Tree Crown Segmentation and Morphological Modelling of Personal Laser Scanning Data

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1. Introduction

Key of LiDAR based forest inventory is the availability of suitable software to extract essential tree features (Calders et al 2020). Most relevant tasks of the computer algorithms are the automatic detection of stem positions, the segmentation of the complete 3D point cloud into single tree crowns, the precise measurement of tree height and stem diameter, and the reliable modelling of the crown morphology. These tasks can become challenging, especially in dense forest canopies with overlapping crowns. To overcome these issues, Gollob et al. (2020) proposed a tree detection algorithm based on density clustering applied to multiple horizontal layers that produces reliable results even in dense stands. Personal Laser Scanning (PLS) has several advantages compared to the stationary Terrestrial Laser Scanning (TLS) (Bienert et al. 2018). Most relevant is that the crowns are scanned from various angles, because the scan positions are not fixed with PLS. In this study, a novel algorithm is presented for the automatic segmentation of the single tree stems and crowns. Additionally, the accuracy of automatically derived crown features is evaluated by means of reference measurements collected in field and manual on-screen segmentations of the 3D point cloud.

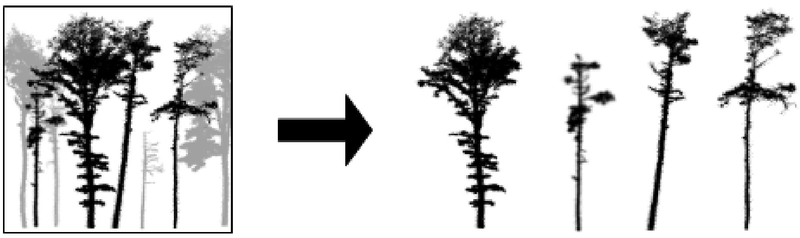

Figure 1: Segmenting the complete point clous into single tree files to be measured subsequently.

2. Data and Methods

The ZEB HORIZON (GeoSLAM Ltd.) used for this research has an acquisition speed of 300.000 points/sec and a maximum beam range of 100 m, the average point density of the point clouds was 45k points per m². A single scan with the PLS system required one person approximately 30 minutes to fully capture one plot area of approximately 4.000 m² each. Sample plots were scanned around Maissau, Lower Austria (48° 34’ 25”N and 15° 48’ 45” E), the forests were single layered with medium density (average 870 trees per ha). The dominating tree species were Scots pine (*Pinus sylvestris L.*) and sessile oak (*Quercus petraea (Matt.) Liebl.*), which were complemented by admixture of Norway spruce (Picea abies (L.) H. Karst.), European larch (*Larix decidua Mill.*), black pine (*Pinus nigra J. F. Arnold*), European yew (*Taxus baccata L.*), douglas fir (*Pseudotsuga menziesii (Mirbel) Franco*) and wild cherry (*Prunus avium L.*). The field reference data for all trees on the sample plots were comprised of the relative stem location, tree species, DBH, tree height, and crown base height.

The routines to perform the individual tree detection, the automatic crown segmentation, and the parameter calculation were programmed in R software (R Foundation for Statistical Computing). The routines also used functionalities of existing R packages (mainly lidR, TreeLS and dbscan). Output tree files were stored in the “las” file-format (American Society for Photogrammetry and Remote

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Sensing ASPRS). To assess the quality of the crown separation algorithm, 235 crowns were randomly selected throughout the stands for a manual on-screen segmentation using the CloudCompare program (Girardeau-Montaut 2017). The manually segmented point clouds were merged with the output files of the automatic crown segmentation to calculate performance measures in terms of the detection rate (number of correctly matched points divided by total number of manually segmented points), the commission error (number of surplus detected points divided by total automatically segmented points), and the overall accuracy (detection rate minus commission error).

3. Results and Discussion

By merging the manual and automatic derived crown files (as seen in Figure 2) the accuracy measures were calculated (average values and standard deviations crowns are given in Table 1). The average detection rate was 94 %, i.e. 6 % of the reference crown voxels (cubes of 2x2x2 cm) were not correctly assigned by the automatic segmentation. The average commission error was 14 %. The number of assigned surplus points was higher than the number of missed points, this can be explained by the inclusion of points in the upper crown section from neighbouring trees and of the understorey vegetation close to the stems that has been included in the automatic tree detection but was removed in the manually segmented trees.

Table 1. Congruence measures of the automatic segmented and manual reference crowns.

n = 235	mean	*st.dev.*
detection rate	93.81 %	*9.64 %*
commission error	13.58 %	*15.14 %*
accuracy	80.23 %	*16.89 %*

When analysing single trees there is a considerable amount of commission in the upper crown regions that was mostly caused by shading effects in the point cloud due to interlocked crowns. Some of the misallocations were also caused by branches from distant trees that were found tangent to other tree stems.

