Tree crown segmentation from LiDAR data based on a symmetrical structure detection algorithm (SSD)

L. Huo[1], E. Lindberg[1], J. Holmgren[1]

[1] Swedish University of Agriculture Sciences, SE-901 83 Umeå, Sweden
Email: langning.huo@slu.se, eva.lindberg@slu.se, johan.holmgren@slu.se

1. Introduction

During the past two decades, the potential of Light Detection and Ranging (LiDAR) in forest applications has been revealed by both scientific research and commercial products. One major application of LiDAR is estimation of forest parameters at a single-tree level, e.g. individual tree height, diameter at breast height (DBH), crown diameter, stem, and crown volume. Accurate estimates of these forest parameters can be achieved using different scanning platforms, including airborne laser scanning (ALS), terrestrial laser scanning (TLS), and mobile terrestrial laser scanning (MLS). Attention has been focused on the dominant and subdominant trees; fewer algorithms have focused on low vegetation (Ferraz et al., 2012; Harikumar et al., 2019; Paris et al., 2016), especially the small trees below the top canopy. In this study, we propose an individual tree segmentation (ITS) method, based on the symmetrical structure of trees (SSD). The SSD algorithm aims at segmenting point clouds of dominant trees and low vegetation accurately, which would be crucial for identifying low vegetation in the future.

2. Data and Methods

2.1 Data

The study area, Krycklan (64°14′N, 19°50′E), is located in the north of Sweden, within boreal forest. The common tree species are Scots pine (Pinus sylvestris), Norway spruce (Picea abies), and birch (Betula pendula and Betula pubescens). A field inventory of 80 m square plots was conducted in 2016. Each 80 m × 80 m plot was divided into 16 subplots of 20 m. For each tree, the positions and DBH were measured and the tree height was calculated from allometric relationships between height and DBH from sampling trees. In total, 251 subplots from 23 plots were used in the study, with exclusion of the subplots with selective cuts during the period from the field inventory to the laser scanning. Subsequently, “plot” refers to the 20 × 20 m subplots. Plot data are presented according to density level (Table 1).

Table 1. Attributes of the study plots.

Category	Density class	Threshold [stems]	Number of plots	Stem density [stems/ha]		DBH [cm]		Tree height [m]	
				Mean	Std	Mean	Std	Mean	Std
D-1	Low	≤700	71	637	241	20.2	3.4	16.0	1.5
D-2	Medium	700–1100	28	704	306	23.4	5.4	17.5	3.2
D-3	High	>1100	18	1383	732	14.7	3.1	12.0	1.9

Multispectral ALS data were acquired on June 28, 2019, with a RIEGL VQ-1560i-DW. This resulted in a scan width of 582 m and a measurement density of 24 pulses per m^2 and channel in each flight strip. TLS data were collected in 2016 using a Trimble TX8 from 4 × 4 scanning stations. The TLS point clouds were co-registered to ALS using the Iterative Closest Point (ICP) algorithm implemented in MATLAB. Then ALS and TLS point cloud for each plot was merged.

2.2 Methods

For this algorithm, the detection and segmentation of dominant trees were based on the symmetrical structure of individual trees. Pine and spruce, the most common tree species in Sweden, usually have

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symmetrical tree shapes: conical tree crowns and cylinder stems. In this study, points of dominant trees ($P_{dominant}$) were identified by creating cylinder spaces for individual dominant trees. The upper cylinder A was designed for tree crowns, with the CR identified as the radius of the cylinder. The lower cylinder B was designed for stems, with the detected CBH as the height of the cylinder. To obtain a proper space for $P_{dominant}$, the key parameters were CR and CBH.

Step 1 Definition of target point clouds for individual trees. We generated seed points from local maximum heights (LMH) detected from the nDSM smoothed by Gaussian filtering. We defined the target point clouds for individual trees as the points within 3 m horizontal distance to the seed points.

Step 2 Plotting the symmetry curve. The coordinates of the target point cloud were transformed from(x, y, z) to (h, r, q) using the method proposed by Huo and Zhang (2019), where h is the voxel height, r is the hornizatol voxel distance to the orgin, and q is the borizontal angle. Let $V = \{v_c\}_{c=1}^{C}$ be the set of voxels with coordinates $h = H_i$ and $r = R_j$, with H_i being the height of the voxels and R_j the distance to the centre of the voxels. If more than $\frac{3}{4}$ voxels in Set V were occupied by laser returns, we determined that a symmetrical structure existed at (R_j, H_i). The curve was plotted for (R_J, H_i), as in Figure 1 (a-1, b-1).

Step 4. Determination of true/false treetops. We determined a seed as true treetops if (1) there was less than 50% R among the upper 1/3 tree height are zero (designed for pines); or (2) there was less than 50% R among the lower 1/2 tree height are zero (designed for spruces).

Step 5 Detection of CR and CBH from symmetry curves. The symmetry curves were first smoothed, and from the curves, CR was determined as the point (R_u, H_u), and CBH as (R_l, H_l) (Figure 1 a-2, b-2). The value of (R_u, H_u) was set to the first point from the top when R no longer increased more than 0.25 m from H_i to H_{i+1}. R_u represented the radius of the symmetrical crown. Point (R_l, H_l) was at the lower part of the curve, indicating the lower edge of a tree crown with a height of H_l and a radius of R_l. Detection continues from H_u to a lower H, until the first local minimum R emerges, with the value (R_l, H_l).

Step 1.6 Creation of the clipping space. For each treetop, a clipping curve (Figure 1 a-e, b-e) was created to include the space for the individual tree according to the (R_u, H_u) and (R_l, H_l) values. Laser points inside the clipped space were classified as $P_{dominant}$ (Figure 1).

