APPLICATION OF TERRESTRIAL LASER SCANNERS FOR THE DETERMINATION OF FOREST INVENTORY PARAMETERS

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ABSTRACT:

The paper presents results from several pilot studies on the application of terrestrial laser scanning in forest inventory tasks with the goal of automatically determining inventory-relevant tree parameters. The basic data sets have been provided using two different terrestrial laser scanners, one based on the time of flight distance measuring technique and the other one based on phase measurement technology. The first part of the paper briefly introduces the two instruments and compares them regarding their suitability for forestry applications. Based on a large number of mixed forest plots, accuracy and handling of the laser scanners were tested. Furthermore a method for the automatic detection of the approximate position of trees will be presented. Co-ordinates of the approximate positions and the number of trees in the plots are a result of the first algorithm. In a second step all located trees will be separated and the DBH (diameter of a tree in 1.3m), the profiles along the stem and their height will be determined automatically. Finally the results of analysis of some plots are presented.

1. INTRODUCTION

Besides airborne laser scanning, terrestrial laser scanning has become more important in forestry in the last few years. The application of terrestrial laser scanners provides a fast, efficient and automatic tool for the determination of basic inventory parameters such as the number and position of trees, diameter at breast height (DBH), tree height as well as stem and crown shape parameters.

A good overview is given by Aschoff/Spieker (2004) and Aschoff et al. (2004). They use a standard pattern recognition method with a Hough-transformation to detect the trees. Aschoff et al. (2004) determine the diameter of a tree as an adjusted circle and adjusted ellipse. By using the circle fitting algorithm better results are produced concerning their arithmetic mean and their maximum in comparison to the ellipse fitting.

In the following section, we will first compare two different laser scanner systems regarding their potential and discuss scan modes for forest inventory geometry data acquisition. Chapter 3 will briefly address algorithms for 3D point cloud segmentation and automatic tree parameter extraction, which are shown in more detail in (Bienert et al., 2006). Some results obtained in a number of pilot studies will be presented in chapter 4.

2. LASERSCANNER SYSTEMS AND SCAN MODES

This chapter introduces the two laser scanners, which were used for the recording of mixed forest plots. (Thies et al., 2004) distinguishes two different ways for measuring forest plots: Single scan mode and multiple scan mode. In the single scan mode the scanner measures from only one position, which is placed in the centre of the plot. The multiple-scan mode comprises typically three positions, placed outside of the plot (Figure 1).
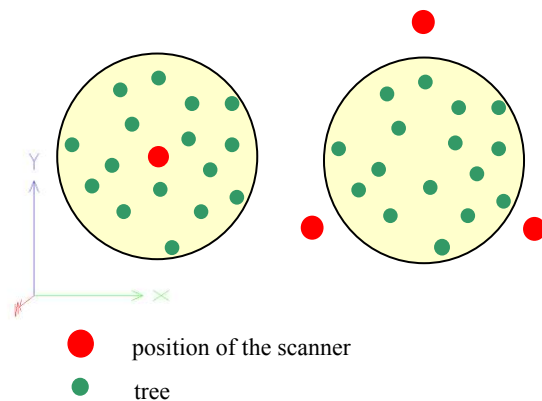

Figure 1. Single scan mode and multiple scan mode

Two plots in a mixed saxonian forest were scanned in a multiple scan mode by using the Riegl LMS-Z420i (Figure 2b). All points of each scan have their own co-ordinate system. By using retro reflective targets and cylinders the positions were registered. Furthermore some plots were scanned in an Austrian forest using the Faro LS 800 HE80 (Figure 2a) in a single scan mode. The technical data of both scanner systems are shown in Table 1.

The single scan mode allows a fast and easy recording of the trees, but occlusions of trees are unavoidable. Full spherical scanners, such as the LS 800 are suitable for this mode. With a panoramic view scanner (LMS-Z420i) the plot can only be scanned completely by more than one scan with tilting the scanner by 45° to the left and right side.

	Riegl LMS-Z420i	Faro LS 800 HE80
Laser Class	1	3b
Range finder	Time of flight	Phase shift
Field of view	360° x 80°	360° x 320°
Measurement range	2m – 800m	up to 80m
Accuracy	5-7 mm	3 mm
Points per second	12000	120000
Beam divergence	0.25 mrad	0.25 mrad
Weight	14.5 kg	14.5 kg
Speciality	W-LAN possible mountable camera	integrated PC

Table 1. Comparison between the two laser scanners

The level of detail is much higher in the multiple scan mode. However it is a very time-consuming process. Besides the necessity of distributing retro reflective targets and the transformation of the three scans to one co-ordinate system, the costs of setting up and re-installing of the scanner equipment occupies the most time.

