

Single-scan TLS methods for forest parameter retrieval

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Abstract

Using a terrestrial laser scanner (TLS) in single-scan mode for achieving plot level reference data in forests is proposed in this paper. In single-scan operation the amount of data is small compared to multi-scan and the registration of different scans is not needed, thus both the measurement and the processing are faster and fully automatic. The scan geometry was utilized in the development of the processing method. The forest scene complexity and that some trees are totally shadowed by the others are the main limiting factors to the use of single-scan TLS. We expect our methods to operate well at least on single layer, pine dominated economically exploited boreal forests. The main result of the TLS based forest parameter method is the location and stem curve for each tree that was detected. In traditional forest ground truth reference measurements, each tree is manually measured in the reference plot and the tree location is not recorded. The possibility to record the location of major trees by TLS makes the plot information usage more practical: corrections can be done, they can be used as permanent plots, they serve as a basis of future individual tree based forest inventory. In our test area, 85% of the 52 trees that were manually found from the TLS data slice inside 60m range could be found automatically.

Keywords: TLS, single-scan, one-storey-forest, stem curve

1. Introduction

Terrestrial laser scanning has been used for detailed modelling of individual trees and canopies in (Pfeifer et al 2004; Pfeifer and Winterhalder 2004; Gorte and Pfeifer 2004; Hosoi and Omasa 2006; Fleck et al 2007; Danson et al 2007; Xu et al 2007 and Chasmer et al 2006). More automatic methods for forest parameter determination have been considered in (Bienert et al 2006a, 2006b, 2007; Aschoff and Spiecker 2004 and Király & Brolly, 2007). Using TLS for plot level inventory offers a fast and efficient means of automatically determining basic tree parameters such as the number and position of trees, diameter at breast height (DBH) and tree height. In Aschoff and Spiecker (2004) semi-automatic tree detection method is presented. The method is based on first filtering the data and, thus, generating the Digital Terrain Model (DTM) and then processing the scanner data in horizontal slices and using the Hough transform to detect circular point distributions. The layer data are then rasterized and saved in image format with different horizontal layers in channel information; the trees are detected from the image data. In Bienert et al (2006a) and Király and Brolly (2007) the tree detection is also based on horizontal layers; starting from breast height, DTM is generated for ground point reduction in order to provide breast height measures for each tree. In Bienert et al (2006a) and Király and Brolly (2007) the points are clustered, in Bienert et al (2007) the clusters are rasterized and the shape of the clusters is studied in order to detect trees. In Bienert et al (2006a and 2007) a method for detection and modelling that works on both single- and multiple scan data was presented.

Most of the previously reported tree trunk modelling methods require total coverage of the trunk and are thus only usable in multiple scan mode (MSM) terrestrial scanner data. These methods operate on single-tree point clouds and the detection of trees is manual. The emphasis is on accurate modelling of the tree trunk and branches. In (Pfeifer et al 2004; Gorte and Pfeifer 2004) an accurate cylinder based model of the trunk is described. A free form curve based model for trunks is presented in Pfeifer and Winterhalder (2004). In most of the models, cylinder or circle fitting is used in the horizontal layers to model the trunk. Least squares circle fitting algorithms are considered in Chernov and Lesort (2005). In Thomas and Mili (2007) a generalized M-estimator is used for robust fitting of circles to laser scanner data in defect detection. The noise level in the forest TLS data is large and the need for either more effective noise reduction or more robust circle fitting is evident in order to have reliably operating automatic forest parameter estimation.

In this paper, we first present the geometric and technical background for processing the data using vertical sweep lines and then give details on the detection, filtering and modelling phases in chapter 2. In chapter 3 results of a pilot study in boreal pine forest are presented, the automatic result is compared with results manually measured from the same TLS data. The results and the applicability of the methods are discussed in chapter 4.

2. Method

The method presented in this paper consists of first detecting possible trunks in a range image clustering and then processing the point clouds corresponding to each cluster separately. The point clouds are first filtered to eliminate non-tree objects; second, the trunk point clouds are filtered to remove branches. For each trunk point cloud, the ground level is estimated using histogram of the points that are situated closer than 1 m from the trunk point cloud centre. Finally, a circle is fitted to each 20 cm horizontal slice of the trunk point cloud and a model is composed using the circles and their centres.

