TREE CROWN DETERMINATION USING TERRESTRIAL IMAGING FOR LASER SCANNED INDIVIDUAL TREE RECOGNITION

U. Pyysalo

Institute of Photogrammetry and Remote Sensing,
Helsinki University of Technology, P.O.Box 1200, 02015 HUT, Finland
ulla.pyysalo@hut.fi

Commission III, WG III/3

KEY WORDS: Method, Development, Image, Tree crown, Error simulation, Laser scanning

ABSTRACT:

A method to measure tree crown dimensions is introduced in this article. The method is based on terrestrial images, which are captured from two different directions. Image orientation is registered during the image acquisition and this geometrical information is utilized in image pre-processing. In pre-processing images are corrected from distortion errors and rectified to plane parallel to tree trunk. Parameters measured from the images are tree height, crown height and crown widths at several heights. Trunk tilting is calculated estimating trunk as three-dimensional vector and determining its parameters from trunk projections in image planes. Special attention is paid to orientation errors, which effects dimension measurement. Errors in ω, ϕ and κ and error in scale are analysed separately. Study aimed at developing method, which would not require special instruments, time consuming tacheometer measurement or positioning of image capture location.

The method development initiated from the need to collect reference material for laser scanned tree crown study. Laser scanning data has been successfully used for single tree wise forest inventory. In forest area, first returns are typically reflections from the top of tree crowns. In addition to pulses reflected from tree crown top, several pulses also reflect from crown sides and inside crown. Utilising these echoes, information below the crown surface is attained. Reference data of captured trees has been previously obtained with tacheometer and hypsometer measurements. However, these measurements didn't include information below crown top. With method suggested in this article that missing information is provided. It was expected that reference material provided with method would be accurate enough to be utilized as reference material for laser scanning tree crown study.

1. INTRODUCTION

The development of laser scanning has offered new challenges in characterization of individual (Brandtberg, 1999; Hyyppä and Inkinen, 1999, Lim et al., 2001; St-Onge and Achaichia, 2001, Næsset and Okland, 2002; Persson et al., 2002). To verify the quality of geometric 3D tree model, however, the effect of digital terrain model and the behaviour of the laser beam on hitting the top of the trees, the effect of slope and the effect of angular trees have to be known. The quality of digital terrain model in forested areas has been investigated by Kraus and Pfeifer (1998) and Hyyppä et al. (2000). It has been shown that the accuracy of the DEM extraction under similar forest conditions with Toposys-1 is between 14 and 22 cm (Pyysalo, 2000; Ahokas et al., 2002). Height of trees can be measured with accuracy better than 1 m (Hyyppä et al. 2001). Hyyppä and Inkinen (1999) demonstrated the possibility to measure single-tree-wise information using laser scanning and to adopt the retrieved parameters (height, crown width, tree species) in forest inventory calculations. In forested areas the effect of slope and angular trees has been reported by (Heurich et al. 2003). Yu et al. (2003) demonstrated that even small changes, such as height growth of forest, are possible using laser scanner data. The factors affecting the quality of high-pulse laser scanners for digital target models have been reported by Ahokas et al. (2002). Rönnholm et al. (2003) reported the integration of laser data and terrestrial panoramic digital images inspecting the behaviour of laser scanner data.

In several studies approach is to process the forest canopy as surface, which is created from laser scanner data. The forest canopy surface is constructed as TIN, contour or grid models. However, laser scanning also provides information below the crown surface. Vertical structure of forest has been studied be Friedlaender and Koch (2000) by analysing statistically laser pulse forest penetration. In Pyysalo and Hyyppä (2002) an other approach was introduced to describe tree crown using vector polygons circulating around crown sides and line estimating shape and location of the trunk.

