Developing Strategies for Large Scale Forest Inventories Combining LiDAR Data, Satellite Imagery and Regional Yield Models

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Abstract

The work illustrates a practical and economical way to combine airborne laser scanning data (ALS) and spectral information from Quickbird Satellite Imagery and digital orthophotos with regional yield models in order to assess the stand volume and other relevant forest parameters. The automatic detection of individual trees from Quickbird Satellite images and true-orthophotos by means of Object Based Image Analysis (OBIA) as well as the detection of trees purely based on laser point data is demonstrated on the example of (a) privately owned single tree selection stands so-called Plenter Woods (stemming from the German term "Plenterwald") in the Black Forest in Baden-Wuerttemberg and (b) state owned and mainly even aged forests in Saxonia and Poland.

The privately owned Plenter Woods are characterised by diverse silvicultural structures resulting from the traditional single tree selection management, therefore the standing wood volume has been assessed by a tree wise calculation based on specific yield tables which were linked-up with data of small sample plots to correlate the tree height with the diameter (DBH) and to verify the results. Even-aged and mono-structured stands are typical for cut and plant systems and normally are well represented by regional yield models, which – under certain conditions – can be used to assess the wood volume stand wise, as demonstrated on the example of the state owned forests in Saxonia.

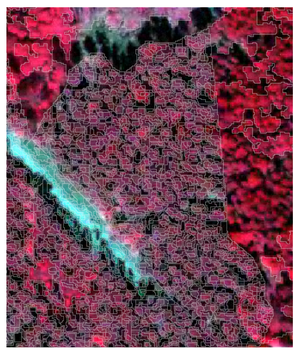
Additional publications and detailed information on both cases – the Plenter Woods and the Forests in Saxonia – can be found at http://laser.landConsult.de

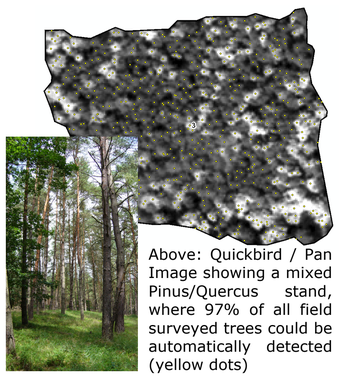
1. Objectives and Material

The more specific objective of this study is to assess the suitability of Object Based Image Analysis (OBIA) to process Quickbird Satellite and/or aerial imagery in combination with Airborne Laser Scanning data (ALS) for the inventory of complex selection forests as well as less structured even-aged stands. Three test plots of typical conifer selection woods in the Black Forest are currently under research. The sites are covered with a Quickbird Satellite Scene from Sept. 2007 (ground resolution panchromatic ca. 60 cm, NIR/MS ca. 2.4 m, color-range 11bit, Off-Nadir 22 degree), and ALS Data from TopScan (ca. 1.4 pt/sqm) plus common orthophotos (RGB, 8bit, ground resolution 25 cm). For the Polish case study another Quickbird Image has been processed to demonstrate the performance of OBIA in even-aged old growth forests. In Saxonia ALS data from TopScan (ca. 1.4 pts/sqm) and from TopoSys (ca. 5 pts/sqm) as well as common NIR orthophotos and a 50 cm true-orthophoto have been analysed to process some 500 ha state forests and automatically determine tree height and species of some 160.000 individual trees.

2. Detection of Individual Trees

2.1 Case Study Even-Aged Forest



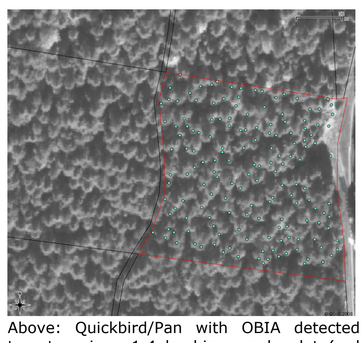


Above: Quickbird / Pan Image showing a mixed Pinus/Quercus stand, where 97% of all field surveyed trees could be automatically detected (yellow dots)

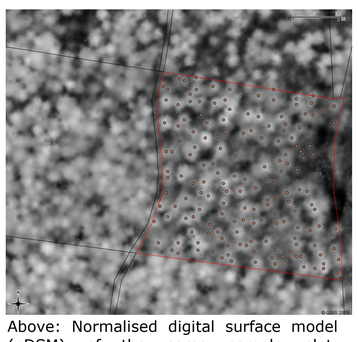
Left: Quickbird /NIR from an old growth mixed pinus forests in Poland. By means of OBIA the crown centre has been delineated to locate the treetop and perform a crown based NDVI analysis to determine tree species and e.g. needle loss. For different pinus forests in Poland a detection rate between 92 to 97% could be achieved.

