AUTOMATED TREE DETECTION AND MEASUREMENT IN TEMPERATE FORESTS OF CENTRAL EUROPE USING LASERSCANNING DATA

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ABSTRACT:

The purpose of this study was to test a method for delineating individual tree crowns using a fully automated object-based pattern recognition methodology. The study material included small-footprint time-of-flight laser scanner data acquired over the Norway spruce (Picea abies) and European beech (Fagus sylvatica) dominated forests of the Bavarian Forest National Park near Passau, Germany. Ground reference data was collected in 28 sample plots, each 0.1 – 0.25 ha in area, containing a range of stand types. Laser data was acquired in the spring and summer of 2002 using a Toposys II airborne laser system. The concept of the evaluated delineation methodology is a pouring algorithm for the estimation of treetops and crown areas basing on a digital crown model. In order to enhance the results additional functions like ray tracing have been introduced to complete this main concept. Three individual tree attributes were sought in this analysis: stem position (x, y, z), tree height and mean crown radius. The number of trees that were detected using laser data was compared with field measurements. Altogether 2666 field measured trees were used for the accuracy assessment. The overall detection rate was 37.5 %. In the top layer 58.0 %, in the middle layer 5.2 % and in the lower layer 1.4 % of the trees were detected. The percentage of detected volume was 74.1 % of the total volume measured in the field. The tree detection was a function of stock density and the number of trees per hectare. The percentage of detected volume was better for coniferous trees (76.3 %) than for deciduous trees (70.4 %). High correlations were found between laser and ground measured tree height, with RMSE values of 1.44 m for all trees, of 1.38 m for coniferous trees and 1.51 m for deciduous trees. The correlation was also high between laser estimated and field measured crown radius. For trees within 20 stands, the RMSE was 0.94 m. The estimations for the coniferous tree crowns (RMSE 0.61 m) were more accurate than the measurements for the deciduous tree crowns (RMSE 0.96 m).

1. INTRODUCTION

In recent years new developments in computer hardware, software and remote-sensing technology are enabling the development of new approaches to image analysis. Hardware has become more powerful; programming tools (including algorithms) more available; and remotely-sensed data is now very high resolution and increasing in dimensionality (spectral, spatial, temporal). These developments will be the door opener for a broader use of remote sensing technology.

At the same time the administration of the Bavarian Forest National Park was seeking for new methodologies to fulfil the data requirements of the national park management. This was necessary because the traditional data acquisition with regularly distributed permanent sample plots and the mapping of forest developmental stages in the park is a very challenging attempt: the remoteness of the area in combination with high amounts of laying and standing dead wood makes data collection expensive and dangerous for the inventory staff. Moreover the traditional methods of forest inventory and stand mapping can hardly deliver continuos information about different forest structures. But this information is especially important for conservation issues like habitat modelling to predict the distribution of species. To bring together the information needs of the national park administration and the new developments in remote sensing the project "Evaluation of remote sensing based methods for the identification of forest structures" was started in 2002. During this project a large amount of different data types were gathered including IfSAR, small footprint laser scanner (different seasons) and imagery of different optical sensors like digital and conventional cameras and optical scanners. Moreover a large ground data set was gathered simultaneously. At 48 reference plots every tree was measured and its x,y,z coordinates were determined with centimetre accuracy. Also 714 inventory plots were measured and a terrestrial mapping of the forest developmental phases was conducted. In the next step of the project several methodologies and data sources have been evaluated in the context of forest structure mapping on an individual tree and stand level. This knowledge will lead to the development of applications which fulfil the needs of the national park administration (Blaschke et al. 2004, Burnett et al. 2003, Heurich et al. 2003, Heurich et al. 2004 a, b, c, Krzystek 2003, Ochs et al. 2003, Tiede et al. 2004 a, b).

In the presented study an algorithm for individual tree detection developed by the department of remote sensing and landscape information systems at the University of Freiburg (Diedershagen et al. 2003, Weinacker et al. 2004) was tested. The algorithm automatically estimates tree position, tree height and mean crown radius of individual trees based on laser data. These results were subsequently checked against field measurements of stem position, tree height and crown radius of different forest types within the Bavarian Forest National Park.

