Full automatic detection of tree species based on delineated single tree crowns - a data fusion approach for airborne laser scanning data and aerial photographs

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Abstract

A full automated classification of tree species was tested on single tree level. This approach intends to classify without any parameter input or predefined knowledge. In the forerun it was therefore necessary to build algorithms which combine the LiDAR data based 2D single tree delineation with the spectral information from colour infrared (CIR) images. During the tree species classification the LiDAR based classification is improved by means of spectral information. The overall accuracy of the classification is more than 83 % for the tree types beech, oak and conifer and more than 90 % for deciduous trees and conifers. Splitting LiDAR based single tree polygons by spectral features improves the results by 7.42 %.

Keywords: tree species, single tree delineation, laser scanning, aerial photographs, data fusion

1. Introduction

Single tree based parameter extraction from airborne laser scanner (ALS) data is of increasing importance for forestry applications. Under special circumstances and for certain questions single trees are the only reliable units to work on. Where several tree species with a different growing behaviour occur within one stand, like in temperate forest, a stand-wise approach is often very difficult and needs a lot of a-priori knowledge (Koch *et al.* 2006). The tree species itself is highly correlated to a large number of other forestry parameters. It is a pre-requisite necessary to derive information like biomass and tree damage.

Tree delineation provides the system with objects that can be further classified. Numerous approaches have been undertaken, which make use of different data types and techniques. First techniques were based on multispectral data and are still being developed (Wang *et al.* 2004, Leckie *et al.* 2005, Wang *et al*. 2006). LiDAR predicated methods can be subcategorized by the usage of first and last pulse data, which mainly find use in 2D delineations (Koch *et al.* 2006, Tiede *et al.* 2006), and full waveform data, which allows to gain more exact 3D models of the crowns (Rossmann *et al*. 2007, Wang *et al.* 2007). In comparison there are only few attempts, as done by Leckie *et al.* (2003) and Wolf *et al.* (2007), to combine multispectral and LiDAR data.

Comparable data types have been used for the classification of tree species on single tree level. Multispectral based methods mostly build on thresholds of the spectral data or derived information (Koch *et al.* 2002, Leckie *et al.* 2005). Bohlin *et al.* (2006) work with crown templates which are matched to the trees on the image. Most of these operations use training samples and are therefore semiautomatic. Liang *et al.* (2007) and Reitberger *et al.* (2006) achieve good results in distinguishing coniferous and deciduous trees with LiDAR based attempts. Ørka *et al.* (2007) test the significance of intensity from multiple return data for classifying tree species. One of the few authors who tested a combination of laser data and multi-spectral images were Persson *et al.* (2006). They achieved an improved accuracy due the combination. Most procedures have in common that they work well for a number of about three species. The average accuracy ranges from 50 to 80 % of correctly classified objects from which the best results are achieved in distinguishing coniferous and deciduous trees.

The method developed in this study is structured in three main steps. (1) First the LiDAR based delineation of single trees is conducted with an algorithm developed by Koch *et al.* (2006). (2) Second the full automated tree species classification is done with spectral data and (3) third the LiDAR based delineation is corrected.

2. Method

2.1 Study areas

The first study area is located in the forest district 'Milicz' in Poland. The method was developed on a test site with a side length of 500 m which covers an area with the most variety and best mixture of tree types (see Figure 1). The algorithm was later tested on a second site with same dimensions. It contains four sample plots with field measured trees, but is characterised by more difficulties like large shadowed areas and more tree height levels.