Collecting large amounts of reference data with traditional ways is time-consuming and expensive. The tree trunk may be estimated as straight line or cone and its location may be measured with positioning instruments, such as tacheometer or GPS-instrument and tree height and crown height may be measured using hypsometer. The width of the tree crown is, however, more difficult to measure. In tacheometer measurements a prism is moved around the crown sides, not just near the lowest branches but also to the tips of the top branches. This is carried out climbing to tree or using some lifting platform instrument instead. Another method is to project visually tips of the branches to the ground level and measure their locations with positioning instrument. Afterwards elevations of the branch tips are measured separately with hypsometer. Both of these approaches take lots of effort and are very time-consuming.

In Haala (2003) terrestrial laser scanning was combined with panoramic images and surface of tree trunks were extracted to analyse tree species. Digital camera has been used to measure individual tree variables from the digital images in the field (Juujärvi et al. 1998). Lee et al. (2003) presented automated methods of tree boundary extraction and Clark et al. (2000) digital terrestrial photogrammetric methods for tree stem analysis.

The objective of this paper was to develop a photogrammetric method based on terrestrial digital images in order to measure the geometric shape and derive parameters of individual trees. The method does not require special instruments, time consuming tacheometer measurement or positioning of image capture location. Equipments required are a digital camera, camera platform, hypsometer, compass, reference scale bar and measurement tape. Error sources of suggested method are analysed separately. This digital-image-based method will be used to verify previously developed geometric 3D tree model (Pyysalo & Hyyppä 2002).

2. MATERIALS

2.1 Test area, field measurements and laser acquisitions

The test area locates in urban environment in the city of Espoo, Finland. Area is park type university campus with lots of vegetation. 30 trees (pines, spruces and birches) were chosen as test trees. 16 trees were imaged from one direction only and 14 trees from two directions. Trees were chosen from group of 50 trees. Tacheometer measurements have been carried out to locate tree trunk positions and digital elevation model profiles.

Area has been scanned with airborne laser twice. The first one was measured from aeroplane with German Toposys instrument in late spring 2000. Flying height was 400 m, scanning frequency 80 0000 Hz and cone diameter of laser footprint 20 cm in ground. Swedish Topeye instrument measured same area in late summer 2002 from helicopter flying in 200 meters. Pulse cone diameter in the ground was 20 cm.

2.2 Instrument

Images were taken using Nikon E-10 digital camera. Camera was mounted to camera platform with flexible elevation and rotation possibilities. Maximum image size, 3008×2000, pixels was utilized and fixed size of camera aperture. During the measurement camera was manually focused to the eternity, which is also the same position the camera was calibrated.

3. METHOD

3.1 Terrestrial imaging

Several tests were carried out in the field to find optimal image capture workflow. The crown dimension measurement task required that both the base and tree crown top would be visible in the same image. In the same time image should be captured as close as possible for detailed measurement and also because during the tests it was observed that even in sparse forests other trees or other objects were typically shadowing the target tree if the image shooting distance was too long. The camera stand was approximately 1.5 meters high and imaged trees were 20-35 meters in height.

The applied image capture workflow was as follows:

- The image capturing location was chosen from 20-30 meter distance from the tree.
- Camera stand was levelled according to bubble level.
- The optical axis of camera was levelled horizontally ($\omega = 0$).
- Angle κ was set to zero using tube level.
- Reference scale bar was attached to the tree trunk.
- Camera was rotated around y-axis (ϕ) in the position where trunk was in the middle of the image.
- ω was set to 20°, angle was measured using hypsometer.
- After capturing the image angle ϕ was measured with compass.
- Distance to the tree was measured.