2. MATERIAL

2.1 Study Area

The study area is located in the Bavarian Forest National Park, which is situated, in southeastern Germany along the border to the Czech Republic (49° 3' 19" N, 13° 12' 9"E). Within the park three major forest types exist: above 1100 m there are sub alpine spruce forests with Norway spruce (Picea abies) and partly Mountain ash (Sorbus aucuparia); on the slopes between 600 m and 1100 m altitude, mountain mixed forests with Norway spruce, White fir (Abies alba), European beech (Fagus sylvatica) and Sycamore maple (Acer pseudoplatanus) can be found; in wet depressions often evidencing cold air ponds in the valley bottoms spruce forests with Norway spruce, Mountain ash and birches (Betula pendula, Betula pubescens) occur.

2.2 Field Data

28 sample plots with a size between 20 by 50 m and 50 by 50 m were selected in all of the described forest zones. The field data was collected from May to November 2002. Two plots (74 and 81) were measured in 1999. Several tree parameters like the diameter at breast height, total tree height and starting point of crown were determined for each tree being higher than 5m. The height measurements were carried out with the "Vertex" III system following the definitions of Kramer and Akca (1995). In the plots 74 and 81 the height measurements were only performed for a sample of trees. To determine the projection of the crown the radii along the 8 main axes were measured with a mirror device (Röhle & Huber, 1985; Röhle, 1986). Out of these measurements the geometric mean for the crown radius was calculated. Crown measurements were only performed for 19 stands. Each stem position was precisely measured by tachometry and DGPS. The absolute accuracy was comprehensively checked and was estimated to 1-2 cm. The volume of each single tree was determined by volume equations derived by Kennel (1973). The description of the different stands can be found in Table 1.

ID	age	height a.s.l.	slope %	decid. %	N / ha	stock dens.	V / ha	H dom	SD height
21	170	860	6.4	86	260	0.86	449	32.9	13.22
22	170	885	29.8	71	250	1.05	668	36.3	11.86
50	160	1240	9.5	0	225	1.0	472	27.0	3.36
51	135	1225	1.5	0	370	1.25	563	27.2	4.73
52	165	1220	11.5	0	300	1.01	453	27.1	7.7
53	65	1235	24.2	1	1950	1.59	344	17.6	3.44
54	70	1160	20.2	100	1880	2.08	365	20.1	4.45
55	250	610	0.4	1	810	1.14	793	43.5	11.07
56	170	640	16.9	4	475	1.42	124	49.0	14.88
57	95	765	13.1	0	410	1.03	121	42.1	3.63
58	90	710	13.6	10	320	0.86	982	44.5	13.88
59	40	810	2.7	6	1610	1.29	588	27.8	6.33
60	110	890	15.3	100	320	1.12	577	34.5	7.89
61	120	850	16.8	74	280	1.17	713	36.6	8.91
62	145	784	3.0	0	390	0.89	824	36.9	11.75
63	75	805	2.9	41	792	1.23	742	35.6	9.08
64	105	835	4.6	100	258	0.69	290	30.8	8.81
65	95	875	13.0	96	758	1.36	582	33.2	8.69
74	85	710	26.7	23	717	1.41	100	36.4	5.58
81	70	690	26.6	100	783	1.18	385	26.6	5.05
91	110	760	15.7	65	258	0.68	498	38.2	11.9
92	110	760	13.3	100	180	0.65	394	36.4	10.78
93	110	760	14.3	61	236	0.8	610	38.0	14.2
94	110	760	15.7	99	253	0.79	447	35.6	11.09
95	110	760	16	4	244	0.67	762	41.2	8.31
96	110	760	16.9	49	310	0.88	683	34.6	12.45
97	110	760	13.9	83	270	0.82	447	33.2	8.84
98	110	760	16	100	230	0.67	398	36.9	12.81

Table 1: Characteristics of the field plots: height a.s.l (height above sea level), slope (slope measured in percent), % decid.(percentage of deciduous trees), stock dens. (stock density), N/ha (number of trees per ha), V/ha (timber volume per ha), H dom (dominant height, average height of the 100 tallest trees per hectar), SD heigh (standard deviation of tree heights measured in the field)

2.3 Laser Scanner:

There were two flights with the "Toposys II" airborne laser scanner system from Topografische Systemdaten GmbH (TopoSys). The TopoSys System is based on two separate glas fibre arrays of 127 fibres each. Its specific design produces a push-broom measurement pattern on ground. For further details see Wehr and Lohr (1999). For this analysis the data of a flight in spring (DTM) and summer 2002 (DSM) was used. The average point density within this flight was 10 pts/m². First and last pulse data was collected during the flight (Table 2).