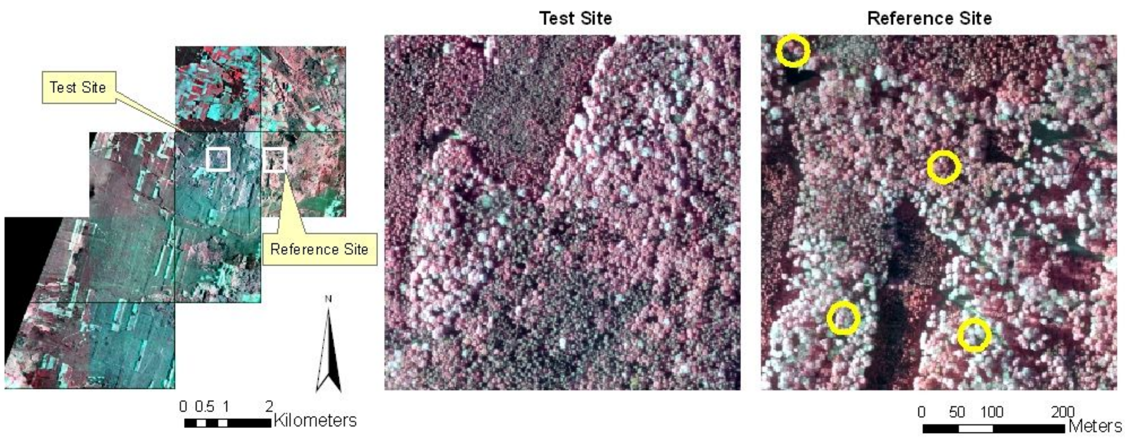

Figure 1: Left: location of the work sites in the 'Milicz' forest district, middle: CIR aerial photograph of the test site, right: CIR aerial photograph of the reference site with sample plots.

A second study area with a side length of 500 m was selected in the black forest in southern Germany close to the city of Freiburg. The developed method was severely tested under very different conditions and with good single tree reference data. In comparison to the Polish area it is characterised by high relief energy of 242 m in a low mountain range, a different time of the year and a lower resolution of the CIR images. Both are mixed forests.

2.2 Data

On the Polish sites LiDAR data and multispectral images have been captured simultaneously with a Falcon II system from TopoSys in 2-3 May 2007 while trees being in a full on-leaf state. The LiDAR raw data consists of first- and last pulse reflections with an average point density of 7 points/m². Due to the structure of the sensor, the points are irregularly spaced in a line pattern. CIR true ortho images with 25 cm pixel resolution were used as spectral information source. Further within 25 sample plots reference data on single tree level was forthcoming. Every circular plot has a radius ranging from 7.98 m to 12.62 m depending on the stand's age and was measured in the field in 2006. The contour of each tree crown was obtained from the ground by orthogonal surveying eight vertices of its borderline. Other parameters are the crown's layer in the vertical structure, the tree species and tree height. Because only crowns were used that are visible from above, the hidden border polygons were deleted manually. We chose different sites for algorithm development and referencing due to the irregular distribution of the sample plots. From the LiDAR raw data three different surface models with 0.5 m and 1 m resolution were calculated. These are the digital terrain model (DTM), the digital surface model (DSM) and the vegetation height model (nDSM). Filtering and interpolation of the raw data was performed with the "active Contour Algorithm" implemented in the software package TreesVis (Weinacker *et al.* 2004).

The data for the German study area was captured with a Falcon I system from TopoSys in 2002. Last pulse LiDAR reflections were acquired on 4 March and first pulse together with spectral data on 22 July. Average point density is 10 points/m² and CIR true orthophotos have a pixel resolution of 50 cm. A DTM, DSM and nDSM with 1m resolution were calculated from the LiDAR raw data. As reference data tree crowns were manually digitised within a 200*200 m field from stereo images taken in June 2001. The digitisation was transferred into 2D with higher trees covering lower trees and showing the tree outlines like seen from above. A visual classification of the tree types broad-leaved and conifers was carried out. Further subdivision of the species was not possible, but due to the dry conditions of midsummer damaged deciduous trees could be spectrally separated. From the forest management plan the following species composition on the test site is given: Broad-leaved trees 57.84 % with beech 48 %, oak 8 %, sycamore 2 % and conifers 42 % with fir 27 %, spruce 4 %, douglas fir 10 %.

