ALGORITHM ON EXTRACTION OF TREES IN VOXEL SPACE FROM TERRESTRIAL LASER SCANS

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Abstract

Terrestrial laser scanning (TLS) is a promising alternative for mapping trees and retrieve their biophysical metrics in natural or urban environment. To make this task efficient and productive, highly automated methods are needed. This poster presentation introduces an algorithm for automatic processing of registered terrestrial laser scans aiming at tree detection as well as estimation of stem diameters and stem curve. Voxels of high relative point density are assumed to represent stem surface and selected as seeds for 3D region growing resulting in individual tree models and a set of classified stem points. Stem diameters are estimated upon circle fitting in consecutive heights combined with linear regression in order to obtain individual stem profiles that are accurate and also consistent in taper. The algorithm was demonstrated on a test plot (0.25 hectare) that was recorded from three scan positions. Two processing strategies were applied: (1) Processing of individual scans (2) Processing of the merged scan. The completeness of tree detection was more related to tree size than to processing mode, and it varied between 45% and 90% when the merged point cloud was used. The DBH estimation accuracy is ±3.1 cm with a bias of 0.5 cm.

Tree extraction

Laser points above the terrain surface were translated into a voxel grid of 5 cm resolution. The resulting data structure served as model space for stem extraction and, at the same time, the voxels were used as spatial index to enable spatial queries on the original point clouds. Knowing the sensor positions and the angular resolution of the scanning, the relative point density for each voxel was computed by normalizing the actual point count with the number of beams emitted toward the corresponding voxel. Voxels of high relative point density are assumed to represent larger surfaces, predominantly stems and a main branches (*Figure 1*). The stems were cleared from branches using a directional (anisotropic) 3D filtering kernel. The remaining stem voxels were grouped into regions applying Connected Component Labelling (CCL) on the horizontal projection of the voxel-space. Regions with vertical extent exceeding 1 meter were regarded as individual stems (*Figure 2*).

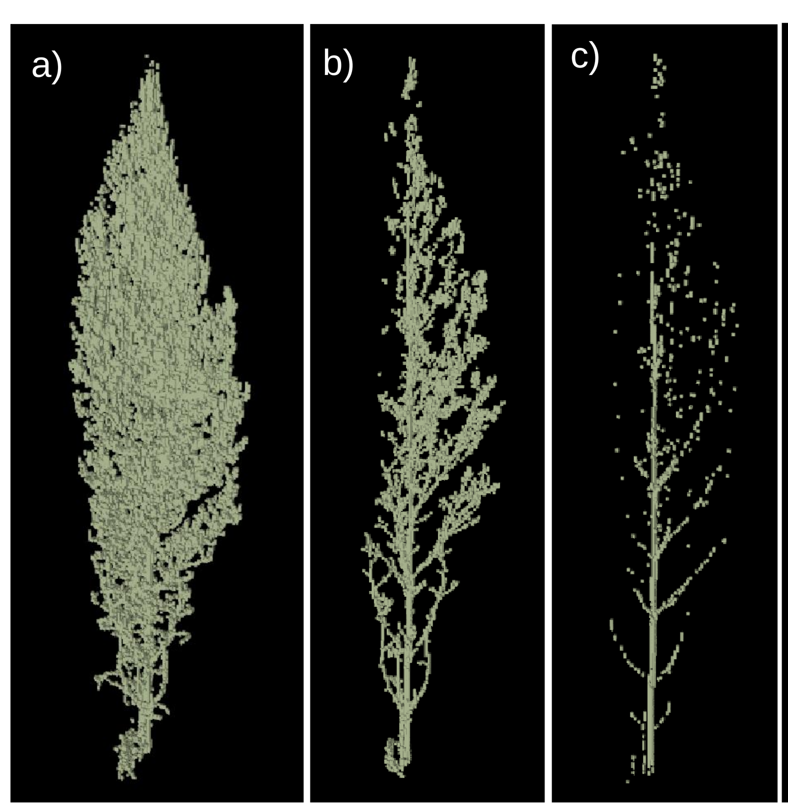

Figure 1: Effect of filtering with Relative Point Density (RPD). Original voxels (a) Voxels with RPD > 40% (b) Voxels with RPD > 60

