EVALUATION AND FUTURE PROSPECTS OF TERRESTRIAL LASER SCANNING FOR STANDARDIZED FOREST INVENTORIES

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ABSTRACT:

Based on experiences from the NATSCAN-project this contribution focuses on the evaluation of two hypotheses:

(i) Terrestrial laser scanning and corresponding data analysis is ready to be used in standardized forest inventory sampling.

(ii) Data quality as well as characteristics related to the technique of laser scanning widen the data base for forest management applications and ecological investigations.

First the characteristics of information needs for forest management planning are presented (such as number of sample plots, interesting parameters etc.). In a second step process and measurement setup of terrestrial scanning of forest sceneries are described. Exemplary results of two different scanning modes, i. e. single-scan-modus and multiple-scan-modus, are compared in respect to the inventory parameters of diameter in breast height (DBH), tree height and height of crown base. The investigation was carried out on a mixed stand of beech and oak with silver-fir and beech in intermediate and suppressed crown layers. Results were evaluated with the help of conventional measurements of these parameters and are discussed to prove the hypotheses (i). Technical aspects connected with data collection, data analysis and possible error sources are summarized and options for future improvements are presented. Possibilities of terrestrial laser scanning which exceed the limits of conventional inventories, such as quality assessment of standing trees, are also added (ii). Advantages of the technique for inventory purposes are for example the high reproducibility of the results of the measurements and the possibility to store information as a data pool for future applications.

A final appeal to make use of terrestrial laser scanning for forest and landscape assessment on a larger scale concludes the results. It is argued that while terrestrial laser scanning offers new options for the assessment of natural sceneries, it must in the current situation be conducted under careful consideration of economic aspects.

1. INTRODUCTION

Traditionally, forest management is strictly based on the principle of sustainability, i.e. in a defined time period harvest and volume increment of forest stands have to be balanced. Sustainability nowadays does not only focus on stand volume but covers the entire spectrum of functions which forests provide to society. These include for example sustainable recreational uses of forests, maintenance of biodiversity, long-term managing of protection forests as well as a sustainable supply of high-value timber. For the implementation of such a wide range of sustainability in practical forest management, decisions have to be based on quantitative information about the current state of the forests. Based on sample plots numerous forest inventory methods have been developed (Shiver & Borders, 1996, Schreuder et al., 1993, de Vries, 1986). To reduce inventory costs, to improve data quality, or to acquire new parameter categories (for example near infrared) the use of new measurement technologies and instruments for forest inventory have been continuously improved. Using this background the following contribution deals with the evaluation of terrestrial laser scanning for forest inventory as it was part of a research project on laser scanning for forest and landscape assessment (Thies et al. 2002). The core is a numerical comparison of selected forest inventory parameters which were measured conventionally with results of the same parameters derived from terrestrial laser scanning. This is to analyse to what extent terrestrial laser scanning at this stage is ready to be used for standardized forest inventories. Finally, an outlook on possible applications, future developments and research needs necessary for the durable implementation of terrestrial laser scanning in forest research and inventory will be presented.

2. METHODS AND MATERIAL

2.1 Conventional Forest Inventories

Examples for parameters of interest which are measured in forest inventories can be taken from the administration directive of the National Forest Inventory of Germany (VwV-BWI II, 2000) or the management unit-based sampling of the forest administration of Baden-Wuerttemberg (Forstliche Versuchs- und Forschungsanstalt Baden-Wuerttemberg, 1995). Both have in common that sampling is done based on systematical sampling grids with defined grid lengths. At each intersection four concentric circles with defined radii form the boundary of the single plots. For each circle information of different scales is acquired, for instance the outer circle of the National Forest inventory is 25 m and only parameters describing the local terrain are measured. Within the next circle with a radius of 10 m only trees and shrubs with a maximum height of 4 m are considered, etc. For comparing the method of terrestrial laser scanning with conventional measurements we follow the sampling method developed for forest management units in

