FIRST EXPERIENCE IN THE APPLICATION OF LASERSCANNER DATA FOR THE ASSESSMENT OF VERTICAL AND HORIZONTAL FOREST STRUCTURES

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ABSTRACT

Airborne laserscanner systems are new devices for the assessment of forest stand attributes. Based on experiences with profiling laser systems, it is expected that laserscanners give exact height information on forest stands at reasonable cost and accuracy, which allows the derivation of different important stand attributes like number of trees, tree crowns, tree height, stand structure etc. The paper gives an overview of a research project on the application of airborne laserscanner data for forest inventory purposes. Within the field of assessment of forest stand attributes, the main emphasis is put on horizontal and vertical stand structures. Several approaches for the assessment of horizontal and vertical stand structures are presented. First results are presented and discussed.

1 INTRODUCTION

Small area forest inventory is typically carried out by using man power, aerial photo interpretation, photogrammetric measurements, growth models and questionnaires. However, the first three methods are time intensive, laborious and expensive. Typically about 50-60% of the overall cost is used for data acquisition and recording. The application of remote sensing in the estimation of forest stand attributes, such as stem volume, height, age and stand structure has been intensively investigated during the last years for both the large area and small area forest inventory. Recently much attention is paid to optical data from satellites as an appropriate tool to assess and monitor forest attributes at a small scale with reasonable accuracy, while a new generation of very high resolution space born optical sensor systems is expected to be powerful for small area inventories.

Considering the state of the art for 3-D measurements using digital photogrammetry and satellite stereoscopy, the extraction of precise 3-D data for forest information is possible, but is more or less restricted to the surface of the vegetation cover. It has been found that forest attributes such as tree height, tree volume, vertical stand structure and understorey can be detected by means of profiling laserscanner measurements (Nelson et al, 1988; Nilsson 1996) as well as from airborne profiling radar data (Hyyppä and Hallikainen 1996). These attributes are of major interest within forest inventories. Together with other information such as tree species and age, most of the end user requirements can be met. According to this the main objectives of this project are to develop, explore and test methods to use laserscanner data for the assessment of forest attributes like:

- timber volume
- tree height
- stand density and
- vertical and horizontal stand structure.

So far laser scanning was not well known to communities dealing with vegetation mapping, only lately laser scanner technique was introduced to a wider community. Currently airborne laser scanner systems are frequently and successfully used mainly for the generation of Digital Elevation Models in the field of land survey. The extraction of 3-D information from data over forests to derive forest parameters is a rather new area of application.

2 AIMS AND OBJECTIVES

The aim of this study is the use of airborne laserscanner data for assessment of forest inventory parameters including ecological measures on forest structures. This is done by developing new methods for extraction and visualisation of

information from laserscanner data as well as by testing present algorithms. Within forest inventory the main interest is focused on automatic measurement of tree height for different tree species and automatic delineation of crowns, because from crown diameter and tree height important inventory parameters can be derived. With respect to ecological parameters the detection of vertical and horizontal structures as well as the development of crown structure models is of importance.
In order to combine spectral information with the information derived from laserscanner data, datasets from high resolution satellites, like IKONOS, will be used. The integrative use of information from both systems will allow the extraction of information from two complementary data sources, which is important for the assessment of forest parameters.
The project is carried out by a consortium consisting of six main partners in four European countries and of some subcontractors associated to the main partners. It is funded by the European Commission, DG XII, under contract No. ENV4-CT98-0747.

3 TEST SITES

In order to cover different forest types and topographical situations, the test sites have been selected in pure coniferous forests, in mixed forests and in pure broadleafed forests. Topographic ranges from flat areas in the upper Rhine plain and in the boreal zone in Finland to alpine regions in Austria have been covered. The test sites in Finland are situated in flat to slightly rough terrain, dominated by Norway spruce (*Picea abies*) and Pine (*Pinus silvestris*). The stands are rather open and are characterised by dense ground vegetation. The test sites in Germany are situated in the upper Rhine plain and in the Black Forest. The stands in the plain are dominated by Oak (*Quercus sp.)* with multi-storey vegetation layers, whereas the stands in the Black Forest test site consist of nearly 100% Norway spruce (*Picea abies*) with a single storey on slight to heavy slopes. Compared to the test sites in Finland, the stands are closed.
The test sites of the Austrian partner are located in Styria and in a part of the Alps called Hohentauern. In Styria the test stands consist of a mixture of Spruce and Beech (*Fagus sylvatica*) and the relief is rather smooth, whereas in the alpine test site pure spruce stands on very rough terrain serve as objects for the research.
The different characteristics of stands and terrain conditions will allow to transfer the results to average forest situations in middle and northern Europe.