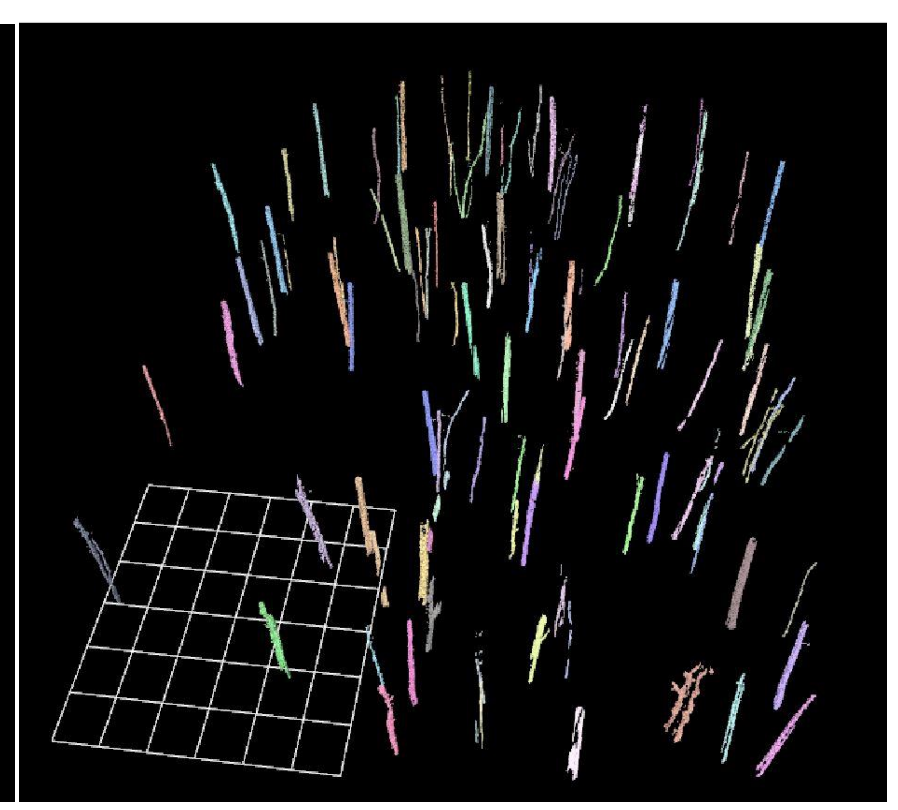

Figure 2: Isolated stem regions obtained by applying CCL on stem voxels. Voxels above 8 m were removed for better visibility.

Diameter estimation

In each layer of the voxel space, stem cross-sections were estimated by fitting circles onto the original points within the stem voxels, which resulted in up to 20 circles in each 1-meter stem interval. Construction of the stem curve is actually the task of selecting the circles that match accurately to the cross-section of the stem. Circles fitted with small RMSE are assumed to be reliable, i.e. free of gross errors. However, using solely these circles would result in deficient selection, because many of the unreliable circles are still accurate enough to be accounted for the creation of the stem curve. Therefore, two aspects were considered in the selection of stem circles: (1) Reliability of the fitting and (2) Consistency of successive circles in their diameter change according to the tapering model established for the individual stem.

Circles fitted with RMSE below 1cm were used for establishing the linear model of the stem taper. Since the actual taper of the trees is not exactly linear, a buffer zone of ±2cm around the regression line was added to specify the interval of diameters acceptable at a given height. Circles whose diameter was within the buffer zone (regardless their fitting residuals) were assumed to be consistent in stem tapering and were selected as stem circles. The final stem curve was computed by taking the mean of stem circle radii in each 1 meter interval (*Figure 3*). Diameter at breast height (DBH) was obtained from the stem curve.

