Accuracy of automatic tree extraction using airborne laser scanner data

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Abstract

The objective of the EuroSDR/ISPRS Tree Extraction project was to evaluate the quality, accuracy, and feasibility of automatic or semi-automatic tree extraction methods mainly based on high-density laser scanner data. This paper summarizes the major general finding based on laser scanning approaches. Results showed that the tree extraction method is the main factor on the achieved accuracy. When the laser point density increases from two points to eight points per m^2, the improvement in crown delineation accuracy was marginal, but in the case of feasible methods the accuracy of the tree location and especially the tree height determination improves, but also deterioration of the accuracy was reported. Individual tree based inventory requires also individual tree based reference collected in the field; this calibration is needed to reduce underestimation of tree height, calibration of the basal area and stem volume and possibly to verify experimentally the quality of the product.

Keywords: tree extraction, airborne laser scanning, automation, EuroSDR, ISPRS

1. Introduction

The first application of airborne laser scanning (ALS) for forestry was the determination of terrain elevations (e.g. Kraus and Pfeifer 1998; Vosselman 2000), followed by standwise mean height and volume estimation (e.g. Næsset 1997a,b), individual tree based height determination and volume estimation (e.g. Hyyppä and Inkinen 1999; Brandberg 1999; Ziegler et al. 2000; Hyyppä et al. 2001), tree species classification (e.g. Brandtberg et al. 2003; Holmgren and Persson 2004) and measurement of forest growth and detection of harvested trees (e.g. Yu et al. 2004). Extraction of the forest variables has been recently divided into two categories: inventories done at stand or plot level and inventories based on individual trees or groups of trees. These categories relate to the need of the forestry information. At the same time laser scanning is increasingly becoming a core data set for mapping authorities and the pulse density of the laser scanning is increasing constantly. In addition to forest inventory, tree information is used e.g. in flight obstacle mapping, power line mapping, real estate visualization and mapping, and telecommunication planning. The results obtained for individual tree extraction has varied significantly from study to study (percentage of correctly delineated trees has ranged from 40 to 93 %) (see e.g. Hyyppä and Inkinen 1999; Persson et al. 2002; Brandtberg et al. 2003; Leckie et al. 2003; Straub 2003; Popescu et al. 2003; Andersen et al. 2002; Morsdorf et al. 2003; Wack et al. 2003). It is not known how much of this variation is caused by the methods and how much by the forest conditions. Concerning the methods there is a trend towards using more efficiently the point cloud data, rather than segmenting pure laser-derived DSMs. In EuroSDR/ISPRS Tree Extraction project twelve participants around the world extracted the trees in given forest test sites. The first objective of this study was to study the accuracy and feasibility of various methods using the same test data. The second objective of the study was to find out how the pulse density affect on individual tree extraction. More detailed comparison of the methods and their differences and similarities is a subject of another paper.

2. Material

2.1 Study area

Two forest test sites were close to each other in southern Finland, about 18 km west of Helsinki. Test sites were very diverse; partly flat and partly steep terrain, areas of mixed and more homogenous tree species at various growth stages. Main tree species were Scots pine, Norway spruce and silver and downy birches. The area of test site A was 2.6 ha and test site B 5.8 ha.

2.2 Delivered data for tree extraction

For test sites ALS data (Table 1) with three different pulse densities (2, 4 and 8 points per m^2) was delivered to the participants. A DTM with 0.5 m grid spacing was calculated using Terrascan (based on Axelsson 1999, 2000, 2001) and visually checked before delivery as ASCII-grid. Delivered training data included species, location, DBH and crown delineation (3-5 points) of 75 trees. Training data was measured in the field using a tacheometer, and it was meant for the participants to calibrate their methods into Scandinavian forest conditions.