Baden-Wuerttemberg (abbreviation “BI”). In this sampling one plot is measured every two hectares whereas at least 500 plots per management unit are required to derive reliable results on the management unit level. Generally three information categories can be differentiated:
(i) header information about forest district, inventory-ID, Gauss-Krueger-coordinates, etc.
(ii) information about the sample plot, such as site conditions, slope, ground vegetation, proportion of generation, etc.
(iii) single tree parameters, such as tree-species, tree height, diameter at breast height (DBH), height of crown base, distance and azimuth from the centre of the sample plot, etc.
Whereas (i) and (ii) include descriptive site information, the third category (iii) contains single tree variables to be measured. For evaluating the use of terrestrial laser scanning for forest inventories from this category of variables, DBH, height crown base and tree height are chosen for direct comparisons. The largest radius of the outer concentric circle of an inventory plot is 12 m; correspondingly, the region of interest is limited to 452.4 m². DBH of the trees in the BI is measured with a circumference tape measure, or in exceptional cases by use of a calliper. Tree height and height of crown base are measured with instruments based on the trigonometrical principle, such as the sonic clinometer Forestor Vertext®. For the acquisition of inventory data as reference for data derived from terrestrial laser scanning, the corresponding devices were used. Especially for DBH measuring, both circumference tape and callipers were used to get an impression about immanent errors in conventional inventories.

2.2 Forest Inventories by Terrestrial Laser Scanning

2.2.1 Measurement Setup

In respect to the beam deflection units of commercially available laser scanners two different systems are available; one is the camera view system, the other is the panoramic view system (Fröhlich & Mettenleiter, 2004). The use of camera view scanners and their application to forest inventory were presented by Hopkinson et al. (2004) and Watt et al. (2003). Results presented in this paper based on the panoramic view system implemented in the Z&F Imager 5003. The field of view covers 360° horizontally and 310° vertically. This is close to the sample design of the concentric plots used in conventional forest inventories (see above). Two different measurement setups were tested; the first, called single-scan-modus, implies that a forest scenery is scanned once with the scanner position being equivalent to the centre of a sample plot. In the second setup, called multiple-scan-modus, a forest scenery is scanned two or more times and each single scan is later transformed into a superior coordinate system (registration of the 3D point cloud). The scanner positions are oriented around the centre of the sample plot in a way that the overlapping area between the scanner positions include the centre of the sample plot. The advantage of the single scan modus is the reduced time for data acquisition, whereas the multiple scan modus is much more time consuming but guarantees considerably better data quality due to the overlapping 3D point clouds and information about the trees from more than one direction (Thies et al., 2003). The stand map (fig. 2) shows the measurement setup for the sample stand which is the basis for the results presented in this paper. Each cross represents one scan. The cross combined with the circle indicates the centre of the sample plot, which is equivalent with the scanner position for the single scan modus.

2.2.2 Data Processing and Parameter Derivation

In respect to the high number of sample plots which are necessary for statistically correct forest inventories it is clear that processing of the produced 3D point clouds has to be done more or less automatically. Following this premise for the detection of trees in point clouds produced by terrestrial laserscanners and DBH-derivation a method presented in Aschoff & Spiecker (2004) and Simonse et al. (2003) was applied. In this process algorithm first a digital terrain model (DTM) is calculated. For DBH calculation at a height of 1.3 m above the DTM the point cloud is sliced by layers of defined thickness. Finally, with the help of a Hough- transformation and fitting circles, coordinates of tree positions and DBH can be derived. In this case the height of DBH measuring depends on the DTM, which might be an error source when comparing the results to the conventionally measured DBH. For this reason, DBH of each single tree in the forest was determined and durably marked with reflecting tape before any measurements were carried out. Because of its reflective property this tape is recognizable in the scans as well (fig. 1).

Figure 1. Intensity image of a part of the sample plot. Reflecting tapes mark a height of 1.30 m above ground.

As a fourth method of DBH derivation the intensity images of the sample plot were used to measure DBH in the scans manually by using a measuring function which is integrated in the analysis software.
Pfeifer et al. (2004) developed a method for reconstructing trees from 3D point clouds automatically by fitting consecutive cylinder to the trunks. The reconstruction based on nonlinear least squares estimation is finalised as far as the RSME of the fitting exceeds a pre-defined value (regularly ± 3 cm). When investigating quality criteria of tree stems such as taper, sweep and curvature it could be observed that this automatic cancellation of the algorithm can often be connected to the height of the first living or dead branch (Thies et al., 2004). Therefore the length of the reconstructed tree trunk in this paper

was taken as the equivalent to the height of the crown base of the tree.

