ANALYSIS OF THE INFORMATION CONTENT OF TERRESTRIAL LASERSCANNER POINT CLOUDS FOR THE AUTOMATIC DETERMINATION OF FOREST INVENTORY PARAMETERS

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ABSTRACT

Terrestrial laserscanners find rapidly growing interest in photogrammetry as efficient tools for fast and reliable 3D point cloud data acquisition. They have opened a wide range of application fields within a rather short period of time. Beyond interactive measurement in 3D point clouds, techniques for the automatic detection of objects and the determination of geometric parameters form a high priority research issue. The quality of 3D point clouds generated by laserscanners and the automation potential make terrestrial laserscanning also an interesting tool for forest inventory.

The paper will first review current laserscanner systems from a technological point of view and discuss different scanner technologies and system parameters regarding their suitability for forestry applications. In the second part of the paper, results of a pilot study on the applicability of terrestrial laserscanners in forest inventory tasks will be presented. The study concentrates on the automatic detection of trees and the subsequent determination of tree height and breast height diameter.

Reliability and precision of techniques for automatic point cloud processing were analysed based on scans of a test region in a Saxonian mixed forest. In the pilot study, which represents an early stage of software development, more than 95% of the trees in a test region could be detected correctly. Tree heights could be determined with a precision of 80 cm, and breast height diameters could be determined with a precision of less than 1.5 cm.

Keywords: Terrestrial laserscanning, forest inventory, automation

1 INTRODUCTION

Forest inventory and forest management and planning tasks require, beyond other parameters, the measurement of some parameters describing the geometry of trees. In the most simple case, these parameters are limited to the tree height and breast height diameter. In some tasks, many more geometry parameters, such as height-diameter profiles, ovality of the stem, open stem height, damages or branch diameters are required. As a full area coverage inventory is usually not possible, inventory schemes based on data acquisition in plots and statistical extrapolation schemes have been developed.

Terrestrial laserscanning, combined with automatic data processing tools, may depict a rather interesting tool to facilitate the data acquisition for tree geometry parameters in larger plots. Several studies on the applicability of terrestrial laserscanners in forest inventory tasks have been published: (Simonse et al., 2003) use a 2D Hough transform to detect trees in point clouds and to determine breast height diameters after height reduction to the digital terrain model. This approach is extended to the determination of diameters in different heights by (Aschoff/Spiecker, 2004). (Gorte/Winterhalder, 2004) and (Gorte/Pfeifer, 2004) generate tree topology skeletons by projecting point clouds into a voxel space, where stems and major branches are extracted by morphology operations using 3D structure elements and connectivity analysis. (Pfeifer/Winterhalder, 2004) model the stem and some major branches of a tree by a sequence of cylinders fitted into the point cloud. (Thies/Spiecker 2004) show the results of a pilot study based on the works mentioned above. They report a relatively low rate of only 22% of the trees detected in single scans and 52% detection rate in multiple scans. While the stem position could be determined at rather high precision, breast height diameters showed a standard deviation of 3.5 cm, obtained from a comparison of laserscanner data processing results with conventional calliper measurements. The standard deviation of tree height determination was 5.6 meters and thus not satisfactory.

The goal of the study presented here is to test the precision and reliability potential of terrestrial laserscanner data processing schemes, which were developed originally for building documentation and facility management tasks, in forest inventory applications. The paper will first give a short overview on the technology and performance parameters of different types of terrestrial laserscanners. Chapter 3 will discuss the techniques used for automatic geometry parameter extraction from laserscanner point clouds. The results of a pilot study in a Saxonian mixed forest will be presented and discussed in chapter 4.

Figure 1: Laserscanner data section with five trees (2D projection at reduced resolution)

2 TERRESTRIAL LASERSCANNER INSTRUMENTS

Terrestrial laserscanners have become rather popular in geodesy and photogrammetry in the last five years. In fact, they can be considered a bridge between engineering geodesy and photogrammetry, combining tachymeter-like instrument design principles with data processing methods mostly derived from photogrammetric techniques. Laserscanners generate 3D point clouds representing an object surface. These 3D point clouds can be considered an end product or a basis for generating value added structured data products.

