AUTOMATIC DETERMINATION OF FOREST INVENTORY PARAMETERS USING TERRESTRIAL LASER SCANNING

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ABSTRACT

In the Natscan project terrestrial laser scanning is used for deriving detailed information about tree quality and forest stand parameters. The authors describe an automatic method for determining tree positions and diameters at breast height (DBH) using terrestrial laser scanner data. Special attention is given to the data-processing that must be carried out before this information can be derived from the raw data. First, a digital terrain model is calculated by creating a subset of coordinates containing lowest Z-values. Subsequently, filter methods are described to delete any noise points which result from the ambiguity problem connected with phase difference scanners. Finally, the process of tree stump coordinate and DBH determination by using Hough-transformation and circle approximation is described.

In comparison with a conventionally measured reference data set results for the stump coordinate and DBH are very promising. The differences fall within the expected range, although some improvement on developed algorithms is still necessary. The information derived so far can be used a basis for further automatic determination of other single tree characteristics such as tree species, tree height, crown projection area as well as location and type of wood defects.

INTRODUCTION

Information about current state and recent changes of forests are important basics for forest management and planning. In addition to well introduced airborne laser scanning, the use of terrestrial laser scanning is quite common in architectural measurements but has hardly been tested for the measurement of natural objects such as local terrain, standing trees or stags.

In the NATSCAN project one objective is to develop methods to automatically quantify characteristics used in conventional forest inventories. In addition, quality assessment of single trees in forest stands based on laser scanning techniques will be improved (Thies et al., 2002). The approach to the project is a combined inventory method which includes aerial laser scanners for covering large-scale areas and terrestrial laser scanners for deriving information about tree quality and inventory parameters as for example diameter at breast height (DBH), branch-free bole length, tapering or sweep of the bole based on sample plots. Terrestrial laser scanning, contrary to aerial laser scanning, measures trees from underneath the canopy and does this with very high resolution which is the basis for the described objective.

In this paper we roughly introduce the use of terrestrial laser scanners for forest inventories. Special emphasis will be placed on the automatic recognition of trees in point clouds representing sample plots with an average size of approximately 500 m². In addition to several filtering methods one pre-requisite for the automatic process is the separation of a digital terrain model (DTM) which is also described.

METHODS

The laser scanner

For our research we used the IMAGER 5003 from Zoller + Fröhlich which is based upon the spot Z+F Laser Measuring System LARA and can be fitted alternatively for two distance ranges, 25.2 m and 53.5 m.

Advantages of a phase difference scanner are both its high accuracy and its speed. The system realises an absolute accuracy within millimetre-range. As well as the distance, a value for reflectivity is also recorded. This intensity image delivers a 15 bit grey value image of the scanned area which is comparable to a black and white picture (Heinz, 2001).

The beam deflection unit enables one to image a 360° horizontal field of view and a 310° vertical field of view (the vertical view is cut off underneath the scanner). The maximum number of pixels vertically is 15,000, the maximum number of pixels horizontally is 36,000. The achieved angular accuracy for this deflection unit after calibration is approximately 0.01° (Zoller + Fröhlich, 2003).

A disadvantage of a phase difference scanner is the limitation of the maximum distance. When objects are beyond the ambiguity interval the results will contain additional point-noise. Measured distances in forests are usually greater than 25 metres, therefore we use a scanner with a range of 53.5 metres.

Measurement setup

The sample plots are scanned from various positions. On average, four scans evenly distributed around the centre of the plot were made, each about 10 to 15 meter distance from the centre of the plot, so that a central overlapping zone was guaranteed. Targets were used to match the data from the different scans and to orientate the point clouds in a georeferenced coordinate. These targets were placed in such a way so that they are visible in most of the scans. At least three targets were necessary to register a scan. To achieve higher accuracy we insured that between five and six targets were visible for each scan (figure 1). For georeferencing the point clouds targets were measured with a total station and connected to the German national coordinate system (GAUSS-KRUEGER coordinates).