Sensor type	Pulsed fibre scanner
Wave length	1560 nm
Pulse length	5 nsec
Scan rate	653 Hz
Pulse repetition rate	83.000 Hz
Scan with	14.3°
Data recording	first and last pulse
Flight height	800 m
Size of footprint	0.8 cm

Table 2: System parameters during the Laser Scanner flight

3. METHODS

3.1 Algorithm

The individual tree recognition was achieved by an approach developed at the University of Freiburg. The procedure is based on a rasterised DSM and DTM. First a digital crown model (DCM) is calculated by subtracting the DTM from the DSM. In the next step the DCM is divided into two height classes, low and high. The class high is smoothed stronger with a gaussian filter as the class low. After this procedure the different patches are merged again. Then the local maxima arre extracted and used as seed points for a pouring algorithm with which the crown areas are approximated. In order to enhance the results additional functions, concerning geometric relations of and between trees that are basing on knowledge about trees are applied. For more details see Diedershagen et al. (2003) and Weinacker et al. (2004).

3.2 Accuracy Assessment

For the evaluation of the results the field trees were linked to the laser trees by their position. In a first step all field trees within a laser crown polygon were selected. To take asymmetric crowns into consideration all field trees within a distance of 3 m to the position of the laser tree were selected in a second step.

After this linking three different classes could occur:

1) One laser tree was linked to one field tree
2) One laser tree was linked to several field trees
3) The laser tree could not be linked to a field tree

For (1) the three was linked to the according field tree, when their height difference was less than 5 m. For (2) the laser tree with a height closest to the height of the field tree was linked if the height difference was less than 5m. The other trees were considered as not detected. For (3) the laser tree was judged as a false positive. The linkage of the individual field tree with the according laser tree offered the possibility to analyse the detection rate and the accuracy of the laser system for height and crown radius estimations. For the computation of the detection rate of the trees three different height classes were distinguished. Upper layer: largest tree height to 2/3 of dominant height, middle layer: 2/3 to 1/3 of the dominant height, lower layer 1/3 of dominant height and lower.

The RMSE was calculated as the root-mean-square of the difference between field-measured and estimated values.
To detect relations between the characteristic parameters of the field plots and the analysis results a Spearman rank correlation was applied. Only results with alpha <0.05 were reported.

4. RESULTS

4.1 Numbers and volume of detected trees

Altogether 2666 trees were included in this study. The algorithm detected 1000 of them, which is 37.5 %. Also 77 which is 2.9 % were detected were there was no corresponding field tree. 32.6 % of the deciduous trees were detected. The percentage of false positives was 2.9 %. For coniferous trees the detection rate was better, 43.5 % of the trees were detected the percentage of false trees was also 2.9 %. The reason for this relatively small amount of detected trees is that the applied method can hardly detect trees beneath the surface. In the middle layer only 5.2 % and in the lower layer only 1.4 % of the field trees were detected. But in the top layer the detection rate was much better with 57.5 %.

Despite the low percentage in the number of detected trees the percentage of detected volume was much higher. Across all stands 74.1% of the timber volume was detected. While 70.4 % of the volume of deciduous trees was detected the percentage of detected volume for coniferous trees was 76.3 %.

The most influential parameter to the proportion of detected trees were the number of trees per hectare and the stock density. A significant negative relation of these parameters was found to the percentage of detected trees, the percentage of detected trees in the top layer and for the percentage of detected volume. For the percentage of false positives a significant correlation to the standard deviation of the tree heights measured in the field and a negative correlation to the number of trees per hectare and the stock density was detected (Table 3).

4.1 Accuracy of tree height measurements

The mean value and the standard deviation were determined only for 383 deciduous and 474 coniferous trees, which were measured in 2002. The trees measured in 1999 were excluded for this analysis.

