USING INDIVIDUAL TREE CROWN APPROACH FOR FOREST VOLUME EXTRACTION WITH AERIAL IMAGES AND LASER POINT CLOUDS

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ABSTRACT:

The objective of this paper is to improve the cost-effectiveness (accuracy of estimates versus applied costs) of present ITC (Individual Tree Crown) approaches which are based on 1) aerial imagery or 2) high density laser scanning data by introducing a hybrid technique (giving the height of each crown with laser data to image derived crown segment) and to compare accuracy of these three approaches. It is also studied whether the inability of ITC approach to separate tree crowns in dense forests affect remarkably on volume estimation. 78 carefully measured pine trees in 10 plots were used in this study. CIR image orthorectified with laser DSM was used as a major data source. Laser data were obtained from 400 m and 800 m (above ground level, AGL) acquisitions with Toposys I providing pulse density of approximately 10 and 5 pulses per m^2. Results of current study demonstrated that the height of individual trees is the most important geometrical parameter for stem volume estimation that remote sensing methods can provide. Aerial image ITC approach, which has been lately even used in commercial operations, was significantly improved by including the height of tree from the laser data (individual tree stem volume R^2 changed from 0.14 to 0.54). This hybrid approach should be further studied as a potential operational forest inventory method, since it may be possible to derive ITC based solution using nationally acquired laser point clouds and already existing CIR imagery giving high quality results at stand level. The results indicate that individual tree volumes can be obtained with random error between 25 to 30 % and that volume related to small tree groups an be obtained with random error between 34 to 40 %. Both accuracies are relatively good, since the present Scots Pine models based on diameter (and requiring manual measurements for each tree) give accuracy of 17 %. The accuracies obtained for individual trees and small tree groups indicate that random error of less than 5 % could be obtained in future at stand level, however, the trees that cannot been seen from the remote sensed data needs first to be estimated by other means. This paper also demonstrates that even though remote sensing can not always provide ITC solutions, the stem volume estimates do not deteriorate significantly from this fact since the existing formulas take into account the widening of the tree crowns. From practical forestry point of view, it may not be so relevant whether all trees are correctly isolated with segmentation. Of course, the correct segmentation stays as a challenging scientific task. More emphasis in the future studies should be placed that the size of segmented crown relates to natural crown size, and how the conversion of remote sensing-derived crown size can be converted into stem diameter correctly.

1. INTRODUCTION

The traditional field based as well as photogrammetry based forest inventory is relatively expensive and time-consuming, but relatively accurate, and thus used mainly for small-area forest inventory, i.e. standwise forest inventory in Europe. The high expenses (e.g. 20 €/ha) are due to the large amount of human labor used in the data acquisition and processing. Semi-automatic and automatic remote sensing based techniques have been heavily investigated during the last two decades to reduce costs in these processes. As a result, it has been shown that satellite images, e.g. Landsat and Spot images, can be used to derive rather reliable estimates for forest attributes in areas of larger than approximately 100 hectares, i.e. they are usable for national forest inventory. It has also been shown that semi-automated forest inventory based on delineation of individual tree crowns (ITC) (Uuttera et al., 1998; Brandtberg and Walter, 1998; Dralle and Rudemo, 1996; Gougeon, 1997) is feasible for standwise and plotwise forest inventory.

ITC-based solutions have been demonstrated both with aerial images (e.g. Gougeon and Moore, 1989; Gougeon, 1997) and with laser scanning point clouds (Hyyppä and Inkinen, 1999; Persson et al., 2002). Finding tree locations can be obtained by detecting image local maxima (e.g. Geogeon and Moore, 1989). In laser scanning, the aerial image is replaced by the crown DSM or the canopy height model (CHM). Provided that the filter size and image smoothing parameters are appropriate for the tree size and image resolution, the approach works relatively fine with coniferous trees (Gougeon and Leckie, 2003). After finding the local maxima, the edge of the crown can be found using the processed canopy height model.