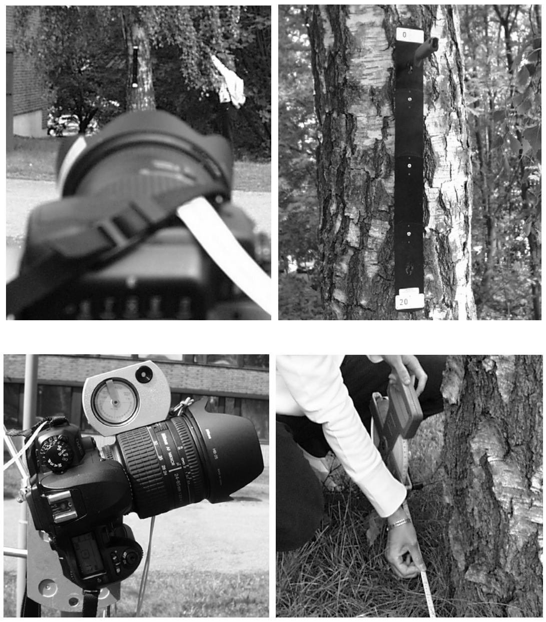

Figure 1. Image capture. Camera was rotated in the position where trunk was in the middle of the image (up left). Reference scale bar was attached to tree trunk (up right). Camera was rotated 20° (bottom left). Distance to the tree was measured (bottom right.)

After imaging a tree the same process was repeated from another location for the same tree so that image capture directions were perpendicularly towards each other.

3.2 The image pre-processing

In the image pre-processing distortion errors were removed utilizing camera calibration file (Figure 3). The calibration was carried out for shortest focal length *f*, which was utilized in image capturing. The images where rectified to plane parallel to the trunk (Figure 2).

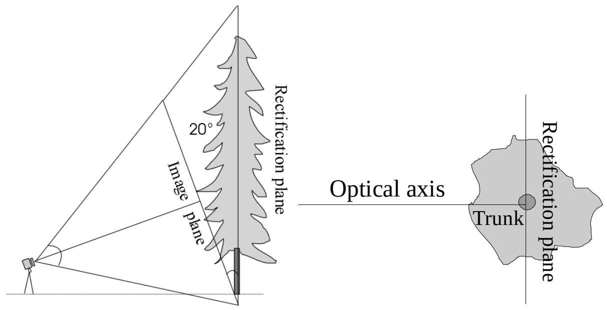

Figure 2. Imaging geometry and rectification plane. The side view (left) and top view (right).

Based on the relative orientation between the image plane and the rectification plane and camera widening angles, locations of the image corner co-ordinates were calculated on the rectified image plane. These co-ordinates and traditional least minimum square adjustment were utilized to determine eight parameters of projective transformation from image plane to plane (Mikhail et al, 2001):

$$X = \frac{e_1 x + f_1 y + g_1}{e_0 x + f_0 y + 1} \text{ and } Y = \frac{e_2 x + f_2 y + g_2}{e_0 x + f_0 y + 1} \tag{1}$$

$$\begin{bmatrix} Xx & -x & 0 & Xy & x & 0 & -1 & 0 \\ Yx & 0 & -x & Yy & 0 & -x & 0 & -1 \\ \ldots & & & & & & & \end{bmatrix} \begin{bmatrix} e_0 \\ e_1 \\ e_2 \\ f_0 \\ f_1 \\ f_2 \\ g_1 \\ g_2 \end{bmatrix} = \begin{bmatrix} X \\ Y \\ \ldots \end{bmatrix} \tag{2}$$

where x, y = image coordinates,
X, Y = co-ordinates in rectification plane and
$e_0, e_1, e_2, f_0, f_1, f_2, g_1, g_2$ = unknown parameters.

After rectification process objects were geometrically correct in rectification plane. As the relative orientation of image plane and rectification plane were constant for all images, same transformation parameters were utilized for all image rectifications.

Figure 3. Original image (left). distortion free image (middle) and rectified image (right).

3.3 The tree crown dimension measurements

The parameters for individual trees, such as tree height and crown height, were extracted from the images. Reference scale bar height and crown width to left and right from trunk in 0.5 m elevation intervals were also extracted. The origin for height measurements was tree base. The pixel units were transformed to metric units based on the known distance in the image, reference scale bar, for enabling comparison to other data sources.