Table 1. ALS data of the study area

Acquisition	29th of June 2004
Instrument	Optech ALTM 2033
Flight altitude	600 m
Pulse frequency	33 000 Hz
Field of View	± 9 degrees
Measurement density	2 per m^2 per echo per strip
Swath width	185 m
Mode	First and last pulse

2.3 Reference data for quality verification

Reference data for quality verification was collected with ground surveys and terrestrial laser scanner. RTK-GPS (Leica SR530) and tacheometer (Trimble 5602S DR200+) equipment were used to create a ground control point (GCP) network over the study area. Location of spherical reference targets for terrestrial laser scanner (Faro LS880HE) was determined with tacheometer measurements on the basis of the GCPs. For RTK-GPS –measurements the same GPS reference station was used as for airborne laser scanning. Terrestrial laser scanning (TLS) was carried out in 48 locations to obtain laser point coverage of all reference trees on five test plots, two plots on test site A and three plots on test site B. Together the five plots covered an area of 0.48 ha (5.7 % of test site area). Reference data included the location and species of 352 trees and the height of 254 trees.

Point clouds of individual terrestrial laser scannings were georeferenced using spherical reference targets and Faro Scene software. Same software was used to transform the point clouds to a 3D-mesh, which was then exported in VRML2 format to Geomagic Studio software for editing and exporting to DXF format. 3D DXF vectors of individual scannings were combined using Bentley MicroStation for additional editing and measurement of tree parameters. Measured tree parameters included tree trunk location, tree top location, tree height and crown delineation. Intensity images of original scannings in Faro Scene software were used to determine tree species and crown base height.

2.4 Produced tree extraction results

Participants were requested to extract trees using the given material. They were allowed to use any method and data combination. Participants were asked to provide from each tree that they could extract tree location and height, crown delineation, and height of crown base or the volume of the crown, if possible. Of twelve participants, eleven used ALS data for tree extraction and nine used solely ALS data.

3. Methods

3.1 Methods used by participants

The methods have been reported in detail in Kaartinen and Hyyppä (2008, forthcoming). Here a more anonymous, brief description of the key elements in the methods is given.

Method A was implemented in eCognition Expert. The method can be divided into four main tasks: 1) creation of a forest mask, 2) initial split of the forest mask, 3) splitting the forest mask into tree crowns and 4) correction of over split crowns. A low pass filter was applied to remove small gaps and too many local minima and maxima. The creation of the forest mask was made by thresholding the CHM images at a height of 2 m. The method uses the highest point/pixel in the object as the seed and expands the seed to the crown boundaries, identified by a positive difference between the current and proposed pixel. This was repeated until all areas within the current object had been included into new objects. The difference required to form a boundary was defined with a threshold. The threshold was initially high and a boundary was formed only where a large difference occurs, in this case 1 m. The key to this method is the classification of objects into two groups, crowns and crown-clusters. Those objects identified as crowns were removed from further splitting iterations and only considered later, while crown-clusters were processed further in the hope of separating the crowns contained within.

Method B was fully automatic using raw laser points and it had the following steps: (1) a DSM was created, (2) a DTM was created, (3) a CHM/nDSM was created, (4) the CHM was filtered with different Gaussian filters resulting in different images, (5) the different images are segmented separately and the segment chosen for a specific area is selected through fitting a parabolic surface to the laser data, (6) the height and crown diameter were estimated for the identified trees.

Method C was based on a tree model with three geometric parameters (size, circularity and convexity of the tree crown). The processing strategy comprises four steps. First, a wide range of scale levels of the DSM was created. The second step was a segmentation, which is achieved by applying a watershed transformation. In the third step the best hypothesis for a crown from the overlapping segments of all levels based on the tree model was selected. The selection of the best hypotheses was achieved with the help of fuzzy functions for the tree model parameters.