4 DATA SOURCES AND PREPROCESSING

4.1 Laserscanner data

The laser scanning system consist of four components:
- The laserscanner itself (see table of parameters below)
- a module for the recording of flight parameters (position above ground, altitude, pitch, roll, shift.)
- a recording and data storage unit and
- a video camera system

Sensor type	pulse modulated laser radar
Range	50 - 1.000 m
Scanning principle	fibre optic line scanner
Measurement principle	run-time measurement
Wavelength of laser	1,5 µm
Laser pulse rate	80.000 Hz
Classification of laser device	Class 1 by EN60825 (eye-safe)
Scanning frequency	600 Hz
Scan angle = field of view	+/- 7° off nadir
Number of measurements per scan (= number of glass fibres)	127
Swath width (at a height above terrain of 1.000m)	250 m
Accuracy of a single distance measurement	< 0,12 m
Resolution of a distance measurement	< 0,06 m
Accuracy of the derived DEM in x/y	< 0,5 m
Accuracy of the derived DEM in z	< 0,1 m RMS

Table 1: System configuration of the laserscanner of TopoSys (after Lohr et al, 1997)

The precise geocoding of the data is provided by using the GPS/LINS (Laser Inertial Navigation System) data taken on board of the plane and GPS data from a ground station set up within the site for postprocessing.
Calculation of digital elevation models is based on the laser distance measurements. For each reflection the system provides the coordinate in the local geodetic coordinate system.

The resolution on the ground is determined by the configuration of the scanning device with its 127 scan lines. This results in different distances between the footprints (each of 30 cm in diameter at a flight height of 850 m): along the track the distance is 15 cm; across track, there is a gap of 1,5 to 1,9 m. As a consequence heights between these scan lines have to be interpolated.

The minimal distance in height for objects hit by the same laser pulse, which can be recognised by the measuring system, is 60 cm. This calls uncertainties for ground measurements due to the fact that any object situated less than 60 cm above ground, reflecting parts of the same laser pulse, makes it impossible to register the reflection from the ground. This is because the two reflected impulses follow up to fast. Additionally, corrections of the datasets have to be performed for signals absorbed by the surface or reflected in directions opposite to the sensor (like on the calm surface of a lake), or where disturbances in the electronic signal processing cause peaks or black spots within the dataset. As long as such areas remain small, they can be corrected with good results. Under standard conditions, the density of reflections measured is about 3-4 per m².

The system of TopoSys allows two modes of measurements: first-pulse and last-pulse. This is a consequence of the measuring principle, recording the run-time of the laser pulses off the system and back. First-pulse mode records the first reflection of a single laser pulse, last-pulse mode records the last reflection. This differentiation means that in first-pulse mode the surface of vegetation is registered whereas in last-pulse mode the laser beam penetrates the vegetation cover.

4.2 Laser campaigns

The laser campaigns were carried out by the TopoSys enterprise. All test sites (with small exceptions) were flown in both modes. For mixed stands and broadleafed stands, the flight in last-pulse mode was carried out in spring before the leaves develop. Over coniferous stands the data take was carried out in both modes at one date. In Finland, the data were recorded in September 1998, for the other test sites the flights took place in Spring 1999 and August 1999.

4.3 Reference data

For all test sites there exist reference data on stand-wise basis for tree species proportions, timber volume, basal area and mean tree height. For most of the test sites single tree measurements have been carried out, recording tree species, geoposition, height, crown length, basal area and breast height diameter. For some test sites CIR-aerial photographs are available.

4.4 Processing of the Laserscanner data

The laserscanner data have been delivered to the partners as binary files. For further processing with standard image processing software, they have been transformed into raster images. This was done in three steps, using the software *ERMapper 6.1*:

1. Transformation from binary to ASCII (XYZ); applying a mask with the coordinates of the test stands measured for ground-truth data.
2. Generation of a triangular irregular network (TIN).
3. Rastering of this TIN with selectable pixel size. For the results described in this paper this has been processed for a pixel size of 0,5*0,5m, which is a good approximation of the above mentioned ground resolution of four reflections per m².

5 METHODS FOR THE ASSESSMENT OF FOREST STRUCTURES

The structures of forest stands are divided into two major classes: horizontal structures and vertical structures.

The major elements of the horizontal structure of a forest stand are:

- its boundaries

- the outlines of crowns
- The height of single trees and the average height of a stand.
- the distribution of single trees on a certain area (e.g. the presence or absence of a planting scheme in younger stands)

5.1 Horizontal Structures

For the description of horizontal structures a basic element is the single tree crown. Therefore in the first step the main interest of this study is focused on the identification of single tree crowns.