As the scan progresses, vertical sweep lines of measured points are saved for each horizontal angle. In Figure 1 in the left image, the pink disc represents the fast vertical sweep pattern and the black arch slower horizontal rotation. In the right image the consecutive sweeps are coloured to visualize the sweeps on a trunk.

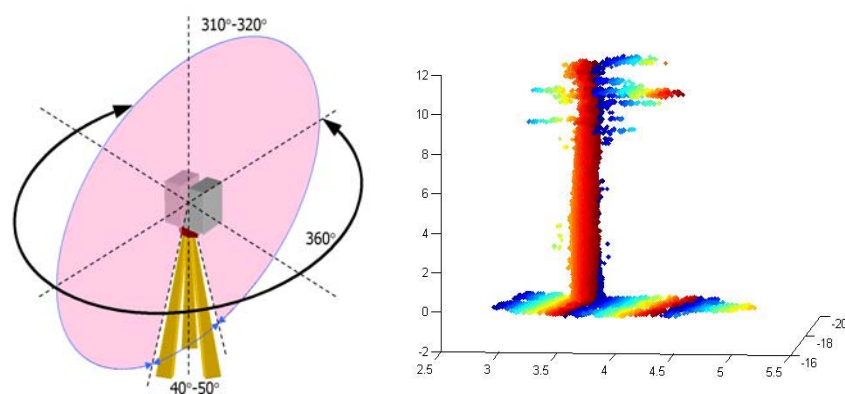


Figure 1: Left: The operating principle of a typical terrestrial laser scanner. Right: A typical single tree trunk point cloud with prism colouring to visualize the vertical scan lines on the tree.

Instead of starting with horizontal layers, the detection is done in range images. In single scan mode data objects that are occluded by others are not seen and thus for each pair of angles, only

one measured distance is possible. Only the points that are visible to the scanner are used in trunk detection. Horizontal layers are applied for each trunk separately after the detection and filtering. The branches that cause difficulties in stem modelling are filtered out before modelling phase.

2.1 Data

TLS-data was collected using a Faro 880HE80 terrestrial laser scanner, which is a high-speed scanner with a data acquisition rate of 120000 points per second. The scanner uses continuous laser to measure the distances based on phase-shift measurement. The scanning was carried out in November 2007 at the test site located near Kajaani in eastern Finland. The measurement resolution that was used in the scanning produced a point spacing of 0.6 mrad (6 mm at the distance of 10 metres) within the single-scan point cloud.

2.2 Trunk detection

The trunk detection algorithm is based on processing the range data as a row-column raster, where rows and columns represent relatively constant scanner angle values. Points close to each other with similar distances from the scanner are assigned to the same cluster. The distance from the scanner is corrected distance in cylindrical coordinates, not the original one in spherical coordinates, so that the distance of points forming a vertical line will be equal. The found clusters are further processed to select the ones with vertical shape and to unite trunks that have been cut into pieces because of occlusions by branches. The detection method used is described in Liang et al (2008). Figure 2 shows the found trunks in a slice of the homogenous Kajaani test site and on a more complex mixed forest site in Nuuksio.