In **method D**, a DSM pixel was considered to be a low, differing pixel, if at least seven (surface models from point density of 8 pulses/m^2), or six (other point densities) of the eight-neighbourhood were more than five metres higher than the pixel itself. These pixels were replaced with the median of the more than five metres larger neighbour pixel values. The DTM was then subtracted from the final DSM to get a CHM for tree crown segmentation. Before segmentation, the CHM was smoothed with height based filtering. Five Gaussian filters were used so that the filter size increased along the height of pixel being smoothed. Smallest and largest σ values were selected by visually ensuring that the number of local maxima was reasonable at both ends of the tree height range. A negative image of the height filtered image was then created for watershed segmentation that was used to separate tree crowns from each other. Watershed regions associated with the local minima in the negative image were identified using a drainage direction following algorithm. To get the boundaries between crowns and background, pixels lower than two metres in the height filtered image were masked out from the crown segments. Finally small segments (at most three pixels in size) were combined with one of the neighbour segments, being it a tree crown or background, based on the smallest average gradient on the common segment boundary. Tree locations and heights were then obtained from the location and value of the pixel having the highest value within each segment.

In **method E**, the process comprises several steps, i.e. retain uppermost echoes, interpolate them into a DSM-grid, find local maxima in the DSM, run a region-growing algorithm with some restrictions in order to derive objects belonging to the class of objects often named star objects. The DSM was now divided into segments that represented tree crowns, while parts of the area were not covered by trees and had no DSM value. The DSM was adjusted (lifted) using the residuals between the DSM and the first echoes. The 90 percentile of the residuals was calculated, and this frequently turned out to be around 70 cm, and this was added to all z values in the DSM. The tree heights were derived as the z value of the local maxima after this adjustment.

In **method F**, tree locations and tree height were computed from the CHM. The CHM was computed by selecting the highest canopy height in each grid cell. Furthermore, each trunk of the training trees was located with a window size of 3x3 (i.e., 3 metres), and a height histogram with one-metre interval was used to build up a laser classification tree model for species determination. The highest laser elevation value among laser hits on a specific area (i.e. 3x3 metres), is assumed to be the potential trunk location of the tree. Two approaches were used to estimate the potential tree locations. The first approach was whereby running a local maximum filter in the CHM with a window size of 3x3 (i.e., three-metre squares), all potential tree locations were selected. The second method was that the 3x3 local maximum filter processes only heights less than 15 metres in the CHM. The first approach was applied to test site B, and the second approach was used on test site A. The crown widths were derived based on the training tree data and the CHM. The expirical relationship between the height of the trees and their searching crown size was defined.

Method G employed an automatic algorithm of local maxima (LM) filter with circular moving window of varying sizes. Local Maximum Filter is often used to locate tree position based on the assumption that the highest elevation corresponds to the tree apex. When applying the LM filter, the window size has great influences on tree identification. On the other hand, the taller the tree is, the larger the crown width. Thus the determination of filter size was based on the relationship between the crown size and tree height. Prior information was utilized to derive such a relationship; to predict the crown size, regression models were fitted with tree height as the independent variable. For the test data, about ninety trees for each test site were visually identified from the CHMs and the corresponding heights and crown width were manually recorded by on-screen measurement. The crown diameter was the average of two values measured along two perpendicular directions from the location of the tree top.

In **method H**, an algorithm, which removes the points (ground and not ground) derived from the echoes penetrated inside the crown from the dataset, was implemented. At first, the algorithm provides a triangulation of all the points; the following step is the removal of all the vertexes that present a difference greater than a fixed threshold. The procedure therefore allows a correct DSM to be obtained. The method applied for tree counting was based on a morphological analysis of the laser point distribution. For this purpose the Top Hat algorithm was implemented. This is a mathematical function of image elaboration, which allows the top elements at the scale of the represented values to be found. The mathematical formulation of the Top Hat is related to the theory of image processing formulated by Serra (1982, 1988). In some cases, because of the presence of small height variations among adjoining points belonging to the same crown, more than one apex can be counted for each tree. In order to minimize this kind of error a control algorithm was introduced. It detects and corrects the apexes, which are erroneously classified (these are often localized at the edge of the crown). In order to delineate single crowns an algorithm of region growing was implemented.