Manual measured inventory parameters like distance and azimuth will be done from the centre point of the plot by generating a local polar co-ordinate system. The co-ordinate system of a single scan mode, where the scanner is placed above the centre point, is very similar to the polar co-ordinate system. An alignment of the zero line of the scanner to north enables the adoption of the scan angle as azimuth. By scanning in the multiple mode a transformation to the centre point must be done. A transformation of this point cloud to the centre point is possible by a tacheometer survey. Another way is the target signalization of the centre point, the north direction and the direction of the x-axis by defining a point 90° from the centre point - north line.
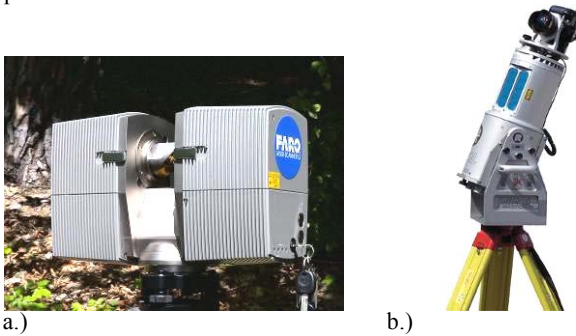

a.)   b.)
Figure 2. (a.) Faro LS 800 HE80 and (b.) Riegl LMS Z-420i

In a forest enviroment the scanner equipment can be carried in a rucksack as the plot of interest cannot usually be reached by car. The Faro Scanner's integrated PC is an important advantage since only a key and start button is required to start the scanning process. To start the scan process with the Riegl scanner a laptop is required. Both systems allow the registration of scans with tie points (Figure 3). The tie points of the Riegl system are cylindrical and flat retro reflectors in different sizes. To register the scans of the Faro scanner spheres with a diameter of 15 cm are needed.
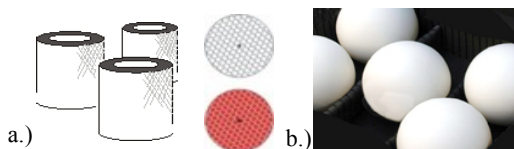

a.)   b.)
Figure 3. tie points from Riegl (a.) and Faro (b.)

3. ALGORITHMS

3.1 Preprocessing

To use the scanner data in an external program it is necessary to export the point cloud in a readable format. The easiest way is to convert the scanner raw data into an ASCII file with x-, y- and z- co-ordinates. For faster data access, a C++ program transforms the ASCII file into a binary format. The next step involves the filtering of the point cloud. All points inside the area of interest will be extracted. The next step is to limit the border of the point cloud.

A typical measurement area is a cylinder of 15m radius. All points outside this radius are filtered out by the program. The filtered point cloud is the base for the next steps.

Typically plot radius are 12 m and 15 m are used. A cylinder with this size is placed in the origin of the plot and all points inside of the cylinder are considered valid.

3.2 Digital terrain model (DTM)

After the pre-processing the next step is generating the DTM. Point clouds produced by terrestrial laser scanners include much more ground points than airborne lidar datasets (Stoker et al., 2006). To find out the ground points the program uses a density allocation along the z-axis of one DTM patch (Figure 4). With this technique it is possible to extract the DTM without ghost points under the ground which are caused by the ambiguity of phase measurement technologies. Out of this data set the slope of the ground can be determined and also the lowest point of a tree. The lowest point is important for the height of the DBH.
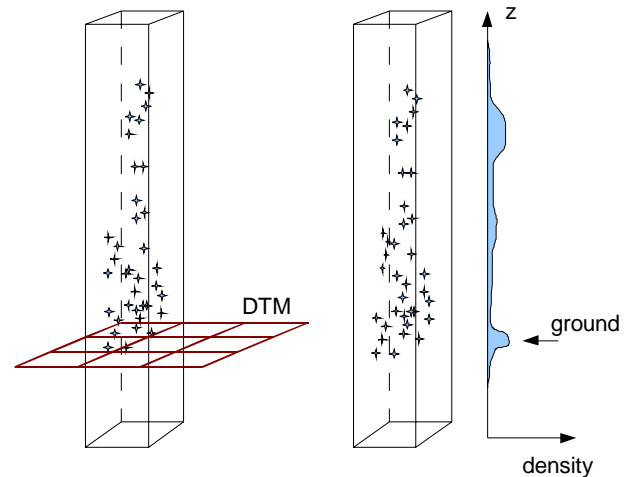