In dense forest stands tree height is difficult to measure directly with terrestrial laser scanners. For this reason a dataset of diameter-/ height values was generated for each single tree by using the described layer extraction and followed by a linear regression to relate the circles in layers of different heights to one certain tree (Aschoff & Spiecker dto., Aschoff et al., 2004). To these diameter-/height datasets a common taper function (Brink & v. Gadow, 1986, Riemer et al., 1995), well known as the modified Brink-function, was applied. Input variables to the base stem model of this parameter parsimonious function is DBH, tree height and a set of three form-determining parameters which are tree-species specific. Because tree height is the parameter to be calculated and at the same time part of the input variables, a direct fit cannot be realised. For this reason as a first approach we iterated tree height in a predefined range from 5 m to 50 m with a step size of 10 cm and calculated for each iteration the RSME of the resulting function to the diameter-/height sets. The height with the minimum RSME was assumed to be the tree height.

The presented data processing fulfils the requirements of a high level of automatisation in a pragmatic manner.

2.3 Characterization of the Sample Stand

The results presented here are based on measurements carried out in a forest stand on a steep, southwest-oriented slope of the Southern Black Forest foothill range. Steepness of the slope is 28°. The sample plot is located on an intensively mixed and unevenly-aged stand which is mainly (95%) composed of beech (*Fagus sylvatica* L.) and a 5% portion of oak (*Quercus spec.*) in the dominant crown layer. The medium and lower crown layers consists of silver-fir (*Abies alba* Mill.) and beech trees. Thin and small trees are neighboured by much thicker and taller ones, so both the vertical and the horizontal structure is very high. According to the forest management plan the mean age of the trees in the dominant crown layer is 135 years (ranging from 68 to 223 years) and the age of the suppressed trees varies from 8 to 33 years (mean age 18 years). All age figures refer to the year 2004. Compared to pure and homogenous plantations in flat regions this test site is meant to represent a "worst case" scenario. As far as methods are successful in this situation they will be easily applicable to simpler forest sceneries.

3. RESULTS

In the sample stand a plot of 50 trees (approx. 30 m x 30 m plot size) was numbered and conventionally measured. In the resulting stand map (fig. 2) these diameters are represented as 'diameters from data base.' From these 50 trees 26 trees (52%) were automatically detected based on five registered scans, whereas on the basis of just one scan 11 trees (22%) were found. Accuracy of tree position determination independent from the method of data acquisition is very high, as can be seen in figure 2. The following comparisons are presented for these 11 trees. Table 1 contains the results of the different approaches for DBH measurement. Three different tree-species with a total diameter ranging from 14.2 cm to 62.4 cm are the basis for the analysis. The results derived from calliper measurement, circle fitting in single and multiple scans as well as the manual measuring in the intensity images are additionally expressed in percent to the reference DBH measured conventionally by circumference tape. The differences between the two conventional measuring methods can be neglected; the mean of diameters measured by a calliper is 0.6% smaller than the

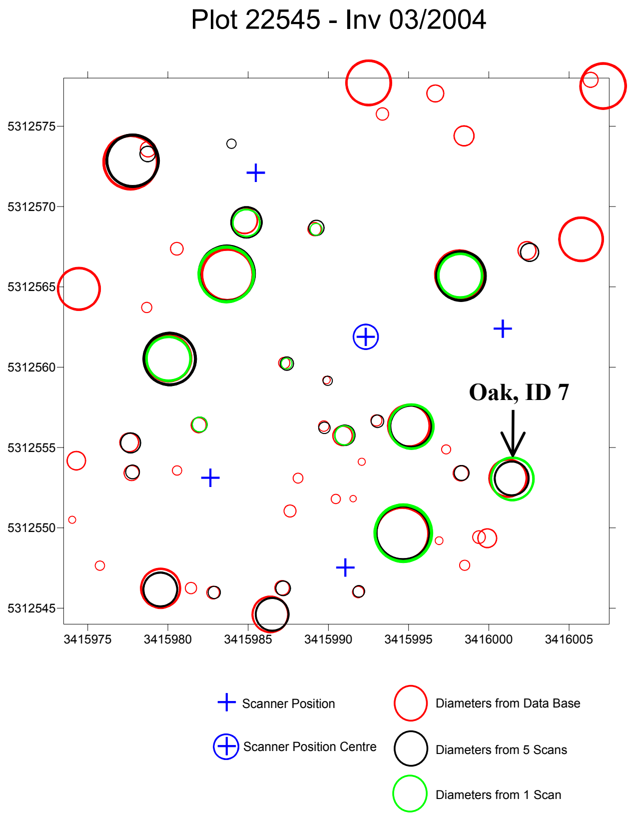

Figure 2. Stand map derived from different scan modi with conventionally measured DBH-reference. Specifics of the marked tree are discussed in the text.