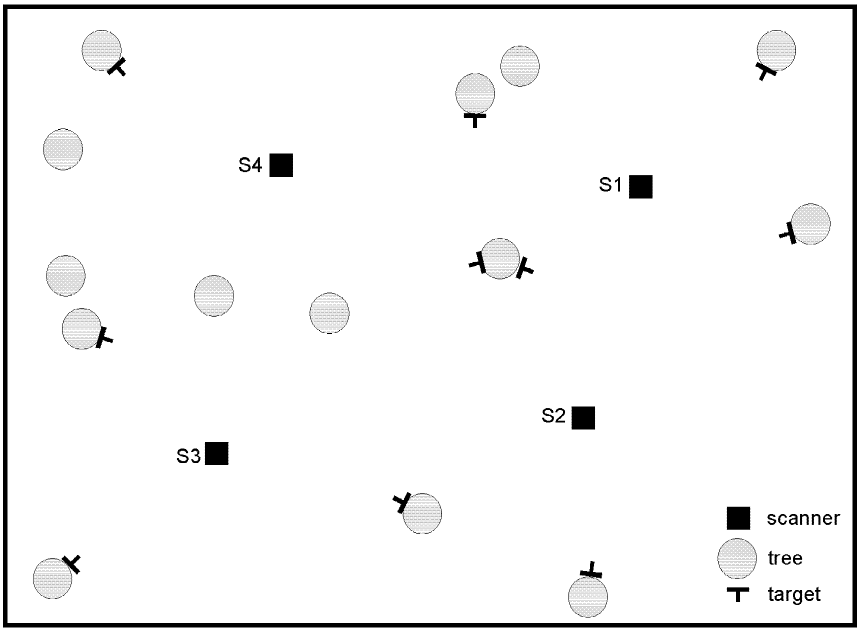


Figure 1: Typical measurement setup.

Digital Terrain Model

In a first assumption a good recognizable feature of a tree is a perfectly circular stem cross-section. For the selection of points representing stem cross-sections, a digital terrain model must first be determined. In later stages of data analysis these terrain models also help to derive tree heights and to calculate the slope and orientation of a stand.

A disadvantage of the laser scanning technique is that all measured points are unqualified. Points only represent their positions and intensity and not on which object they reflected. To select points which represent the ground surface the first step is to search for the lowest points. For this purpose the point cloud is separated in a grid with a regular size of 50 x 50 cm. In each grid cell the point with the lowest Z-value is selected. This sub-sampling of coordinates is the base point collection for further analysis. In the next step these data points have to be tested against an exclusion cone around the scanner and a-priory information about what the estimated maximum terrain height and the maximum steepness of a slope are. From the scanner position a cone is projected which describes the relation of surface height and distance to the scanner (figure 2). Coordinates inside this cone will be ignored.

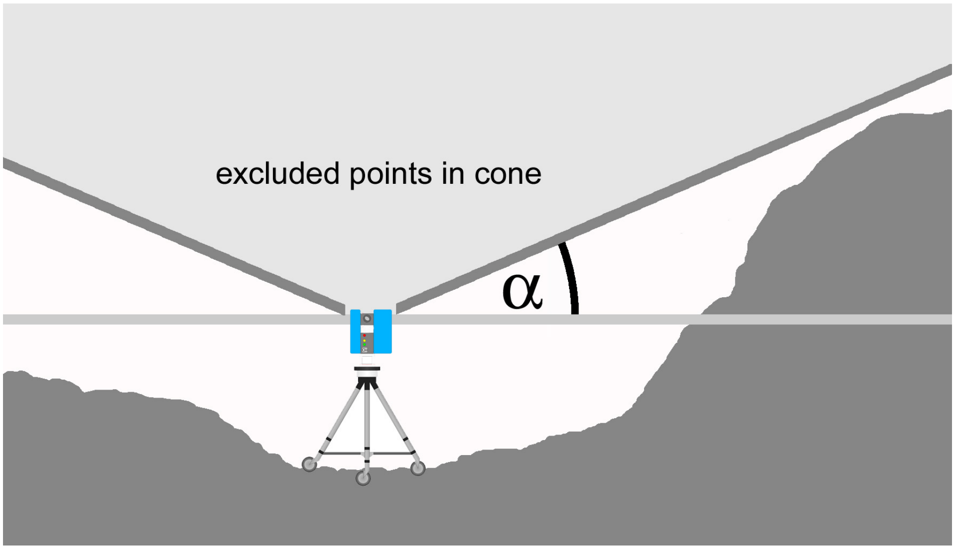


Figure 2: Exclusion cone. All reflected scanner points within the cone above the scanner will not be used for the determination of the ground surface. The dihedral angel of the cone is 180° - 2α.

Clearly a point representing a height above the maximum terrain height cannot be part of the ground surface, so if a point in the selection is much higher than its neighbouring points and exceeds a given maximum the point will be deleted. The last automatic test on the surface points is a maximum slope test. If a point causes a steep slope in the surface it will be removed.

An optical test is still essential after finishing the automatic derivation of the collection representing terrain coordinates. This test can be carried out on the drawn points. Points that are obviously not part of the surface can be manually removed from the selection.

A digital terrain model with a grid size of 50 x 50 cm is calculated with the selected points.