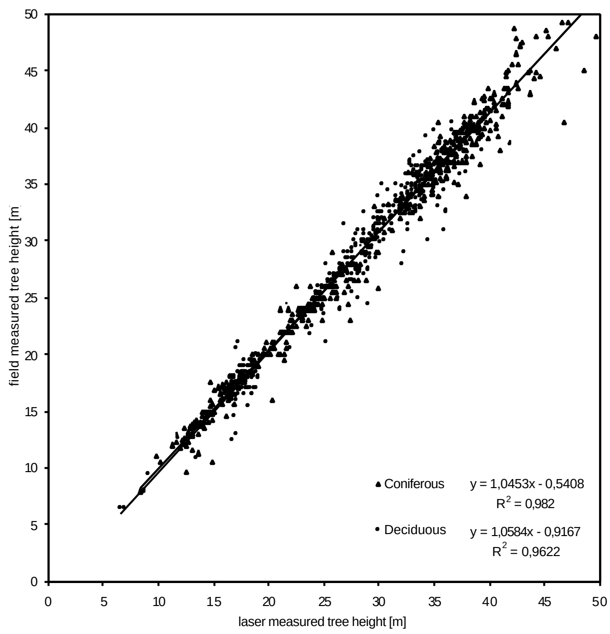

Figure 1: Laser measured tree height versus field measured tree height (857 trees).

For all trees the mean value of the differences between laser tree height and field tree height was –0.74 m, the standard deviation was 1.50 and the RMSE 1.44 m. For the deciduous trees the mean value of the height differences between laser trees and ground trees was –0.71 m, the standard deviation was 1.56 m and the RSME 1.51 m. For the coniferous trees the mean value was –0.76 m the standard deviation was 1.45 m and the RSME 1.38 m. The coefficient of determination for all trees was 0.98, for the deciduous trees 0.96 m and for the coniferous trees 0.98 m.

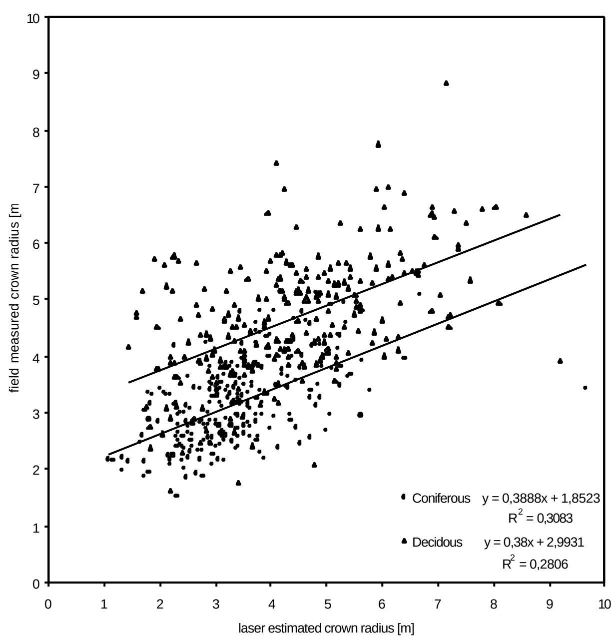

Figure 2: Laser measured crown radius versus field measured crown radius (546 trees).

Between the parameters characterising the field plots and the results of the analysis the following significant relation were found. The mean difference of field and laser height measurements was correlated to the number of trees per hectare and the stock density. The mean of the absolute differences of the same measurements was correlated to the dominant height of the stand. The values for the RMSE showed a significant relation to the standard deviation of the tree heights measured in the field (Table 3).

4.2 Accuracy of tree crown measurements

Altogether 546 field-measured trees could be linked to laser trees. 287 of them were deciduous and 259 coniferous trees.

The mean value of the differences between field measurements of the crown radius and the laser scanner estimated crown radius were 0.05 m for all trees, 0.22 m for coniferous and -0.21 m for deciduous trees. The standard deviations for the same measurements were 1.16 m, 0.89 m and 1.32 m for all trees, deciduous trees and coniferous trees respectively. The RMSE values showed the same tendency with 0.94 m , 0.61 m and 0.96 m for the three classes. The coefficients of determination were 0.37, 0.31 and 0.28 for all trees, coniferous trees and deciduous trees respectively (Figure 2).