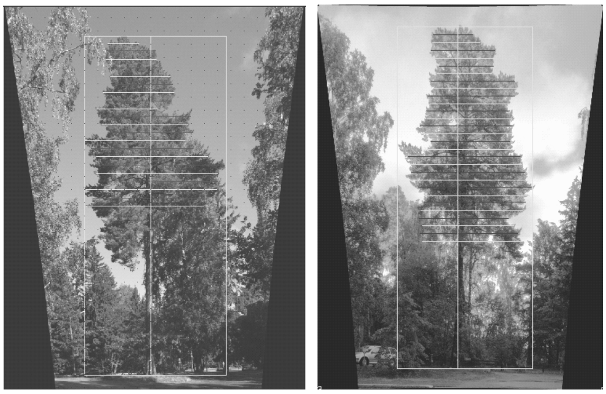

Figure 4. The tree height and crown widths were measured from first and second image.

3.4 The determination of trunk tilting

In remote sensing aided forest inventory tree trunks are typically assumed to be straight. In this study, trunk tilting was estimated. The tree top shift *dx*, that is deviation from vertical line initiated from the tree base, in horizontal direction was determined in both images. The trunk was represented as a vector (Figure 5).

$$\bar{v} = a\bar{i} + b\bar{j} + c\bar{k} \tag{3}$$

where $\bar{i}$, $\bar{j}$ and $\bar{k}$ are unit vectors in direction of co-ordinate system axes, *a* and *b* are unknown parameters and *c* is vertical component of trunk vector. A vertical trunk vector is simplified

$$\bar{v} = c\bar{k} \tag{4}$$

where *c* is the height of the tree. Unknown parameters *a* and *b* were solved from equation pair:

$$\begin{aligned} a &= aa + ab \\ b &= bb - ba \end{aligned}, \tag{5}$$

where *a* and *bb* are projections of shifts *dx1* and *dx2* to co-ordinate system axis:

$$aa = \frac{dx2}{\cos(\beta - \pi/2)}, \; bb = \frac{dx1}{\cos(\alpha)}, \tag{6}$$

ab and *ba* are calculated from angles between image planes and parameters *a* and *b* (Figure 5):

$$ab = b \cdot \tan(\beta - \pi/2) \tag{7}$$

$$ba = a \cdot \tan(\alpha)$$

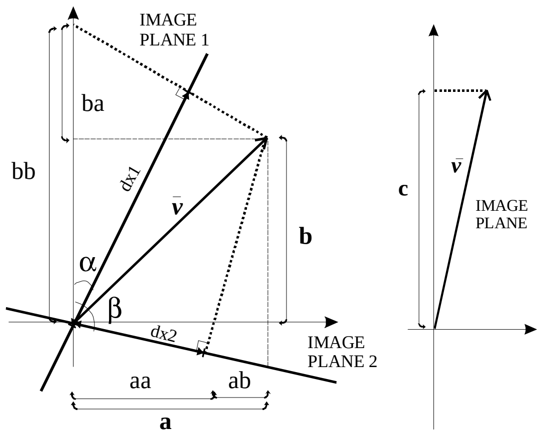

Figure 5. Vector projected in ground plane (left). Vector projected in vertical plane (right).

The trunk tilting angles towards image planes were calculated from vector components a, b, and c and angles α and β. In future processing images are rectified to plane parallel to the tree trunk.

4. ERROR ANALYSIS

During the field measurement, rotation angels ω (x-axis), ϕ (y-axis) and κ (z-axis) were determined with simple instruments, a hypsometer, a compass and a tube level. Influence of rotation errors to tree crown dimension determination was considered.

4.1 Error in ω

Rotation along x-axis, ω, was measured with hypsometer. Accuracy of hypsometer rotation measurement was estimated to be $\pm 1°$. This estimation was based on instrument ruler index and field measurement experience. The error influence was simulated rotating image plane 1° degrees and –1 ° around image bottom edge and calculating shift of each pixel compared to the correct image. Pixel movement was two directional.

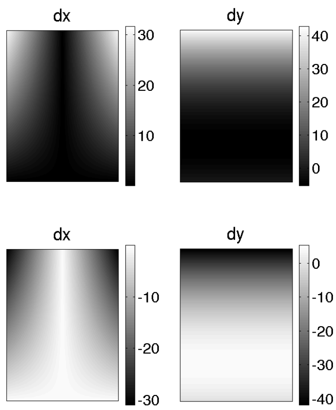

Figure 6. Error surfaces. Pixel *dx* shift for +1° ω error (up left). Pixel *dy* shift for +1° ω error (up right). Pixel *dx* shift for -1° ω error (bottom left). Pixel *dy* shift for -1° ω error (bottom right).

