RECONSTRUCTING TREE CROWNS FROM LASER SCANNER DATA FOR FEATURE EXTRACTION

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ABSTRACT:

The objective of this study was to carry out reconstruction of single tree crowns from laser scanner data to use the obtained vector model for feature extraction. The reconstruction was implemented in several stages. First, pulses which have reflected from each tree were marked off from the original point cloud. Ground points were then separated from all points using digital terrain model and analysing the histogram of terrain height values. In the next stage canopy was described with vector polygons, and the location of the trunk was estimated. With respect to the location of the trunk, tree points were transferred from *(xyz)*-co-ordinate system to the polar-co-ordinate system *(a,r,h)*, and features were estimated from the vector model. Evaluation of the reconstruction was performed choosing a test area and processing 50 single trees, and comparing results to the field measurements. In the study it was found that dense laser scanner data detail describes the upper canopy of forest and therefore is suitable for tree height information extraction. The lower crown was found less detail measured with laser scanner and parameters extracted from that part were less accurate, but trend setting. Obtained distance profile seemed to give tendency for the tree specie.

1. INTRODUCTION

In the airborne laser scanning of forest, tree canopies reflect pulses transmitted by the laser instrument. Several echoes are typically obtained from laser return. As treetops are usually the highest objects of the area and so closest to the instrument, they are registered specially with the system registering the first pulse. When the measurement point density is as high as ten points in one square meter, objects on top of the ground surface, such as trees and bushes, can be distinguished visually from the measurement data on the basis of their geometric form (see Figure 1). These data sets can be produced using laser system with measurement frequency up to 80 000 Hz and with slowly flying platforms.
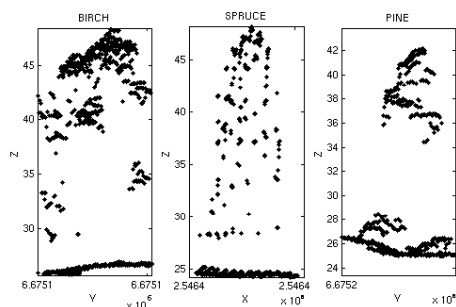

Figure 1. Side view to laser scanner data

The rapid development of computer-related techniques has enabled the introduction of the powerful process of semi-automated detection of single tree crowns. Several authors have achieved promising results using high resolution optical images (e.g. Brandtberg, and Walter, 1998, Gougeon, 1997). Airborne laser scanner data is used widely in terrain models (Krauss and Pfeifer, 1998, Pyysalo 2000, Axelsson 2000), but to some extent also in the field of tree species classification (Törmä

2000) and extraction of tree parameters (Nilsson 1996, Nässet 1997, Hyyppä et al. 2001). Laser scanning has shown the potential of producing accurate single tree information for forest inventory (Hyyppä and Inkinen, 1999, Hyyppä et al. 2001). The accuracy of field inventory measurements (hypsometer) is typically better than 0.5 m but for taller trees (>25 m) it can be up to 1 m. In Hyyppä and Inkinen (1999), the correspondence between laser-derived tree height and field-measured tree height was 1.0 m including the field inventory errors. Therefore, the obtained accuracy seemed to be incredibly promising for operational activities. Persson (2001) has also compared the heights of the automatically detected trees with the measured heights. The correlation coefficient (r) showing the linear relationship of the heights was 0.82 and the mean error + 1.83 m. The average positional error of the detected trees 0.94 m with the standard deviation of 0.57 m.

In this study, an attempt was made to reconstruct tree crown deeper than just the canopy surface, and to use the obtained vector model for feature extraction. In a dense forest, the pulses are typically reflected either from the top of the canopy or from the ground, and therefore the reconstruction was restricted by the difficulty of getting laser pulses from lower branches of the canopy. However, in more open areas laser pulses are able to reach the middle and sometimes even the lowest branches of the crown without interfering crowns of the surrounding trees. Closer attention was paid to lower tree crown, as it was hypothesised to characterize tree specie. In Finland main tree species are spruce, pine and birch. Evaluation of the single laser point co-ordinate accuracy was left out of the study.