ID	Species	Tape (refer.)	DBH measurements [cm, deviation in %] Calliper	Single Scan	Multiple Scan	Image
3	Beech	58,8	57,8 (98,3)	51,5 (87,6)	57,6 (97,9)	54,6 (92,9)
4	Beech	50,9	51,1 (100,4)	51,9 (101,9)	49,1 (96,4)	51,5 (101,2)
7	Oak	47,5	46,8 (98,5)	50,0 (105,2)	***39,9*** ***(84,0)***	45,1 (94,9)
12	Beech	60,9	61,8 (101,5)	66,7 (109,5)	63,4 (104,1)	63,0 (103,4)
17	Beech	23,6	23,5 (99,6)	22,5 (95,2)	23,7 (100,3)	23,2 (98,3)
19	Silver-fir	17,0	16,4 (96,5)	14,0 (82,3)	17,9 (105,2)	15,3 (90,0)
20	Beech	14,2	14,1 (99,3)	12,7 (89,2)	15,6 (110,1)	13,5 (95,1)
31	Beech	19,1	18,8 (98,4)	17,3 (90,6)	17,6 (92,0)	17,4 (91,1)
32	Beech	62,4	62,9 (100,8)	64,4 (103,3)	64,9 (104,1)	62,8 (100,6)
33	Silver-fir	32,2	31,9 (99,1)	31,7 (98,5)	35,9 (111,6)	31,8 (98,8)
36	Beech	56,3	57,0 (101,2)	51,9 (92,1)	60,8 (108,0)	53,9 (95,7)

Table 1. Results of different methods of DBH measurement. DBH from circumference tape is used as the reference, deviations of the others are given in percent to the reference (in brackets).

diameters measured by a circumference tape. Deviations vary between 96.5% and 101.5%. The differences between the other methods in comparison to the reference are higher. In a descending order the largest mean difference of -4.1 % (range: 82.3% to 109.5%) can be observed for diameter derivation based on one scan. The next largest difference is -3.5 % for the manual measurements based on the intensity images with a range from 90.0% to 103.4%, whereas the best mean results with a deviation of 1.3% can be achieved by automatically calculating DBH based the five scans, although the range between 84.0% and 111.6% is much higher than for the image measurements. The estimated tree heights based on the iteration of the taper function in the mean are 7.0% higher than those measured conventionally (tab. 2). However, the single deviations, which range from a minimum of 54.6% to a maximum of 190.7% indicates that the chosen method needs to be improved.

ID	Species	Tree height [m, deviation in %]		Height of crown base [m, deviation in %]	
		Vertex	Taper function	Vertex	Cylinder fitting
3	Beech	26,3	17,7 (67,5)	7,8	11,5 (147,8)
4	Beech	28,3	23,3 (82,2)	14,4	11,8 (81,9)
7	Oak	26,1	14,3 (54,6)	8,2	9,2 (111,8)
12	Beech	30,2	26,3 (87,2)	17,4	10,0 (57,6)
17	Beech	18,5	18,1 (98,1)	8,0	6,5 (81,4)
19	Silver-fir	6,9	13,2 (190,7)	4,0	2,5 (62,3)
20	Beech	9,3	16,2 (173,7)	5,3	-
31	Beech	14,6	15,6 (106,8)	4,0	3,3 (82,0)
32	Beech	32,4	31,7 (97,7)	16,1	15,8 (98,1)
33	Silver-fir	17,5	20,8 (119,0)	5,3	5,0 (95,1)
36	Beech	32,2	32,2 (99,8)	20,1	16,4 (81,3)

Table 2. Comparison of estimated tree height and automatically reconstructed height of crown base with height measured conventionally with a Forestor Vertex® measured height. The conventional measurements were used as the reference, deviations of the others are given in percent to the reference (in brackets).

