AN AUTOMATIC TECHNIQUE FOR DECIDUOUS TREES DETECTION IN HIGH DENSITY LIDAR DATA BASED ON DELAUNAY TRIANGULATION

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ABSTRACT

Individual tree detection in Light Detection and Ranging (LiDAR) data has been widely investigated in the literature. However, most of the methods work well on conifers but lead to poor accuracy in broad-leaved forest. The detection of deciduous trees is a complex task due to: (i) multiple local maxima present in the same canopy, and (ii) the tree-top (TP) can be in a different location from the canopy center. This paper presents an automatic technique which exploits high density LiDAR data to refine the detection of deciduous trees. First, the candidate tree-tops (CTPs) are detected using the standard level set method (LSM). Then, the Delaunay triangulation is used to generate a network topology which connects neighboring CTPs. For each pair of connected CTPs, geometrical features are extracted to automatically determine if the CTPs pair belongs to the same tree or to different canopies. The groups of CTPs identified as belonging to the same tree crown are merged into one TP. Preliminary numerical results show that the proposed method halves the commission errors of the initial TP detection by increasing the overall detection accuracy of 8.2%.

***Index Terms*—** Tree Detection, Airborne Laser Scanning, Point Clouds, Deciduous Forests, Delaunay Triangulation, Remote Sensing (RS).

1. INTRODUCTION

The use of Light Detection and Ranging (LiDAR) data has become a standard for forest management inventories in many northern European countries [1]. The possibility of collecting objective height measures over large areas enables a high-precision characterization of forest, which is fundamental for forest management. In this operational scenario, the detection of the individual tree location represents an essential component.

In the last two decades, many algorithms have been developed for the accurate detection of individual trees [2]. Most of the methods typically rely on the raster-based canopy height model (CHM) interpolated from the airborne LiDAR point cloud. The locations of the TPs are associated with the peaks present in the CHM, which can be detected by local maxima filtering approaches [3], or by applying a level set method (LSM) [4]. Recently, attention has been devoted to methods that can be directly applied to LiDAR point clouds [5, 6]. In [5], the authors compare different clustering methods to partition the LiDAR point cloud into a group of clusters. Each cluster is associated with a tree. In [6], a voxel-based approach is proposed to delineate the individual trees in the 3-D point cloud space.

Although these methods work well for mixed coniferous forests, the detection accuracy decreases when they are applied to deciduous forests. Due to the complex shape of deciduous crowns, the TP position can be several meters away from the canopy center [2]. Moreover, high numbers of commission errors are usually obtained due to the presence of several local peaks within the same canopy [7]. Few works focus the attention on the detection of deciduous trees, mainly assuming leaf-off acquisition condition [8, 9]. Here, the absence of leaves in the canopy strongly facilitates the penetration of the laser beam, thus making the delineation of the canopy structure easier. However, LiDAR surveys are mostly performed during the summer [8].

This paper proposes an automatic technique for the accurate detection of deciduous trees in high density LiDAR data. Differently from the literature, the proposed method does not require leaf-off condition acquisitions. In contrast, the technique takes advantage from the high density LiDAR data to analyze the shape of the uppermost part of the tree canopies. In greater details, it first performs an initial TP detection by using the standard LSM [4]. Then, it generates a network topology by connecting neighboring CTPs trough the Delaunay triangulation. For each pair of CTPs, geometrical features are extracted to automatically determine if the analyzed edge connects local maxima belonging to the same tree or to different canopies. Finally, groups of CTPs that have been identified as belonging to the same canopy are merged into a single TP by discarding all the CTPs except the one with the highest height value.

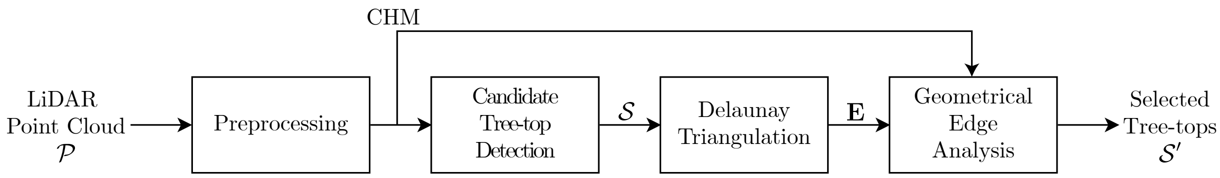


Fig. 1: Block scheme of the proposed detection method for deciduous forest.