The plane rotation away from the camera inflicted expanding of the image plane. Tendency of error behaviour is expressed in Figure 6. Respectively the plane rotation towards the camera inflicted shrinking of image plane. Maximum errors were calculated from surface values:

$$Dx = 2 \cdot |\max(dx)| \qquad (8)$$
$$Dy = |\min(dy)| + |\max(dy)|$$

The maximum errors are illustrated in table 1. In order to compare values for other data sources errors were transformed from pixels to metric values. Scale was expressed as ratio distance between project centre and rectification plane (*f+dc*) and distance between projection centre and target *D*:

$$s = \frac{D}{(f + dc)} \qquad (9)$$

During the field measurement image capture distance was typically 25 meter, but all images were taken from less than 30 meters. Maximum errors in meters for 30 m distance are calculated in Table 1.

4.2 Error in κ

Rotation around z-axis (κ) was adjusted to zero with tube level. Maximum error in rotation measurement was estimated to be $\pm$ 2°. Maximum error in dimension measurement was carried out if distance was measured from edge to edge. For image size 3945×2928 errors are:

$$3945 - 3945/\cos(2) \approx -2{,}4$$
$$2928 - 2928/\cos(2) \approx -1{,}8$$

Maximum errors in metric values for 30 m distance are calculated in Table 1.

Rotation Angle	**Error type**	**Error, pixels**	**Error, m, for distance 30 m**
ω=1°	*Dx*	62	0.48
ω=1°	*Dy*	48	0.38
ω=-1°	*Dx*	-62	-0.50
ω=-1°	*Dy*	46	-0.37
κ=2°	*Dx*	-2.4	-0.002
κ=2°	*Dy*	-1.8	0.014
κ=-2°	*Dx*	-2.4	-0.002
κ=-2°	*Dy*	-1.8	0.014

Table 1. Maximum errors

4.3 Error in ϕ

Image capture direction (ϕ) was straight towards the tree trunk. After image capture ϕ was measured with compass. Error in ϕ measurement does not affect inner accuracy of image measurement. Objects, which are in rectification plane, perpendicular towards the imaging direction, are geometrically correct. Error has influence when measurements are compared to other data sources. Eranto, (declination between compass north and Finnish local co-ordinate system vertical axis) is 6° in Southern Finland. To improve measurement accuracy compass measurement were carried out by two persons and value was calculated as average of observations.

4.4 Error in scale

Images are in central projection and therefore objects in different depths have different scales. Scale is correct only for objects, which are in rectification plane like the scale bar. It is assumed that tree crown is widest in rectification plane. However, tree crowns are irregular in shape. Typical image capture distance was 25 m and crown width 5 m. Therefore distance from crown to the camera is varying from 22.5 to 27.5 m. In this interval the scale is changing from 0.006 to 0.0073. If crown width measured from the image is 1200 pixels and its real distance to the camera is 24 m instead the 25 m, error in dimension is 36 cm.

5. DISCUSSION

5.1 Method advantages

In the study a photogrammetric method is suggested to measure tree crown dimensions. The suggested method does not require expensive instruments, such as terrestrial laser scanner or real-time-kinematic GPS. Instruments required are digital camera, camera platform, hypsometer, compass and reference scale bar. Collecting reference data with the method is faster than with traditional method. Capturing images does not require lifting platform or climbing to the tree.

The automation level of image pre-processing is high because relative orientation between image plane and rectification plane is constant. Therefore, image rectification is batch process. Image rectification does not require known points in image area or their signalisation.

5.2 Method restrictions

The terrestrial image based method has several limitations. The basic problem is whether imaging from two directions is enough for crown modelling? Measurements were not three-dimensional. A three dimensional model could have been extracted by traditional stereo imaging procedure. Reason for not to do that is to keep imaging procedure simple and efficient. Stereo measurements also require common points for relative orientation and known points for outer orientation. With deciduous trees, these points were difficult to find.