2.3 LiDAR based single tree delineation

The 2D single tree delineation was conducted with a parameter reduced program executing the algorithm developed by Koch *et al.* (2006). The input data given to this program are the DSM and the DTM. Setting program internal height class thresholds for trees was abdicated and substituted by a new method to improve the results. Therefore a supplemental program module was developed in C++ with use of the Halcon 8.0 image processing library (MVTec 2007).

From the nDSM a histogram of the gray values was calculated and its local minima were used as thresholds for the height classes. In the case of the Polish test site, two classes could be separated at a height of 2114 cm (see Figure 2 and Figure 3).

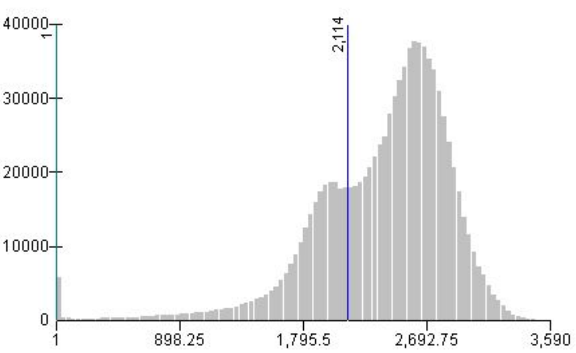

Figure 2: Local minimum separating height classes in the gray value histogram of the nDSM. The abscissa indicates the gray values (heights in cm), the ordinate indicates the number of occurrence for every value interval.

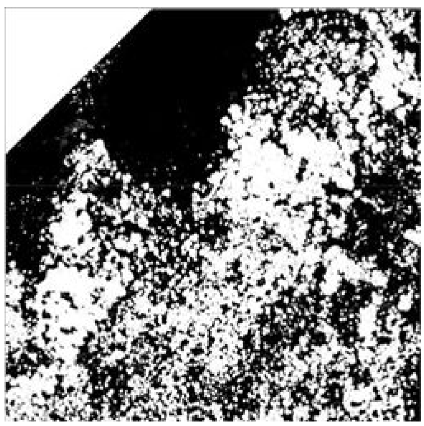

Figure 3: nDSM classified in two height classes. High regions are white low regions black colored (the top left corner is out of the valid area and defined as no data).

The 2D delineation program is then run with a 0.5 m and a 1 m resolution DSM. The more generalized lower resolution DSM achieves better results for the high trees and the higher resolution DSM for the low trees. Larger crowns are represented by more pixels and are therefore more structured. A DSM with a lower resolution works similar like a higher smoothing of the crowns. The delineation algorithm (Koch *et al.* 2006) itself works by finding local maxima on a Gaussian smoothed image, from which regions are extended until neighbouring pixels with a lower or the same height value are met. From this first approximation of the tree shape several morphological corrections are conducted. Finally the actual crown-edge is determined by separating the tree from neighbouring canopy gaps. A vector starts from the tree top to each border point and stops at the inflexion point or at a local minimum.

As result one delineation for each DSM resolution is achieved. Together with the determined height threshold these are used as input images for the new algorithm. Each tree is defined as a region with a certain height value. Referring to this, the tree regions are taken from the concerning delineation (see Figure 4 and Figure 5) and copied into a new image (see Figure 6). The result allows single lower trees to be placed between higher trees which is not the case when large connected height level regions are used instead. After combining the tree regions several small regions, derived from intersections, occur at the borderlines. They are iteratively reallocated to neighbouring larger polygons corresponding to spectral, height concerning and morphological conditions. If these requirements are fulfilled the small region is allocated to that neighboured region with the least spectral difference, which is defined as the mean value of all spectral bands.