The typical hypothesis for ITC laser based forest inventory (Hyyppä and Inkinen, 1999) is that by measuring major individual tree characteristics, such as the height of the tree, tree species, and crown diameter, it is possible to derive other valuable tree characteristics, such as stem diameter, stem volume, and age for the same tree and to use these information to calculate standwise forest information (mean height, dominant height, stem volume, basal area, tree species proportions). The advantage of the ITC approach is the capability to measure directly physical dimensions from the trees and, thus, it requires smaller amount of training material than e.g. regression-based methods (compare with e.g. Næsset, 2002).

The accuracy obtained with ITC approach depends on the structure of the forest (number of tree layers, tree species, density), quality of images and density of laser point clouds and applied processing technique. It has been shown that trees can usually be recognized only in the dominant tree layer (Persson et al., 2002; Maltamo et al., 2004b). With laser scanning, it has also been shown that multi-layered stand structures can be recognised and quantified using quantiles of laser scanner height distribution data. However, the accuracy of the results is dependent on the density of the dominant tree layer (Maltamo et al., 2005). With ITC, standard error at stand level typically ranges between 10 and 25% when using high-density laser point clouds (Hyyppä and Inkinen, 1999; Persson et al., 2002; Maltamo et al., 2004). In the case of aerial images the corresponding figures are usually considerably higher being 35-60 % (Anttila and Lehikoinen, 2002; Huitu, 2005; Korpela et al., 2005). The processing of laser point clouds into forest informatics can be significantly more automatic than using merely aerial images. The costs of laser scanning are however significantly higher than with aerial imaging. Presently, data acquisition costs for high-density laser scanning data range between 1 €/ha (order size 5000 km^2) to 5 €/ha (10 km^2). Thus, these costs could be reduced by using laser for height determination and aerial image for crown segmentation. For height estimation, even the nationally collected point clouds could be accurate enough.

The objective of this paper is to improve the cost-effectiveness (accuracy of estimates versus applied costs) of present ITC (Individual Tree Crown) approaches based on aerial imagery or high density laser scanning data by introducing a hybrid technique (giving the height of each crown with laser data to image derived crown segment) and to compare accuracy of these three approaches. It is also studied whether the inability of ITC approach to separate tree crowns in dense forests affect remarkably on volume estimation.

2. STUDY AREA AND DATA

Test Site - The test site was situated in a state owned forest area of approximately 50 hectares located in Kalkkinen, southern Finland, 130 km north of Helsinki. The tree stock of the area is naturally regenerated and there have been no silvicultural operations in most parts of the area during the last decades. Therefore, the tree stock can be considered to be in a semi-natural state.

Field reference - During the summer of 2001, 33 systematically located rectangular sample plots were established on the test site. The basic size of a sample plot was 30 m by 30 m, but to get around 100 trees per plot, plot sizes of 25 m by 25 m and 30 m by 40 m were also used. Most of the sample plots included dense understorey and were dominated by Norway spruce, although, each sample plot included more than one tree species. All trees having a diameter at breast height (DBH) of more than 5 cm were mapped using a measuring tape, and tree species, DBH, tree height, and height to the living crown were registered. All individual trees were classified as belonging to either the dominant or the suppressed tree layer. On the average there were 414 dominant and 435 suppressed trees per hectare in the data. 78 pine trees in 10 plots were selected to be used in this study.

Image data - CIR image, in the scale of 1:20000, was acquired on August 13th 1998. CIR image was rectified by FM-Kartta Oy using laser-derived and filtered canopy DSM to help in finding the corresponding trees in both data sets. Pixel size of the CIR was 0.5 m.

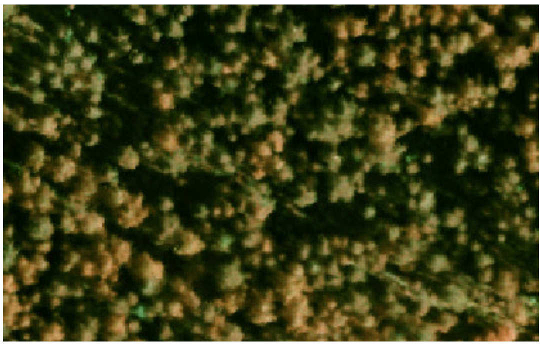

Figure 1. Orthorectified CIR image used in the test.

