

LASER SCANNING FOR IDENTIFICATION OF FOREST STRUCTURES IN THE BAVARIAN FOREST NATIONAL PARK

Marco Heurich¹, Thomas Schneider² and Eckhard Kennel³

1. Technological University of Munich, Department of Ecosystem and Landscape Management, Freising, Germany; marco.heurich@fonpv-bay.bayern.de
2. Technological University of Munich, Department of Ecosystem and Landscape Management, Freising, Germany; tomi.schneider@lrz.tu-muenchen.de
3. Technological University of Munich, Department of Ecosystem and Landscape Management, Freising, Germany; kennel@wbfe.forst.tu-muenchen.de

ABSTRACT

In the year 2002 the project "Evaluation of remote sensing based Methods for the identification of forest structures" was started. During 2002 and 2003 an extensive dataset was collected on an area of 30 km² distributed over 4 test areas. There were airborne surveys with a laser scanner, a multifrequent radar system, two optical scanners and conventional color and color infrared aerial photography. On the ground tree data was collected on 44 reference sites and tree bole positions were determined with an accuracy of centimetres. In addition, data of 712 permanent sample plots of the forest inventory was collected.

To assess the height accuracy of tree measurements a digital crown model was derived from lidar data and 3055 trees larger than 5 meters in height were measured on the ground. Out of these 32.77 % could be clearly identified and were used for the comparison of the different measurement methods. The mean of the differences between ground measurements and the DCM was -0.53 m with a standard derivation of 1.24 m. The mean of the absolute differences was 1.01 m with a standard derivation of 0.90 m. To correct the underestimation of tree heights resulting from lidar data linear regression models have been developed. Different error sources were analysed and considered to be of minor relevance for forest applications. As a result, height determination on the basis of lidar data is as least as accurate as conventional ground measurements and is almost operational.

INTRODUCTION

The research described herein was conducted in the Bavarian Forest National Park which is located in south-eastern Germany along the border to the Czech Republic. Within the park three major forest types exist: montane spruce forests with *Picea abies* and partly *Sorbus aucuparia* above 1100 m; submontane mixed forest with *Picea abies*, *Abies alba*, *Fagus sylvatica* and *Acer pseudoplatanus* on the slopes between 600 and 1100 m; and spruce forests in wet depressions, often evidencing cold air ponds, in the valley bottoms. The montane spruce stands were severely affected by the spruce bark beetle (*Ips typographus*) in the 1990s.

In the year 2002 the Project "Evaluation of remote sensing based methods for the identification of forest structures" was initiated. New methodologies are necessary because data acquisition in the forests of the national park is challenging: the remoteness and the high proportion of dead wood makes data collection expensive and dangerous for the inventory staff. Moreover, the traditional methods of permanent inventory and forest structure mapping can not deliver continuous information about the horizontal forest texture, which is of high importance for conservation issues.

The aim, therefore, of the study is the evaluation of different remote sensing techniques and analysis methods for detecting and mapping forest structures (Table 1). In a further step, there are plans to develop special applications for the needs of the national park administration. Here the main task is to develop a semi-automated approach for the mapping of forest development stages.

Table 1: The research focus in the project is on the following forest structures

Single Tree	Tree stand
position	boundary
species	closure
height	layer structure
crown area	volume

The first period of the project which continued until June 2003 was characterised by data acquisition, preparation and data storage. Four test areas with an overall size of 30 km² were selected. Two of these test areas were established in the core zone of the National Park where the forests have been unmanaged since 1970. The two other sites were established in an area which was incorporated into the park in 1997. Here, commercial forestry took place until this time. The stratum of the first two test areas is considered as “natural forest” and the other one as “managed forest”. The test areas within each stratum are distributed in such a way that they include examples of all three forest types.