Filtering

Due to the ambiguity problem the resulting point cloud from a laser scan includes point noise. Points reflected at a 60 meter distance from the scanner behave as if they were only 6.5 metres away (60 meters minus the wave length of 53.5 meters). Before any algorithm can be applied to the data, these pixels must be identified and removed.

The first filter technique we use is a filter that deletes isolated points. Searching along the scan direction every single point has four neighbouring pixels. If the distance of a pixel is extremely different from its neighbouring pixels it is separated as isolated coordinate and deleted from the point cloud (figure 3b). The second filter used for noise detection is based on the intensity of the reflection. The intensity value of measured points ranges from 0 to 32,767. A very low value indicates a reflection from a point beyond the ambiguity range and can be considered to be point noise. According to our experience natural objects never have high intensity values. This means that a very high intensity (e.g. 20,000 or higher) also indicates point noise when measuring in forest stands. After using both filters most point noise is deleted from the dataset (figure 3c).

Figure 3a: Intensity Image of a scan; b: point cloud without isolated points, filter by a value of 2 metres; c: point cloud b filtered by points of an intensity less then 500 and more then 20,000.

Another disturbing factor for the automatic separation of trees based on 3D-point clouds are the foliage and branches between the scanner and trees. These have to be detected. To isolate tree boles from overlapping branches regions with only slight differences in distance values between neighbouring pixels are separated. The density of pixels is relatively high close to tree boles (corresponding to little distances between neighbouring pixels). If a chosen distance is exceeded pixels are not recognised.

Coordinates of tree stump base and diameter at breast height

Using the digital terrain model a search for circles as a model of tree cross-sections has been implemented. To find these circles all coordinates in a layer with a height between 1,25 and 1,35 metre above terrain were extracted from the point cloud. The 3D coordinates were converted to a regular raster image (figure 4). For this conversion a pixel size of 1 cm² was chosen.

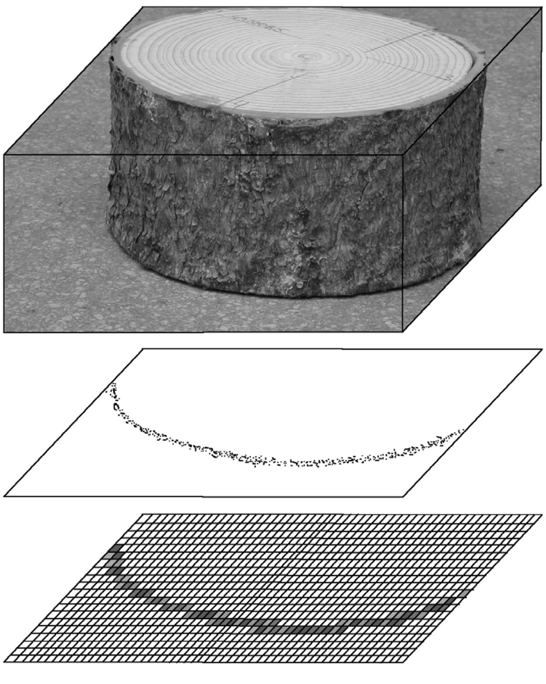
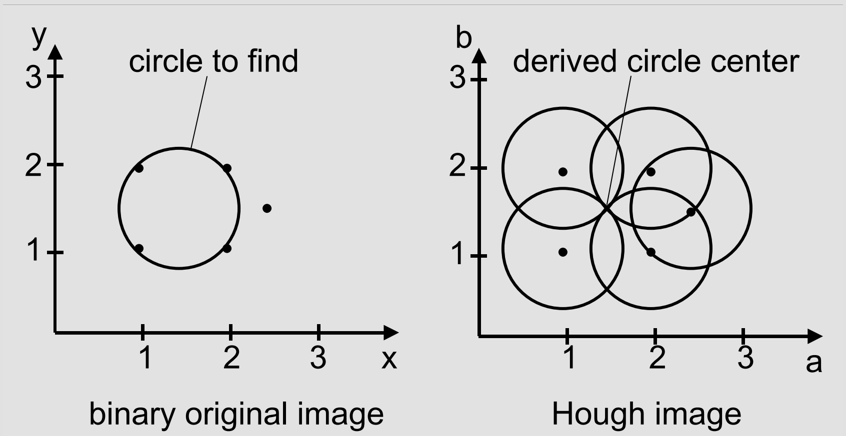


Figure 4: The selected layer of 10 cm height will be covered with scan points. These scan points will be mapped on a plane and fitted to an regular raster of 1x1 cm.