Above: a true-orthophoto (NIR) of an even-aged forest stand in Saxonia. The different coloured polygons are the result of the OBIA process, illustrating the crown centre with different NDVI values, used to discriminate tree species.

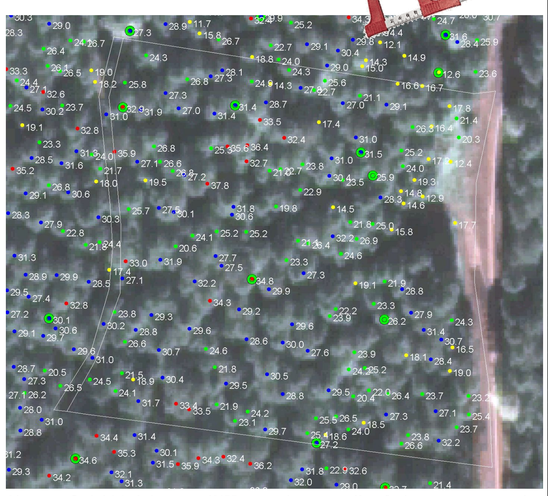
2.2 Case Study "Selection Forest" (Plenter Wood)



Above: Quickbird/Pan with OBIA detected tree tops in a 1.4 ha big sample plot (red polygon) of a a typical selection forest (Plenter Wood) in the Black Forest. Different from the other two plots, the stand is characterised by a high percentage of young growth and naturally regenerated trees in the second story, which influences the detection rate negatively (about 66% of the total volume and some 16% of all trees could be automatically detected).



Above: Normalised digital surface model (nDSM) of the same sample plot, generated from ALS data with a density of 1.4 points/sqm. Alternatively, the nDSM has been processed with a local maxima algorithm to detect single trees. But compared to the OBIA tree detection rate, the results could only slightly be improved by 1.8 %.



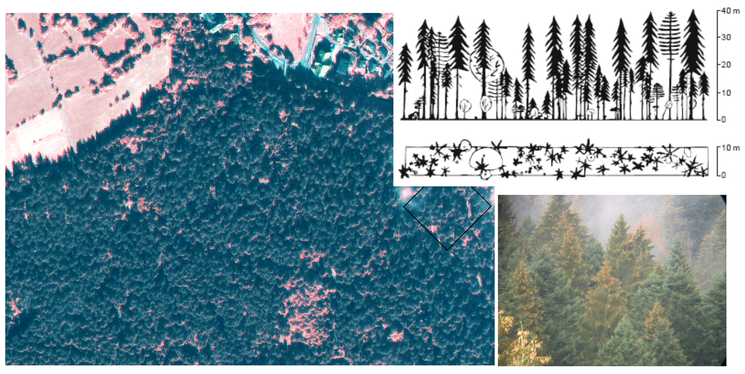
Above: Quickbird image (NIR pansharpened) of the same sample plot (white polygon, 1.4 ha), showing the detected trees grouped in height classes indicated by different colours and labelled with their tree height in meter, which is derived from the Laser nDSM.