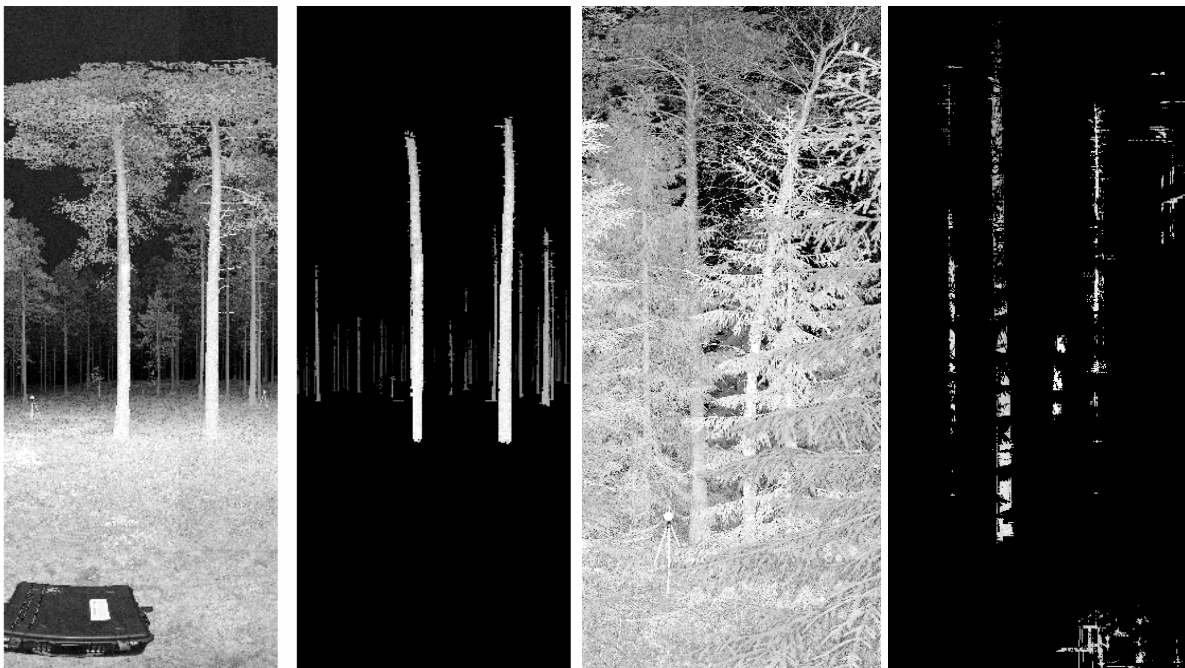


Figure 2: Two pairs of images: original intensity image left and the corresponding found trunk clusters right (dark image). Left pair: a pine forest slice. Right pair: a more complex forest scene.

From Figure 2 it can be seen that the method is working well on a single layer forest, but with more details and tilted trees, the performance is not as good. Due to the tree branching and occlusion from the canopy in the upper part of the trunk, there remain some points in the

clustered trunk that have to be filtered out in order to have an optimal trunk point cloud. It is probable that different forest types require different parameters in the clustering.

2.3 Trunk filtering and local ground level determination

The trunk point cloud obtained from the detection contained some branch and ground points that had to be filtered out before modelling. The sweep that contained mostly trunk points consists of points whose plane distance from the scanner is close to constant. In Figure 3, three trunk point clouds located at different distances from the scanner are shown. Although the vertical and the horizontal spacing between the consecutive points and sweep lines is a function of the distance, long vertical lines of scan points mark the trunk. The points that fall on the branches in the two sides of the tree result in shorter and more shattered lines. Lines where the minimum vertical difference between consecutive points exceeded some limit were removed and only lines whose length exceeded a suitable threshold were accepted in order to remove the branch points on the sides. Ideally the limits could be derived from the scanner geometry so that the limits would be distance dependent.

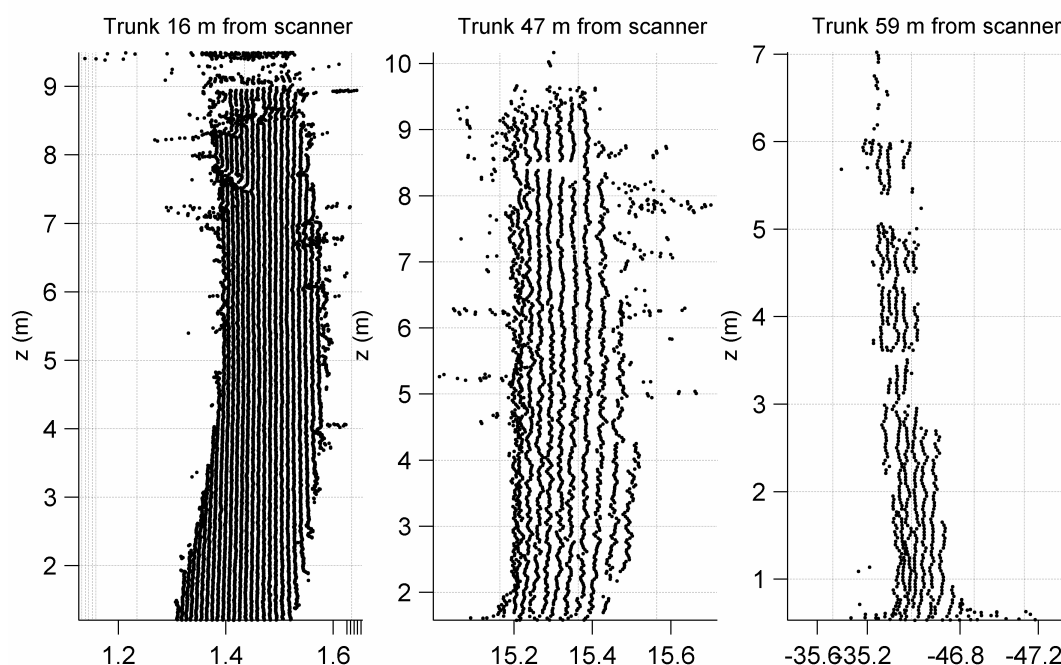


Figure 3: Left and middle: two trunks of approximately the same diameter that are located in different distances from the scanner. Right: a trunk 59 metres away, the point cloud could not be modelled.