The Hough-transformation uses a parametric description of simple geometrical shapes in order to reduce the computational complexity of their search in a binary edge image. The method for searching circles use the parametric description:

$$(x-a)^2 + (y-b)^2 = r^2 \quad .$$

With a fix radius *r* the parameters *a* and *b* stretch a parameter matrix *P(a,b)*. For every filled pixel (value 1) in the binary edge image a set of corresponding parameter values *a* and *b* is calculated matching the defined value *r*. The appropriate parameter matrix *P(a,b)* will be increased by 1 for these parameters. At the end of the procedure, each parameter matrix element *P(a,b)* shows the number of parameters that satisfy. If this number is above a certain threshold a circle is declared (Pitas, 2000 and Paulus et al., 2001).



After this conversion is done, standard pattern recognition methods can be applied. We decided to use a Hough-transformation (see info box) to detect circles in raster images.

The Hough-transformation needs to have a diameter value before it can recognise a circle. Because the tree diameter is not known before applying the algorithm we start with a value of 100 cm and reduce the value in increments of 10 cm.

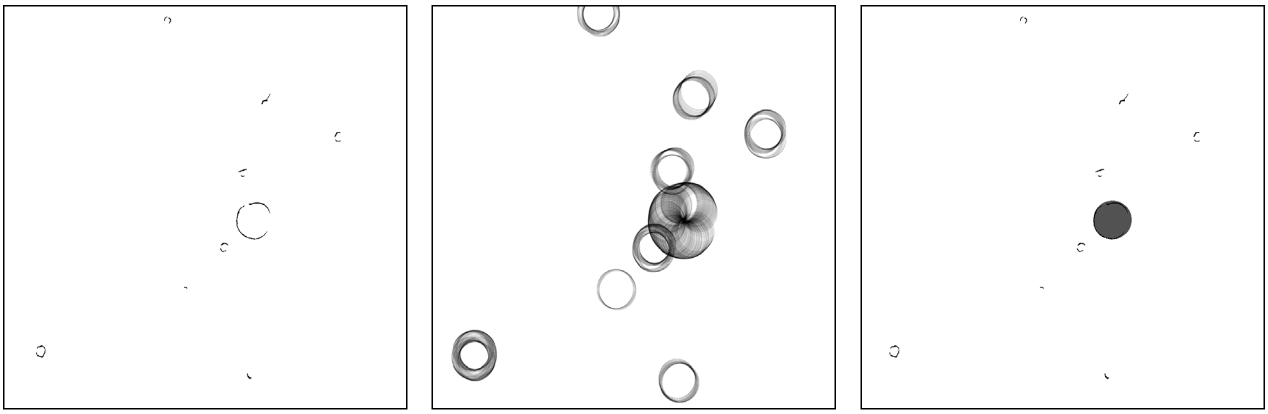


Figure 5a: Binary image layer with `C´ circle ring; b: Hough image; c: Hough circle

The determined Hough circle is expanded by 10% to ensure the identification of all pixels that could be part of the stem. On the selected pixels an algebraic algorithm is used to fit the circle precisely. The centre coordinate minus 1,30 m is assumed to be the tree stump coordinate and the diameter of the circle is equivalent to the DBH.

RESULTS

In one test area, 28 Douglas- and silver fir trees with a diameter above bark in DBH of greater than 7 cm were measured conventionally. The reference data was measured with a total station (position) and a calliper (two cross-wise measurements in DBH). With the coordinates and DBH we derived using the laser scan data we could correctly identify 26 out of the 28 trees. We consider this very promising. The two trees that could not be identified were densely overlapped by small branches in the direct line of sight from the scanner to the tree. The branches disturbed or blocked the measurement of the trees too much.