The estimation of the height of the crown base as equivalent to the automatically reconstructed bowl length with the help of a cylinder fitting algorithm results in an underestimation with a mean deviation of –10.1% and a range of 57.6% to 147.8%. For one tree the fitting process could not be initialized. Compared to the estimation of entire tree height this range is much smaller, but nevertheless unsatisfactory.

4. DISCUSSION

The positions of trees in a sample plot of defined area size show only minor differences between conventional tachymetrical measurements and automatic derivations from laser scanner data. The multiple-scan-modus clearly allows more trees in total to automatically be detected because a larger area is covered. However, accuracy of both single-scan- and multiple-scan modus is satisfactory. In respect to DBH derivation based on a feasibility study of 11 trees it could be observed that the differences between the two conventional measurement methods are comparable to the error range of ± 0.5- 1% reported by Prodan (1965) and in addition, are much smaller than the differences in the laser scanning methods. It was to be expected and is represented in the results of Watt et al. (2003) as well that manually measured diameters in intensity images of laser scans tend towards a slight underestimation of the diameters. The reason for this is that due to stem roundness the laser beam at the outer parts of the stem will produce inaccurate distance and intensity measurements. From the viewpoint of the scanner position from the tree's circumference at 1.3 m approximately only one third shows a homogenous intensity, while the outer parts show irregularities. The deviations of the diameters based on just one scan are produced for the same reason. The fit of the circle is mainly determined by the coordinates of a stem surface which are closest to the scanner. Other regions on the opposite side of the tree stem cannot be measured and therefore are not represented in the fitted dataset. For the same reason in single scans models more complex than a circle cannot be fitted. Automatic diameter determination based on multiple scans delivers satisfying results compared to the conventional reference measured by circumference tape. The error is similar to the results presented by Hopkinson et al. (2004) and are only slightly higher than the application of this method on a mixed stand of Douglas-fir (Simonse et al. 2003). Moreover, the data source from multiple scans allows us to fit advanced models such as an ellipse to further improve the results (Aschoff & Spiecker, 2004). On the example of oak no.7 (see fig. 2) the importance of the distribution of the scanner positions becomes apparent; although the tree position is within the overlapping area of three scanners just the scanner in the north delivers data without occlusions of neighbouring trees. This is one reason why diameter calculation of this tree is unsatisfactory. The resulting diameter is comparable to the largest negative derivation of the trees scanned with the single scan modus (tab. 1). In any case of the automatically derived DBH a possible error source might be the DTM. Dense ground vegetation, snags, branches, or rocks on the ground influence DTM derivation and therefore indirectly lead to incorrect 1.3m height determination. This, consequently results in differing DBH. Tree height estimation by use of a taper function depends on the number of upper diameters of higher tree heights. The more diameters close to true tree height can be extracted, the better tree height estimation will be (see for example beech no. 36 and 32). Additional diameters at the base of the tree trunk do not significantly influence height estimation.

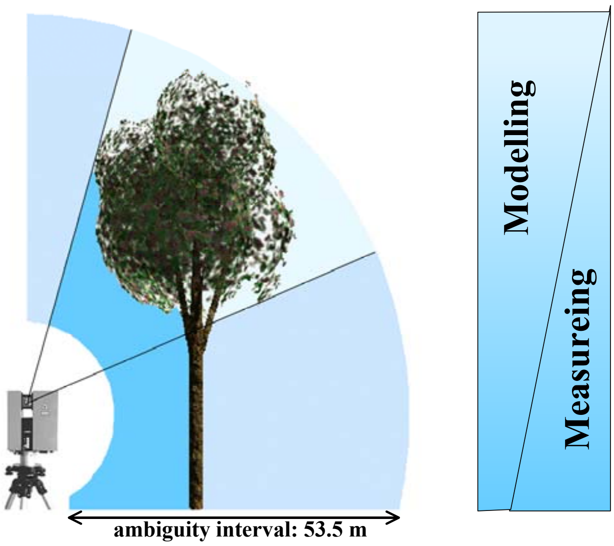

Figure 3. Relation of measuring and modelling by reconstructing forest sceneries using terrestrial laser scanning.

In dense forest stands in the 3D point cloud coordinates from the tree crown and especially parts of the light crown are rare, consequently by reconstructing trees the portion of modelled regions increase with increasing tree height or in general with increasing distance between the object to be measured and the scanner position (fig. 3).