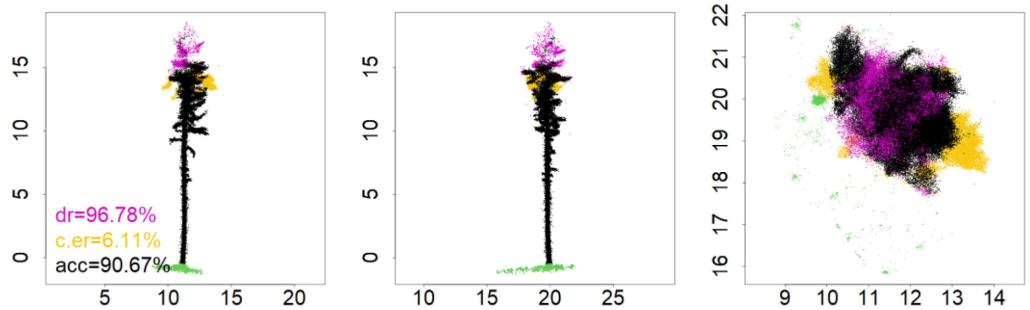

Figure 2: Matching manually clipped tree (pink) with automatic segmented crown (yellow), correctly assigned points black, (dr = detection rate, c.er = commission error, acc = accuracy).

Table 2 shows the differences between automatically measured individual tree parameters and field reference data. The automatically measured DBH and tree height showed only small deviations from the reference data. Please note that the exact definition of the DBH is often challenging in practice using traditional measurement instruments, especially for non-circular stem cross-sections. In fact, the manual DBH measurements can have large variation depending on the orientation of the calliper. In contrast, the automatic measurement is derived by fitting a natural cubic spline to the circumference of the local laser point cloud. Tree height was estimated with less precision than DBH, because the density of the point clouds was often reduced in the upper crown regions. The crown base height was underestimated on average 3.95 m. This bias mainly resulted from the automatic decision rule for the crown base height detection.

Further geometrical measures, such as the extent, the projection area, and the volume of the crown (see Figure 3) were measured with relative high accuracy and precision. The average crown extent (mean of x- and y-extent) and the projection area were only slightly overestimated and the average crown volume was slightly underestimated. Distant points, that might increase the volume, matter less than missing parts within and especially in the upper crown sections. This phenomenon would suggest further improvements of the crown segmentation algorithm to mitigate a possible "overgrowing" into adjacent trees.

Table 2. Comparing the automatic measurements with field reference data.

n=235	mean.ref	RMSD	RMSD.pct	bias	bias.pct
DBH	26.8 cm	3.94	14.7%	-0.67	-2.5%
height	20.0 m	2.25	11.2%	-0.92	-4.6%
crown base	11.5 m	5.61	48.8%	-3.95	-34.3%
crown dimension[1]	4.6 m	0.65	14.1%	0.15	3.2%
crown projection area[1]	13.8 m²	2.83	20.5%	0.19	1.4%
crown volume[1]	19.0 m³	4.65	24.5%	-0.51	-2.7%

[1] *comparing automatic segmentation with manually clipped reference crowns.*

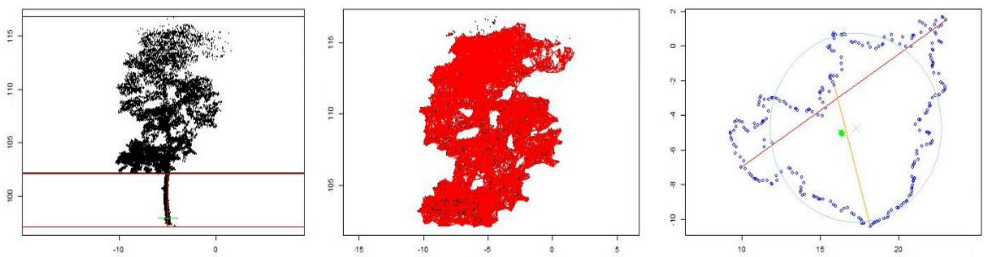

Figure 3: Automatic measurement of crown parameters for oak (left: crown base detection, middle: crown volume alpha hull, right: crown projection area and dimensions).

Precise crown segmentation is regarded as an essential functionality of automated 3D point cloud analysis to obtain geometrical crown features. The proposed automatic routine was successfully approved in comprehensive evaluations and showed only minor misallocations, mainly occurring in the upper crown sections. However, it was demonstrated that these few upper-crown discrepancies had only a negligibly small effect on the precision of the crown variable measurements, as the RMSD of the crown volume and crown projection area estimates were less than 5 %. Further research and software development is required to improve the automatic crown base detection and to find proper approximations of the crown volume using the manual field measurements, such that the latter could serve as reference data for further evaluations.

4. Conclusions

The proposed automatic crown segmentation algorithm provides accurate and precise crown measures of the single tree crown morphology. Hence, a detailed analysis of the spatial crown allocation patterns can be now performed in greater detail and on a larger scale than with traditional measurement techniques. These novel techniques will also facilitate a precise quantification of the inter-tree competition in the crown layer that will be useful for future analyses of individual tree growth patterns.

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