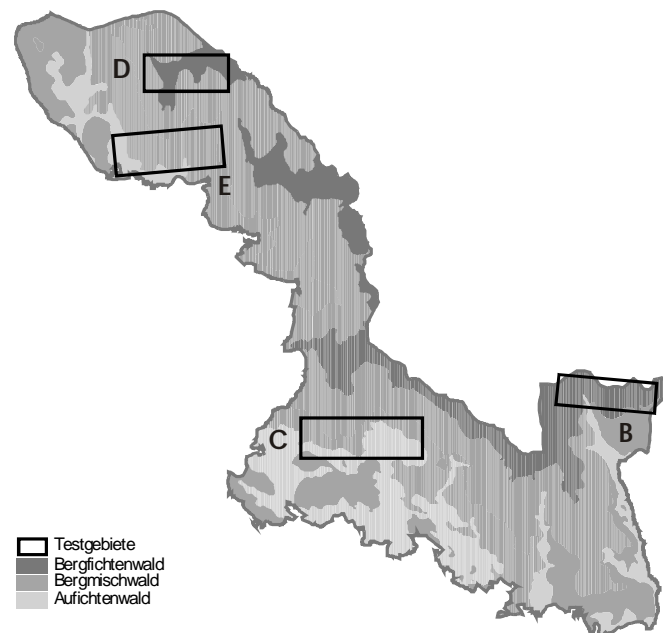


Figure 1: The different forest types in the Bavarian Forest National Park and the location of the Test areas. B and C are within the “natural forest” area, D and E are in the “managed forest” stratum. (Light grey: spruce forests of the valleys, medium grey: mixed mountain forests, dark grey: mountainous spruce forests).

Data that has been collected in the project:

Lidar:

There were two flights with the “Falcon” airborne lidar system from TopoSys. The first flights were in March 2002 (valleys; C,E) and May 2002 (high elevations, B,D) after snowmelt but prior to foliation of the deciduous trees. Height measurements were acquired with a measurement density of 5/m². The second flight was on September 3rd 2002 and measurement density was 10/m². For more details see WEHR and LOHR (1999).

Table 2: System parameters of the TopoSys laserscanner (TOPOSYS, 2003)

Sensor type	Pulsed fiber scanner
Range	< 1600 m
Wave length	1560 nm
Pulse lenght	5 nsec
Scan rate	653 Hz
Pulse repetition rate	83 000 Hz

Distance resolution	1,95 cm
Scan with	14,3°
Range	< 1600m
With (at max. range)	390m
Data recording	First Echo, Last Echo, Intensity
Average measurement density (at max. range)	3 meas./m ²

Multifrequent Radar:

A flight with the experimental SAR-System (E-SAR) from the German Aerospace Center was also flown on September 3rd 2002, but data acquired covered only test area C. The settings of the radar system are described in Table 3.

Table 3: Frequencies and configurations during the E-SAR flight.

Frequency	Polarisation	Interferometry	Spatial Base-lines	Temporal Base-lines
P-Band	HH-HV-VH-VV	-	-	-
L-band	HH-HV-VH-VV	Repeat-Pass	0,5,10,15 (x2)	10 min.
C-band	HH-HV / VH-VV	-	-	-
X-band	VV	Single-Pass	1	-

Aerial Photos:

In May 2002, after the snowmelt, color infrared aerial photographs (CIR AP) were acquired with a scale of 1:3500 in test area B. These photographs were scanned at 10 micrometers, resulting in a ground resolution of 0,035 m.

In October 2002, a second AP acquisition was made with a scale of 1:10000. These images covered the whole park and were scanned at 15 micrometers, resulting in a ground resolution of 0,15 m.

In addition, we had access to a relatively long time series of historical color infrared photographs. Since 1988 there have been flights every year in scales ranging from 1:5000 and 1:15000.

Optical Scanners:

Electro-optical images were acquired simultaneously to the lidar range measurement acquisition. Image data was recorded with the line camera of Toposys. The camera records four channels: B (440-490 nm), G (500-580 nm), R (580-660 nm) and NIR (770-890 nm). The ground resolution of these images is 0,5 meters.

Another optical data source was flown more recently. On June 30rd Z/I Imagings Digital Mapping Camera (DMC) was used to produce images with a ground resolution of 0,045 m in test area B and 0,2 to 0,3 m in the other areas. The system is equipped with four pan and four multispectral camera heads (red, green, blue and near infrared).