By using a camera view-system with side views and calculating tree height as the difference of the lowest and highest elevation the results of tree height determination are much better (Hopkinson et al., 2004), but from our point of view are not applicable to mixed stands with two or more crown layers in the understorey. Consequently, as the portion of measured coordinates is much higher the reconstruction of the branch-free bole length delivers better results than the modelled tree heights. The reconstruction algorithm is finalised automatically as far as the pre-defined RSME is exceeded and therefore of course is not able to differentiate between crown base or height of the first dead branch. Nevertheless mean deviation is about -10%, including coniferous trees from the understorey such as silver-fir no. 19 where on this steep slope the regions of overlapping branches can be expected to be very high. A manual setting of the heights to be reconstructed in the intensity images would help to improve the results considerably.

5. CONCLUSIONS AND OUTLOOK

At this stage it is too early for a final evaluation of the use of terrestrial laser scanning for standardized forest inventories. Some case studies have been published but methods, aims and forest sceneries differ significantly, so direct comparisons of the results need to be made carefully. The systematical investigation of larger test sites with different scanning techniques as well as different data analysing methods would be desirable. These investigations should include economic aspects because automatic data analysis currently requires long calculation times (Aschoff & Spiecker 2004) or is very time consuming when done manually. This would deliver a decision base on which information needs and costs could be balanced for future applications. In general it becomes clear that inventory parameters which are derived from models based on a high amount of directly-measured 3D coordinates show smaller errors, whereas errors increase with a decreasing number of directly measured coordinates. This effect maybe substituted by improving the adapted models. Instead of using a conventional taper function specific functions for determining tree height from taper can be derived directly. Based on the observation that high trees show stronger butt swells, stem regions that can be measured directly with the help of the laser scanner should get more emphasis in such kinds of functions. Summarizing the first results of Thies et al. (2004) and approaches of Pfeifer et al. (2004) and Schütt et al. (2004) it can be expected that at the current stage inventories with terrestrial laser scanners will offer the opportunity to determine timber quality of standing trees with high accuracy. This offers us new options we have not had in forest inventories until now. One advantage of using terrestrial laser scanners for forest inventory is that data acquisition and analysis (as far as it is done automatically) is more or less independent from subjective influences of the measuring person. Repeated measurements at different times but identical scanner positions can be compared directly, whereas repeated conventional forest inventories done by different persons possibly differ remarkably. Finally another advantage of terrestrial laser scanning of forests should be mentioned; scanning of forests provides a large data pool that can be used for a wide range of investigations. One example from forest ecology could be the analysis of relative light distributions from laser scans of wooden areas (Wagner, 1994, Anderson, 1964), which could be derived from panoramic scanner systems with only minor alterations of the analysis software. These results could be used for a prognosis of the success of natural regeneration of certain tree-species. A scanned 3D point cloud of forest sceneries can be seen as an intensive documentation of a certain place at a certain time, so the mentioned data pool could be the base for analysing changes of the states of natural sceneries. Terrestrial laser scanning of forests therefore extends the spectrum of data acquisition methods in forest inventories to a new dimension. On the other hand future improvements in hardware technology, algorithms which reduce calculation time as well as robust models for data analysis are required to establish this technique in the future.

6. REFERENCES

Anderson, M.C., 1964. Studies of the woodland light climate. *Journal of Ecology,* 52, pp. 27- 41.

Aschoff, T.; Spiecker, H., 2004. Algorithms for the automatic detection of trees in laser scanner data. In: Thies, M.; Koch, B.; Spiecker, H.; Weinacker, H. (ed.), Laser-Scanners for Forest and Landscape Assessment. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* Vol. XXXVI- 8/W2.

Aschoff, T.; Thies, M.; Spiecker, H., 2004. Describing forest stands using terrestrial laser-scanning. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* Vol. XXXV, Comm. 5, pp. 237- 241.

Brink, C.; Gadow, K.v., 1986. On the use of growth and decay functions for modelling stem profiles. *EDV in Medizin und Biologie,* 17(1/2), pp. 20- 27.

Forstliche Versuchs- und Forschungsanstalt Baden-Wuerttemberg, 1995. *Betriebsinventur auf Stichprobenbasis (BI) Baden-Wuerttemberg.* Verfahrensbeschreibung und Aufnahmeanweisung. Freiburg. pp. 20. (in German).