A line was fitted to the sweep line points and points that deviated from the linear trend were filtered out to remove the branch points that were in the direction towards the scanner. Before line fitting, points further away from the line median distance than twice the standard deviation were discarded. In Figure 4, the line filter result and the principle are demonstrated. In the left plot, a very noisy set of trunk points is plotted in black and the stem points after line filtering in colours. A single sweep line filtering is shown in the right plot. The original points are plotted in black and the points that are selected as trunk points are plotted in cyan with the fitted line in blue.

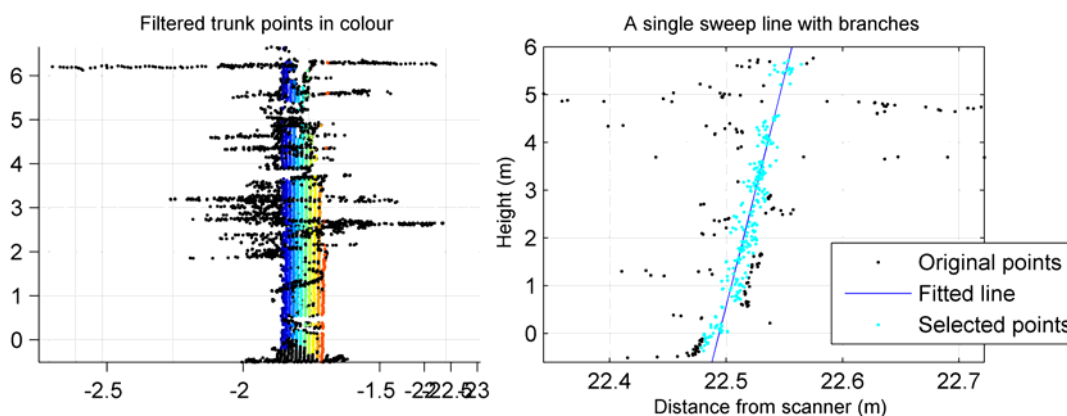


Figure 4: Left: a very noisy point cloud in black dots with the line filtered trunk points in colour. Right: line filter operation in a noisy line: cyan points are selected as true trunk points

To compare the modelling result with DBH reference measurement, the ground level was robustly determined using the histogram of the points inside 1 m radius from the detected trunk point cloud centre.

2.4 Trunk modelling

The trunk was modelled in a two-stage procedure, where first circles were fitted to the trunk point cloud in 20 cm high horizontal slices. The circle-fitting algorithm was least squares where the objective function is the Euclidean distance from points to the circle. The optimization method used was Nelder-Mead. Second the statistics of the distribution of the centre points and radii of the fitted circles were studied and the slices whose circle had a too large or small radius or whose centre was too largely offset from the others were discarded. The model is a collection of circles at different heights along the trunk. For this study we have used one circle per height meter. For each meter, the circle with the least deviation from the fitted radius value was selected. The centre points of the circles represent the stem curve of the tree. The trunk parameters can be estimated at any height between the maximum and minimum height of the model by linear interpolation from the closest circles. The different stages of the filtering and modelling process are shown in figure 5.