Method I is based on local maxima detection in the CHM and a following cluster analysis of the raw data with found local maxima as starting points. The DSM generation includes the choice of four parameters, which are destination grid resolution, search radius, and size and shape of a Gaussian smoothing function. The outcome of the cluster analysis is the raw data being flagged with a distinct number of all returns presumably belonging to a tree. This cluster is then treated by a routine, which takes the relevant measures from the point cloud. These are the following:

- Position (x, y) is derived as the centre of gravity of the echo positions belonging to the cluster.
- Tree height is computed as the maximum height of the cluster's echos.
- Crown diameter is estimated using the convex hull of the cluster by transferring the circumdistance of the convex hull to a radius assuming circular shape.

3.2 Methods used for evaluation

Tree location accuracy was evaluated by measuring distances from every reference tree to the nearest tree found on the delivered model. For tree location the coordinates of the reference treetop were used. Only distances within 5 metres from the reference tree were included in the analysis. If several reference trees have hits on the same tree in the analyzed model, only the best match according to distance and height was accepted to analysis, other observations were disregarded. Location accuracy was analyzed for two cases: all trees and trees over 15 m tall. The trees approved for location accuracy evaluation were also used for tree height evaluation, and again two cases were used: all trees and trees over 15 m tall.

The crown delineation accuracy was evaluated by comparing the total delineated area of reference trees on test plots to delivered model delineation. If a participant did not deliver crown delineation as vector data, the crown covered area was determined as a circle around the trunk location by using the radius or area delivered by the participant, and final delineated area was obtained as a union of these circles.

Trees in the reference test plots were extracted also manually by an FGI employee to get an idea of what accuracy can be achieved this way. Extraction was executed using laser scanner data (8 points per m^2) and GIS software. Also aerial images were used for interpretation purposes. Trees were delineated visually by using laser points which were colour coded based on the elevation, and the location and height were measured by finding the highest laser points within the delineated trees. Ground height was interpreted visually in a 3D-view. The results of this manual extraction are marked as "Manual" in the figures in section 4. Results and discussion.

If the observed value differed from the reference value more than mean ± 3*STD, it was considered as gross error, or outlier, and was removed. In tree height analysis first all values deviating more than 10 metres from the ground truth were removed.

4. Results and discussion

In following figures the laser point densities are marked after the method ID, for example, B_2 for two points, B_4 for four points and B_8 for eight points per m^2.

4.1 The amount of extracted trees

The amount of extracted trees on the reference test plots is shown in Figure 1. The amount of extracted trees reveals how many percent of the true trees have been extracted. In order to provide non-biased estimates e.g. for volume, the correct percentage rate should be as high as possible. The percentage of detected trees varied between 25 to 90% implying different capabilities in detecting suppressed trees. Best models were significantly better in separating tree groups into individual trees compared to the manual method. Surprisingly, there was no improvement in the detection rate when the pulse density was increased from 2 to 8 points per m^2. It is still expected that there should be more focus on finding smaller trees under the dominating storey. In principle, the higher pulse density should result in better tree finding capability, but that is subject to the forest type. It seemed that the test site was relatively suitable for individual tree detection even with a pulse density as low as 2 points per m^2. We expect that in younger stands density of 8 points per m^2 would have been beneficial.