Fröhlich, C.; Mettenleiter, M., 2004. Terrestrial Laser Scanning – New Perspectives in 3D Surveying. In: Thies, M.; Koch, B.; Spiecker, H.; Weinacker, H. (ed.), Laser-Scanners for Forest and Landscape Assessment. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* Vol. XXXVI- 8/W2.

Hopkinson, C.; Chasmer, L.; Young-Pow, C.; Treitz, P., 2004. Assessing forest metrics with a ground-based scanning lidar. *Can. J. Forest Research,* 34, pp.573- 583.

Pfeifer, N.; Gorte, B.; Winterhalder, D., 2004. Automatic reconstruction of single trees from terrestrial laser scanner data. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* Vol. XXXV, Comm. 5., Part B, pp. 114-119.

Pfeifer, N; Winterhalder, D., 2004. Modelling of tree cross sections from terrestrial laser scanning data with free-form curves. In: Thies, M.; Koch, B.; Spiecker, H.; Weinacker, H. (ed.), Laser-Scanners for Forest and Landscape Assessment. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* Vol. XXXVI- 8/W2.

Prodan, M., 1965. *Holzmesslehre*. J. D. Sauerländer's Verlag. Frankfurt a.M., pp. 644. (in German).

Riemer, T.; Gadow, K.v.; Sloboda, B., 1995. Ein Modell zur Beschreibung von Baumschäften. *Allgemeine Forst- und Jagdzeitung,* 166(7), pp. 144- 147. (in German).

Schreuder, H. T.; Gregoire, T. G.; Wood, G. B., 1993. *Sampling methods for multiresource forest inventory*. Wiley, New York, pp. 446.

Schütt, C.; Aschoff, T.; Winterhalder, D.; Thies, M.; Kretschmer, U., Spiecker, H., 2004. Approaches for recognition of wood quality of standing trees based on terrestrial laserscanner data. In: Thies, M.; Koch, B.; Spiecker, H.; Weinacker, H. (ed.), Laser-Scanners for Forest and Landscape Assessment. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences* Vol. XXXVI-8/W2.

Shiver, B. D.; Borders, B. E., 1996. *Sampling techniques for forest resource inventory*. Wiley, New York, pp. 356.

Simonse, M.; Aschoff, T.; Spiecker, H.; Thies, M., 2003. Automatic Determination of Forest Inventory Parameters Using Terrestrial Laserscanning. *Proc. ScandLaser Scientific Workshop on Airborne Laser Scanning of Forests*, Umeå, Sweden, pp. 251- 257.

Thies, M.; Pfeifer, N.; Winterhalder, D.; Gorte, B.G.H., 2004. 3-D reconstruction of stems for taper, sweep and lean assessment based on laser scanning of standing trees. *Scandinavian Journal of Forest Research*. (in review).

Thies, M.; Aschoff, T.; Spiecker, H., 2003. Terrestrische Laserscanner im Forst - für forstliche Inventur und wissenschaftliche Datenerfassung. *AFZ/Der Wald,* 58(22), pp. 1126-1129. (in German).

Thies, M.; Koch, B.; Spiecker, H., 2002. Einsatzmöglichkeiten von Laserscannern für Wald- und Landschaftsinventuren. *AFZ/ Der Wald,* 57(8), pp. 395- 397. (in German).

Vries, P. G. de, 1986. *Sampling theory for forest inventory: a teach yourself course*. Springer, Berlin; Heidelberg, pp. 399.

VwV-BWI II, 2000. Allgemeine Verwaltungsvorschrift zur Durchfürhung der Bundeswaldinventur II (VwV-BWI II). *Bundesanzeiger 52*(146a), pp. 20. (in German).

Wagner, S., 1994. Strahlungsschätzung in Wäldern durch hemispärische Fotos – Methode und Anwendung. *Berichte des Forschungszentrums Waldökosysteme,* Reihe A, Band 123, pp. 165. (in German).

Watt, P.J.; Donoghue, D.N.M.; Dunford, R.W., 2003. Forest Parameter Extraction Using Terrestrial Laser Scanning. *Proc. ScandLaser Scientific Workshop on Airborne Laser Scanning of Forests*, Umeå, Sweden, pp. 237- 244.

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