Tree Height in m	DBH Class	DBH in cm	Height/Diameter Ratio	Standing Stock (in cbm)
37.8	21	84	0.45	9.43
36.4	20	80	0.46	8.32
35.9	20	80	0.45	8.10
35.6	20	80	0.45	7.96
34.8	19	76	0.46	7.23
34.3	19	76	0.45	7.02
33.5	19	76	0.44	6.70
33.5	19	76	0.44	6.70
33.4	19	76	0.44	6.66
33.0	18	72	0.46	6.16
32.9	18	72	0.46	6.12
32.7	18	72	0.45	6.05
32.4	18	72	0.45	5.94
32.2	17	68	0.47	5.54
32.2	17	68	0.47	5.54
32.2	17	68	0.47	5.54
31.9	17	68	0.47	5.43
31.9	17	68	0.47	5.43
31.8	17	68	0.47	5.40
31.7	16	64	0.50	5.05
31.5	16	64	0.49	4.99
31.4	16	64	0.49	4.96
31.4	16	64	0.49	4.96
31.4	16	64	0.49	4.96
31.0	16	64	0.48	4.83
31.0	16	64	0.48	4.83
31.0	16	64	0.48	4.83
31.0	16	64	0.48	4.83
30.7	16	64	0.48	4.74
30.7	16	64	0.48	4.74
30.6	16	64	0.48	4.71
30.5	16	64	0.48	4.68
29.6	15	60	0.49	4.12
28.4	14	56	0.51	3.54
27.1	13	52	0.52	3.00
25.8	12	48	0.54	2.50
24.4	11	44	0.55	2.05
22.9	10	40	0.57	1.65
21.3	9	36	0.59	1.29
19.7	8	32	0.61	0.97
17.8	7	28	0.64	0.70
15.8	6	24	0.66	0.47
13.6	5	20	0.68	0.29
11.0	4	16	0.69	0.15
7.9	3	12	0.66	0.06
4.3	2	8.5	0.50	0.01

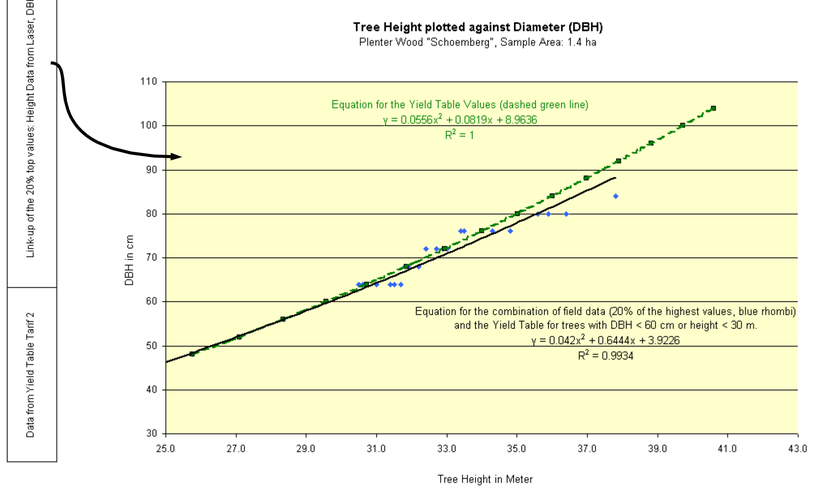
3. Wood Volume Calculation with ALS and Regional Yield Models

3.1 Case Study "Selection Forest" (Plenter Wood)

Right: Quickbird/NIR showing an old Plenter Wood in the northern part of the Black Forest and the marked 1 ha sample plot (black square on the right image border). The sketch (taken from Schütz 1969) and the photo on the lower right illustrate the diverse structure of this nature-like conifer dominated forest type.
Apart from the technical quality of the ALS and Image data, the accuracy of the volume assessment mainly depends on the percentage of old growth trees within the stand. Preliminary results of the study indicate that in this sample plot on the right figure a detection rate of up to over 90% of the total volume can be expected.