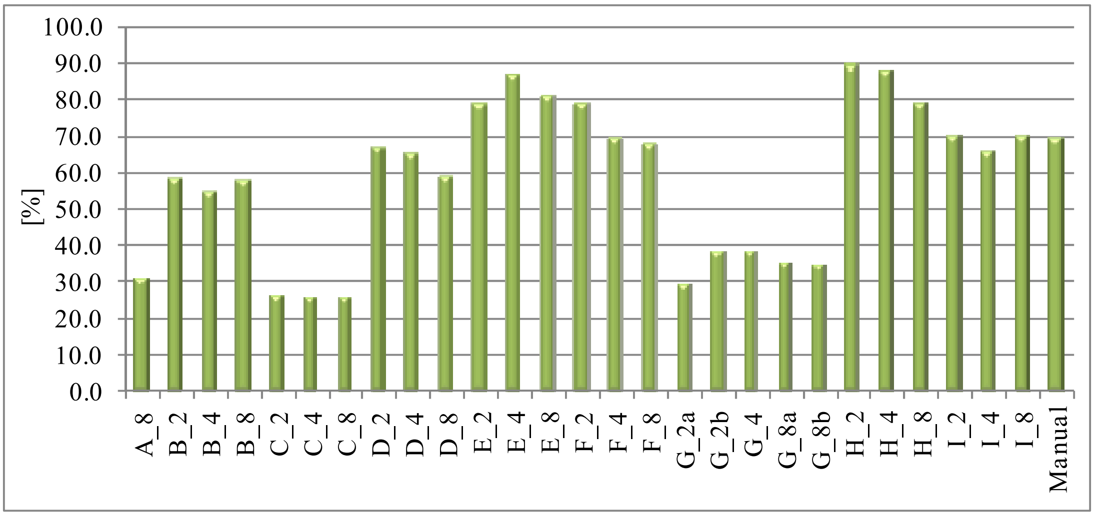

Figure 1. Amount of extracted trees.

4.2 Tree location accuracy

The results clearly showed that the variability of tree location is small as a function of point density and it mainly changes as a function of the model provider (Figure 2). Obviously, the calibration of the models with the given training data has not been successful and several models assumed the trees to be significantly larger in width (e.g. A, C, I). With the best models for all the trees, the mean location error was less than 1 m and the difference with 2, 4 and 8 points per m^2 was negligible. With trees over 15 m, standard deviation of 0.5 m was obtained. The automatic models were as good as manual processing of the point cloud in determining the tree locations. In tree finding, there were in general few outliers.

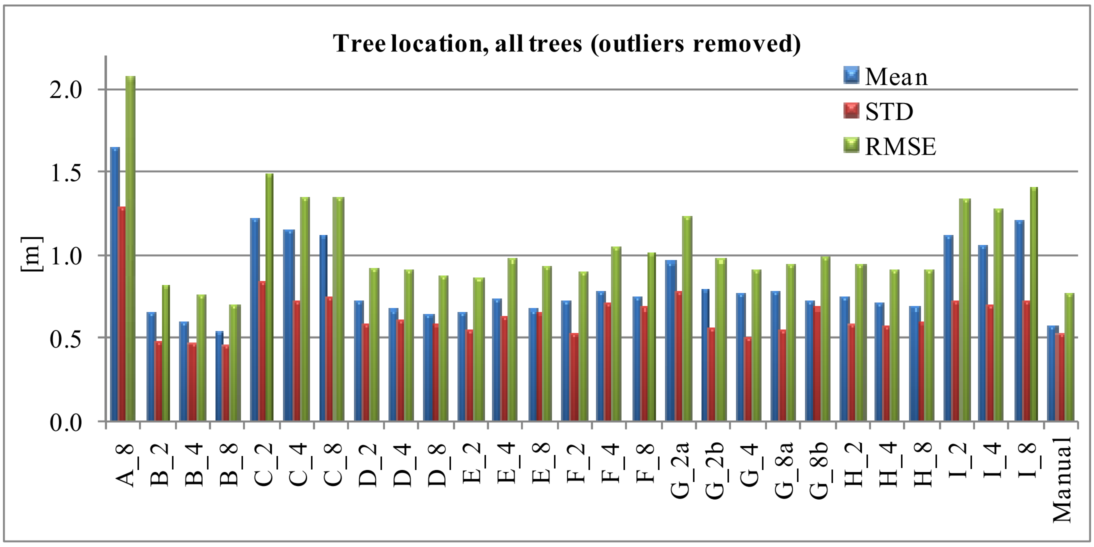

Figure 2. Tree location accuracy.