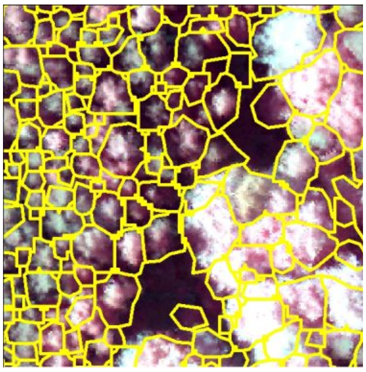

Figure 4: Delineation with 0.5 m DSM

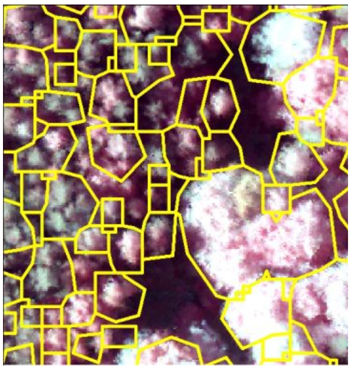

Figure 5: Delineation with 1 m DSM

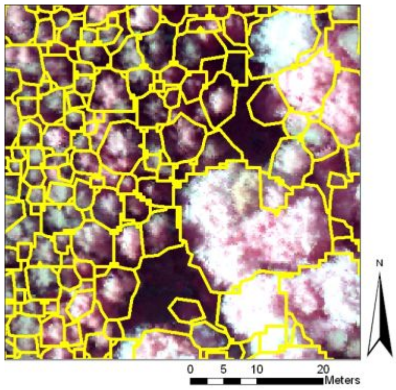

Figure 6: Combined delineation for both height classes

On the German study area only one main height level occurs and all the delineation is done with a 1 m resolution DSM.

2.4 Tree species classification

The LiDAR data derived single tree polygons are classified by species according to their spectral features. In advance some pre-processing has to be done. To enhance the contrast of the CIR image its histogram is linearised after equation (1) (Gonzales *et al.* 2002, p 115).

$$s_k = T(r_k) = \sum_{j=0}^{k} p_r(r_j) = \sum_{j=0}^{k} \frac{n_j}{n} \qquad k = 0,1,2,\ldots,L-1 \tag{1}$$

r_k = pixel in the input image, s_k = pixel in the output image, k = discrete pixel value, L = total number of possible gray levels in the image, p_r = probability density function of variable r, n = total number of pixels in the image, n_k = number of pixel that have gray level r_k

Then the spectral bands are separated into near infrared (NIR), red and green and further transformed into the channels hue (H), saturation (S) and intensity (I). The HSI colour model is used due to its ideal applicability to describe colours intuitively to human perception. Hue describes the pure colour, like yellow or red, saturation indicates to which degree the pure colour is diluted by white light and intensity is an achromatic measure of what the human interpreter calls brightness (Gonzales *et al.* 2002, p 317). Prior to classification the tree polygons are fitted to the usable spectral data and too shaded areas are removed. This is done by subtracting pixels with an intensity value between 0 and 100 from the tree polygons. Colors within that intensity interval are defined to be too dark for any interpretation. The contour of the resulting regions is smoothed with a morphological opening operation.

The classification itself is divided into two steps (see Figure7). Within both, classes are separated relative to histogram features and the according tree species is assigned later due to the reference data.

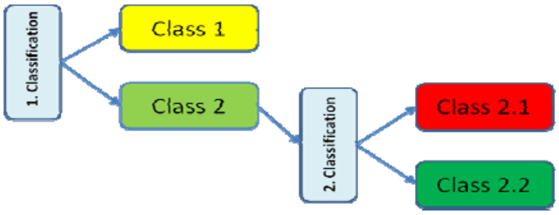

Figure 7: Hierarchy of the tree species classification

During the first cycle two classes can be separated at the local minima from the due-channel’s histogram (see Figure 8). The thresholds are determined automatically by smoothing the histogram with a Gaussian function as long until the number of local minima is appropriate.