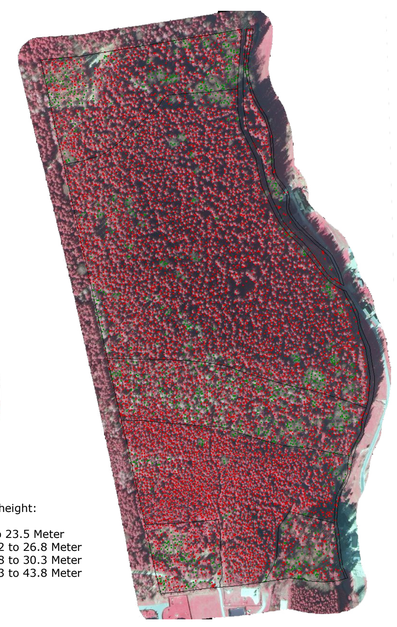


In order to assign the DBH to the height measured trees, one has to know the ratio between height and DBH. This ratio is implemented in regional yield models or tables, such as the specific yield model for Plenter Woods (Landesforstverwaltung Baden-Württemberg, 1993). The model is divided into 5 different "height-scales" ("Höhentarife"), which consider the specific site fertility and consequently the different ratio between tree height and DBH. In order to select the right model, the DBH and the tree height of some sample trees have to be measured (with the known accuracy problems of heights measured from the ground).
More accurate laser heights in combination with a few DBH measurements on the ground can be used to generate a representing height/DBH ratio, if the sampling occurs on a predefined area and if the assumption is valid, that the highest conifers in a collective stand correlate to the highest DBHs. Under these pre-conditions one can link-up the top laser tree heights with the top field surveyed DBHs. Doing so, will result in a height curve representing the highest trees only. Therefore data from the existing yield table has to be added for smaller trees to represent the entire population. This process is illustrated on the left figure and the results are shown in the following graphs below.
The generated equations can then be used to calculate the wood volume for large areas.

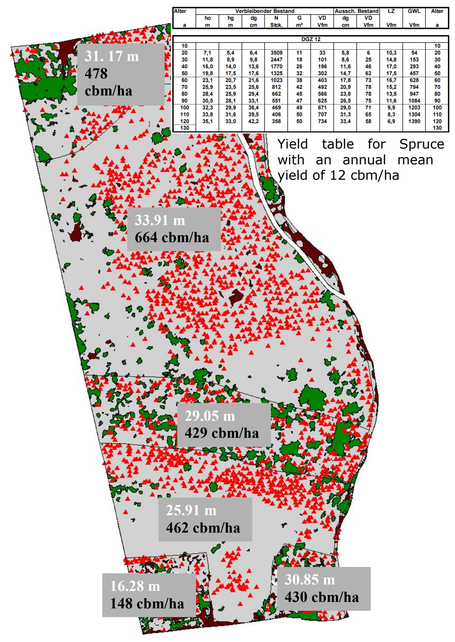


3.3 Case Study: using Yield Tables for even-aged forests

Above: Individual tree tops and tree height after processing the nDSM with a *local maxima* algorithm. From the individual tree heights, the mean average height of all trees and the maximum height of the hundred highest trees per ha and per stand will be calculated.

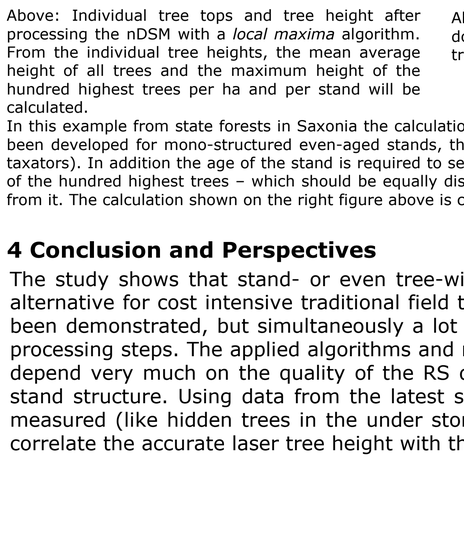


Above: CIR Mosaic with individual trees (red dots are conifers, green dots are broadleaf trees).