Figure 4. Density allocation along the z-axis of one DTM patch

3.3 Segmentation and classification of the trees

For detecting the trees a slice 1.30 m above the DTM with a thickness of 0.10 m is generated. Using the single-scan mode all trees in the slice are displayed as points in a 160 degree circular arc. A structure element moves over the slice in X/Y projection and searches point clusters with more than *n* points (Figure 5). Every cluster found defines an object. One object will be separated into two objects if the distance between one point and the nearest one is bigger than *s/2*. Thus the whole slice will be analyzed and spanned. (Scheller et al., 2006)
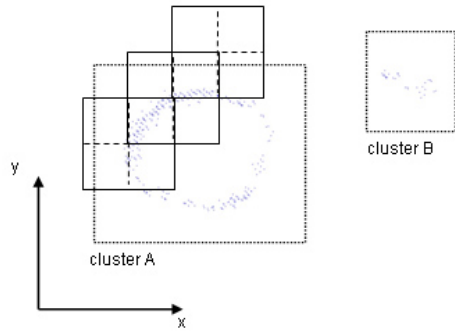
Figure 5. Structure element for the segmentation

To classify the objects as a tree or a shrub for example, all points of one cluster are used for calculating an adjusted circle. If the error of unit weight is smaller than a defined threshold and / or the DBH is bigger than the smallest DBH of interest the object is classified as a tree. Some clusters caused by branches or shrubs may also be classified as trees by virtue of points being arranged in a circle within the cluster. To avoid this incorrect classification another slice a few cm above is necessary. Using the results of two independent clusters, one on top of the other, the classification can be done reliably.

Figure 6 shows the detected objects. Green colored objects are classified as the trees and the red ones are the unclassified objects.
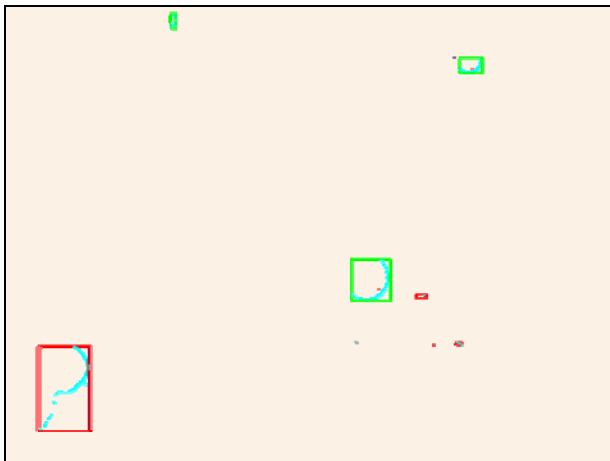

Figure 6. Detected and classified objects

3.4 Determination of the breast height diameter (DBH)

The breast height diameter (DBH) is defined as the diameter 1.3m above the point from the finished grade at the end of the trunk. Normally on flat terrain the lowest point next to the tree defines the basis for the breast height determination. But this method causes erroneous calculation on sloping terrain (red point in Figure 7). Therefore the slope of the terrain close to the trees will be utilized. Tree classification results in the approximate co-ordinates for the centre point and an approximate radius of the stem being produced. A cylinder with a radius d, placed at the centre point, selects all points of the tree. A DTM close to the trunk with a grid size of 20 cm is produced. Thereby the lowest point inside of each grid defines the grid centre point. These points are used for calculating an adjusted plane Σ (Kampmann et al., 2004). The vector with the highest slope (gradient g) will be derived by using the normal

vector of the plane. The outcome of this is a point on the real surface 20 cm next to the trunk (blue point in Figure 7).
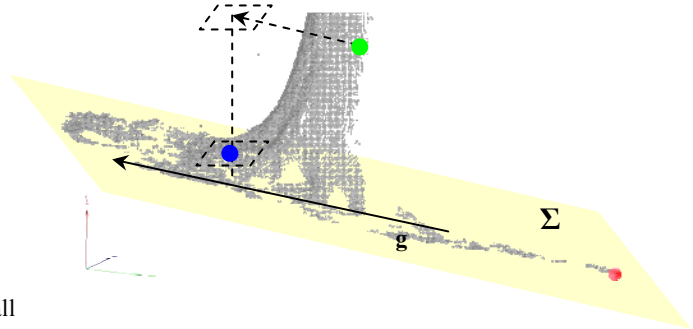