2. RECONSTRUCTION METHOD

The reconstruction was implemented in several stages. At first digital surface model (DSM) and digital terrain model (DTM) were created from dataset. Pulses which have reflected from

each tree were then marked off from the original point cloud and tree crown was described with vector polygons from the lower limit of the crown to the top of the tree

2.1 Digital surface model and digital terrain model

Creation of the DSM was carried out by fetching the measurement points that have reflected from each pixel giving the highest z co-ordinate of these points as the value of the pixel. In this article, digital surface model refers to the surface in which objects, such as trees and buildings and the ground elevation are presented. The resolution of the model indicated the size of the area in terrain described by one matrix cell, i.e. pixel. The applied pixel size was 1 m (see figure 2).
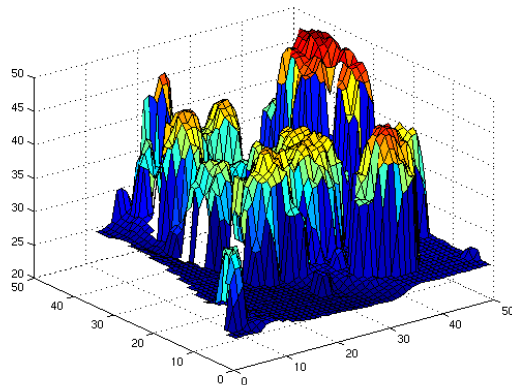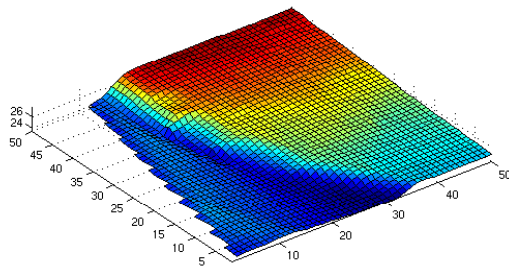

Figure 2. Digital surface model

Figure 3. Digital terrain model

Digital terrain model (see figure 3) was created using laser scanner data and TerraScan software, which has been programmed by TerraSolid company. The description of the TerraScan DTM algorithm has been published by Axelsson (Axelsson, 2000). The DTM was needed in the reconstruction process in order to get the absolute height of trees and for separating ground points from other measurement points.

2.2 Separation of tree points

Two different methods were used in tree points separation; manual delineation of single trees and automatic delineation using the segmentation surface. Manual delineation was utilized using TerraScan software. Points were visualized on top of the DSM and fence was drawn around each tree crown based on the visual interpretation of the crown geometry in top view. Points inside a fence were exported to separate file.

For the automatic delineation the digital tree height model (DTHM) was calculated as the difference between the DSM and the DTM. Heights in the DTHM model matrix were the heights of the trees (Fig 4 left). The DTHM was segmented by using the Watershed algorithm. The algorithm turned the surface upside down, picked up the local minima (tree tops) and examined the environment of minima with the help of the direction and size of the gradient. Pixels where flooding ended at the same minima were marked with an integrating mark. Those pixels were merged as a segment (Fig. 4 right). The Watershed algorithm utilised in this study has been programmed by Arbonaut Ltd, (Arboreal Forest Inventory Tools).
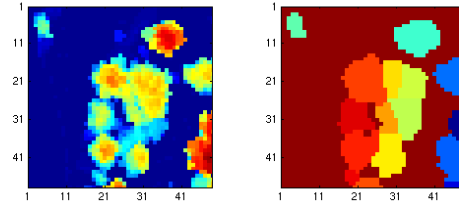

Figure 4. Top views, left DTHM, right segmentation surface.

2.3 Creation of the vector model

Each individual tree crown was described with vector polygons from the lower limit of the crown to the top of the tree. The lower limit of the crown was examined from the histogram of the z- co-ordinates. Points that were closer than the threshold of the DTM-surface were marked as ground and ignored. The widest continuous area in z-direction where measurements were not found (histogram value zero) was searched and the next found elevation was taken as the lower limit of the crown.