The stand characteristics, which show a significant relation to results of the analyses of the crown estimations, were the standard deviation of the height of the field trees the number of threes per hectare, the stock density and the percentage of deciduous trees in the stand. While the standard deviation of the field measured tree heights was negative correlated to the mean value of the differences between laser and field measured crown radii the number of trees per hectare and the stock density were positive correlated. The RMSE showed a negative relation to the number of trees per hectare and a positive to the standard deviation of the tree heights measured in the field. The RMSE showed also a positive relation to the percentage of deciduous trees (Table 3).

ID	height[m]		crown [m]		detection [%]		
	mean	rmse	mean	rmse	trees	false	volume
21	-0.82	2.18	-1.17	0.80	63.64	11.49	81.78
22	-0.02	1.79	-0.22	1.02	59.46	8.82	75.31
50	-0.44	0.92	0.50	0.74	88.37	8.70	91.19
51	-0.76	0.62	0.75	0.62	85.71	2.04	89.21
52	0.25	1.06	0.57	0.39	76.92	2.56	84.92
53	-0.23	0.97	-	-	60.83	0.00	63.47
54	-0.06	1.07	-	-	60.67	4.26	70.11
55	-0.22	2.34	-	-	72.22	2.61	67.98
56	3.51	3.38	-	-	88.24	4.82	83.09
57	-1.78	1.24	1.38	0.44	61.36	0.00	67.08
58	-1.46	1.89	-	-	53.33	10.87	63.22
59	-0.32	0.83	-	-	60.26	0.92	52.31
60	-1.29	1.77	0.15	0.69	58.06	0.00	68.09
61	-1.26	1.48	1.43	0.71	55.17	2.22	62.72
62	-0.33	0.71	-	-	52.94	3.92	63.17
63	-0.56	1.10	0.63	0.68	68.42	2.59	72.45
64	-0.95	1.72	0.98	0.70	67.57	2.04	75.26
65	-0.55	1.83	0.16	0.75	51.85	0.00	69.84
74	0.64	1.02	-	-	40.59	0.00	56.57
81	1.82	0.86	-	-	39.47	0.00	51.18
91	-0.75	1.65	-0.25	0.87	71.19	9.47	79.70
92	-1.84	1.22	-0.02	0.93	82.76	5.13	92.80
93	-1.15	0.78	-0.75	0.74	77.97	9.09	84.10
94	-1.45	0.83	-0.46	0.64	75.47	1.37	84.27
95	-1.67	0.82	-0.28	0.48	80.77	1.75	84.95
96	-1.36	1.67	-0.44	0.73	84.62	6.56	86.62
97	-0.55	0.74	0.25	0.44	67.65	0.00	83.25
98	-0.83	1.59	-0.52	1.14	92.00	4.17	93.25
Av	-0.52	1.36	0.14	0.71	67.77	3.76	74.93

Table 3: Results for the field plots: height mean (mean of the height differences between laser and field measured trees), height rmse (rmse of the height differences between laser and field measured trees), crown mean (mean of the differences between laser and field measured crown diameter), crown rmse (rmse of the differences between laser and field measured crown radius), detection trees (percentage of detected trees belonging to the top layer) detection false (percentage of false positives), detection volume detected (percentage of detected timber volume and volume determined on ground).

5. DISCUSSION

These results clearly show the ability of laser scanner data for the identification of individual trees. In this study all forest zones of the National Park with its different structures were included. Ranging from simple single layer, single species spruce stands in the sub alpine zone to very complex, multi layered, mixed stands in the zone of the mixed mountain forests. Although the percentage of detected trees seems low, only 37.5 % of the field measured trees were detected, one have to take into consideration that most of the trees which were not detected are the smaller ones which belong to the lower and middle layer. From an economical point of view this portion of trees is not important so that for most commercial forestry activities only the trees of the top layer that contain most of the valuable timber were taken into account. In this layer the detection rate ranged between 40 % in young and dense stands up to more than 90 % in old and sparse stands. Across all stands 67.8 % of the trees were detected. In comparison to these results Heurich et al. (2003) were able to detect 72.1 % of the trees belonging the top layer by visual interpretation using the digital crown model. For that study 21 stands from the same data set were analysed. In comparison to the automatic delineation a higher percentage of trees was detected in the middle (21.7 %) and lower layer (8.27 %) by the human interpreter. Because manly the tallest trees with the largest crowns were delineated, the proportion of the detected timber volume was even higher. Therefore the average proportion of detected volume for all stands was 75 %. As a result the applied method underestimates the number of the trees, but the reliability of the delineated trees was very good. Only 2.9 % of them were false positives. The most influential factors on the detection rate in this study were the number of trees per hectare and the stock density as to expect.