For the delineation of single tree crowns the study starts with the thesis that every local maximum in the grey values of rastered laserscanner data represents a crown tip or at least an area a crown tip is supposed to be located in. As we know from the configuration of the laserscanner system with its gaps between the scan-lines in flight direction, it is a matter of chance for a single laser pulse to hit a crown tip.

For the delineation of crowns two main approaches are available:

5.1.1 Delineation by means of contour lines semi-automatically created by processing the raster datasets.

A set of contour lines is created from a raster dataset showing a forest stand. A polygon that encloses no other polygon can be supposed to enclose the area near the position of the tip of a tree. An automatic extraction of such polygons is supposed to deliver an approximated map of the inner tree crowns and as a derivation the position of the trees which allows for an automatic counting of trees. The biggest polygon that is created around a local maximum of grey values and does not enclose a second local maximum is supposed to give the outline of a full single tree crown. This approximation depends on two variables: the entry level for the creation of contour lines within the given grey values, and the vertical step width of the contouring. The setting of the threshold is an interactive process.

5.1.2 Delineation of crowns by a vector based algorithm

In contrast to the above presented method, this approach is no implementation of standard tools of image processing software, but an adaptation of an algorithm originally developed for the identification and delineation of vessels on cross-sections of oak wood.
This algorithm starts from a randomly selected local maximum and creates eight radiuses. Following each radius, it determines the boundary of a crown by detecting the point where the slope either changes direction upwards or reaches nadir direction due to the presence of a gap in the canopy. These eight points are then connected by a line that is created in a knowledge based way, taking into account the average curvature of the outlines of the crowns in the image that is processed.
The adaptation of this algorithm from its original object, the wood vessels, to the laserscanner images of forests has just started. The programming will be done in a way that the routines developed will be used later as plug-ins within the *ERMapper* software package.

5.2 Vertical structures

The laserscanner system provides, depending on the recording mode and on the density of the forest, a certain amount of signals reflected from the forest floor. Obviously, if the system works in last pulse mode and a broadleafed forest in winter condition is scanned, the majority of signals is from the ground. But also in first-pulse mode and under summer conditions, the system delivers enough signals from objects beneath the upper crown surface. This allows the assessment of information on the vertical structure of stands.
A first approach to an assessment of the different storeys of a stand is to plot the position of laser signals in a dot graph with the height as x-axis and either the eastings or the northings as y-axis. This gives a elevation plot viewed from the South or the East respectively. The distribution of the dots representing single laser signals represents the different storeys present in a stand.
Based on this approach the percentage of signals representing the different storeys can be calculated to derive statistical evidence about the vertical structure of stands.

5.3 Assessment of single tree height and average stand height

In coniferous stands, most often the tree top has a surface of less than 25 cm². Compared to this, broadleafed trees in summer conditions provide a better chance for a signal reflection representing the maximum in height. But broadleafed

stands cause other uncertainties. A single crown may have several local maxima, resulting from different major branches within the crown.
Taking into account these restrictions, is a matter of chance to identify one top for a single tree from a set of laser signals or a rastered dataset.

One approach to assess the dominant height of a stand from a rastered laserscanner dataset is to record the height of signals being local maxima in the laser dataset, subtract the average value of ground height in their neighbourhood and to compare their values with tree heights measured from the ground. Regarding broadleafed stands with multi-storey structure, this will work with reasonable accuracy only for trees being part of the upper storey of the stand. In single storeyed stands it gives a figure for the accuracy of the height measurement from laserscanner data.