Ground data:

Between 2001 and 2002, 16 reference plots were established and 28 existing permanent research plots were measured within the vegetation period. The size of these reference plots ranges between 20 by 50 to 50 by 50 meters. In 30 reference plots every tree position was measured with an accuracy of centimetres, in 14 with an accuracy of decimetres. From each tree higher than five meters DBH, height and crown base were measured. On eight plots we also measured the crown size.

In 2002 a forest inventory was conducted in the test areas. Inventory sample points were distributed in a regular grid with an edge length of 200m. Each sample unit consists of a permanent inventory plot with concentric circles with graduated diameters in breast height. That means that the trees with a DBH between 0 and 5.9 cm are measured on a sampling area of 25 m², the trees with a DBH between 6 and 11.9 cm on a sampling area of 50 m², the trees with a DBH between 12 and 29 cm on a sampling area of 150 m², the trees above a DBH of 29 cm on a sampling area of 500 m². In these plots tree position (only trees larger than 12 cm), DBH, height and other inventory parameters were measured. Altogether we have collected data from 712 plots in the test areas.

In 2003 forest structure mapping will be done. During the summer of 2003 homogenous forest patches (developmental phases) have been mapped by a combination of ground work and interpretation of aerial photos.

The first step to analyse the data was an accuracy assessment of the digital terrain model (DTM) and of the digital crown model. The main questions were: How is the accuracy in dependency on tree species, tree height, slope and what will be the effect of an improved DTM accuracy, by other filter techniques.

METHODS

Height measurements on the ground

The ground work was conducted in the summer season 2002. The measurements were carried out with the "Vertex III" system. This altimeter uses subsonic impulses for the distance measurements. The basic principle for the measurements is the trigonometric principle. For the height measurements we used the definitions of KRAMER (1995).

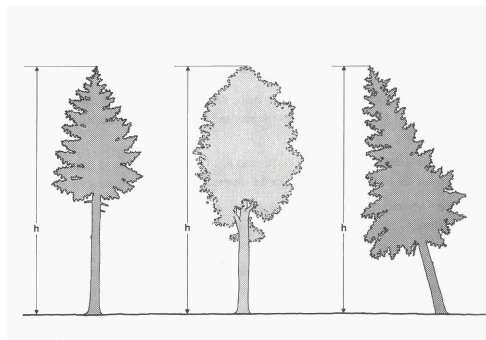


Figure 2: Definitions of tree height for coniferous and deciduous trees as well as for angular trees according to KRAMER.

Creation of the DSM and DTM

The coordinates (Northing, Easting and Elevation) for the desired coordinate system were calculated for each lidar stripe, using data from the GPS processing, the aircraft INS (Inertial Navigation System) and the single laser distance measurements. In a following step, the points were firstly sorted into a grid with a spacing of 0,5 m and a height resolution of 0,01 m. The Data for the DTM then was resampled to a destination spacing of 1m. The calculated DSM data (Digital Surface Model) was processed from the first return lidar data, with an emphasis on the higher values. The calculated DSM data contains height information on buildings, vegetation, terrain and other features. Noisy pixels were removed by filtering. The DTM-data (Digital Ter-

moved by filtering. The DTM-data (Digital Terrain Model) was processed from the last echo data with an emphasis on the lower values. In order to obtain a model without buildings and vegetation, a further filtering step was necessary. Both models may show spots of total reflection. The holes resulted from the DTM filtering, as well as spots of total reflection are closed by interpolation. Data procession was done with the TopPit software from TopSys (TOPOSYS, 2002).

Data preparation and analysis

In the first step the binary data was clipped to the sizes of the reference sites and transformed to dBase IV format. For the DTM we used the spring flight data while for the DSM we used that from the summer flight. In the next step the point data was rasterized with Arc View GIS 3.2 and the Spatial Analyst Extension. After that the digital crown model (DCM) was calculated by subtracting the DTM from the DSM.