The space between lower limit of the crown and the tree top was split in half meter deep layers in z-direction. The points that were found inside a particular height layer were always processed at the same time. The point cloud was ordered by first calculating the arithmetical center of the cloud. At the next stage, an angle between the x-axis and a line that combines the point under calculation and the center point was calculated for every point. The points were then arranged and connected to each other according to the rising angle. This created a polygon that went through every point. The polygon was drawn to the model in the middle of the height of the layer. The forming and drawing of polygons was repeated for all the height layers in the crown (see figure 5A).
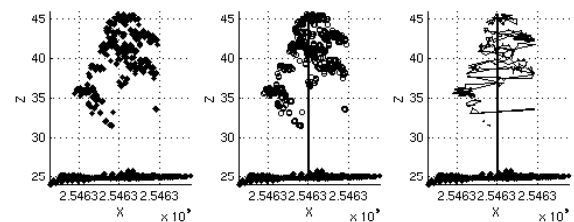

Figure 5. A: a Birch, B: a birch with trunk, C: a birch crown polygons.

2.4 Estimating the place of the trunk

At the last stage, an estimate of the location of the trunk was calculated from crown points as mean value of x- and y- co-ordinates weighted with point height. The reason for weighting was that the branches are usually closer to the trunk near the top, where the tree narrows and also because most of the laser pulses were reflected from the tree top and, therefore, the geometric shape of tree was more accurate. The trunks were described as straight lines from the top of the tree to the surface of the DTM (see figure 5 B.)

3. EXTRACTED FEATURES

Features extracted from the model were the height of the tree, the height of the canopy and the average distance of points from trunk in different heights.

Tree height was calculated as difference between the highest measurement point and the ground height at trunk location. In order to get the ground height, DTM was used. The height of the crown was calculated as difference between the highest measurement point in tree segment and lower limit of the crown.

For calculating average distance of points from trunk in different heights, points were transfer from the *(x,y,z)* co-ordinate system to the *(a,r,h)* system:

$$h = z - z_r \tag{1}$$

$$r = \sqrt{(x - x_t)^2 + (y - y_t)^2} \tag{2}$$

$$a = \arccos \frac{(x - x_t)}{r} \tag{3}$$

where
    h = point height
    r = point distance from the trunk
    α = angle between x-axis and point vector
    (x_t, y_t) = trunk location,

Mean distances r_m in half meter deep layers in z-direction were calculated for each individual tree.

4. TEST

The reconstruction method was utilised for test area. The test area was in urban environment, in the city of Espoo, Finland. Area was university campus with standing single trees and grass undervegetation.

4.1 Lasers scanning

The laserscanning was done using TopoSys-1 measurement system in June 2000, when leafs were already in trees. Measurement was made from the altitude of 400 meters resulting in stripe width of about 100 meters, and point density of 10 points per m² whereas the measurement frequency was 83000 Hz. The measurement was made from one measurement stripe only. In this study, first pulse data were used.

4.2 Field measurements

The field measurements were carried out in summer 2002. Instruments used were tacheometer with prism and hypsometer. For evaluation of DTM accuracy four profile lines were measured. Points were measured in terrain break points specially. Tree trunk locations were also measured at the breast height (at ab. 1.3 m height) with tacheometer. Tree species were checked and tree heights and heights of the lower limit of the crowns were measured using hypsometer from 15 meters distance.

5. RESULTS AND THEIR ANALYSIS

5.1 Evaluation of the reconstruction steps

DTM accuracy was evaluated comparing z-co-ordinates of the tacheometer measured profile points to the surface profile heights. Standard error in height was 0.16 m. Result was expected and in line with previous studies concerning forest floor DTM accuracy (Pyysalo, 2000, Hyyppä et. al. 2001). The maximum errors occurred in the areas were laser points that had not reached the ground and estimation of these heights had been carried out by interpolation using distant points.
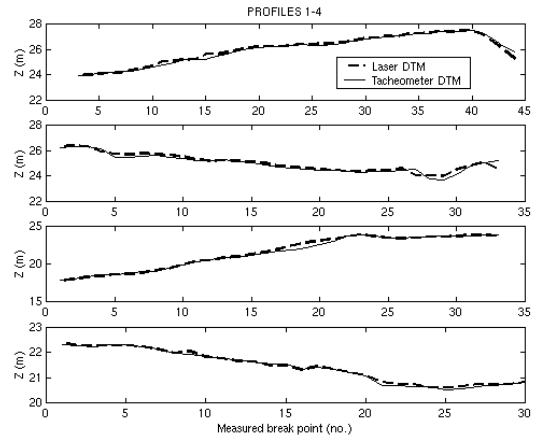

Figure 6. Profiles

In the DSM (window size 1'1 m) almost 99.5 per cent of pixels had value, which means that one or more pulses had hit the area. Pixels without value were usually shadow areas behind some tall object (see figure 2). The DSM accuracy was not separately tested, except the tree heights, which is discussed later. The DSM was utilised in calculating DTHM.