Yield table for Spruce with an annual mean yield of 12 cbm/ha

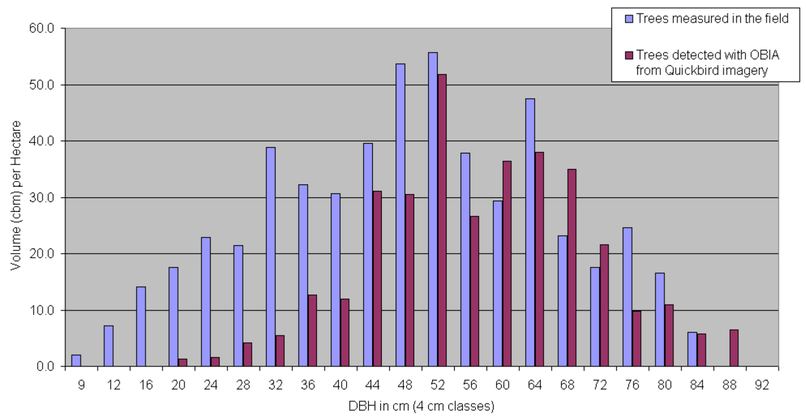
Alter a	Verbleibender Bestand: ho m	hg m	dg cm	N Stck.	G m²	VO Vfm	Ausgesch. Bestand: dg cm	VO Vfm	LZ Vfm	GWL Vfm	Alter a
					DGZ 12						
10											10
20	7,1	6,4	6,4	3509	11	33	5,8	6	10,3	54	20
30	11,8	9,9	9,8	2447	18	101	8,6	25	14,8	153	30
40	16,0	14,0	13,6	1770	26	196	11,6	46	17,0	293	40
50	19,6	17,5	17,6	1335	32	302	14,7	62	17,5	457	50
60	23,1	20,7	21,6	1033	38	403	17,8	73	16,7	628	60
70	26,9	23,5	25,6	812	42	492	20,9	78	15,2	794	70
80	28,4	25,9	29,4	662	45	566	23,8	78	13,8	947	80
90	30,6	28,1	33,1	551	47	625	26,5	75	11,6	1084	90
100	32,3	29,9	36,4	469	49	671	29,0	71	9,9	1203	100
110	33,8	31,6	39,5	406	50	707	31,3	65	8,3	1304	110
120	35,1	33,0	42,2	356	50	734	33,4	58	6,9	1390	120
130											130

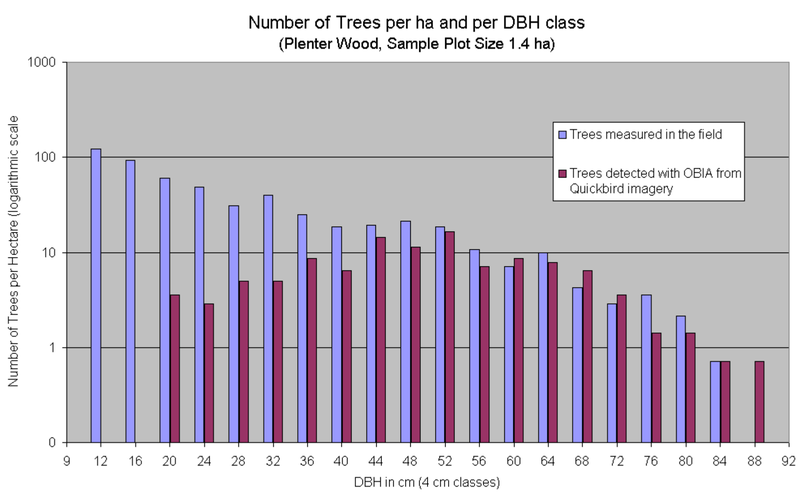


Above: Map with the calculated conifer wood volume in solid cubic meter of standing crop per ha (cbm/ha, black numbers) and the mean height of the hundred highest conifer trees per ha (in meter, white numbers). The top 100 conifers are represented by the red triangles.

In this example from state forests in Saxonia the calculation of the stand wise wood volume is based on regional yield models for even aged forests. Those models have been developed for mono-structured even-aged stands, that´s why the delineation of homogeneous stands beforehand is necessary (unless already done by the forest taxators). In addition the age of the stand is required to select the adequate model and to assess the wood volume properly. If these preconditions are fulfilled the height of the hundred highest trees – which should be equally distributed over the stand - and the stand age are used to link the yield model and to retrieve the stand volume from it. The calculation shown on the right figure above is considering tree species (broadleaf areas are green, areas with conifers are grey) and openings (brown spots).

3.2 Comparison of Field Inventory and OBIA/ALS Inventory





4 Conclusion and Perspectives

The study shows that stand- or even tree-wise forest inventories based on Laser and Spectral Data are operational and provide an economical alternative for cost intensive traditional field taxations or generalising sample plot inventories. Here, only the assessment of the wood volume has been demonstrated, but simultaneously a lot of other forest relevant parameters can be delivered, often as a by-product of one of the necessary processing steps. The applied algorithms and methodologies are robust enough to process large areas. The critical detection rate of individual trees depend very much on the quality of the RS data (laser point density, spectral colour range of true-orthophotos, etc.) and finally on the vertical stand structure. Using data from the latest sensors and scanners can improve the shown results significantly. Where objects cannot directly be measured (like hidden trees in the under story), additional statistical methodologies have to be improved and applied, also to serve the need to correlate the accurate laser tree height with the DBH and the tree volume.