4.3 Tree height accuracy

Tree height quality analysis showed again that the variability of the point density was negligible compared to method variability (Figure 3). With the best models RMSE of 60 to 80 cm was obtained for tree height. High quality tree heights were obtained by models of B, D and G. The results with the best automatic models were significantly better than those with the manual process. In general, both the underestimation of tree height and standard deviation were decreased as the point density increases. The overestimation of the model E to tree height was due to the correction applied to the tree height in the preprocessing phase. The main reason for the difference of the laser-based methods was that some of the methods used significantly stronger filtering in the preprocessing phase. It can also be concluded that when comparing the results from literature, the forest conditions play a major role. With the model D, a low detection rate for tree finding has been published, but in the comparison, it showed to be one of the best algorithms.

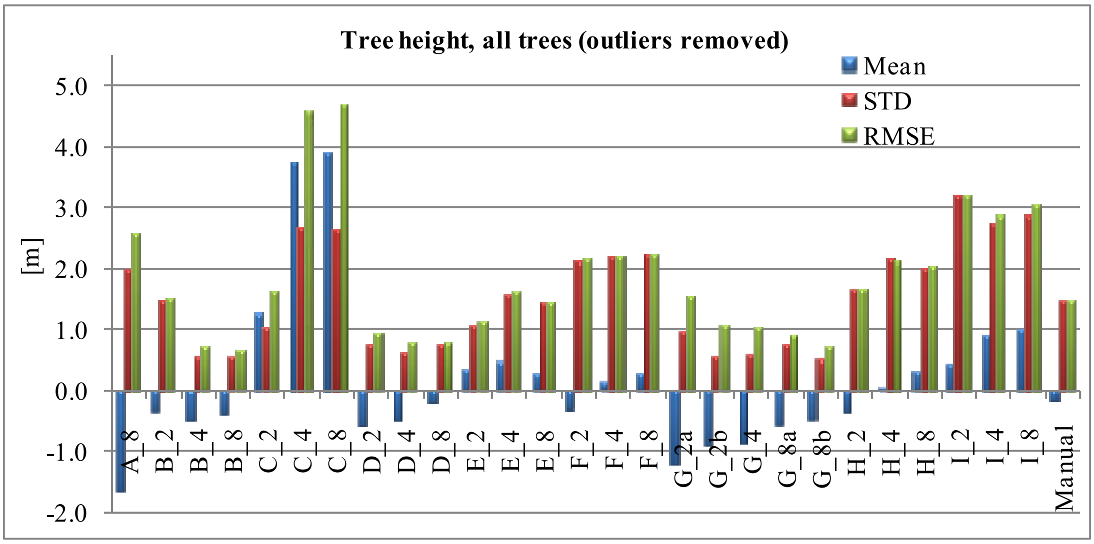

Figure 3. Tree height accuracy.

4.4 Crown delineation accuracy

Total crown area seems to vary significantly between the models (Figure 4). The errors leading to false total crown area are: inadequate tree finding capability (small trees missed), inadequate filtering of the raw point cloud data or DSM (leading to too large crowns but too few of them) and inadequate calibration of the method with the given reference data. The models, which have been tested more with practical forestry, have already more experience in this calibration, such as the B and E methods.