2. PROPOSED TECHNIQUE FOR THE DECIDUOUS TREES DETECTION

Figure 1 shows the block scheme of the proposed technique. After a standard preprocessing step where the LiDAR point cloud is converted into the raster CHM, the method: (i) detects the initial set of CTPs present in the scene by using the standard LSM, (ii) defines the local network topology connecting the CTPs through the Delaunay triangulation, and (iii) refines the TP detection by analyzing the geometrical features extracted along each edge of the network.

2.1. Candidate Tree-Top Detection

To perform an initial CTP detection the LiDAR point cloud $\mathcal{P}$ is converted into the raster format to generate the CHM. To this end, the Digital Terrain Model (DTM) is subtracted from the LiDAR data and the laser points are regularized over a bi-dimensional grid. Possible gaps present in the grid due to missing points are removed using an interpolation algorithm [10].

In the considered implementation, the standard LSM [4] approach is used to identify the CTPs present in the scene. However, any other method can be employed. Due to the umbrella shaped crown morphology of deciduous trees, many commission errors are expected. Indeed, broad-leaved trees are usually characterized by a round canopy almost flat on the uppermost part, where several false local maxima can be detected. However, the high resolution LiDAR data allow us to refine the results obtained by analyzing the geometry of the crowns. Let $\mathcal{S} = \{\mathbf{s}_i\}_{i=1}^{N}$ be the set of N initial CTPs detected in the scene, where $\mathbf{s}_i = (x_i, y_i)$ represents the position of the ith CTP in the CHM.

2.2. Delaunay Triangulation

In order to detect local maxima belonging to the same deciduous tree, the proposed method analyzes the geometrical behavior of the horizontal profiles connecting pairs of CTPs. We assume that the horizontal profile connecting two local peaks belonging to the same crown is characterized by a geometrical pattern different from the one connecting different CTPs. Based on this assumption, in this step we generate a local network topology that connects the CTPs detected in the analyzed stand plot. Let $\mathbf{G} = (\mathbf{V}, \mathbf{E})$ be a graph with a set of vertices $\mathbf{V}$ connected by a set of edges $\mathbf{E}$. In the considered implementation the vertices are the CTPs identified in the previous step, $\mathbf{V} = \mathcal{S}$. The edge connecting the pair of nodes i and j is associated with a set of geometrical features $F_{ij} = F(\mathbf{s}_i, \mathbf{s}_j) = \{f_{ij}^1, f_{ij}^2, \ldots, f_{ij}^K\}$, with $i \neq j$.

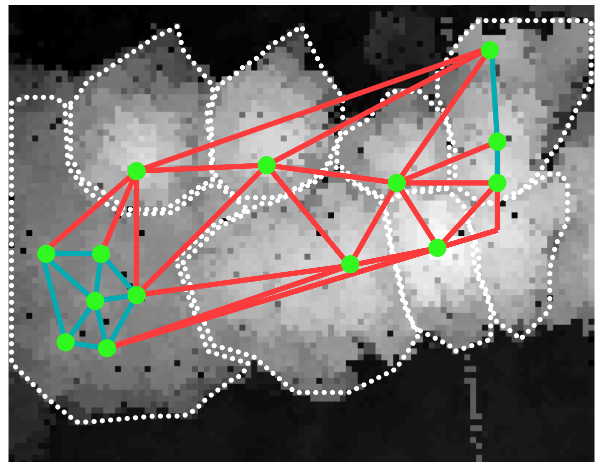


Fig. 2: Qualitative example of network topology derived by Delaunay triangulation on a set of CTPs (highlighted in green) overlapped to the CHM. The white dotted lines represent the boundaries of the tree crowns. The solid lines depict the edges defined by the triangulation, where the links connecting CTPs belonging to the same tree are in blue, whereas the links connecting different crowns are in red.