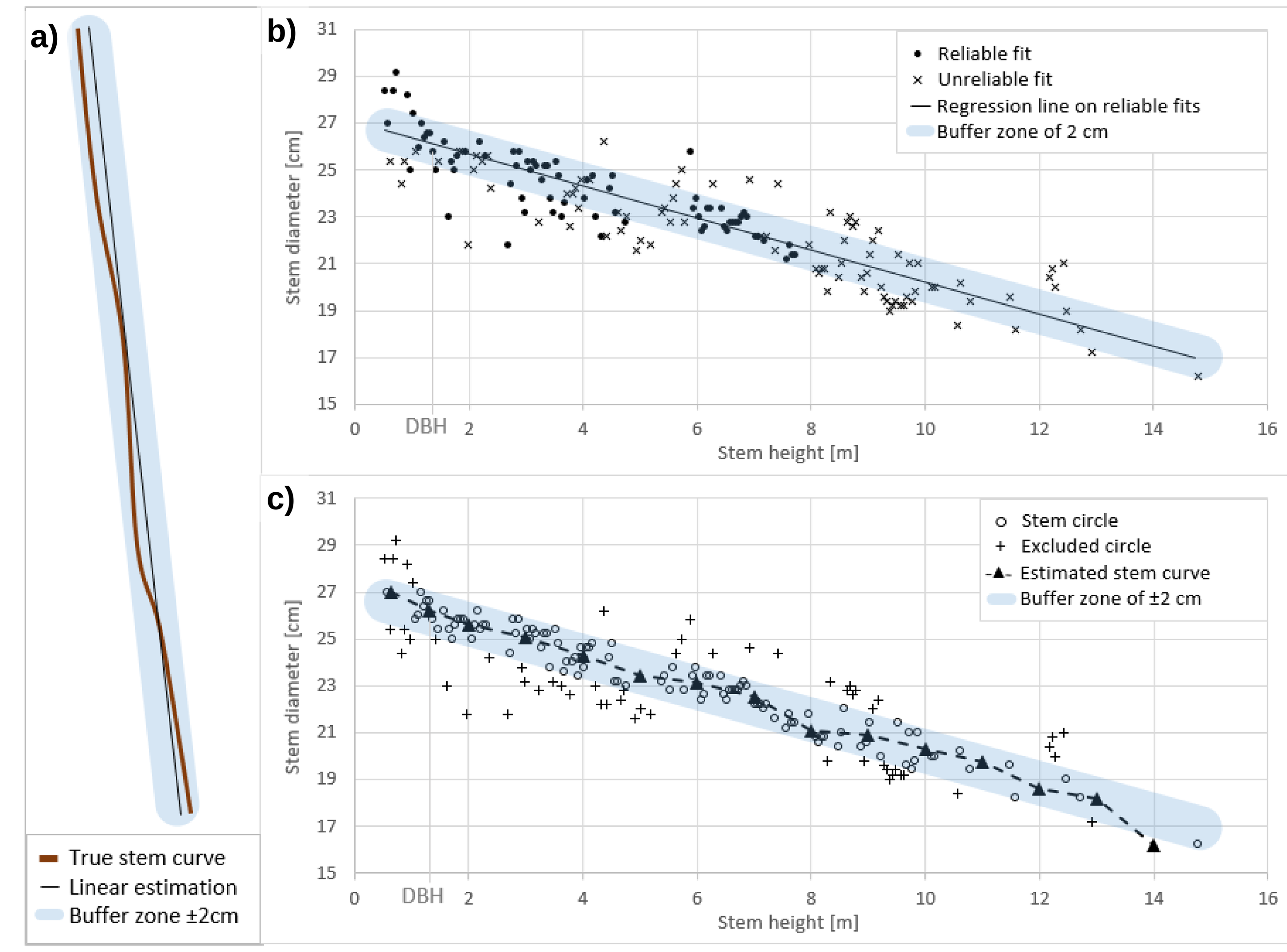

Figure 3: Construction of the stem curve is actually the task of selecting the circles that match accurately to the cross-section of the stem. In this study, a linear model and a corresponding buffer zone were used to specify the expected change in diameter of each individual tree (a). To create the linear model, the estimated diameter of the circles with RMSE < 1 cm was used. A buffer zone of ±2 cm was added to account for the natural deviations from the linear model (b). All circles (regardless of their fitting reliability) that comply with the specified interval of acceptable diameters were selected and included in the creation of the stem curve (c).

Validation

The algorithm was validated in a mixed mature stand with subcanopy layer located in West Hungary (N 46.9, E 16.4). The ground is naturally clear of undervegetation (*Figure 4*). Three scans were made using a Leica Scan Station® C10 in leaf-less state in a quadratic sample plot of 45 × 55 meter.

The terrain model was created using the commercial LiDAR processing software packages OPALS and Scop++. Since both have been developed for processing of airborne data, special parametrization and workflow were applied. A coarse surface was generated from the lowest points within a grid of 2 meter. Points within 0.5 meter vertical distance of this surface were used as input for Robust Filtering.

Tree positions and DBH estimates were obtained through the introduced algorithm which had been implemented as console application developed in C. Two processing modes with identical parameter set were applied to demonstrate the effect of different data integration strategies:

1. Merging in point cloud level (Multi-scan processing: MS): All scans were merged into one point cloud prior to tree extraction
2. Merging in object level (Single-scan processing: SS): Individual scans were processed separately and the resulted tree models were fused by taking the mean of coherent positions and diameters.