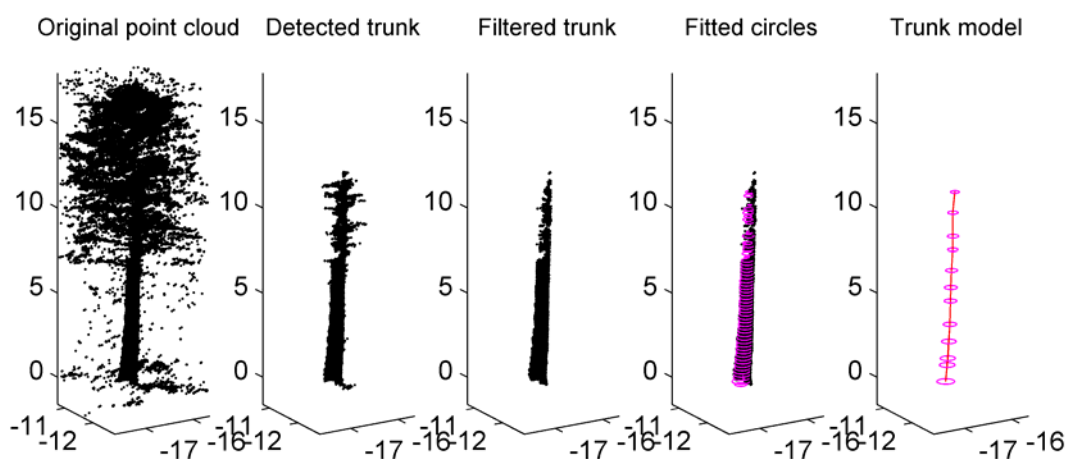


Figure 5: From left: the original point cloud, the detected trunk cluster, filtered trunk point cloud, circles fitted to the point cloud and rightmost the circles selected to form the trunk model.

3. Results

Manual trunk detection was performed on a slice of the pine forest data seen in Figure 2. Faro Scene software was used for the manual measurements. The location of the tree trunk was visually determined and measured from the intensity image of the scanned point cloud; also a 3D-view of the measured points was used to verify the correctness of the measurement. The result for the manual detection is plotted in Figure 6 in red circles. The automatically found and modelled trunks are plotted on the same plot with black crosses (+). In addition to the modelled trunks, there were also trunks that were detected but could not be modelled. These are marked with 'x'. (An example of a trunk point cloud that could not be modelled can be seen in Figure 3, far right.) The small trees marked with green circles in Figure 6 are so narrow that there were not enough scan sweep lines that hit the trunk for successful detection.

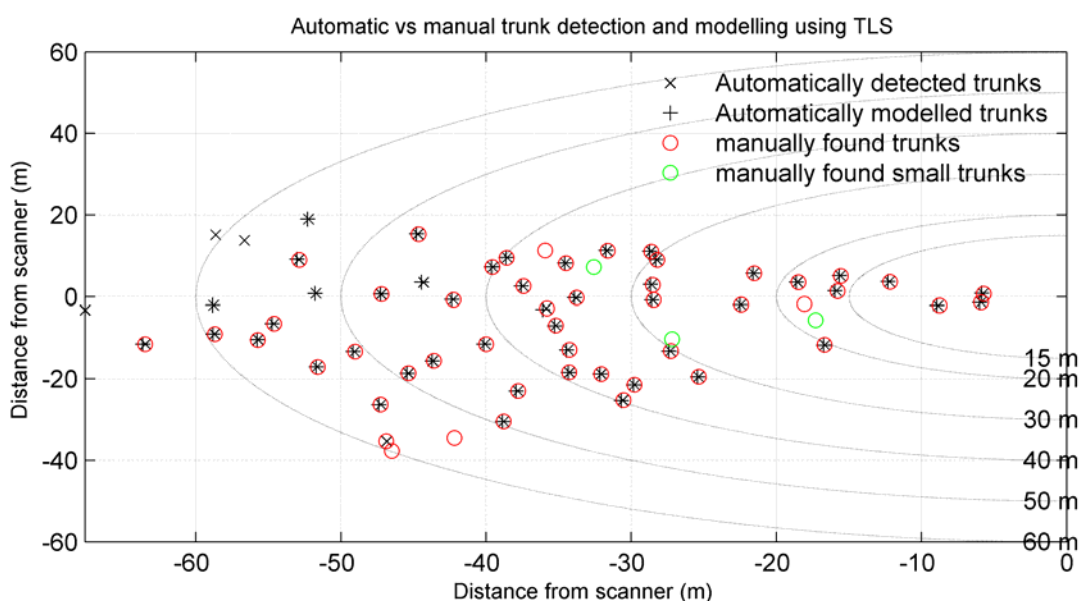


Figure 6: Results for tree trunk modelling in one layer forest. The scanner is in the origo. Black asteriks inside a red circle denotes a succesful detection and modelling. Red circle alone is a trunk that the automate missed. Black asteriks alone is a trunk that was not found manually and black x an automatically found trunk that could not be modelled.