As a second layer, we imported the ground data. For a better visual interpretation of the DCM the resulting grid was converted to a triangulated network (TIN) and the trees of the ground data were visualized as points according to the species and their height (figure 3).

The height of the trees were measured in the DCM and compared with the measurements on the ground. The measurements were only used when it was possible to identify the same tree in DCM and ground data. For the measurements the data was interpreted in the way that we did not measure directly above the bole position (ie. the tree trunk) but at the highest peak of the same tree in the DCM proximal to the bole position of the ground data. Besides the height of the DCM and of the ground measurement we also recorded the distance between the bole position and the assumed tree top.

For the accuracy assesment of the DTM we used measurements of high accuracy GPS in combination with traverse. For the interpolation of the ground data we used a bilinear interpolation. After that the differences between DTM and surveyed data were compared. (FISCHER and KNÖRZER 2002).

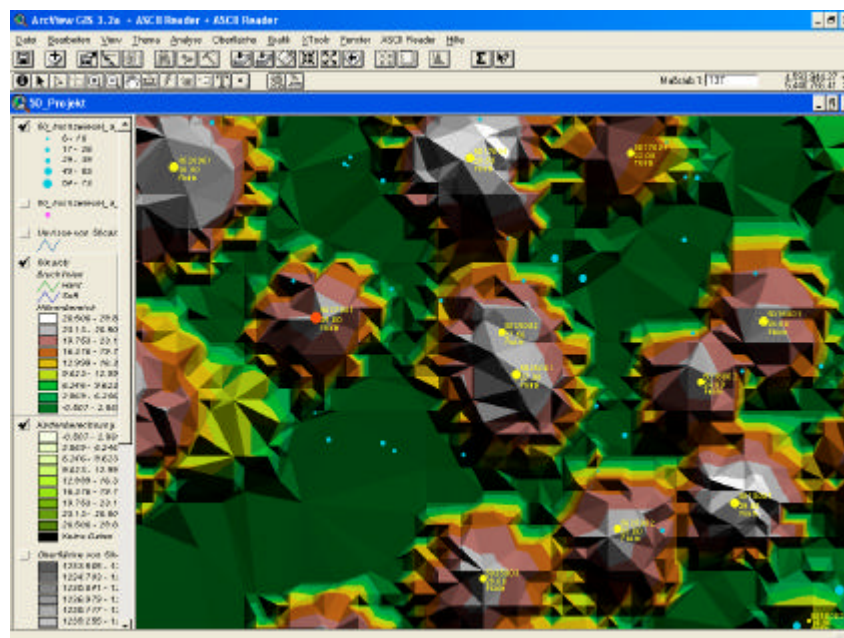


Figure 3: Working environment for the visual interpretation of the tree heights. The dots show the bole position of the trees measured on ground. The TIN represents the DCM.

RESULTS

Accuracy of height measurements

Deciduous trees

The number of trees measured was 308. The mean of the differences between ground measurements and the DCM was -0,37 m with a standard derivation of 1,43 m. The mean of the absolute differences was 1,01 m with a standard derivation of 0,90 m.

Coniferous trees

The number of trees measured was 448. The mean of the differences between ground measurements and the DCM was -0,79 m with a standard derivation of 1,25 m. The mean of the absolute differences was 1,14 m with a standard derivation of 0,95 m.

Dead wood

The number of trees measured was 245. The mean of the differences between ground measurements and the DCM was -0,26 m with a standard derivation of 0,79 m. The mean of the absolute differences was 0,55 m with a standard derivation of 0,62 m.

All measurements

The number of trees measured was 1001. The mean of the differences between ground measurements and the DCM was -0,53 m with a standard derivation of 1,24 m. The mean of the absolute differences was 1,01 m with a standard derivation of 0,90 m.

