological aspects:

- Application of mathematical morphology algorithms, following a dynamic approach, to extract the canopy apexes (Barilotti et al, 2007a);
- Identification of the laser points belonging to the single crowns by means of a cluster analysis algorithm (Barilotti et al, 2007b).

Resuming this last point, the single crowns are identified by means of a region growing algorithm. Starting from the apexes previously extracted, the algorithm classifies the vegetation points according to the criteria defined below:

- If the points located in the proximity of the starting apex are lower (height difference) than a fixed threshold, these are marked as belonging to the same cluster;
- When the same laser point is marked as belonging to different apexes (this is particularly true when the forest is characterized by close vegetation), the algorithm associates the point to the nearest apex.

An example of clustered data resulting from this method is given in Figure 3.

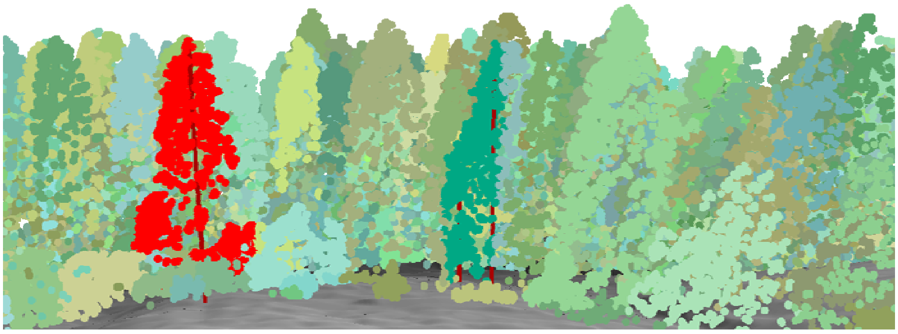

Figure 3: Example of clustered laser data in the ecotone of MB area. The red colored cluster emphasizes the cases in which the same cluster contains both dominant tree and dominated vegetation undercover.

As can be noticed, the cluster shape is not predefined but is closely related to the vertical distribution of the LiDAR point cloud. For this reason, if points reflected by low vegetation are recorded, they are located within the dominant clustered tree. A method for cluster filtering was implemented to isolate these low points. First, the histogram of the height frequency distribution of points is calculated cluster by cluster. Afterwards, a polynomial regression function is used to interpolate frequency histograms, obtaining a curve of frequency distribution for each one. Finally, the curves are explored by means of a study function looking for the presence or absence of a local frequency minimum. If this value is present, this is used as a threshold to perform a local filtering of the cluster, making it possible to eliminate those points that have less height than the class corresponding to the function minimum. An example of this process is given in Figure 4. The figure shows some different clusters of the MB area reported with their relative height frequency distribution (blue histograms) which was calculated using a height class of 1 meter. The first cluster is located within a mono-storey forested area (see figure 1-A2) while the other two clusters are located in the ecotone (see fig. 1-A1 and fig. 3). In the histogram images, the respective interpolating curves (in black) are reported as well.