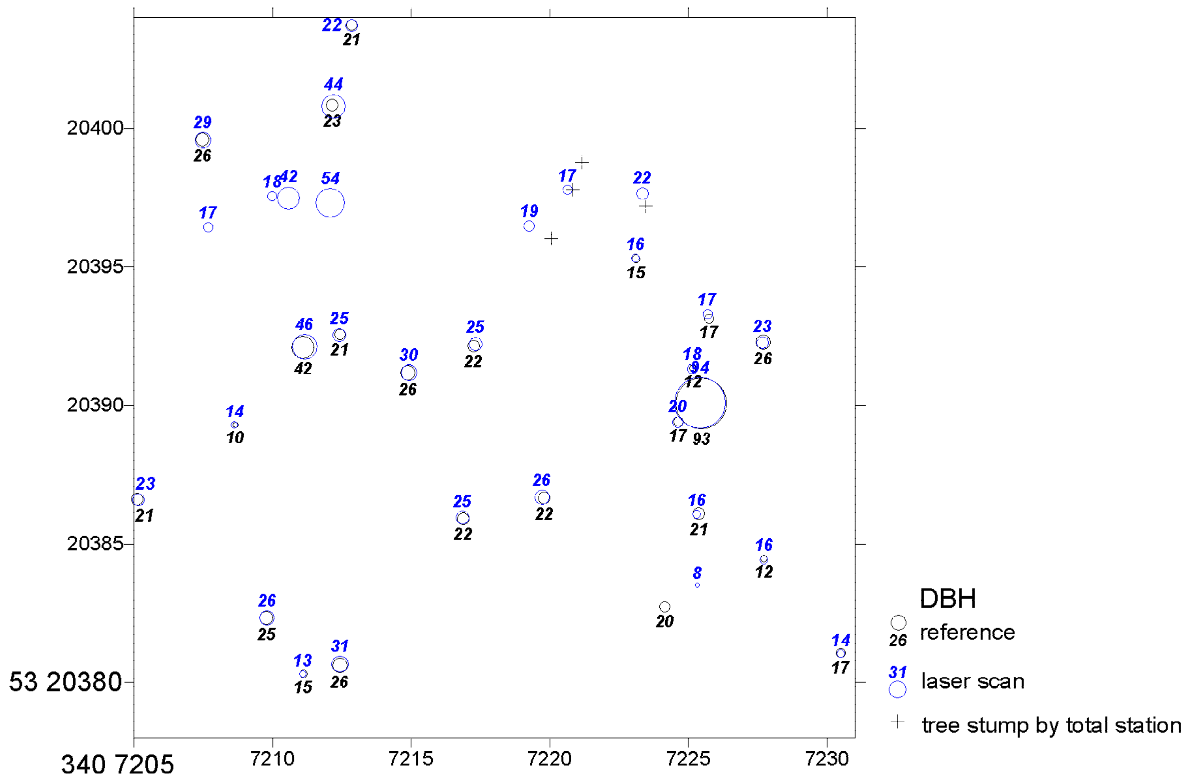


Figure 6: Plot with DBH measured by total station and derived out of the laser scan data.

For two trees the difference between the reference and derived tree reaches up 90 cm. This is due to an extreme sweep close to the base of the stump. Because tree positions are measured at 1.30m height, sweep has a very strong influence on their positions. For all other trees the differences are less than 20 cm.

One of the trees shows a great difference in DBH compared to its reference. Noticeable for this tree is that the circle determined by the Hough-transformation resulted in a more accurate approximation than the circle resulting from the algebraic algorithm that is supposed to be superior.

Table 1: Comparison of the reference data and the results from the laser scan. Originally 28 trees were measured. 26 were automatically identified in the point cloud. Two were excluded because of their sweep and one was excluded because of an error in the algebraic algorithm. The calculated position differences are based on 23 trees.

	min [cm]	max [cm]	mean [cm]	standard deviation (σ) [cm]
Radial position differences	2.0	17.1	5.0	3.6
DBH differences	-5.8	5.6	1.7	2.8

The method used to locate trees in the laser scan identified more trees than were actually present. This effect was caused by a dead tree lying on its side, the thick branches of which were themselves recognised as trees. A repetition of the automatic diameter estimation in upper parts of the bole would help to identify these specific patterns.

CONCLUSIONS

The approach for deriving tree characteristics from terrestrial laser scanner data described in this paper allows an automatic identification of trees, their positions and the DBH (as well as additional diameters in variable tree heights). The results can be used as a basis for further automatic determination of other single tree characteristics such as tree species, tree height, crown projection area as well as location and type of wood defects.

Developed methods and algorithms must be improved, especially the combination of Hough-transformation and algebraic algorithm needs some enhancement. In the near future RGB colour information will be added to the 3D geometry data. This will certainly improve filter methods and also facilitate the determination of other forest inventory parameters, especially wood defects and biomass distribution.

In the future, the main point of emphasis will be to separate information about crown structure from the 3D point clouds, to estimate crown variables such as crown width, crown surface area, etc. and compare them with results derived from airborne laser scanner data as well as conventionally measured crown parameters. In addition, the implemented algorithms should be tested based on just one scan from the centre of the sample plot, so that it is an option to use the terrestrial laser scanner technique for deriving precise 3D models of certain forest stands or for collecting a high number of data from different sample plots as is usual in most national forest inventories.

In addition to the accuracy of the data the great advantage of this technique is to obtain repeatable results of measurements because of the high level of automatism. Effects resulting from subjective influences like different measuring persons, accuracy of a number of different measurement devices etc. are excluded.

ACKNOWLEDGEMENTS

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