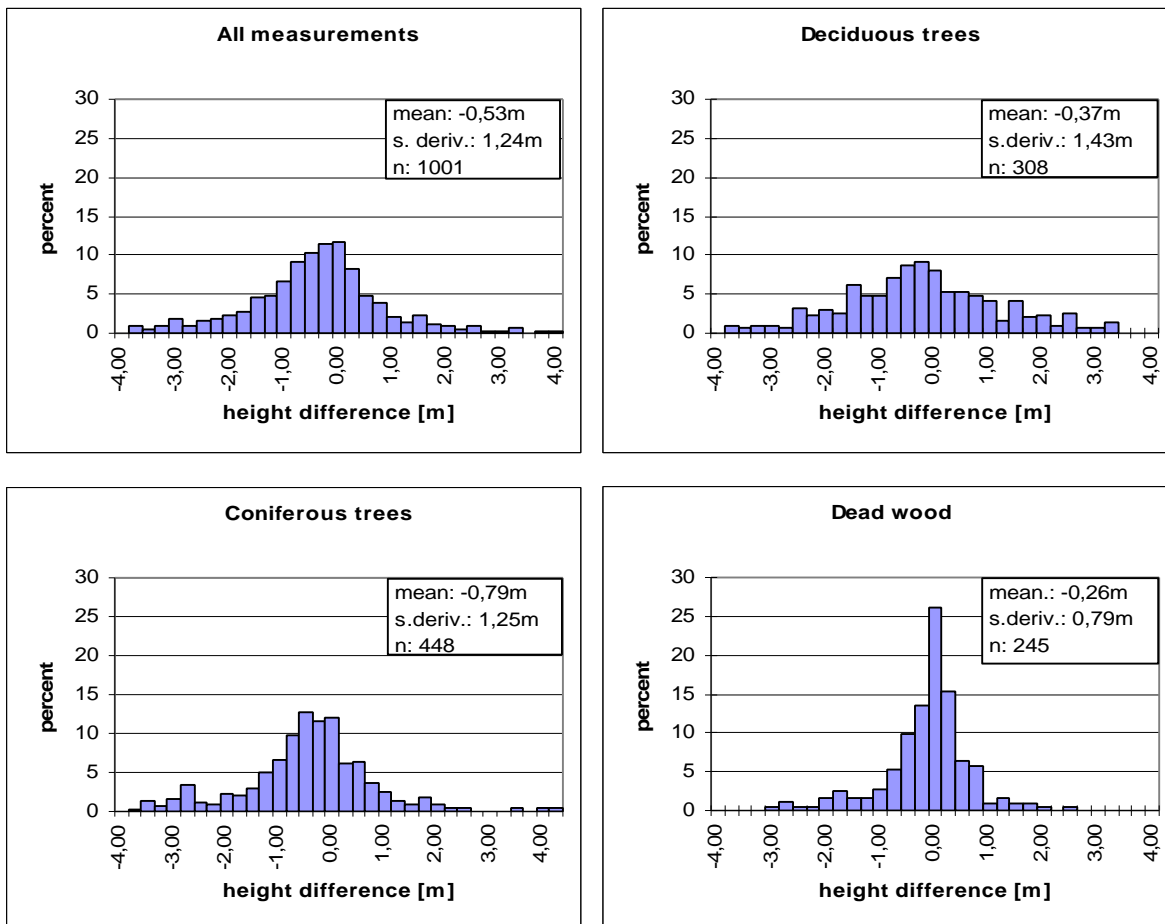


Figure 4: Frequency distributions of the differences between ground measurements and DCM.

Quality of measurements in dependency of tree height

In Figure 5 it is clear that the differences between ground data and lidar data are relatively small in small trees, especially in small coniferous trees. The larger the trees, the larger the scattering of the measured differences becomes. Surprisingly the variation of the differences is not higher in deciduous trees. With increasing in tree height the mean measured difference decrease. The numerical value of the mean measurement difference decreases 4,6 cm per meter in deciduous trees and 3,1 cm per meter in coniferous trees.