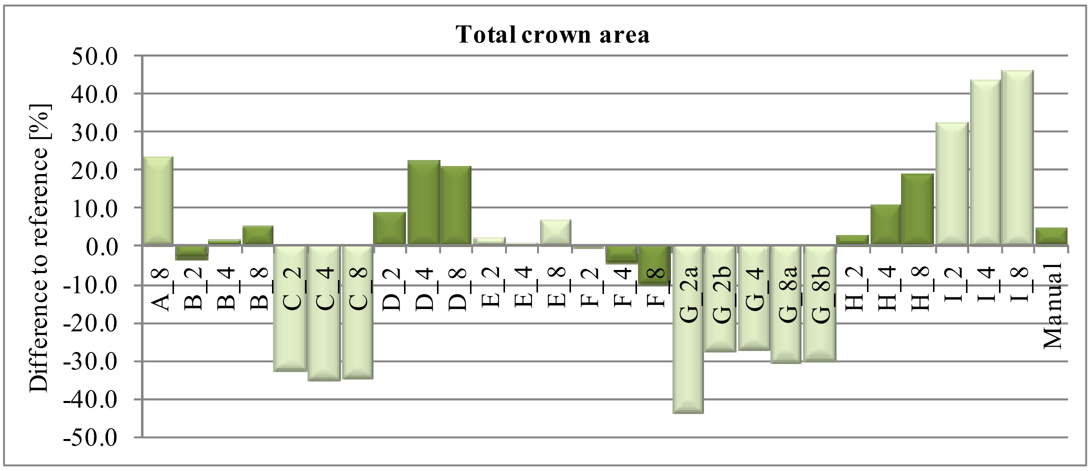

Figure 4. Total crown area accuracy.

5. Conclusion

The following conclusions were drawn:

- Results showed that the extraction method is the main factor on the achieved accuracy and surprisingly high variability of the results were provided by various methods.
- Before using the methods into operational forests inventory, the methods should be carefully verified.
- The quality of the method versus other methods cannot be verified without testing the methods in the same forest conditions since the effect of the variability of the forest conditions is assumed to have a high impact on achieved accuracy (by comparing the results achieved those with previous literature). Thus, more comparison of the methods should be done in the future.
- More detailed analysis of reasons why certain method failed and succeeded in this test should be reported in near future. Differences and similarities of the methods should be reported.
- When the laser point density increases, the accuracy of the tree location, detection rate of smaller and more trees and especially the tree height determination can be improved, but in practise, the improvement depends on the method. Surprisingly, deteriorating of the accuracy by the applied methods was also reported.
- Individual tree based inventory required individual tree based reference collected in the field. Visual interpretation of the airborne laser point cloud is not a feasible way to do the calibration of the extraction method, since this calibration is needed to reduce especially the underestimation of tree height, and for the calibration of the basal area and stem volume.
- Individual tree based solutions may be applied even with lower point densities (e.g. using 2 points per m^2), but the optimal point density is most probably dependent on tree

size and density of the forest. This proposes further possibilities of using individual tree based methods.

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References

Andersen, H-E, Reutebuch, S. and Schreuder, G., 2002. Bayesian Object Recognition for the Analysis of Complex Forest Scenes in Airborne Laser Scanner Data. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34, part 3A, pp. 35-41.

Axelsson, P., 1999. Processing of laser scanner data - algorithms and applications. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54, pp. 138-147.

Axelsson P., 2000. DEM Generation from Laser Scanner Data Using Adaptive TIN Models. In *International Archives of Photogrammetry and Remote Sensing*, 33, Part B4, pp. 110-117.

Axelsson, P., 2001. Ground estimation of laser data using adaptive TIN models. In *Proceedings of OEEPE workshop on airborne laserscanning and interferometric SAR for detailed digital elevation models*, Royal Institute of Technology, Stockholm, Sweden. Publication No. 40. CD-ROM. pp. 185-208.

Brandtberg, T., 1999. Automatic individual tree-based analysis of high spatial resolution remotely sensed data. PhD thesis, *Acta Universitatis Agriculturae Sueciae, Silvestria* 118, Swedish University of Agricultural Sciences, Uppsala, Sweden. 47 p.

Brandtberg, T., Warner, T., Landenberger, R. and McGraw, J., 2003. Detection and analysis of individual leaf-off tree crowns in small footprint, high sampling density lidar data from the eastern deciduous forest in North America. *Remote Sensing of Environment*, 85, pp. 290-303.

Holmgren, J. and Persson, Å., 2004. Identifying species of individual trees using airborne laser scanning. *Remote Sensing of Environment*, 90, pp. 415-423.