Laser data - Laser data were acquired with TopoSys I on 2nd September 1998 (altitude 400 m above ground level, AGL) and 15 June 2000 (800 m AGL). The technical information of the laser system is depicted in Table 1.

Parameter	**Performance(s)**
Sensor	pulse-modulated see www.toposys.com
Laser pulse frequency	83 000 Hz
Scan frequency	653 Hz
Field of view	± 7.1 degrees
Measurement density	Ca. 5 pulses per m^2 at 800 m Ca. 10 pulses per m^2 at 400m
Beam divergence	1 mrad
Number of shots per scan	128 parallel shots (one of which is the reference)
Laser classification	class 1 by EN 60825 (eye-safe)

Table 1. TopoSys performance parameters

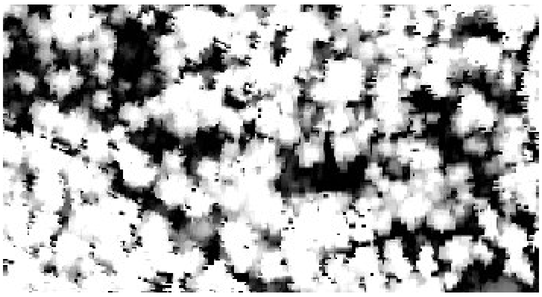

Figure 2. Canopy height model derived from laser scanner data, 15 June 2000, 800 m (AGL).

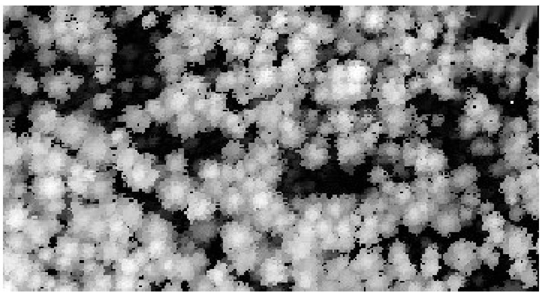

Figure 3. Canopy height model derived from laser scanner data, 2 September 1998, 400 m (AGL).

3. METHODS

3.1 DTM Creation From Laser Data

DTM was calculated from first pulse mode using methods of Yu et al. (2004). A raster DTM grid with a 50 cm pixel size was created from classified ground points by taking the mean value of the ground points within the grid. Missing points in the DTM were afterwards interpolated using Delaunay triangulation and the bilinear interpolation method. The accuracy of estimated elevation was evaluated using about 2000 tacheometric measurements in 8 of these plots (Yu et al. 2005). RMS errors ranged from 0.05 to 0.3 m.

3.2 Laser Canopy Heights

Laser canopy heights were calculated as the difference between z values of laser hits and estimated ground elevation values at the corresponding location in the DTM. Points, for which the canopy height value was over 0.5 meters, were expected to be vegetation hits.

3.3 Segmentation of Aerial And Laser Imagery

The aerial image and canopy height models were segmented using commercial software (Arboreal Forest Inventory Tools of Arbonaut Ltd). The algorithm used is described in Hyyppä et al. (2001a), and the performance of the segmentation algorithm compared to two other algorithms (developed at Joanneum Research in Austria and the University of Freiburg in Germany) is described in Hyyppä et al. (2001b).

During the segmentation processes, the tree crown shape and location of individual trees were determined. First, trees were located by looking at the local maxima in the low-pass filtered canopy height model. Then a watershed-type segmentation procedure was applied. In order to get a good-quality segmentation, trees were segmented with seven separate layers (7 different parameter combinations corresponding to each tree size) and the best segment out of the seven possible was visually chosen to represent the tree or the tree group. The segmentation was considered as good as visually done segmentation.