6 RESULTS

6.1 Assessment of horizontal structures

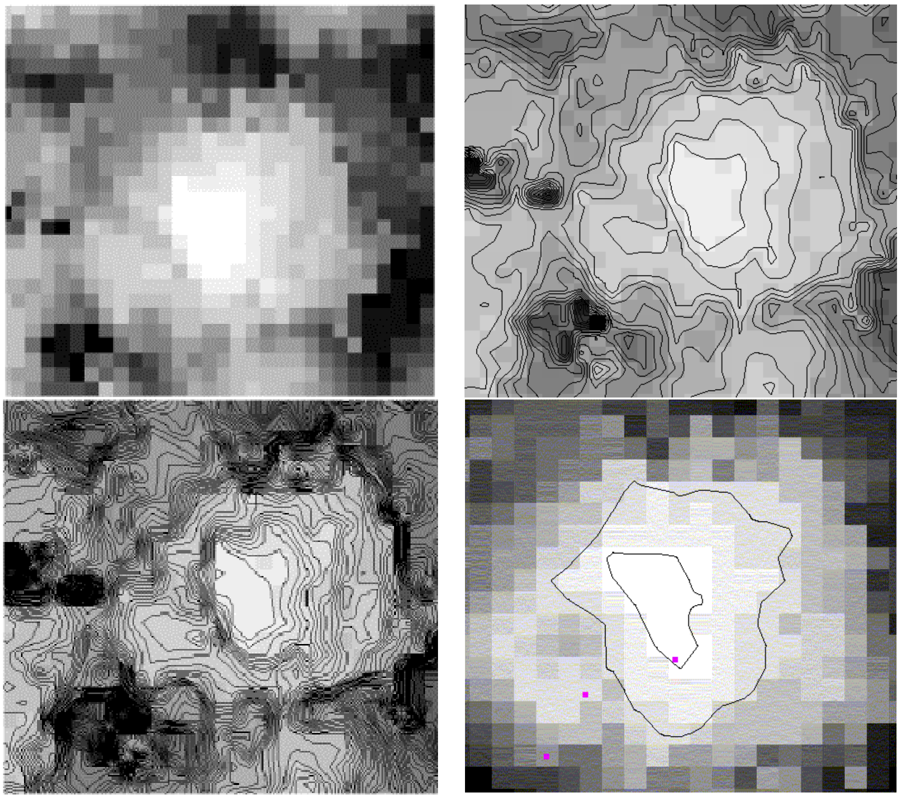

Figure 2: **Upper left:** Raster dataset showing one dominant Hornbeam (*Carpinus betulus*) crown in a broadleafed stand in the Rhine plain test-site. **Upper right:** Contour lines with a vertical distance of 100 cm. **Lower left:** Contour lines with a vertical distance of 25 cm. **Lower right:** Selected contour lines. Magenta dots: positions of stems.

The figures above show how contour lines generated with *ERMApper* image processing software can be used for the delineation of crowns from rastered laserscanner data. The step width between the contour lines is a major criterion for the success of this method, together with the starting height. In the lower right image two contour lines have been identified: the inner one enclosing a rather homogeneous cluster of grey values representing the top of this Hornbeam crown, and the outer one being the last contour line around this single maximum. The next lower contour line already enclosed a second local maximum and therefore was not selected.
The magenta spots are the positions of stems measured with survey methods in the field. In this figure one stem position is located within the area of the crown top. The position of the stem within the inner crown area is to some extent a matter of verticality of the stems, which again differs significantly between coniferous and broadleafed stands. First calculations proved good results in the delineation of crowns by contour lines , but further studies have to be applied to

secure the results. One approach will then be to calculate the geometric centre of gravity from the inner contour lines and comparing its position to the position of stems.

6.2 Assessment of vertical structure

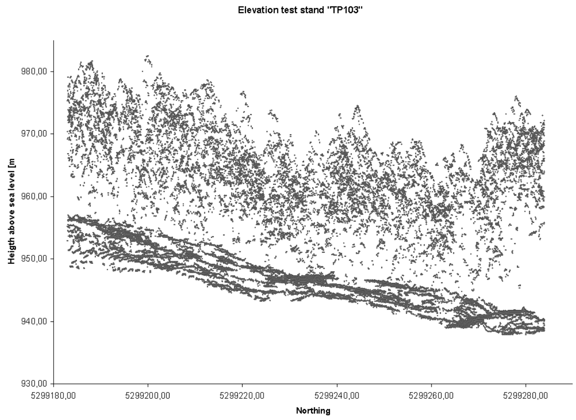

Figure 3: Elevation of a coniferous test stand at the test site "Schluchsee" in the Black Forest, Germany. View from the East.

This figure shows the elevation of a test stand on a medium slope in eastern as well as in northern direction. The slope in northern direction is very easily detectable from the decrease in height of the reflections in the lower part of the figure, whereas the slope in eastern direction can only be roughly estimated by interpretation of the vertical dimension of the lower stripe of reflections. The typical shape of coniferous trees can be easily detected in the upper part of the figure.

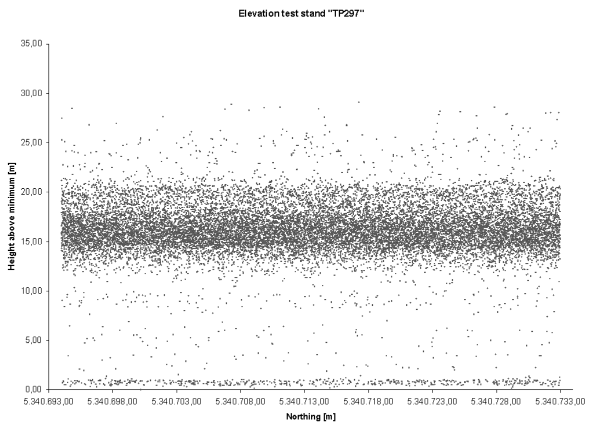

Figure 4: Elevation of a broadleafed stand at the test site "Weisweil" in the Upper Rhine plain, Germany. View from the East.