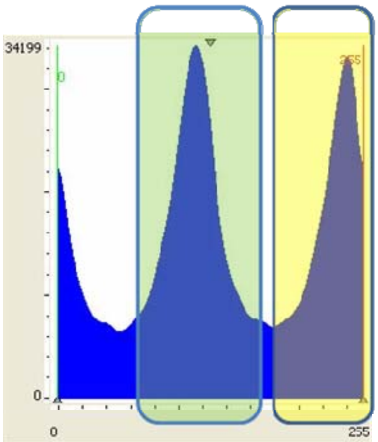

Figure 8: First classification threshold. Smoothed histogram of the hue-channel with gray values on the abscissa and frequency on the ordinate. Class 1 and class 2 are separated at the local minima and indicated by color.

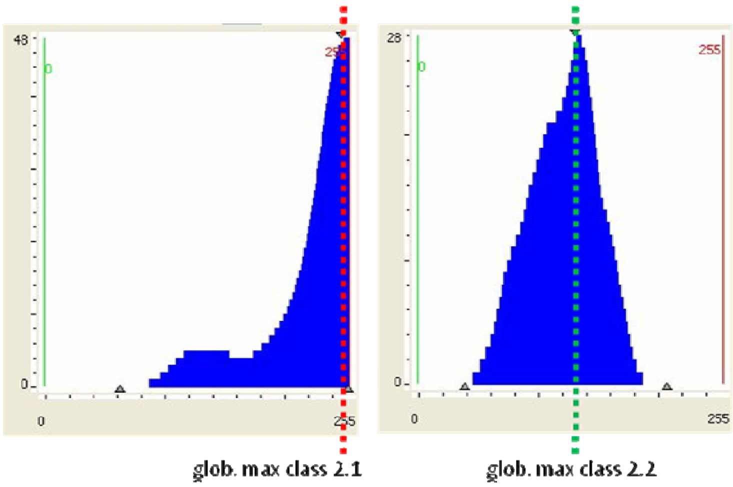

Figure 9: Second classification threshold. Global maxima from single polygons. The position in the left diagram belongs to class 2.1, the position in the right to class 2.2. Abscissa and ordinate same as in Figure.

The second classification cycle subdivides class two as shown in Figure 9. It is carried out by calculating the global maximum position of the NIR band within each tree polygon (see Figure 9). From these values a function is derived that describes the frequency of the maximum distribution for all trees. The discrimination threshold is gained from the local minimum of the automatically smoothed function.

On a first approach the classification results were visually compared to the reference sample plots located on the reference site for the Polish dataset and visually interpreted based on the known species composition for the German dataset. From this comparison it was possible to allocate all classes to certain tree species or compositions of them. The resulting classes from the first classification match with the following species:

Poland:	Class 1:	oak/hornbeam	Germany:	Class 1:	deciduous healthy
	Class 2:	beech/conifers		Class 2:	conifers/ dec. damaged

The subdivision of class 2 refers to the following species:

Poland:	Class 2.1:	beech	Germany:	Class 2.1:	deciduous damaged
	Class 2.2:	conifers		Class 2.2:	conifers

Finally a total of 3 classes could be separated (see Figure 10).