3.4 Volume Calculations

Aerial imagery ITC solution - In the phase 1, diameters of segments derived from the CIR were calculated. The diameters were converted into stem diameter and volume using existing formulas (Kalliovirta and Tokola, forthcoming; Laasasenaho, 1982) as follows. From the Kalliovirta and Tokola (forthcoming), the relation between crown diameter and stem diameter at breast height $d_{1.3}$ was defined as

$$\sqrt{d_{1.3}} = 2.065 \cdot \sqrt{\mathrm{d_{crm}}} + 0.548$$

The volume of the stem was calculated based on Laasasenaho (1982) using the diameter at breast height $d_{1.3}$ as predictor

$$\ln(v) = -5.39417 + 3.48060 \cdot \ln(2 + 1.25 \cdot d_{1.3}) - 0.039884 \cdot d_{1.3}$$

Aerial imagery ITC approach assisted by laser height - In the phase 2, CIR derived segments were given height from the laser derived canopy height model (altitude 800 m). Stem volume was calculated using Laasasenaho (1982) formulas for pine using both the height and diameter at breast height of the stem as obtained in phase 1.

From Kalliovirta and Tokola (forthcoming), the relation between stem diameter and height and crown diameter was obtained as

$$d_{1.3} = -3.405 + 0.783 \cdot \sqrt{h} + 1.280 \cdot \sqrt{d_{crm}}$$

From Laasasenaho (1982), the volume was obtained as a function of height and diameter at breast height as

$$v = 0.036089 \cdot {d_{1.3}}^{2.01395} \cdot (0.99676)^{d_{1.3}} \cdot h^{2.07025} \cdot (h - 1.3)^{-1.07209}$$

Laser ITC approach – In the phase 3, laser-derived crown diameters and tree heights were directly converted to stem volume at the same manner with phase 2. This was done separately for laser data acquired from 400 m and 800 m altitude.

Splitting of large crowns by knowledge – In the phase 4, laser-derived crowns were split using knowledge and heuristic methods. According to Ilvessalo (1950), there is a high correlation between the crown diameters and the breast height diameter *d* for tree species such as *Pinus sylvestris*, *Picea abies*, *Betula pubescens* and *Betula pendula* when stratification into height classes is made in the boreal forests. Since the height and species (i.e. pine) were known, the upper and lower limits to crown size were known as well. If the upper limit was exceeded, the crown was split into two to several crowns. Correspondingly, the derivative of crown upper 3D surface was calculated to find any discontinuities to help in the splitting of tree crowns.

3.5 Evaluation

In order to evaluate the accuracy of each phase, mean squared error (abbreviated to MSE), was calculated.

$$MSE = \sum_{i=1}^{n} (e_{1i} - e_{2i})^2 / (n-1)$$

where e_{1i} is the result obtained with the described ITC approach for stand i, e_{2i} is the corresponding field measured value, and n is the number of trees. MSE was divided into systematic (x) and random error (std). Random error divided by the mean reference volume was denoted by std(%). Additionally, coefficient of determination R^2 was calculated.

Reference volume was calculated using Laasasenaho (1982) formula by summing up the volumes of those trees that locate within the defined segment. Analysis was done separately for all segments (including multiple trees) and individual trees. The average volume and standard deviation of the reference data are given in Figure captions for each case.

4. RESULTS

Figures 4-11 show the results for phases 1 to 3. Figures 4 and 5 show aerial image ITC solutions for all trees and individual trees separately. Figures 6 and 7 show corresponding results for the new hybrid approach for all trees and individual trees separately. Figures 8 and 9 show corresponding results with laser scanning from 800 m (AGL) and figures 10 and 11 shown results with laser scanning from 400 m (AGL).