As shown in other studies, a systematic underestimation of the tree height by using the laser data was found. The average of the differences between field and laser measurements was 0.74 m. Coniferous and deciduous trees show similar values. This underestimation can be explained by the structure of the treetops. The new shots or small branches are to small to cause a backscattering, which can be recorded by the sensor. Also the RMSE values of coniferous and deciduous trees showed no big differences (1.51 m, 1.38 m). In a study which took place in boreal forest conditions in southern Sweden a RMSE of 0.63 m was achieved (Persson et al. 2002). From tree height estimations also in a forest dominated by Norway spruce and Scots pine, Hyyppä et al. (2000) reported a RMSE of 0.98 m. Heurich et al. (2003) found almost the same underestimation of coniferous trees (-0.79 m) but with – 0.37 m a smaller underestimation of deciduous trees. Also the standard deviation for the differences between field and laser measurements was higher for deciduous

(1.43 m) than for coniferous trees (1.24 m). By comparing the different stands the dominant height and the standard deviation of the heights measured in the field were the most influential parameters for the height determination. The dominant height of the tree theoretically should not have an influence on the quality of the laser measurements. Therefore this source of error can be related to the field measurements. In the field it is especially difficult to get good height measurements for deciduous and very high trees. For both classes it is hard to detect the shoots of the trees especially in the vegetation period. Moreover the measurement angle becomes very steep for high trees which can cause a larger error. In comparison with the accuracy of methods for height determination in the field (Eckmüllner and Rieger 2000, Bauer 2001) the laser measurement seems to be at least as accurate but probably even more accurate especially for deciduous and high trees..

Also the height variation in the canopy has an impact on the quality of the laser height measurements. This could be caused by the difficulties to generate the DSM in such stands. Further analysis will focus on this issue. Also the tree measurements in field are more difficult in such stands because a large variability in tree height is often accompanied by a dense regeneration and understory which makes it difficult to spot the treetops.

The analysis of the crown radius estimations showed an underestimation of deciduous trees and an overestimation of coniferous trees. The means of the differences between field and laser measurements were – 0.21 m and + 0.22 m for deciduous and coniferous trees respectively. Also the algorithms applied by Hyyppä et al. (2001) lead to an overestimation of the estimated crown size in coniferous stands. The variability between field and laser derived grown measurements, described by the RMSE was higher for deciduous trees (0.96 m) and lower for coniferous trees (0.61 m). In comparison Persson et al. (2002) report a RMSE of 0.61 m for boreal forest conditions. By comparing the different stands the standard deviation of the heights measured in the field was found to have a significant influence on the crown radius estimation. As discussed for the height measurements this could be caused by the difficulties to generate the surface model for such stands. Also the accuracy of the field measurements with a crown mirror device could be a source of error (Röhle, 1986).

6. CONCLUSIONS

As presented in other studies the laser scanner measurements show pretty accurate results for tree height estimation. The crown estimation is not as accurate as the tree height estimation. Especially for deciduous trees the crown delineation has to be improved which could also led to a better detection of deciduous trees. To find out the best season for laser scanning campaigns the presented evaluation should be repeated for a data set of deciduous trees in winter and comlpleted by estimating stem diameter, timber volume and biomass.
Besides the limitation that more or less only the large trees of the top layer were sampled the evaluated method is well suited to provide us with information which we were not able to gather with a reasonable effort up to now. The results are a continuous representation of the horizontal and (limited) vertical forest structure. With this data it is possible to gather information about small planning units were the traditional sampling methods fail to provide us with sound data. In addition this data will also be a very important source for other environmental applications like habitat modeling were a continuous representation of the forest is needed.

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