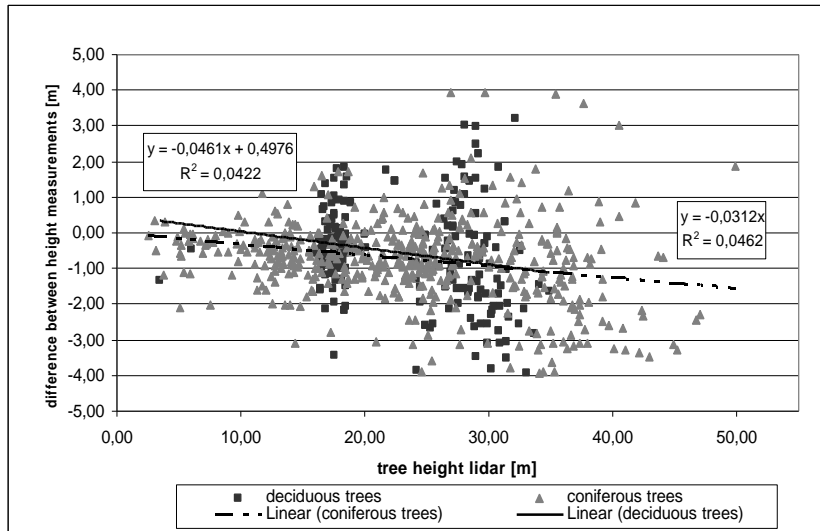


Figure 5: Dependency between the difference of height measurements on ground and out of the DCM and the tree height.

Influence of slope

According to KRAMER (1995) the tree height is perpendicular from the tree top to the ground (Figure 1). In Figure 6 the principle of height measurements at slope are shown. Here the tree height is the difference between an assumed vertical line from the root position and the apex of the tree. Because of this principle there is a systematic difference between ground measurements and the DCM for leaned trees calculated the by subtracting the DTM from the DSM. This error is shown in Figure 6. The steeper the angle of the slope and the larger the distance of apex to root position the larger this systematic error becomes.

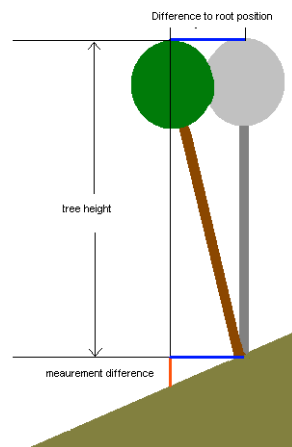


Figure 6: Schematis showing measurement difference between ground measurements and measurements out of the DCM of leaned trees on slopes.

The mean distance between root position surveyed in the field and the tree apex identified in the DCM is only 0,88 m for coniferous trees. For deciduous trees the mean difference is much larger: here the mean is 1,54 m. For all measured threes the mean is 1,08 m. In Figure 7 you can

see the measured differences in dependency to the tree heights. The difference between bole position and apex increases with the height of the trees. For the deciduous trees it increases with 2.5 cm per meter and for the coniferous trees it increases at 3.3 cm per meter. The variance is much higher for the deciduous than in the coniferous trees.

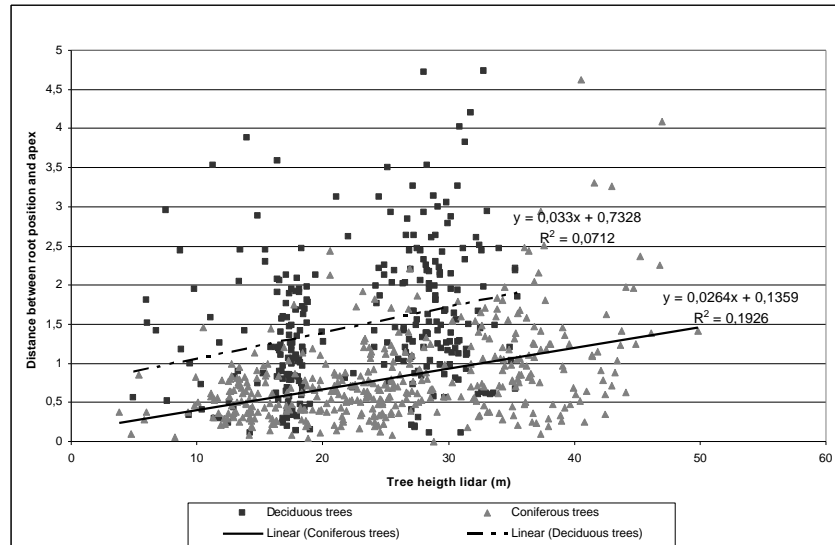


Figure7: Distance between surveyed bole position and lidar tree apex as a function of tree height.