Images could be easily captured perpendicular to each other if surrounding is open. Typically only few poses were available. Also light direction excluded several image capture poses. It is not realistic to assume that tree could be imaged in forest surroundings from all directions.

5.3 Laser scanning accuracy

The method development initiated from the need to collect reference material for laser scanned tree crown study. In laser scanning, co-ordinates of the reflecting object are calculated based on the known position of the scanner, pulse flight direction and the distance between the scanning instrument and the object. The main factors affecting accuracy of each point are (a) range measurement accuracy, (b) instrument's positioning accuracy and (c) laser beam direction accuracy (Baltsavias, 1999).

Accuracy of the range measurement is dependent on the accuracy of pulse flying time measurement, the length of the pulse and the shape of the echo (Katzenbeisser, 1998; Baltsavias, 1999). The range measurement is most accurate when whole pulse is reflected from one plain surface only, which is in perpendicular position towards pulse flying direction (Katzenbeisser, 1998). It is realistic to assume that in tree crown laser pulse is not reflected from one surface only, but from several small surfaces, such as leaves or needles. Pulse echoes from different surfaces are separated only if their distance is longer than pulse length. It is assumed that planimetric accuracy of individual laser point is 20 cm. Dimension measurement variance from one laser point to another laser point is sum of single point measurement variance, 0,4 m.

6. CONCLUSIONS

In the study, a new method is suggested to measure tree crown dimensions. The method's accuracy was estimated based on the rotation angle determination accuracy. Maximum errors of vertical and horizontal measurements were 0.4 m, respectively. However, measurement accuracy was usually better, because tree is located in the middle of the image and largest errors take place at image corners and edges (see Figure 7). The method is, therefore, suitable for intended use, verification of laser scanned tree crown evaluation.

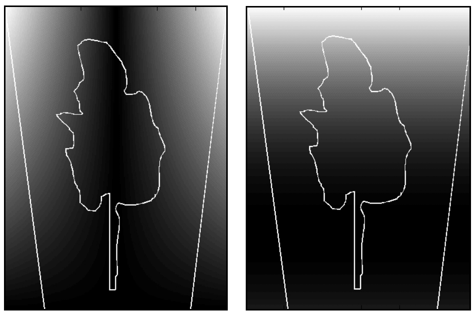

Figure 7. Error surfaces and tree profile.

Accuracy of method may be improved with more accurate rotation measurement. Level of tree crown shape reconstruction may be increased if images are captured from more that two directions.

ACKNOWLEDGEMENT

The author would like to thank Jenny and Antti Wihuri Foundation, Foundation for Research of Natural Resources in Finland and Finnish Academy for financial support.

REFERENCES

Ahokas, E., Kaartinen, H., Matikainen, L., Hyyppä, J., Hyyppä, H., 2002. *Accuracy of high-pulse laser scanners for digital target models*. In: Observing our environment from space. New solutions for a new millenium. Proceedings of the 21st EARSeL Symposium, Paris, 14-16 May, 2001, pp. 175-178. Balkema Publishers.

Batsavias, E.P., 1999. *Airborne laser scanning: basic relations and formulas*, ISPRS Journal of Photogrammetry and Remote Sensing 54, s.199-214

Bradtberg, T., 1999. *Automatic Individual Tree-Based Analysis of High Spatial Resolution Remotely Sensed* Data, Acta Universitatis Agriculturae Sueciae, Silvestria, No. 118

Friedlaender, H., Koch, B., 2000. *First experience in the application of laserscanner data for the assessment of vertical and horizontal forest structures*. In: International Archives of Photogrammetry and Remote Sensing. Vol. XXXIII, Part B7. Amsterdam 2000. pp 693-700.

Haala, N., Reulke, R., *Tree species recognition by combination of terrestrial laser scanning with high resolution panoramic images.* Proceedings of the ISPRS working group V/1 'Panoramic Photogrammetry Workshop' Dresden, Germany 19-22 February 2004.