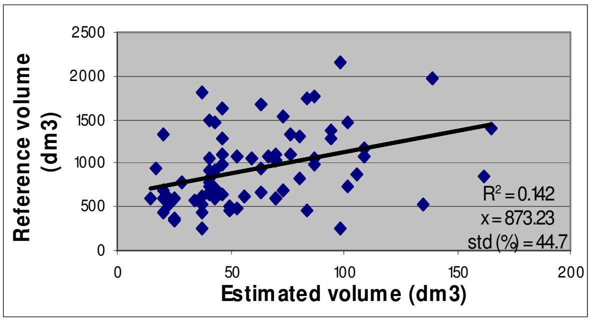

Figure 4. Scattergram between estimated and reference volume when estimation was done using only diameters of segments from CIR. The reference consists of all trees within the segment. Phase 1. Mean volume 934.4 dm^3 and std 428.6 dm^3 for the reference.

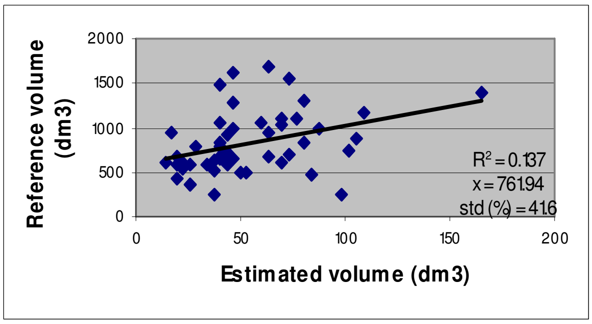

Figure 5. Scattergram between estimated and reference volume when estimation was done using only diameters of segments from CIR. The reference consists of individual trees correctly segmented. Phase 1. Mean volume 815.7 dm^3 and std 349.3 dm^3 for the reference.

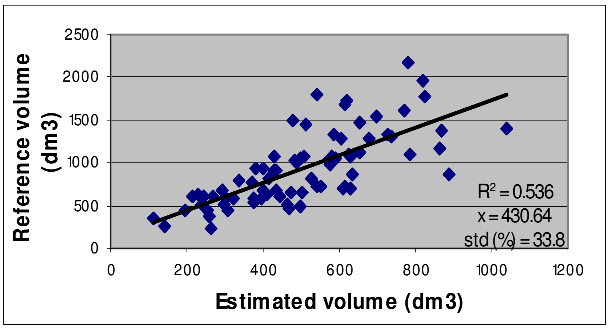

Figure 6. Scattergram between estimated and reference volume when estimation was done using diameters of segments from CIR and height from laser data. The reference consists of all trees within the segment. Phase 2. Mean volume 934.4 dm^3 and std 428.6 dm^3 for the reference.

The low coefficient of determination with aerial image ITC approach (R^2=0.13-0.14) implies that at least in this test the obtained crown diameter did not correlate well with stem volume. The result is surprising, since proper segmentation for each tree was visually selected from seven possible choices. In typical ITC solution using aerial images, one stand is treated with same parameters in the segmentation. There was a large underestimation of stem volume, most probably due to the fact that the above-seen crown diameter is significantly smaller than that of the real one. Also, the trees are much taller and narrower (concerning crowns) in Kalkkinen than typical Finnish trees, in which Laasasenaho (1982) formulas are based on. It should be noticed that the test site has been difficult for remote sensing tests also previously, see Hyyppä et al. (2000). Anyhow, the results show that aerial image based ITC does not work in all forest conditions.

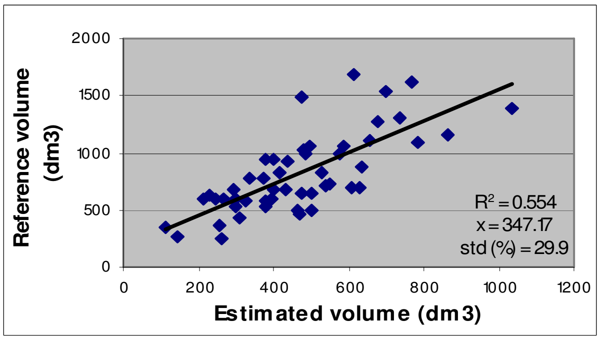

Figure 7. Scattergram between estimated and reference volume when estimation was done using diameters of segments from CIR and height from laser data. The reference consists individual trees correctly segmented. Phase 2. Mean volume 815.7 dm^3 and std 349.3 dm^3 for the reference.