Laserscanner instruments, which are currently on the market, can be categorized after different criteria:

- Field of view: Many laserscanners offer a panoramic 360° horizontal field of view with a vertical opening angle between 80° and 135°. Fewer scanners offer a camera-like limited field of view.
- Range measurement principle: Most scanners use time-of flight measurement for range determination. The precision of time-of-flight measurement is usually limited to 5-10 mm. Some scanners use phase modulation techniques to achieve a higher range measurement precision of 1-3 mm. This principle comes with the disadvantage of a limited range due to wave number ambiguities. The highest precision, however at a rather limited range, can be achieved by scanners following the triangulation principle with a laser source and a receiver delivering an angular measurement arranged at a fixed base.
- Beam deflection principle: Laserscanners scan an object surface sequentially, with the beam deflected by galvanometric mirrors, polygon wheels, rotating elliptical mirrors, rotation of the instrument or combinations thereof.

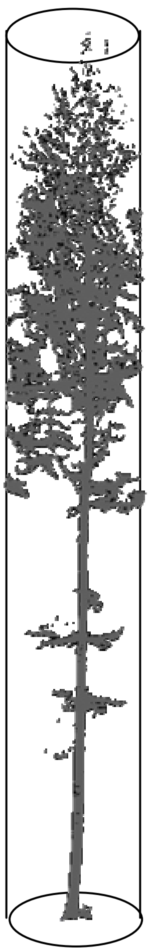
Further differentiating factors may be the maximum range (between less than 20 meters for triangulation scanners and more than 1000 meters for some time-of-flight scanners) or the data rate (2'000 … 625'000 points per second with current instruments). Some instruments offer an integrated camera, allowing for the acquisition of high resolution surface texture and for the fusion of point cloud and image data processing.

A laserscanner to be used in forest inventory applications should have a maximum range of 20 … 100 meters and a data rate of at least 10'000 points per second. For flexibility in data acquisition, it should offer a panoramic field of view. The range measurement precision should be better than 10 mm. Special consideration has to be paid to problems caused by multiple echoes obtained from a single pulse, such as from twigs partially occluding each other: All range measurement principles may produce ghost points in these cases (Böhler/Marbs, 2004), which have to be considered in the development of data processing schemes.

3 DATA PROCESSING METHODS

Terrestrial laserscanners may be used as 3D point cloud generation tools with the goal of interactive measurement of relevant parameters in the point cloud, thus shifting the interpretation task from the field to the office. Much more interesting from an economic point of view, however, are techniques for automatic derivation of task-relevant parameters from point clouds. In the following, we will show a technique for point cloud segmentation with the goal of detecting and extracting stems, the determination of tree heights and the determination of breast height diameters and diameter-height profiles. The techniques presented here represent only an early stage of development, mainly documenting the applicability of techniques, which were originally developed for other purposes (Bienert, 2006; Scheller, 2006), to forest inventory tasks. Task-specific knowledge can be used in the parameterization of the methods in order to optimize the success rates.

3.1 Detection of trees



The tree detection process is based on the analysis of horizontal slices in the laserscanner data. A slice with a thickness *d* is cut out of the point cloud at a height of 1.30 meter above the ground. In rough terrain the digital terrain model can be obtained from percentile filtering of the point cloud. A structure element of a size *s* is moved over the X/Y-projection of the points in the slice in a morphology-like technique, defining clusters with more than a preset number of *n* points as an object and separating objects which are more than *s/2* cm apart.