The results for different distance slots from the scanner are presented in Table 1. In the columns “manual”, “automatic” and “automatic/manual%”, the manual result is considered to be true and the success in finding the same trees automatically is reported in the two following columns. There were also four trunks that were found by the automatic system but not by the manual detection, these were located at the distance 40 – 60 m from the scanner. The trunk detection location accuracy could not be evaluated, because the manual location is in the side of the tree and the automatic result is the centre of the trunk. The DBH was not measured manually because the accuracy of the result would be inconstant due to increasing point cloud deviation as the distance from the scanner increases. For trees within 15 m radius from the scanner, on site reference measurement was available. The reference material consists of DBH measures taken clockwise on the plot with no location data. The error from the reference was computed for 10 trees that were inside the 15-meter reference plot, six trees from another data slice (in Figure 7.) that were not in the manual reference were included in addition to the four that can be seen in Figure 6. The Root Mean Squared (RMS) error from the calliper-measured reference was 0.03 m.

Table 1: Detection and modelling results at different distances from the scanner for the slice in Figure 6.

Distance (m)	Manual	Automatic	Automatic /manual%	Distance (m)	Cumulative detection %
0 – 15	4	4	100 %		
15 – 20	5	3	60 %	0 – 20	78 %
20 – 30	7	6	86 %	0 – 30	81 %
30 – 40	17	15	88 %	0 – 40	85 %
40 – 50	9	9	100 %	0 – 50	88 %
50 – 60	10	7	70 %	0 - 60	85 %
Total	52	44	85 %		

The cumulative detection percentage is represented two rightmost columns of Table 1. It can be seen that the detection result seems to be high through the distances. In reality, it is likely that small trees exist further away from the scanner also, but they have not been detected in the manual process.

The detection and modelling result for another slice of data is shown in Figure 7. It can be seen that the result is similar to Figure 6. There was no manual reference data for this slice, but visual inspection of the point clouds proved that most of the detected point clouds were trees or of cylindrical shape. Results for both of the slices indicate that the visibility to the scanner is the main factor in detection and modelling success. As the distance to the scanner increases, the point cloud gets sparser. In circle fitting, however, the coverage of the trunk cross section is more relevant to the success of the modelling than the point cloud density.

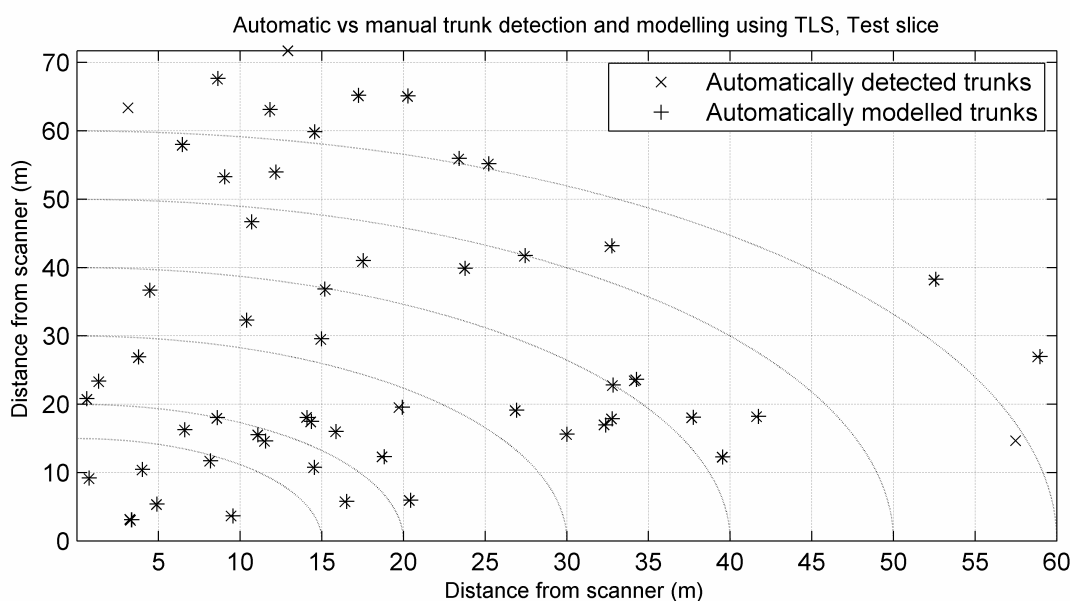


Figure 7: Trunk detection and modelling results for a test slice. The scanner is in the origo. Black x are the centers of trunk point clouds and black + are the centers of trunk models.