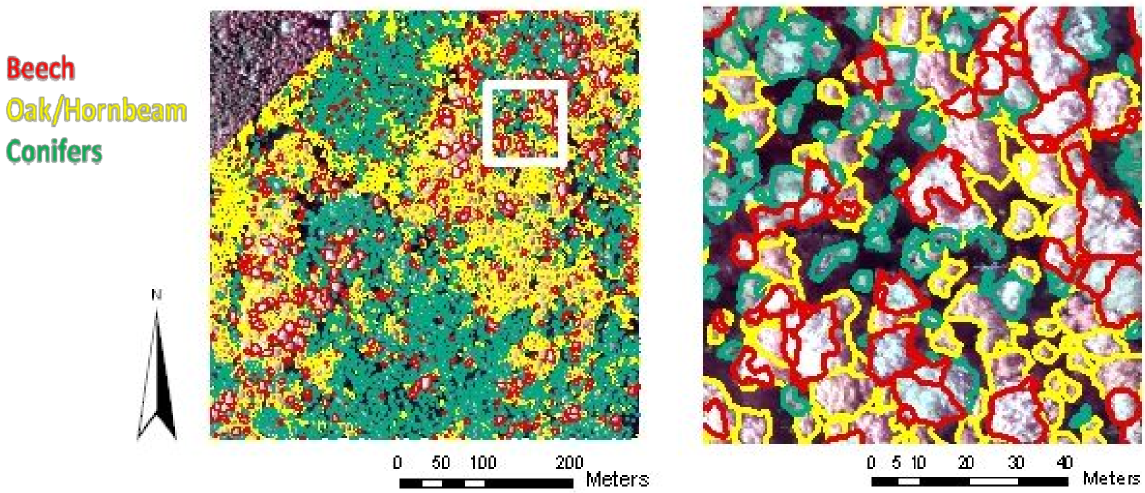

Figure 10: Final tree species classification (Poland). Left figure shows the complete test site, right figure shows a subset.

2.5 Multispectral correction of the single tree delineation

The original LiDAR-based 2D delineation was improved and corrected by multispectral data. These corrections are calculated simultaneously with the spectral adaption of the polygons and the species classification.

While fitting the LiDAR derived polygons to the spectral information certain polygons are divided into two and more crowns. This happens when a polygon contains two or more crowns which are divided from their neighbors by a gap in spectral intensity. Small residual connections between the new splitted polygons are broken by a morphological opening operation in advance.

The crowns of mature deciduous trees are often interlocked and not always possible to delineate with geometrical information. On the Polish test site this was the case with the crowns from oaks and beeches. Due to the spectral domain of each species, which is detected automatically in the hue channel, it is possible to separate beeches from oaks as well as conifers from oaks within one polygon (see Figure 11). On the German study area it was the same for the corresponding classes. For separation further conditions must be fulfilled and a minimum relative area of at least 20 % from the original polygon is required. A series of morphological opening and closing operations smoothes the borders and fills gaps within the new polygons.

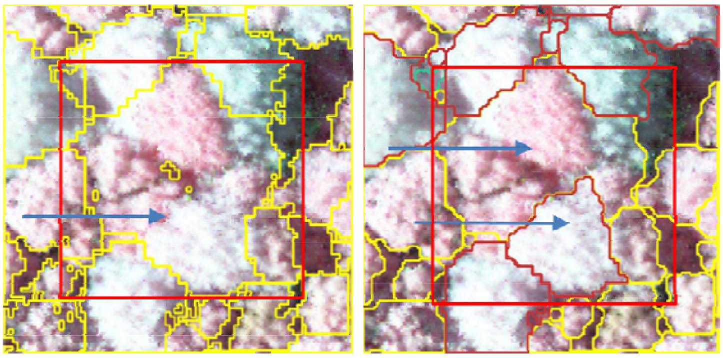

Figure 11: Separation of tree crowns by information of the hue channel (Poland). Here the beech crown is delineated from the neighbored oaks. The blue arrows point to the LiDAR derived polygon on the left and the separated polygons on the right.

On the German study area the problem occurred that different spectral regions can be within a single tree crown. This is due to partly damaged tree crowns or differences in illumination. If the algorithm would be run without an adaption to this situation, single LiDAR based polygons could be divided though they only contain one crown. Because the differences within one crown are in most cases significantly smaller than between two crowns of different classes a sensitivity factor was implemented. This factor refers to a minimum distance of the mean spectral values from divided subparts of a polygon. It ranges from 0 (no reduced sensitivity) to 1 (completely reduced sensitivity) where polygon splitting is not possible anymore. If it is undercut the two neighbored subparts are merged again (see Figure 12).