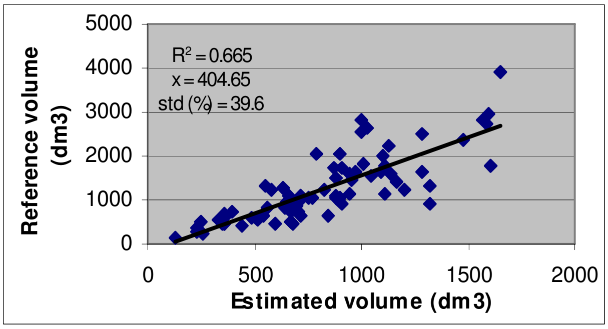

Figure 8. Scattergram between estimated and reference volume when estimation was done using diameters of segments and height from laser data, 800 m. The reference consists of all trees within the segment. Phase 3. Mean volume 1246.8 dm^3 and std 756.2 dm^3 for the reference.

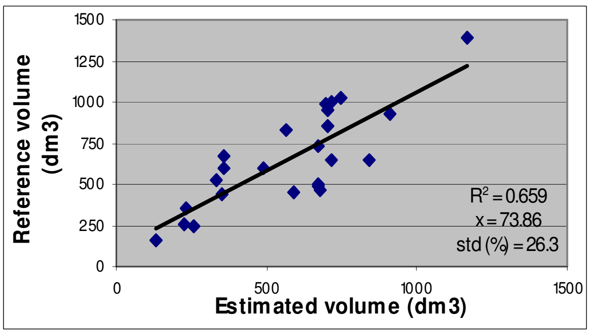

Figure 9 Scattergram between estimated and reference volume when estimation was done using diameters of segments and height from laser data, 800 m. The reference consists individual trees correctly segmented. Phase 3. Mean volume 655.5 dm^3 and std 295.7 dm^3 for the reference.

There is a significant improvement in performance when tree height information was added into the aerial image based ITC solution, Figures 6 and 7. In addition to the improvement in R^2 values, the underestimation was significantly reduced. The results obtained with segments including only one tree showed slightly better results (0.55-0.56, 29.9 % error in segment wise volume estimation) compared to all segments (0.54, 33.8 %

error in segment wise volume estimation), but the difference was not significant.

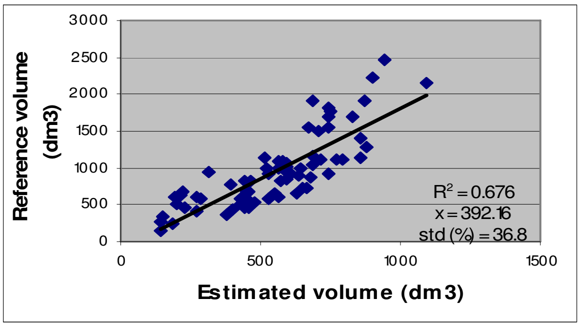

Figure 10. Scattergram between estimated and reference volume when estimation was done using diameters of segments and height from laser data, 400 m. The reference consists of all trees within the segment. Phase 3. Mean volume 939.4 dm^3 and std 503.4 dm^3 for the reference.

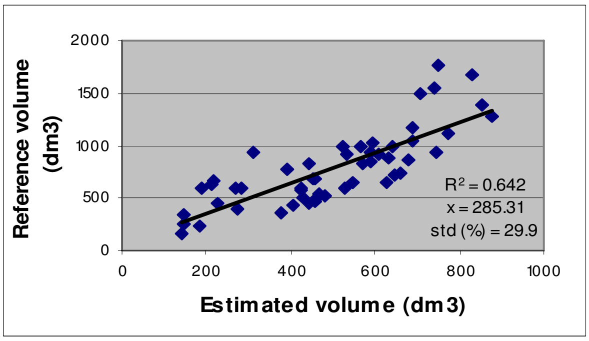

Figure 11. Scattergram between estimated and reference volume when estimation was done using diameters of segments and height from laser data, 400 m. The reference consists of individual trees correctly segmented. Phase 3. Mean volume 790.4 dm^3 and std 361.4 dm^3 of the reference.