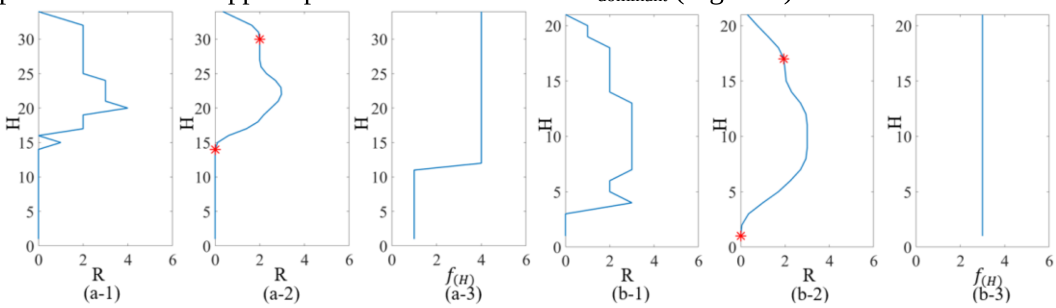

Figure 1. Two examples of the symmetry curve. (a-1, b-1) An unsmoothed symmetry curve, and (a-2, b-2) a smoothed symmetry curve, with (R_u, H_u) (upper red stars) and (R_l, H_l) (lower red stars). (a) An example of a pine with a funnel space. (b) An example of a spruce with a cylindrical space.

Detection results were validated by matching with the field data. The detection rate (DR), recall (R), precision (P), and F-scores (F) were calculated.

3. Results and Discussion

When averaging all the plots, the SSD algorithm achieved a value of 0.86 for DR (Table 2). Similar to other ITC segmentation algorithms, the detection rates decreased for plots with higher densities. Figure 2 shows two examples of the SSD segmentation.

By testing the symmetrical structure of trees, the SSD algorithm segments point clouds of the dominant trees and low vegetation. The next potential use of the SSD algorithm could be the identification and analysis of low vegetation, by removing the point clouds of dominant trees from a plot and keeping the point clouds of low vegetation.

Attribute	Category*	*DR*	*R*	*P*	*F*
Density	D-1	0.93	0.93	0.83	0.88
	D-2	0.87	0.88	0.89	0.89
	D-3	0.78	0.80	0.93	0.86
All plots		0.86	0.87	0.83	0.84

Table 2. Detection accuracy of SSD algorithm

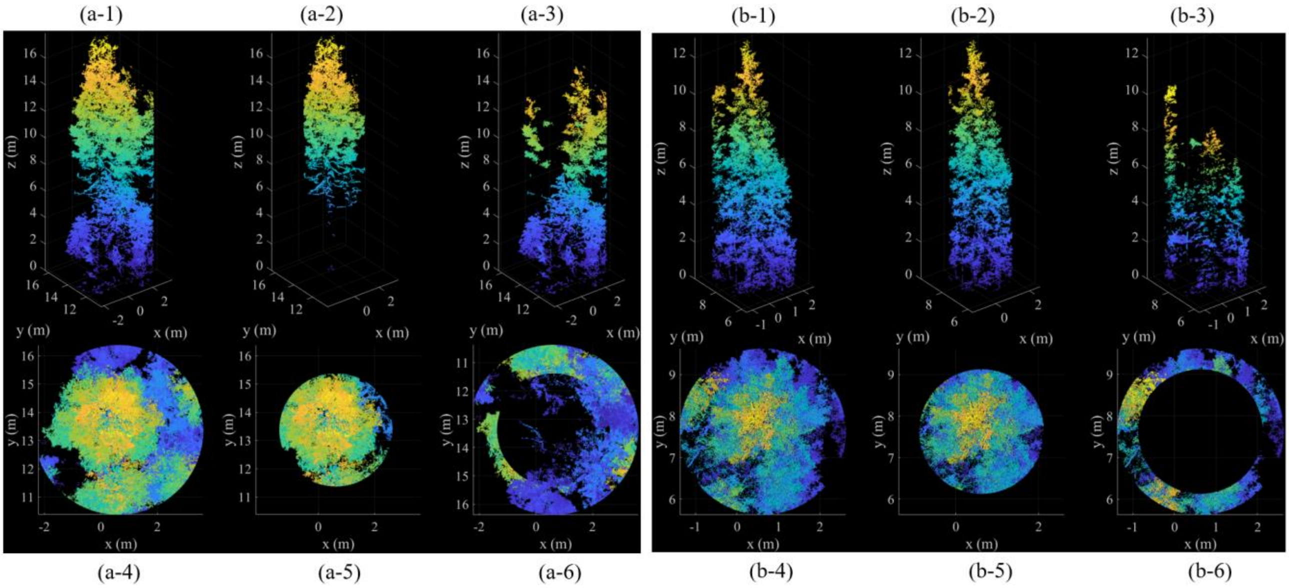

Figure 2. Two examples of classifying $P_{dominant}$. (a) Point clouds of a pine. (b) Point clouds of a spruce. (1 – 3) Side view of the P_{target}, $P_{dominant}$ and the rest of the points, respectively. (4 – 6) Top view of the P_{target}, $P_{dominant}$ and the rest of the points, respectively.

4. Conclusions

In this study, we proposed an algorithm of ITS by testing the symmetrical structure of individual trees. The crown radius and crown base height were estimated from a vertical symmetry curve of a tree. By creating cylinder spaces of the dominant trees, laser points were segmented into dominant trees and low vegetation. The SSD algorithm achieved 0.87 detection rate and 0.84 F-scale when matching the detected trees with the field records. Segmenting point clouds of dominant trees and low vegetation accurately could potentially contribute to the identification of low vegetation.

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