From the mean distance between surveyed bole position and lidar apex and the mean slope of 10,3 degrees of the reference sites, we calculated an average difference of 0,20 m. For 87,4 % of all the measured trees we found an difference smaller than 0,5 m.

Identification of single trees

For this work only the trees measured on the ground, which could be clearly identified as a single tree in the DCM are used for the analysis, as it was done in the high measurements. For the evaluation the trees are classified into three height layers. Top layer: from 2/3 of the top height (medium height of the 100 highest trees) to highest tree; middle layer, 1/3 to 2/3 of top height, bottom layer: 5 m to 1/3 of top height. Of the trees in the top layer, 72% could be visually identified. In the other layers the percentage of detected trees is much lower. For more details see Table 4.

Table 4: Visual identification of individual trees out of a DCM with a resolution of 0.5 m.

	Mixed forest	Coniferous	Dead wood	Total
Top layer	69,31%	73,41%	77,68%	72,11%
Middle layer	17,11%	14,57%	59,78%	21,66%
Bottom layer	2,89%	0,74%	40,93%	8,27%
Total	24,38%	36,99%	56,16%	32,77%

Accuracy of the digital terrain model

To evaluate if it would be worth investing more effort in testing and adjust different DTM filter algorithms the differences between the measured tree root position and the DTM were calculated. Together 7654 ground measurements of tree bole positions and ground surface positions were used for the accuracy assesment. These measurements were done at 23 different reference sites. The DTM of the summer flight was only available for 14 reference sites. The mean difference between surveyed terrain height and the DTM was 0,027 m in the data of the spring flight and 0,078 m in data of the summer flight. Standard derivation was 0,286 m in spring and 0,348 m in summer.

CONCLUSIONS

The results of the height measurements with the lidar data shows the underestimation of tree heights especially in coniferous trees. As it was shown in the studies of NAESSET (1997) MAGNUSSEN and BOUDEWYN (1998). This is because the used measurement density of the lidar system, used in this study, is still not dense enough to capture the shoots of the trees. These differences are lower in deciduous trees as they have a flatter crown with no single shoots and their shoots are covered with leaves. On the other hand the scattering of the measurements in deciduous trees is larger. It is assumed that this is simply because of the difficulties in measuring deciduous trees from the ground. In dense deciduous stands it is sometimes challenging to decide which is the highest point of the crown as there is no single peak. In addition sometimes the peak is hidden behind a green wall of leaves because the branches of different trees interdigitate; it sometimes even happens that the wrong tree is measured. Further reasons for measurement errors and inaccuracies are detailed discussed in ABETZ and MERKEL (1962) and LÖTSCH et al. (1973). The best accuracy we found for dead trees. Here the tree tops are normally broken, so that it is easier to find the spot to measure from the ground. Also the target for the laser beams is larger in comparison to healthy trees. Moreover dead trees are not as tall as healthy trees. This seems to be important because when we differentiated the measurement accuracy between trees larger than 30 m and trees smaller 30 m and found that the accuracy was much better in small trees (mean:-0,32 m; standard derivation: 1,04 m) than in the larger trees (mean:-1,8 m; standard derivation: 1,55 m). It is assumed that this difference is also strongly influenced by the ground measurements. Especially the high trees are pretty difficult to measure from the ground. It is hard to detect the shoots of the trees and the angle for the measurement becomes very steep, when the distance to the root position is not as far as the assumed tree length. But if the ground personal has the right distance it is more difficult to see the top of the tree.