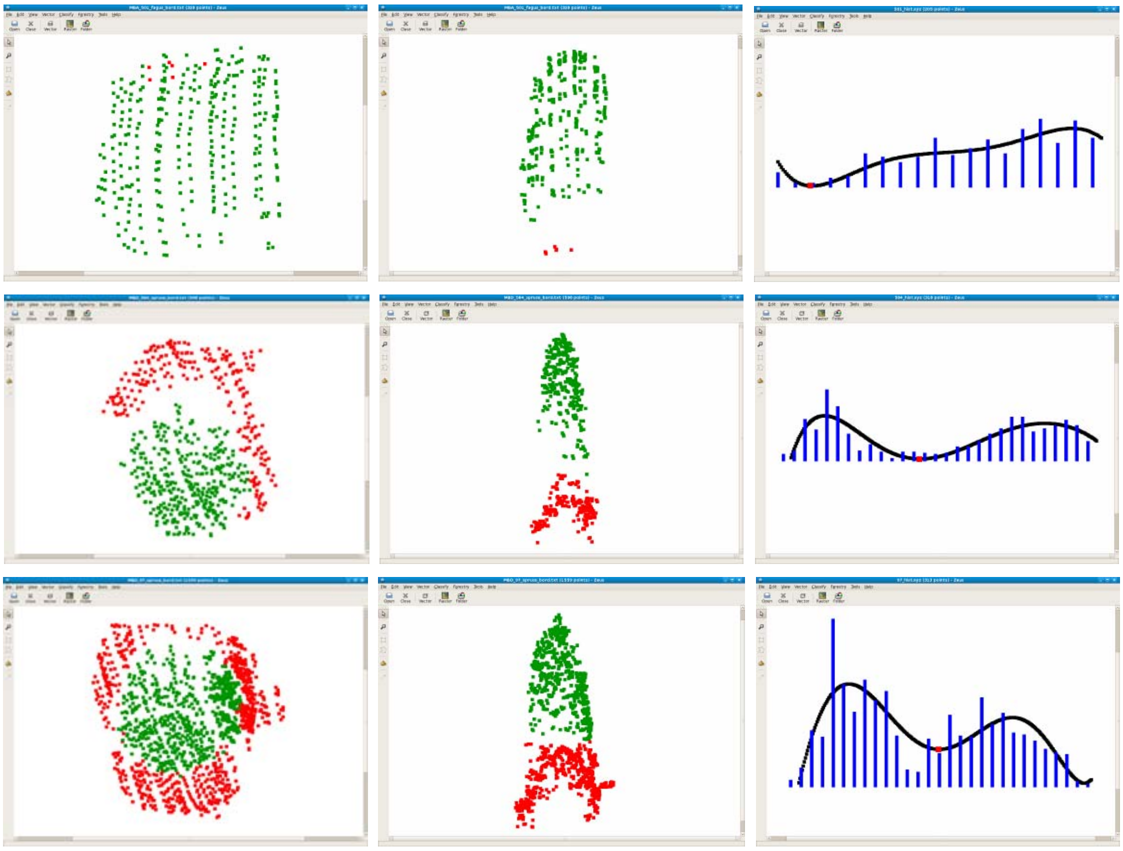

Figure 4: Cases of clustered trees located in different positions in the forest. From the top to the bottom respectively: tree within close vegetation and two trees dominating low vegetation. On the right the relative height frequency distribution of clusters is reported (blue line). For each frequency diagram, the polynomial regression is calculated (black line) and then it is used to re-filter the sub-clusters after its minimum (in red) is calculated by means of a study function.

In the three examples, the minimum of interpolated curves is reported in red. In the first cluster the minimum is found in the lower height classes and the curve shows an increasing trend. In this case, the tree seems to be well clustered and just a few low points are filtered. On the contrary, the other two examples (cases 2 and 3), showing a bi-modal trend, indicate the presence of anomalies in the height frequency distribution (higher point density in the lower classes of points). Such anomalies are evidently caused by the presence of vegetation under the dominant tree. Those points can be re-filtered and classified as low vegetation by using the curve minimums as local threshold value.

3. Results

Starting from this re-filtering approach on single clustered crowns, it is possible to obtain a zonal distribution of laser points belonging to the undercover vegetation. Two examples of the elaboration process are given in Figure 5 and 6. The left side shows in a green ramp color the clustered dominant layer while the re-filtered points, classified as belonging to the undercover vegetation, are shown in red. Those points are highlighted on the right side in the image sequence. The right side of the two figures also highlights the peculiar parts of the study areas:

1. the ecotone (A1) and the georeferenced transect (A2) in the mono-storey forest;
2. the dense undercover vegetation (B1) and the sparse one (B2) in the bi-storied forest.

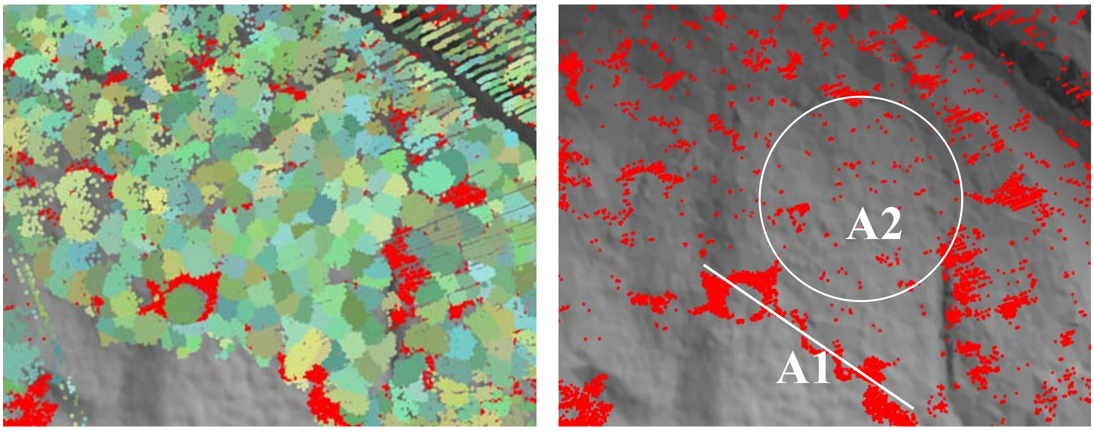

Figure 5: Example of cluster re-filtering method to locally isolate the low vegetation (red colored points) under dominant trees (green colored cluster) in the MB area. The ecotone (A1) and the mono-storey MBD transect (A2) are shown in white in the image on the right.