Not surprisingly, the highest coefficient of determination was obtained with dense laser scanning data (R^2=0.63-0.68), but the superiority to hybrid technique was small. Surprisingly there was not distinguishable difference in R^2 value between 400 m and 800 m laser scanning data, nor there was significant difference whether all the trees or only individual trees were treated. The number of detected individual trees was low for 800 m laser scanning data as can be explained by the across-track point spacing of 1.6 m; see also Figure 9.

The splitting of large crowns did not significantly improve the volume estimates. When several trees grow close to one another, it is impossible to delineate each crown separately. It was checked for each phase whether ITC approach derived value correlates better with the segment volume (including all trees under the segment) or with the volume corresponding to the tallest trees in the segment. In all cases, higher correlation was found with the segment volume. The highest improvement was found in the laser scanner 800 m case, since with that data it is difficult to find individual trees, as can been seen from Figure 9. The results implies that it might not be necessary to have all the trees correctly delineated since volume equations will take care that the total volume is likely to represent the volume of the group.

5. DISCUSSIONS

The possible error sources to the analysis include the rectification of the aerial image, use of the relatively dense laser data for retrieval of the height for CIR image and relatively small number of trees in the analysis. The rectification of the CIR to an ortho image have influenced on the true size of the crown. It was estimated that the correction however, has not affected the results remarkably. The conversion of the dense data into sparser have a relatively small effect on the results in Figures 6 and 7. It is favorable to use the canopy height models to give the tree height instead of using individual points of the laser point clouds. It is expected that the type of the trees selected and number of trees is the most significant possible error source. This kind of test should be carried out in different forest conditions to confirm the results. The possibility to use low-cost low density point cloud to derive tree height and low-cost aerial images to give individual tree crow size is a potential operative forest inventory technique, that needs to be further studied.

In the case of aerial images the results were quite modest which was not surprising. It is still relatively reliable to find and locate trees from the image (e.g. Pitkänen 2001) but the segmentation of tree crowns and calculation of tree variables from above-seen crown information have been found to be very problematic tasks (e.g Ikonen 2004). Tree crowns overlap each other and crown area measures from the field and from image do not correspond to each other. Furthermore, models predicting tree diameter from crown characteristics are not very reliable and should be locally calibrated. Finally, the information included in aerial image is, however, quite limited and the variation between different images and also within one image is a serious problem.

The results indicate that individual trees volumes can be obtained, roughly speaking, with random error between 25 to 30 % (Figures 7, 9 and 11) and the volume related to small tree groups or segments with random error between 34 to 40 %. In conventional forest inventory, the random error of the volume estimation using the diameter as predictor is 17.2 % for Scots Pine (Laasasenaho, 1982). These models are still used to calculate the volume of the individual tree from manual diameter measurements. From that point of view, the results are good.

6. CONCLUSION

Results of current study demonstrated that the height of individual trees is the most important geometrical parameter for stem volume estimation at tree level that remote sensing methods can provide.

Aerial image ITC approach was significantly improved by including the height of tree from the laser data (R^2 from 0.14 to 0.54). This kind of approach should be further studied as a potential cost-effective operational forest inventory method.

This paper demonstrated that even though remote sensing can not always provide ITC solutions, the stem volume estimates do not deteriorate from this fact since the existing formulas take into account the widening of the tree crowns. It is clear that the correct segmentation stays as a challenging scientific task. The future studies should focus on how the size of segmented crown relates to natural crown size, and how the conversion of remote sensing-derived crown size can be converted into stem diameter correctly and especially how the retrieved crown size of larger tree group matches with needed tree attributes, since there are cases where it is impossible to isolate some tree crowns which naturally form one large crown.

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