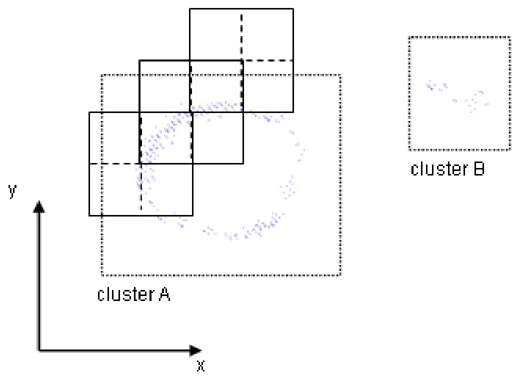


Figure 2: Reduced 2D representation of a scanned tree and vertical cylinder, cluster search procedure

In a next step, a circle is fit into the cluster. The cluster is accepted as a tree if the radius r of the circle is above a threshold r_{min} and if the standard deviation σ of the cluster points to the circle is smaller than a preset maximum σ_{max}. The center of the circle defines the *(X,Y)* coordinate of a detected tree. The technique can be applied to multiple scan data delivering full circles as well as to single scan data delivering ca. 160° sectors of tree cross sections.

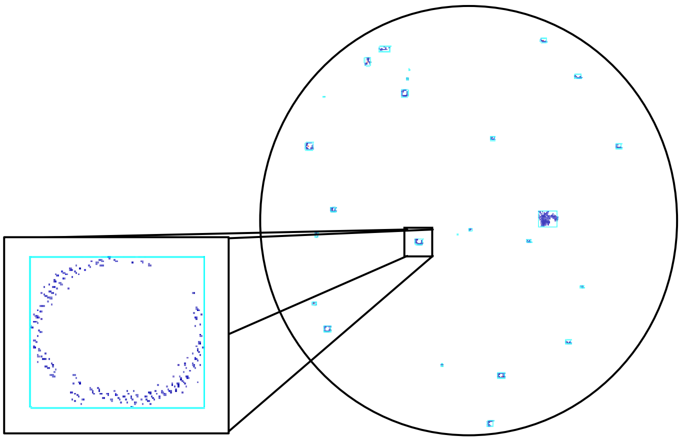


Figure 3: Tree detection

3.2 Tree height determination

The tree height is defined as the height difference between the highest point of the point cloud of a tree and the terrain model, accepting that the highest point of the cloud may not always represent the top of the tree and that a better definition of the representative terrain model point has to be used in rugged terrain. The point representing the terrain model is defined as the lowest point in a vertical cylinder of a radius r_1 around the tree center coordinates *(X,Y)*. The tree top is defined as the highest point in a vertical cylinder of a radius r_2 around the tree center coordinates (Figure 4), with $r_1 \leq r_2$.

3.3 Diameter determination

The breast height diameter is determined by cutting a slice of thickness d in a height of 1.30 meter above the representative terrain model point. An adjusting circle is fit into the 2D projection of the points of the slice. As a result, we obtain the breast height diameter, the standard deviation of unit weight and the standard deviation of the diameter. Proceeding with the technique, stem diameters in arbitrary height and stem diameter height profiles can be determined straightforwardly.

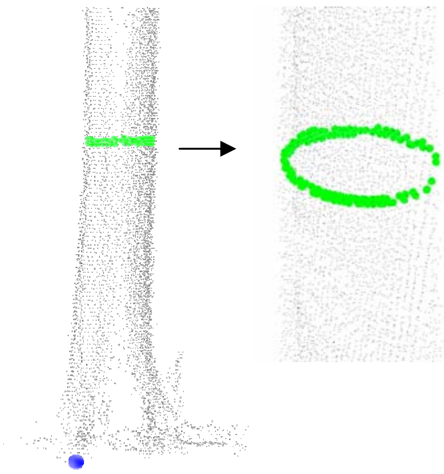


Figure 4: Breast height circle

4 PRACTICAL RESULTS

The practical data for the pilot study on the applicability, precision and reliability of the methods shown in chapter 3 were acquired with a terrestrial laserscanner *Riegl LMS Z420i*. The test site was a plot of mixed forest in Saxony. The plot contained a total of 14 trees and was recorded from two laserscanner positions.