In Figures 6 and 7, a modelled trunk is a trunk for which reasonable circles could be fitted and thus DBH, location and volume could be estimated. The trunk models could only be evaluated for DBH measures of the ten trees that were in 15 m distance from the scanner. For full model performance evaluation, field data from several heights is needed. In visual inspection, most of the model circles were well aligned with the trunk point cloud. The estimation of model performance using model deviation from trunk point cloud was not used, because this deviation

does not tell if the model describes the trunk, it only tells if the model fits the points. In close ranges the model deviation from point cloud is mainly indicative of the point cloud deviation (surface noise), further away the number of points is reduced and thus the deviation due to the large number of points is lessened. In high parts of the trunk, occasional branch points can lead to fitting a too large circle with small deviation from point cloud, which visual inspection can prove wrong although the model error is acceptable. This kind of errors cannot be handled if manual reference measurement is not available.

4. Conclusion and discussion

We anticipate that during 2010s, major forest areas in Scandinavia will be assessed using airborne laser scanning. Since the point density of laser scanning is also increasing, it is possible to start using individual tree based forest inventory techniques, which require reference plots having the following capabilities:

- Small amount of dominant tree heights used to calibrate tree height underestimation of ALS
- Location of trees to allow the calibration of tree finding capability of individual tree based inventory
- Tree species classification for the detected trees
- Correct basal area and stem volume of the plot to calibrate applied volume retrieval algorithm

The height underestimation of ALS can be calibrated using e.g. couple of dozen correct height measurements obtained from several plots. High density TLS have previously shown to be superior to hypsometric measurements. The location information can be improved using several single scan TLS measurements without registration, since correct stem number and location of stem is expected to be more important to individual tree based ALS inventory than the knowledge of diameters of each tree. Accurate basal area and stem volume can be obtained even though the accuracy of individual stem diameter estimation would be in the order of several cm. We have a method for retrieving two of the four above listed capabilities, location and volume, and we expect in future studies to be able to model also tree species and dominant tree heights.

The result of this study shows that in one-storey forest it is possible to automatically detect and model trees that are visible to the scanner and within some predetermined distance from the scanner, i.e. fixed plot size. The overall tree detection result of 85 % in 60 m range from the scanner is acceptable, though optimistic when more general plots are considered. Bienert et al (2006a) reported 87 % to 100 % results in single scan mode for 15 m circular plots and 100% for 12 m plot in multiple scan mode. In Bienert et al (2007) 97 % overall detection rate was reported for several 15 m plots and 94 % for a similar size plot with heavy branching. The result presented in Table 1 shows that instead of a distance limit, a visibility limit could be used in single scan TLS tree detection. According to our results, the achievable plot size for a single scan TLS measurement could be larger than the plot sizes used in manual measurements. New reference measurements from larger plots will be needed to validate this assumption.

The modelling part of the work was left with less attention than the detection and filtering parts for two reasons 1: we did not have reference data from many heights and distances 2: we found that a clean trunk point cloud allowed for many different modelling schemes including cylinder- and circle fitting, and the model should be selected only after considering what is the purpose of the data collecting. Inside 15 m the RMS error to reference was 3 cm. Bienert et al (2006a) reported standard deviations from calliper-measured reference between 1.23 and 2.47 cm for different types of plots. In Bienert et al (2007) standard deviation from harvester data was 2.48 cm. In Pfeifer and Winterhalder (2004) a single tree was modelled in multiple-scan mode with

stem point cloud deviation from the model 1.75 cm using cylinders and 1.54 cm using B-splines.

We expect that the by the combined use of higher density ALS and TLS, a universal solution to forest inventory can be developed and the need to use forest inventory models will decrease. In such a concept the problems of plot boundary effects will decrease. We also expect that superior stem volume estimation can be obtained using individual tree based forest inventory compared to the distribution based inventory, since presently the individual tree based forest models (deriving stem volume from DBH and height) produce a significant systematic and random error source. When tree bark structure and the fact that the trunks do not have circular cross sections are considered, the use of DBH measures whose accuracy is very high is questionable. Our study indicates that single scan mode data are of considerable interest in single layer, pine dominated economically exploited boreal forests because the accuracy of the results compared with the multiple scan mode accuracy is eligible especially when processing time is considered.

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