Hyyppä, J. and Inkinen, M., 1999. Detecting and estimating attributes for single trees using laser scanner. *The Photogrammetric Journal of Finland*, 16, pp. 27-42.

Hyyppä, J., Schardt, M., Haggrén, H., Koch, B., Lohr, U., Scherrer, H.U., Paananen, R., Luukkonen, H., Ziegler, M., Hyyppä, H., Pyysalo, U., Friedländer, H., Uuttera, J., Wagner, S., Inkinen, M., Wimmer, A., Kukko, A., Ahokas, E. and Karjalainen, M., 2001. HIGH-SCAN: The first European-wide attempt to derive single-tree information from laserscanner data. *The Photogrammetric Journal of Finland*, 17, pp. 58-68.

Kaartinen, H. and Hyyppä, J., 2008. EuroSDR/ISPRS Project, Commission II "Tree Extraction", Final Report. *EuroSDR – European Spatial Data Research, Official Publication*, in press.

Kraus, K. and Pfeifer, N., 1998, Determination of terrain models in wooded areas with airborne laser scanner data. *ISPRS Journal of Photogrammetry and RemoteSensing*, 53, pp.193-203.

Leckie, D., Gougeon, F., Hill, D.,Quinn, R., Armstrong, L. and Shreenan, R., 2003. Combined high-density lidar and multispectral imagery for individual tree crown analysis. *Canadian Journal of Remote Sensing*, 29(5), pp. 633–649.

Morsdorf, F., Meier, E., Allgöwer, B. and Nüesch, D., 2003. Clustering in airborne laser scanning raw data for segmentation of single trees. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34, (part 3/W13), pp. 27-33.

Næsset, E., 1997a. Determination of mean tree height of forest stands using airborne laser scanner data. *ISPRS Journal of Photogrammetry and Remote Sensing*, 52, pp. 49-56.

Næsset, E., 1997b. Estimating timber volume of forest stands using airborne laser scanner data. *Remote Sensing of Environment*, 61, pp. 246-253.

Persson., Å, Holmgren, J. and Söderman, U., 2002, Detecting and measuring individual trees using an airborne laser scanner. *Photogrammetric Engineering & Remote Sensing*, 68(9), pp. 925-932.

Popescu, S., Wynne, R. and Nelson, R., 2003. Measuring individual tree crown diameter with lidar and assessing its influence on estimating forest volume and biomass. *Canadian Journal of Remote Sensing*, 29(5), pp. 564–577.

Serra, J., 1982. *Image analysis and mathematical morphology*, Vol. 1. Academic Press.

Serra, J., 1988. *Image analysis and mathematical morphology: theoretical advances*. Academic Press.

Straub. B., 2003. A top-down operator for the automatic extraction of trees - concept and performance evaluation. In *Proceedings of the ISPRS working group III/3 workshop '3-D reconstruction from airborne laserscanner and InSAR data'*, 8-10 October 2003, Dresden, Germany, pp. 34-39.

Vosselman, G., 2000. Slope based filtering of laser altimetry data. *International Archives of Photogrammetry and Remote Sensing*, 33, No. B3/2, pp. 935-942.

Wack, R., Schardt, M., Lohr, U., Barrucho, L. and Oliveira, T., 2003. Forest inventory for Eucalyptus plantations based on airborne laser scanner data. In *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34, Part 3/W13, pp. 40-46.

Yu, X., Hyyppä, J., Kaartinen, H. and Maltamo, M., 2004. Automatic detection of harvested trees and determination of forest growth using airborne laser scanning. *Remote Sensing of Environment*, 90, pp. 451-462.

Ziegler, M., Konrad, H., Hofrichter, J., Wimmer, A., Ruppert, G., Schardt, M. and Hyyppä, J., 2000. Assessment of forest attributes and single-tree segmentation by means of laser scanning. *Laser Radar Technology and Applications V*, 4035, pp. 73-84.