To get information about the accuracy of height measurement from the ground, BAUER (2001) analysed the height measurements and control measurements of 1203 trees. These measurements were done by inventory teams during the regular inventory within the Bavarian state forests. The mean of the measurement differences was 0.07 m, with a standard derivation of 1.40 m. The mean of the absolute differences was 1.01 m with a standard derivation of 0.98 m. It is not surprising that the mean of this data is closer to zero than the one from the lidar data. The interesting thing is that the mean of the absolute differences and variance of this data is almost the same as in this study. Also ECKMÜLLNER and RIEGER (2000) found that the error in groundmeasurements was between +/- 1.23 and +/- 1,57 in Norway spruce and +/- 1,64 and +/-1,78 in European beech. Out of this we conclude that the height measurements from the lidar data are, besides the underestimation, at least as accurate as the measurements in standard forest inventories and probably more accurate. We suppose that the variance in our results is strongly influenced by the ground data and probably less by the lidar data. HYYPPÄ et al. (2000) and Persson et al. (2002) also found that the accuracy of the measurements achieved from the ground is comparable to the height estimations from the lidar data. The problem of underestimation of the height measurements by using the lidar data can be adjusted by the proposed linear regression equations.

To improve the filtering of the DTM has no high priority for our test areas because the measurements are already pretty accurate for forestry purposes. A better algorithm can only enhance the accuracy of tree measurements by some centimetres. Therefore no big effort will be invested in this field within the project.

The principle difference between height measurements according to the definition of KRAMER (1995) and out of the DCM has a bigger impact on the results. When the slopes are steeper than 20 degrees must be done a correction. This correction will be done on basis of the measured differences between tree root and apex position collected in this study and the steepness of the slope out of the DTM.

As a result DCMs derived from lidar data are a powerful and fully operational method for tree and stand height determination. The results using this method are at least as accurate as conventional methods basing on the trigonometric principle.

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REFERENCES

- Bauer, A., 2001. Möglichkeiten zur Extensivierung der Forsteinrichtung im Hochgebirge durch Einsatz moderner Techniken der Luftbildauswertung. Forstliche Forschungsberichte München. Nr. 137.
- Eckmüllner and Rieger, 2000: Informationen für den Forstbereich aus Laserscannerdaten. In J. Strobl, T. Blaschke und G. Griesebner (Hrsg.) Angewandte geographische Informationsverarbeitung XII. Beiträge zum AGIT-Symposium Salzburg 2000.
- Fischer F. and Oliver K., 2002. Statistische Analyse von digitalen Geländemodellen und Waldstrukturen im Nationalpark Bayerischer Wald mit Hilfe von hochaufgelösten Laserscanningdaten and GPS-Messungen. Unpublished Master Thesis. University of Applied Science Munich. 118 p.
- Hyypä, J., Pyysalo U., Hyypä, H. and A. Samberg, 2000. Elevation accuracy of laser scanning-derived digital terrain and target models in forest environment. Proceedings of the 4th EARSeL Workshop on Lidar Remote Sensing of Land and sea, 16-17 June, Dresden, Germany, pp. 193-147.
- Kramer and Akca, 1995. Leitfaden zur Waldmeßlehre. J.D. Sauerländers Verlag. Frankfurt am Main. 266 p.
- Magnussen, S. and B. Bouldewyn, 1998. Derivation of stand heights derived from airborne laser scanner data with canopy-based quintile estimations. Can. J. For. Res. 28, pp. 1016-1031.
- Naesset, E. 1997. Determination of mean tree height of forest stands using airborne laser scanner data. ISPRS Journal of Photogrammetrie & Remote Sensing. 52. pp 49-56.
- Persson, A. , Holmgren, J. and U. Södermann, 2002. Detecting and Measuring Individual Trees Using an Airborne Laser Scanner. Photogrammetric Engineering & Remote Sensing. Vol. 68, No.9. pp 925-932.
- Toposys GmbH, 2002. Auswerteprotokolle der Höhendaten im Bayerischen Wald. p.
- Toposys GmbH, 2003. Falcon Lidar Sensor System. Technical outline. 6p.
- Wehr, A. and Lohr, U., 1999. Airborne laser scanning – an introduction and overview. ISPRS Journal of Photogrammetrie and Remote sensing 54, 68-82.