To determine the network topology in a fast and efficient way, the method employs the Delaunay triangulation technique. This technique has the advantages of providing locality, scaling well and being a constant spanner (i.e., the shortest path between any pair of nodes is at most a constant times longer than their Euclidean distance) [11]. For all these reasons, it can be used to perform the detection of TPs from a set of CTPs also on wide area forests. Figure 2 shows a qualitative example of network topology derived by Delaunay triangulation on a set of CTPs.

2.3. Geometrical Edge Analysis

In the last step, the proposed method extracts for each edge of the local network topology a set of geometrical features F_{ij} that are used to detect false CTPs. In the considered implementation, two simple physical features are considered: (i) the distance between the two CTPs, and (ii) the standard deviation of the height values of the CHM along the edge connecting the two CTPs. Indeed, it is reasonable to assume that local peaks belonging to the same crown are spatially close and present small variations of height of the canopy profile along the edge. In contrast, pairs of CTPs belonging to different crowns are expected to be at a relatively large distance and to show large oscillation (and thus variance) of the connecting height canopy profile.

We compute the two features for all the edges in $\mathbf{E}$, thus obtaining for the generic pair of CTPs (i, j) the features $F(\mathbf{s}_i, \mathbf{s}_j) = \{f_{ij}^1, f_{ij}^2\}$, where f_{ij}^1 and f_{ij}^2 represent the distance value between vertices and the standard deviation value of the profile heights, respectively. By simply applying two threshold to the considered features, we can detect pairs of CTPs belonging to the same crown. For a given edge, the vertices $(\mathbf{s}_i, \mathbf{s}_j)$ (i.e., the two CTPs) are considered to belong to the same tree crown if the features satisfy the following conditions:

$$f_{ij}^1 \leq t_{\mathsf{d}} \text{ and } f_{ij}^2 \leq t_{\mathsf{s}}, \tag{1}$$

where t_{d} and t_{s} are the two thresholds. To compute these thresholds values in an adaptive way, we analyze the features extracted for all the edges of the local network. In particular, t_{d} and t_{s} are computed as the 25th percentile of the distance and the standard deviation features of all the edges, respectively. This is done considering the fact that edges connecting CTPs in the same tree crown show features values compactly clustered in the lower portion of the range of possible values. Note that by computing the thresholds values considering all the edges the proposed technique is more robust to the diverse characteristics of different forest stands. To identify the groups of local maxima representing the same tree we exploit the local network topology searching for groups of CTPs connected by edges whose features satisfy the condition defined in Equation (1). Figure 2 shows two groups of CTPs that have been identified as belonging to the same tree crown. For each groups, we select the highest CTPs thus generating a new set of TPs $\mathcal{S}' = \{\mathbf{s}_i\}_{i=1}^M$ with $M << N$.

3. EXPERIMENTAL RESULTS

3.1. Dataset Description

To asses the effectiveness of the proposed method we considered a study area located in the Pellizzano municipality in the Trentino province, southern Italian Alps. The coordinates of the central point of the study area are $46°17'31,00''$N, $10°45'56,49''$E. The considered forest presents a complex topography characterized by an altitude which ranges from 900 m to 2000 m above sea level, where most of the deciduous trees are located at the lower altitudes. The LiDAR data were acquired in 2012 by Riegl LMS-Q680i sensor mounted on an airborne platform. The point cloud has a maximum pulse density of 50 pls/m^2 with four returns registered for each pulse.

Since the considered study area is a mixed forest where deciduous trees are scattered in small groups, 13 stands composed of an average of 8 deciduous trees were selected. To validate the method, for each stand we manually identified and delineated the individual tree crowns. In total 101 trees were identified.

Table 1: Numerical results of the proposed method compared with the standard LSM [4].