Figure 4: Validation of the algorithm. The test plot was established in a mature mixed stand with subcanopy layer (a). The scanning was done in leaf-less state with Leica Scan Station 10 instrument (b, c).

Results

A total of 103 trees (75.7%) out of 136 were detected automatically regarding the union of the results from the two processing modes (*Table 1*). There was no false detection, although there was no understory vegetation that could have interfered with the automatic tree extraction. Processing of the merged point cloud (MS mode) resulted in about 10% more detections compared to the processing of individual scans (SS mode). Especially trees distant to any of the scanning positions could be detected from the merged point cloud only (*Figure 5*). In a few cases of multi-stem shoots, SS mode proved to be more efficient resulting some additional small trees. Dependency of the detection rate from tree size is evident from *figure 6*.

Regarding diameter estimates, the bias is somewhat smaller in MS mode but there is no significant difference in estimation accuracy among the processing modes (*Table 2*). The moderate accuracy of ±3 cm is partly explained by a few gross errors that can be traced back to insufficient detections, e.g. small multiple stems are treated as one larger.

Table 1: Tree detection results

	Tree counts	%
Reference trees	136	100.0
Detected in SS	90	66.2
Detected in MS	98	72.1
Detected in SS and MS	85	62.5
Detected in SS or MS	103	75.7
Detected in SS only	5	3.7
Detected in MS only	13	9.6