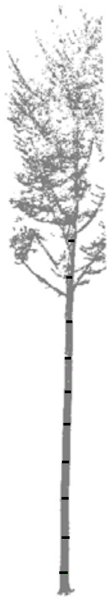
All trees in the plot could be detected successfully (Figure 3). In a second test site, 32 out of 33 trees could be detected. The results of breast height diameter determination for the detected trees of the plot are listed in Table 1. The standard deviation of unit weight was 1.4 cm. The interior standard deviation of tree diameter determination, obtained from the circle fit procedure, was 0.5 cm. The RMS of the differences between tree parameters derived from laserscanner data and reference measurements with a tree calliper was 1.5 cm. On average, the diameter is determined slightly too high. This can be explained by the laserscanner spot diameter and could be compensated in the future by a distance and beam divergence dependent correction term, thus further improving the precision of tree diameter determination.

Table 1: Differences between breast height diameter from laserscanner data and reference measurements

	diameter [cm]
minimum deviation	-0.8
maximum deviation	3.3
arithmetic mean	0.9
RMS	1.5

Tree height reference measurements were available for only two trees of the plot. The height of the remaining trees was determined by an extrapolation technique based on the breast height diameter, as usual in today's forest inventory. The height differences of the two trees with reference measurements were 0.22m and 1.47m, respectively. Here it is doubtful if the conventional hand-held-tachymeter based measurement can be considered a reference. In a second test plot, reference heights of four trees were determined by a tachymeter. Here the comparison delivered an RMS tree height error of 80 cm.

In addition to the determination of breast height diameter, a height-diameter diagram was determined for one tree by repeating the diameter determination in regular height intervals (Table 2).



Height [m]	Diameter [cm]
1.30	19.5
3.30	18.6
5.30	17.9
7.30	17.2
9.30	16.5
11.30	16.0
13.30	15.4
15.30	14.7
17.30	12.9
19.30	10.6

Figure 5 & Table 2: Beech tree with 10 diameters in 2m height intervals, height-diameter diagram

5 DISCUSSION & CONCLUSION

Although the results presented here are only the outcome of a pilot study, which can be improved in many aspects, they show the application potential of terrestrial laserscanner in forest inventory and forest management tasks. Terrestrial laserscanning, combined with automatic data processing tools, may bridge the gap between conventional inventory techniques and airborne laserscanning. While conventional inventory techniques are based on small plots and have to rely on statistical extrapolation techniques, airborne laserscanning acquires full area data, but is limited to the determination of tree parameters, which can be derived from terrain and crown height model by applying suitable models. Terrestrial laserscanning has the potential of delivering reliable and precise information on geometric parameters of trees in larger plots.

The techniques shown in chapter 3 and 4 can be further improved by using multiple layer techniques to optimize the tree detection process and by slicing the cylinders used for tree height determination in order to avoid points of neighbouring trees affecting height determination. In addition to the parameters discussed in chapter 3, further parameters such as ovality of the stem, structure and damages of the bark, open stem height, tree topology, branch angles and diameters can be determined by an extension of the techniques. Using shape and texture information derived from laserscanner data in combination with classification techniques applied to images of an integrated camera, an automatic tree species recognition may be envisaged. Due to the character of an automated, objective measurement technique, the method is also well suited for change detection tasks in multi-temporal scans.

A very interesting option for the reduction of the effort of data acquisition is provided by novel range cameras, which will soon be commercially available. Range cameras (e.g. Oggier et al., 2003) are based on CMOS sensors, where each pixel can be considered an electro-optical distance meter. They deliver a greyscale image plus a range image with a distance measurement for each pixel. Range cameras are very compact, they can be used in a hand-held manner and their price will be much lower than the price of a terrestrial laserscanner system. Current cameras show several limitations such as a sensor format of only up to 176x144 pixels, a maximum range of 7.5 meters and a distance precision of about 1%. Once these limitations are overcome, range cameras could well be used for fast and flexible data acquisition in forestry tasks.

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