Manual separation of single tree points was taken to the applied process as the automatic segmentation had a rather low accuracy. Typical problem utilising automatic segmentation was that close growing trees were merged in one segment but also that several segments were created from one tree only because of grainy crown top. In Hyyppä et al. (2001), various segmentation algorithms for single tree delineation were tested showing an average value of 50 % for correct crown segmentation. Both manual and automatic segmentation approaches fail to separate points correctly if branches of two trees were crossing. In some occasions under vegetation areas around trees were partly merged to the tree segments. However, laser points from those areas were not used in crown polygons as they were ignored as measurements coming under the lower limit of the crown.

Trunk location estimates were then compared with tacheometer measurements. During the field measurement trees with tilted trunk were registered. These trees were ignored in comparison. The standard error of x co-ordinate was 0.87 m and std. error of y co-ordinate was 0.79 m. Analysing the trunk location errors according to the tree specie, it was noticed that spruces were located most accurately (see table 1). The reason for this could be that spruce crowns are usually smaller that i.e. birch crowns.

(m)	Birch	Pine	Spruce	All
Mean x	0.60	0.33	0.10	0.42
Std x	1.00	0.81	0.40	0.87
Mean y	-0.25	-0.34	0.05	-0.21
Std y	0.85	0.92	0.23	0.79

Table 1. Tree trunk location errors.

One reconstruction stage was forming polygons around tree crown. The polygon areas could give an estimate about crown areas in different heights.

5.2 Evaluation of the extracted features

Heights of the trees were compared to the field measurements. Standard error in the comparison was 1.2 m and bias + 0.29 m. The maximum errors were related to tallest trees. Standard error concerning the crown height was 4 m and bias – 3.0 m. The negative bias indicates that the echoes from the lowest branches were not registered with the measurement system. On the other hand during the field measurements it was noticed that the lower limit of the crown could have been measured in several places depending which branches where understood belonging to the continuos crown.

Mean distance from the trunk (r_m) was utilised to draw a crown profile for each tree. Example of typical, 23 m high spruce, birch and pine profiles is illustrated in figure 6. Per cent in the x-axis is height relative to the tree height. The figure indicates that the birch crown is wider than pine or spruce crowns in all heights. Moreover, pine crown would seem to be significantly shorter than spruce crown. The results were in line with the visual observations.
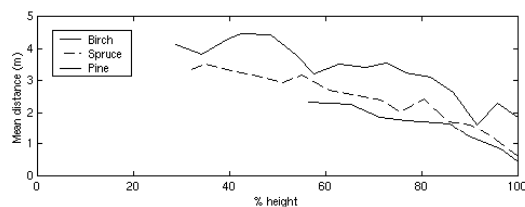

Figure 7. Single tree crown profile, birch, spruce and pine.

6. CONCLUSIONS

In the study laser scanner data were utilised for tree crown reconstruction. It was found that dense laser scanner data detail describes the upper canopy of forest, and therefore is suitable for tree height information extraction. The lower crown was found less detail measured. In the test area the average crown depth measured with hypsometer was about 14 m. Average laser derived crown depth was about 11 m. The result suggests that information under canopy surface could be extracted from laser scanner data.

Tree trunk locations where extracted with accuracy 0.87 m for x and 0.79 m for y. Location-based single-tree information is essential in various applications. In this study trunk locations where used to calculate mean distance profile. Special attention was paid to the distance profile as differences between main tree species in Finland where observed from the profile.

7. FUTURE PLANS

Based on the knowledge received from the study the authors would be interested to test the method to laser data, where the system has measured several echoes from return pulse instead just the first or last. The lowest branches are probably causing return echoes but they are net registered with instrument measuring only one echo. In the future the authors shall also make an attempt to find a method to classify tree species based on the distance profile.

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