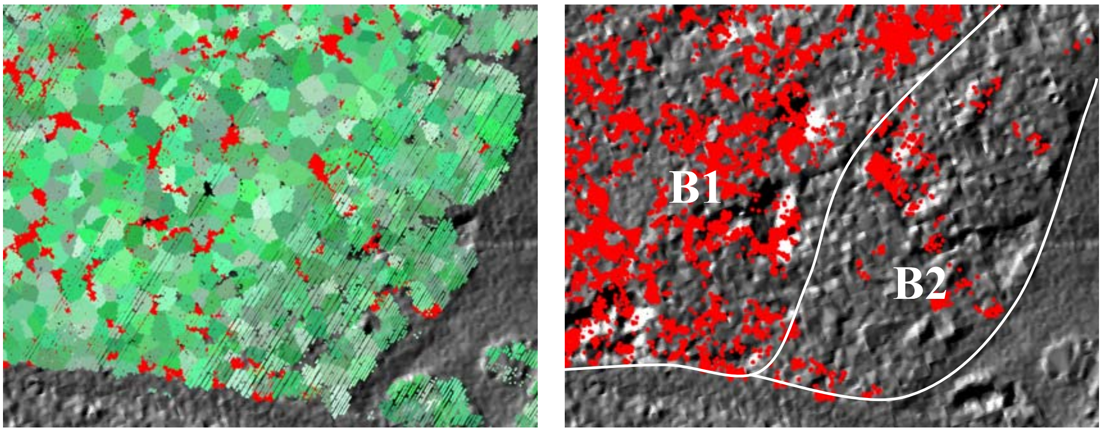

Figure 6: Example of cluster re-filtering method to locally isolate the low vegetation (red colored points) under dominant trees (green colored cluster) in the BA area. A dense understorey zone (B1) and a sparse one (A2) are shown in white in the image on the right.

Some qualitative considerations are possible by comparing the LiDAR-extracted forestry layers and the corresponding field evidences. In the MB area, the first part of the ecotone is directly individuated by the tree extraction process, as a matter of fact that here the vegetation has a direct access to the light. The second part, composed by co-dominant trees (red points in the fig.5), was correctly individuated by means of the re-filtering process. As expected, in the mono-storey transects (e.g. A2) just few isolated points were removed from the clusters of the dominant storey. The elimination of these points does not seem to reduce the quality of dominant crown shape. On the contrary, those points can be considered as outliers because resulting from some random reflections on the lower part of the dominant layer (e.g. trunks or branches).

As far as the BA area is concerned, the re-filtering method enables the localization of the second storey. Differences between the two different composed areas (B1 and B2 in Fig. 6) are also mapped in terms of consistency: in B1 the low re-filtered points assume a homogeneous distribution, corresponding to the rather spread density of the understorey vegetation. Differently, in B2 just few clusters of points are filtered given that in this area the second storey assumes a patched distribution. In this cases, confronting the field surveyed area of the dominated vegetation with the correspondent area resulting from the filtered points, an underestimation of about 15% was observed. This is probably due to the poor density of the LiDAR point clouds used in this work.

4. Discussion and conclusions

In this paper we explored the potential of Airborne Laser Scanning to measure the understorey vegetation in variously composed Alpine forests. A complete processing chain was developed, starting with the point cloud as input data and ending with derived three dimensional parameters for each single tree of the dominant layer as well as the automatic individuation of the understorey cover. As far as the dominant storey is concerned, the accuracy level of the extracted parameters is generally high as reported in the previously cited works.

Concerning the understorey, a statistical analysis of the height (z) frequency distribution was performed allowing the local (single tree level) re-filtration of the low laser points that belong to the forestry ecotone or to the under-canopy vegetation. The method enables the automatic determination of the spatial distribution of the dominated layer, without a-priori knowledge of the forestry structure.

Comparing the approach shown in this paper with the one presented in Maltamo et al. (2005), follows that both are based on the analysis of histogram of height frequency distribution of laser point cloud. However, in this paper a tree level analysis is used whereas a plot level analysis was performed in the paper by Maltamo et al. (2005). This could give significant differences when the study site is composed by heterogeneous bi-storey structure, particularly when the dominated level is characterized by different population heights. In these cases, the analysis carried out by the single tree approach should increase the capacity of the histogram method to find gaps between the two structural storeys.

A field survey campaign in some mountainous geo-referenced plots was performed in coniferous and mixed forests characterized by mono-storey and bi-storey structures. The analysis of the extracted data highlighted that the method is able to correctly individuate the areas characterized by the presence of dominate forestry layers. Moreover, the method does not introduce false positive vegetation layer in the mono-storey transects, as expected.

However, some problems in finding bi-modal frequency distribution has been noticed when the branches of under-storey are very close to the crowns of dominant layer. Moreover, the reduced penetration capacity of the laser beam in correspondence of very dense dominant storey contributes to affect the results in terms of understorey discrimination. Further studies will concern the application of the re-filtration method to the full waveform data that increases the capacity of LiDAR technique to collect data on lower vegetation strata.

The approach presented in this paper gives information on the existence and the area covered by the dominated tree layer. These information are of primary interest for forestry assessment an planning, due to high naturalistic value of bi-storied areas as peculiar habitats and also because of their relatively higher fire risk, compared to the mono-storey areas.

Starting from here, further works will be also devoted to investigate the possibility to obtain quantitative information on the number, size and composition of suppressed trees, which could be of interest in the determination of carbon content of the above ground biomass.

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