Heurich, M., Schneider, T., Eckhard, K. 2003. *Laser scanner for identification of forest structures in the Bavarian Forest Natioinal Park*. Proceedings of the ScandLaser Workshop on airborne laser scanning of forests, Umeå, Sweden, September 2-4, 2003. pp. 98-107.

Hyyppä, J., Inkinen, M., 1999. *Detecting and estimating attributes for single trees using laser scanner*, The Photogrammetric Journal of Finland, Vol 16, No. 2, pp. 27-42.

Hyyppä, J., Pyysalo, U., Hyyppä, H., Haggrén, H., Ruppert, G. 2000. *Accuracy of laser scanning for DTM generation in forested areas*. In: Laser Radar Technology and Applications V, Proceedings of AeroSense'2000, April 24-28, 2000, Orlando, Florida, USA, Proc. SPIE 4035, p. 119-130 (2000)

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, A., Karjalainen, M., 2001. HIGH-SCAN: *The first European-wide attempt to derive single-tree information from laserscanner data.* The Photogrammetric Journal of Finland, Vol 17 No. 2, 18: 58-68.

Juujärvi, J., Heikkonen, J., Brandt, S., Lampinen, J. 1998. *Digital image based tree measurement for forest inventory*. SPIE Conference on Intelligent Robots and Computer Vision XVII: Algorithms, Techniques, and Active Vision. Vol. 3522:114-123.

Katzenbeisser, R. *Digital Elevations Models by Laser Scanning Principles and Result*s, Workshop on Laser-Scanning, Lifelong Learning Institute DIPOLI, April 20,1998, Espoo, Finland

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

Lee, S., Clark, N., Araman, P. 2003. *Automated methods of tree boundary extraction and foliage transparency estimation from digital imagery.* Proceedings of the 19th Biennial Workshop on Color Photography & Videography in Resource Assessment. October 6-8, 2003. Logan, Utah, USA

Lim, K., Treitz, P., Groot, A., and St-Onge, B., 2001. *Estimation of individual tree heights using LIDAR remote sensing*. Proceedings of the 23rd Annual Canadian Symposium on Remote Sensing, Quebec, QC, August 20-24, 2001.

Mikhail, E., Bethel J., McGlone, C. *Introduction to Modern Photogrammetry.* Jonh Wiley & Sons, Inc. 2001

Næsset, E., and Økland, T., 2002. *Estimating tree height and tree crown properties using airborne scanning laser in a boreal nature reserve*. Remote Sensing of Environment, 79, 105-115.

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

Pyysalo, U., Hyyppä, H. *Reconstructing Tree Crowns from Laser Scanner Data for Feature Extraction*. International Society for Photogrammetry and Remote Sensing - ISPRS Commission III Symposium (PCV'02). September 9-13, 2002. Graz. Austria.

Pyysalo, U., 2000. *Determination of elevation models in wooded areas with 3-dimensional point cloud measured with laser scanner* (in Finnish), Master thesis, Helsinki University of Technology, Department of Surveying.

Rönnholm, P., Hyyppä, H., Pöntinen, P., Haggrén, H., Hyyppä, J., 2003. *A method for interactive orientation of digital images using backprojection of 3D data.* The Photogrammetric Journal of Finland, Vol. 18, No. 2., pp. 58-69.

St-Onge, B. A., Achaichia, N., 2001. *Measuring forest canopy height using a combination of LIDAR and aerial photography data*. Workshop on Land Surface Mapping and Characterization Using Laser Altimetry, Annapolis, Maryland, USA, October 22-24, 2001.

Yu, X., Hyyppä, J., Kaartinen, H., Maltamo, M., Rönnholm, P., Hyyppä, H., 2003. *Automatic Determination of Forest Growth and Detection of Individual Cut and Fallen Trees using Laser Scanning.* Proceedings of the ScandLaser Workshop on airborne laser scanning of forests, Umeå, Sweden, September 2-4, 2003. pp. 115-124.