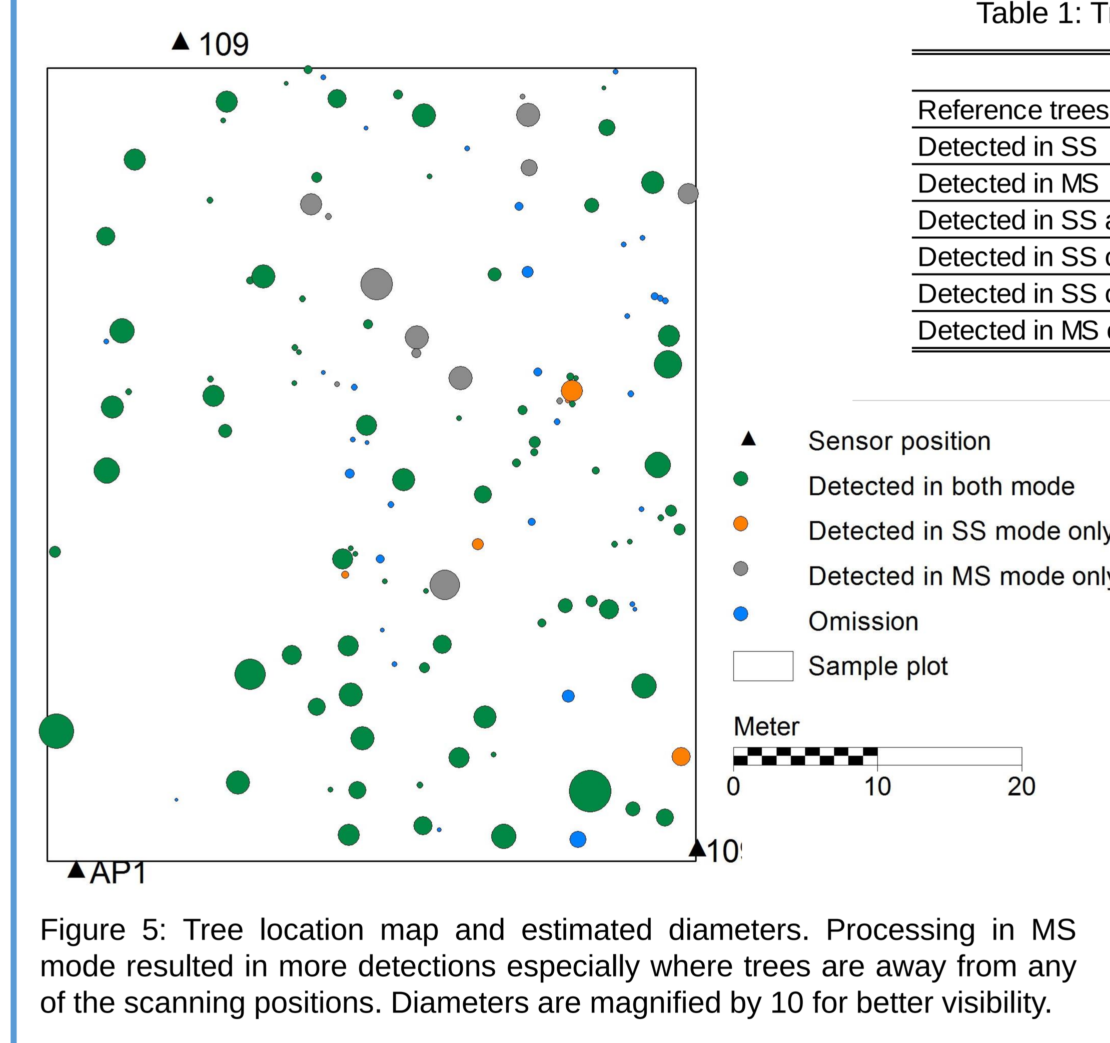

Figure 5: Tree location map and estimated diameters. Processing in MS mode resulted in more detections especially where trees are away from any of the scanning positions. Diameters are magnified by 10 for better visibility.

Table 2: DBH estimation errors [cm]

	SS	MS
Mean	1.5	0.5
Sd	3.2	3.1
Min	-6.2	-6.0
Max	12.1	14.3

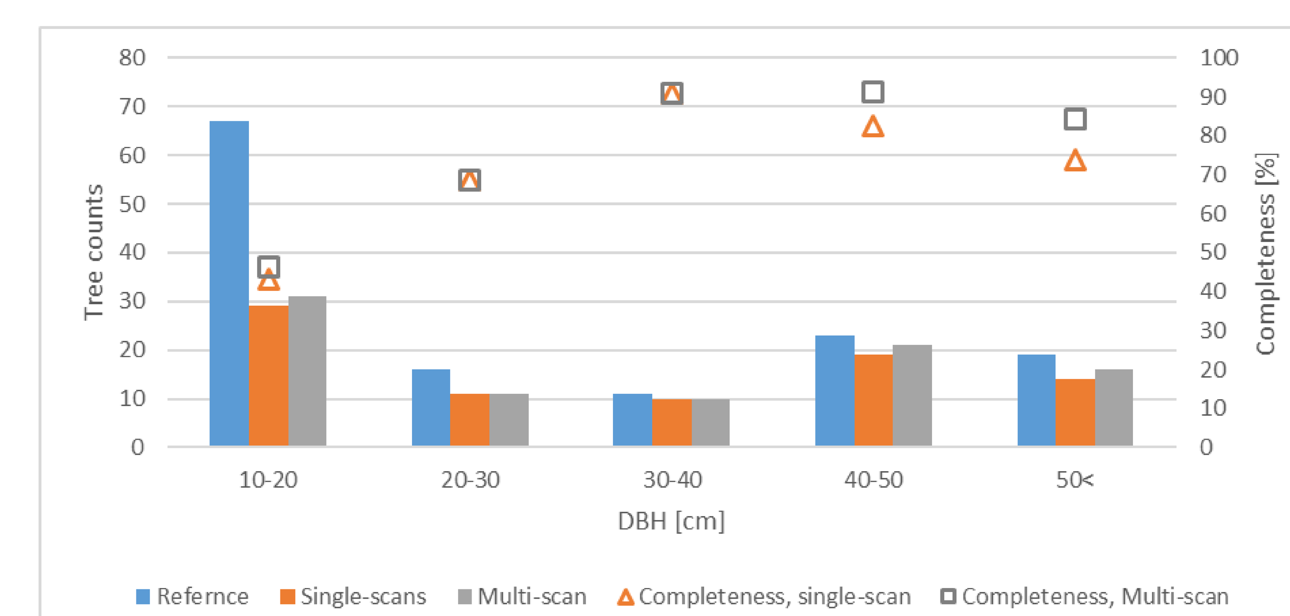

Figure 6: Counts (left axis) and completeness (right axis) of tree detection in diameter classes. The performance of tree detection is strongly related to tree size, as the completeness improves from below 50% to above 80% according to increase in of stem diameters.

Summary

A new algorithm on automatic tree extraction was introduced that utilizes voxels for tree detection. Stem diameters - including DBH - are estimated through individual stem curves which is generally more accurate than estimation from single circle fits. Instead of smoothing the diameters, that may be heavily effected by a few circles with gross errors, the proposed method applies a selection schema to create a stem curve with consistent tapering. The algorithm was validated on a relatively large test plot of 0.25 hectare that was scanned from three positions. Using the merged point cloud as input, the achieved completeness of tree detection was 45-90% depending on tree size, with DBH estimation accuracy of ±3.1 cm (bias: 0.5 cm).

Acknowledgement

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