Figure 7. Defined points for breast height calculation

The z-value of the lowest point is used as a basis for the profile fitting along the stem using the same circle adjustment algorithm. Parameters of the profile, like interval and thickness are implemented as variable values. Starting with the position and size of the DBH, profiles at constant intervals Δz above and below the breast height profile are determined. The diameters of previous profiles are used to cut out the points for the next profile of the stem. The previous profiles are filtered and a threshold is added to guide how the points for the next profile are extracted. This acts like a sliding a cylinder up along the tree trunk following the profile centre points.

Figure 8. Profiles along the stem

3.5 Position, angle and tree height

The position of a tree is defined as the co-ordinates of the centre point of the DBH in right-hand system. If a single scan mode is used, it is necessary to align the zero line of the scanner to north. In multiple scan plots a transformation to the centre point should be done (chapter 2) to get the azimuth. If there is no alignment to north while scanning, the azimuth can be offset.

The tree height (Figure 9) is defined as the difference between the lowest point (base of the DBH) and the highest point inside of the cut cylinder.
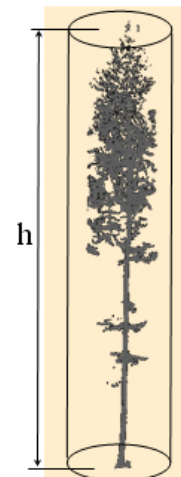

Figure 9. Tree height determination

4. RESULTS

4.1 Data analysis

The detection of trees inside the plot-radius must be a reliable process. A differentiation between detected objects which are trees and those which are not is critical. Detected objects designated as a tree when they are not are considered a type II error (Figure 10b). A type II error can be rectified in the following manner, by checking the viability of the DBH and the height of the tree. Trees which are not detected caused by occlusions or by failing the classification criteria, are considered type I errors (Figure 10a). These trees are excluded from the following process. Table 2 shows the spanned objects with the classification results.
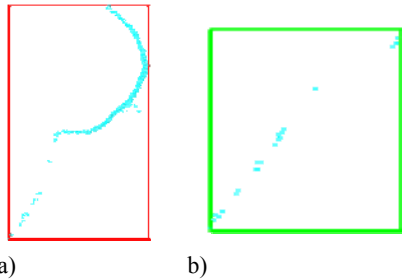

a)   b)

Figure 10a. non-classified tree – type I error
Figure 10b. shrub classified as a tree – type II error

	Plot 1	Plot 2	Plot 3	Plot 4
Number of trees	15	29	24	14
spanned objects	15	29	27	15
Detected trees	13	28	24	14
Type I error	2	1	0	0
Type II error	2	1	3	1

Table 2. Results of the classification

The reference DBH measurement in the plot was done with a tree caliper. The results between the DBH from the program and the reference measurement are listed in Table 3. The DBH of a tree where only a small part of the stem is visible, because of occlusion, could result in a smaller than realistic DBH as the reference value. To avoid this problem the circle fitting algorithm needs to have a minimum number of points, depending on the distance of the tree, the scan resolution and the thickness of the slice for filtering the DBH points.

diameter [cm]	Plot 1	Plot 2	Plot 3	Plot 4
arithmetic mean	-0.93	0.04	-0.96	0.93
standard deviation	1.23	1.39	2.47	1.21

Table 3. Differences between DBH from laser scanner data and calliper measurements

4.2 Processing time

The recording time of a plot depends on the selected scan mode. In multiple scan mode, the majority of time is spent distributing the reflective targets and relocating the scanner equipment to the next scan position. At least three tie points which are visible in all scans are needed in order to combine separate scans. Because of the occlusions caused by the standing trees, more targets (19) were used. The greater the number of tie points the greater the accuracy of the registration process. The targets were distributed inside and outside the plot, so the distances between the tie points was relatively large. The following table shows 4 plots with a radius of 15 m (plot1-plot3) and 12 m (plot 4). The data volume is the size of filtered plots as binary *.dat files.