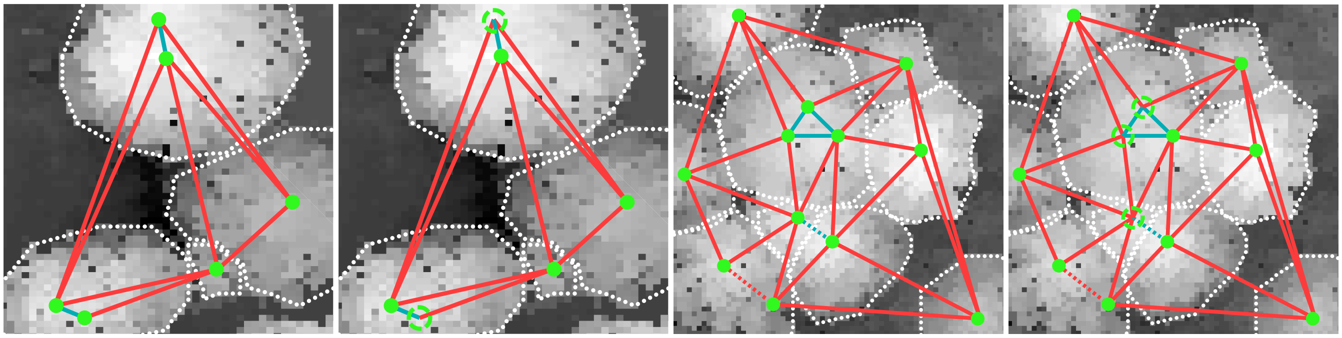
Method	Trees	CE		OE		OA
	#	#	%	#	%	%
LSM [4]	101	49	48.5	6	5.9	63.3
Proposed	101	22	21.8	13	12.9	**71.5**

3.2. Experimental Results

Figure 3 shows two real examples of the proposed link analysis based on the Delaunay triangulation. Note that after the link analysis the groups of CTPs identified as belonging to the same tree are reduced to one TP. From a qualitative evaluation, one can notice that the proposed method is able to accurately remove many false local maxima present in the scene due to the complex crown shape of deciduous trees. This is confirmed by the quantitative analysis.

Table 1 shows the TP detection results obtained by the proposed method and the standard LSM [4] in terms of Commission Errors (CE), Omission Errors (OE) and Overall Accuracy (OA) considering all the stands. The same LSM settings used in the standard approach are used for the initialization of the proposed algorithm. The initial number of identified CTP is 144 and 343 links between the CTPs were obtained using the Delaunay triangulation. Note that the number of links is relatively small compared to the one that would be obtained by connecting all the CTPs. This condition allows us to significantly decrease the computational cost.

Although the LSM achieves a lower OE rate compared to the one obtained by the proposed method (5.9% versus 12.9 %), many CE severely affect the OA since multiple maxima are identified in many deciduous trees. Therefore a very high CE rate is recorded for the standard LSM (i.e, 48.5%). In contrast, the pairwise analysis of CTPs performed by the proposed method allows us to sharply reduce the CE (from 48.5% to 21.8%), while slightly increasing the number of OE. This is due to pairs of deciduous trees very close to each other that are not well distinguishable (blue dashed line in Figure 3c). Note that most of the remaining CE are due to upper branches separated from the bottom part of the tree crown. Figure 3c shows an example of deciduous tree where a tree branch appears in the CHM as a prominent maximum (red dashed line).



(a) (b) (c) (d)

Fig. 3: Real example of TP analysis using Delaunay triangulation: (a,c) CTPs detected by the LSM, (b,d) CTPs selected by the proposed method. The blue solid lines link CTPs that have been identified as belonging to the same tree. The green dashed circles are the CTPs eliminated by the proposed method. The red and blue dashed lines are links that have not been identified correctly by the proposed method.

4. CONCLUSION

In this paper we presented a method for the identification of deciduous trees in high density LiDAR data. This is a complex problem since typically tree detection is performed by searching for maxima in the CHM. However, typically deciduous tree crowns are characterized by more than one maximum for each tree. To solve this problem, the proposed method first applies a TP detection based on a standard LSM and then analyzes the CTPs to decide if there are groups of CTPs that represent the same tree. This is done by considering the characteristics of the canopy profile between adjacent CTPs in terms of distance and standard deviation. The pairs of CTPs are identified using a Delaunay triangulation, which allows us to reduce the number of pairs to analyze. Preliminary numerical results show that the proposed method is capable of reducing the CE showing an increase of OA of 8.2%. The increase of OE is due to the very dense forest and requires further analysis. In particular, cases in which a CTP is connected to a group of CTPs belonging to the same tree crown by only one edge that satisfies the conditions of (1) should be analyzed. To address this problem, as future development we plan to take into account the connectivity of the local network topology and to consider also the Voronoi diagram to reduce the number of CE and OE. Moreover, we plan to use other relevant features and a more refined decision strategy.

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