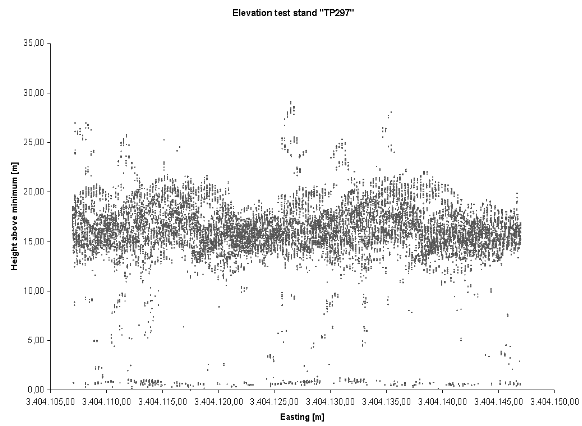

Figure 5: Elevation of a broadleafed stand at the test site "Weisweil" in the Upper Rhine plain, Germany. View from the South.

Looking at these two figures, it is obvious that this stand is growing on almost flat terrain. The crown storey of this stand appears to be very homogeneous regarding vertical dimension and height. Due to the procedure of setting the zero value on the lowest reflection occurring within the dataset, we see the ground reflections appear in a height of some meters above zero. This can be easily corrected in future steps of processing the data. Another aspect is the fact that the direction of view and the direction of the scanner flight influence the distribution of the signals plotted.
Nevertheless, according to the visibility of different vegetation storeys, it will be possible to derive measures which characterise the vertical structure of stands.

6.3 Assessment of single tree heights

Height from laserscanner	Height measured from the ground	Difference
17,00	7,75	9,25
17,00	19,00	-2,00
15,00	14,75	0,25
15,00	16,75	-1,75
15,00	16,75	-1,75
14,00	16,00	-2,00
15,00	18,00	-3,00
14,00	17,75	-3,75
15,00	17,00	-2,00
14,00	13,00	1,00
13,00	11,75	1,25
15,00	16,75	-1,75
16,00	16,50	-0,50
17,00	22,25	-5,25
15,00	18,25	-3,25
15,00	18,25	-3,25
14,00	18,50	-4,50
15,00	17,00	-2,00
14,00	17,75	-3,75
14,00	17,00	-3,00
16,00	17,75	-1,75
19,00	23,25	-4,25
18,00	13,25	4,75
19,00	21,25	-2,25
15,00	16,75	-1,75
16,00	10,00	6,00
19,00	20,25	-1,25
19,00	17,25	1,75
17,00	18,00	-1,00
	Average	**-1,09**

Table 2: Height measurements from a broadleafed stand, testsite "Weisweil".

The table indicates that in general the laserscanner underestimates the height of the trees measured from the ground. The average underestimation is 1.09 m. Regarding this value, it has to be taken into account that the average accuracy for the height measurements from the ground is in the range of 0.5 to 1 m. Nevertheless the tendency of underestimation by the laserscanner can be detected. This was also documented by NILSSON (1996).

7 CONCLUSIONS

The use of laserscanner data for the assessment of forest stand attributes is a fairly new topic for the communities dealing with forest inventory on the one hand and with laser application for the generation of digital surface models on the other. Bringing these two fields together allows the development of new approaches, especially for assessing stand structure in horizontal and vertical dimensions.

The first results presented are promising. It is possible to identify single crowns from the laserscanner data which means that at least the number of trees within a stand can be calculated. The first steps towards an automatic delineation of crowns are provided. Also first steps towards an assessment of vertical forest structures have been carried out. It is possible to derive statistical evidence about vertical structures of stands as well as information about the height of single trees or groups of trees from the laserscanner data.

For the assessment of tree height and the counting with high precision two conditions have to be fulfilled: the delineation of crowns at reasonable accuracy and the availability of a precise surface model of the forest floor.

For the latter aspect, other working groups within the project have already achieved promising results.

8 FUTURE ASPECTS

The future research will be focused on the development of automatic or semi-automatic routines for delineation of crowns and assessing vertical stand structures, which can be implemented into common image processing software like *ERMapper*.

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