	Plot 1	Plot 2	Plot 3	Plot 4
Scan mode	single-scan	single-scan	single-scan	multiple-scan
Scanner	Faro	Faro	Faro	Riegl
radius	15 m	15 m	15 m	12 m
Tree population	mixed forest	mostly spruce	mixed forest	beech
points	6651050	31769600	25657685	2363221
Data volume	35 MB	178 MB	205,8 MB	27.6 MB

Table 4. Characteristics of the plots

In addition to the fast data collection in the forest fast processing time is also desirable. The processing is divided into three parts. Firstly the binary scanner files will be converted to files with their own binary format to allow a faster processing. The next part includes the filtering, the DTM generation and the segmentation which is followed by the object classification. Only points inside the radius of interest are considered, so all other points will be filtered out (Figure 11). It is with this filtered point cloud that the DTM generation, the segmentation within the slice (1.30m above the terrain) and the object classification is done.
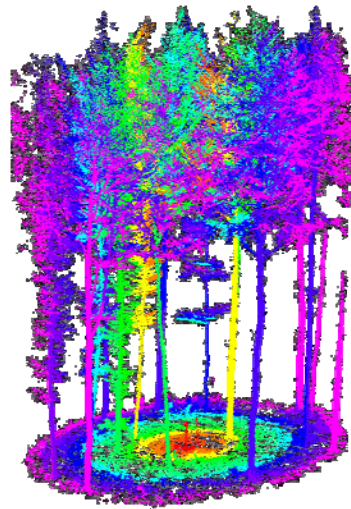

Figure 11. Filtered plot with 12 m radius

Finally the determination of the basic forest inventory parameters (distance, azimuth, DBH, profiles and tree height) are completed.
The displayed time in Table 5 was produced by an Intel Xeon CPU (2.4 GHz) with 1.0 GB RAM. The processing time for the segmentation and classification depends primarily on the number of points in the slice.

	Plot 1 [min:sec]	Plot 2 [min:sec]	Plot 3 [min:sec]	Plot 4 [min:sec]
data conversion (min/ppm)[1]	0:48 (0:15)	5:08 (0:17)	4:12 (0:16)	4:12* (2:00)*
Filtering, DTM, Segmentation and Classification (min/ppm)[1]	0:02 (~4:00)	0:07 (~4:00)	0:07 (~4:00)	0:01 (~3:00)
Inventory parameters (min/ppm)[1]	0:46 (0:15)	5:28 (0:18)	5:39 (0:22)	0:55 (0:23)
Absolute time	1:36	5:43	9:58	5:08

* 4 minutes are used for reading the ASCII file; excluding the time for conversion of binary *3dd to ASCII file

[1] – minutes per million points

Table 5. Time for data processing

5. CONCLUSION AND OUTLOOK

This paper presents an approach for the automatic determination of forest inventory parameters from laser scanner point clouds. Furthermore two laser scanners were introduced and compared concerning their applicability for forest applications.

Besides the type of laser scanner system used, the scan-mode is also important in terms of data processing. The data collection time in the forest is considerably faster using the single scan mode. The amount of detail is restricted on account of having only a single view position. The consequences of any resultant occlusions (caused by trees standing close to the laser scanner) are scan shadows which can at worst cause more distant trees not be detected.

The approach to the segmentation of trees is presented as follows. The algorithm uses a structure element for searching point clusters within a slice. To classify these clusters a preliminary circle fitting is done. If the required criteria are fulfilled the object is classified as a tree.

The DBH and the profiles along the stem are determined by fitting circles. An accuracy of the DBH and the centre point can be calculated based on adjustments to the fitted circle.

This work will continue, by improving the accuracy of the classification algorithm. Segmentation at multiple heights can be added to avoid incorrect classifications. Also a filter algorithm, for a more reliable profile fitting along the stem will be developed. Furthermore the tree height determination can be improved by considering point density inside the cylinder, and thus ghost points above the real tree will have no effect.

Overall the algorithms presented here allow a fast and efficient determination of forest inventory parameters. Also the volume of trees, which can only be determined on sawed trees, could be calculated by fitting a frustum.

6. ACKNOWLEDGEMENTS

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