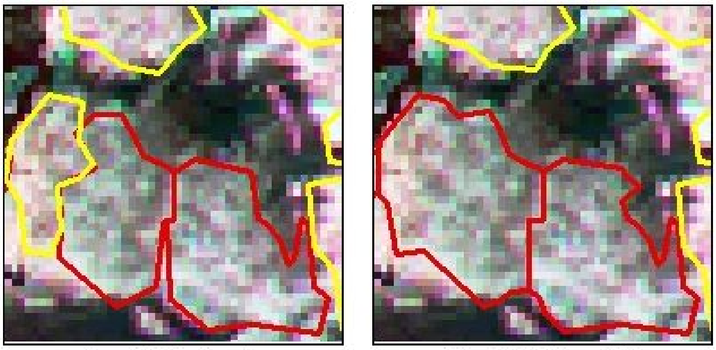

Figure 12: Left figure shows a split crown when not using a reduced sensitivity. Right figure shows the same crown with half sensitivity (Germany).

2.6 Assessment of the classification

The tree type classes are determined automatically by features of the image histograms. An allocation to certain species and an accuracy assessment is done with help of the reference sample plots in the case of the Polish study area and for the German area by the visual interpreted stereo delineation. Therefore the developed algorithm was executed on the reference sites and the classified crowns are compared to the species or damage degree of the reference crowns. Because the automatic delineation doesn't fit completely to the reference delineation in all cases, it is visually determined to which reference polygon they accord. If a polygon is not possible to assign this is recorded in the statistics and it is not further considered.

On the German test site additionally the single tree delineation was verified. According to Leckie et al. (2003) six grades of matching with the corresponding reference crowns (refs) were defined for the automatic isolated crowns (isols): perfect match (one-to-one correspondence), good match (one-to-one, but overlap less than 50 %), grouped (isols with more than one ref), split (more than one isol per ref), commission error (isol without ref) and not detected (ref without isol).

3. Result and discussion

The main aim of this study was to use LiDAR data based single tree delineation for a fully automated multispectral tree species classification. Due to the adaption of the LiDAR polygons to the spectral data and the following classification procedure it was also possible to improve the delineation results. For the Polish site the delineation improvement was only evaluated visually as stated above and occurs in every polygon were the described conditions are fulfilled. For the German site verification was conducted with 579 reference crowns on an area of 200*200 m.

The accuracy assessment of the tree species classification showed an overall accuracy of 83.87 % of correctly classified polygons for the Polish and 90.79 % for the German site. The total number of delineated trees is 31 with 26 correctly classified and 467 with 424 respectively. Two reference polygons on the Polish and 31 on the German site were not assignable. The confusion matrices in Table 1 and Table 2 additionally show the wrong classified crowns and their classes.

Table 1: Total statistics for accuracy assessment (Poland)

	Automatic classification				
	Class	**Oak/hornbeam**	**Beech**	**Conifer**	∑
Reference data	**Oak/hornbeam**	**16**	0	1	17
	Beech	1	**8**	3	12
	Conifer	0	0	**2**	2
	∑	17	8	6	31

Table 2: Total statistics for accuracy assessment (Germany)

	Automatic classification				
	Class	**Deciduous healthy**	**Deciduous damaged**	**Conifer**	∑
Reference data	**Deciduous healthy**	**221**	7	5	233
	Deciduous damaged	4	**68**	18	90
	Conifer	4	5	**135**	144
	∑	229	80	158	467

In both matrices most frequent failures happen in classifying class 2.1 (beech/deciduous damaged) as class 2.2 (conifer). This shows that the threshold for distinguishing classes in the NIR band seems to be some weaker than the first classification with the hue band. The current state of algorithm development needs a forest composition with all three tree types being present and a minimum contingent of about 20 % for each species. This value is empirical and not fixed. It depends on the overall gray value distribution of the used images.

Two definite and stable spectral features have been determined which allow a classification of mixed forest even under different conditions. The content of the derived classes must be referenced on the used dataset whereas the base classes “conifer” and “deciduous” seem to be constant. Since full automation was the aim of this study no standard classification methods like nearest neighbor were used. Most of them need interaction by setting training samples.

The LiDAR based single tree delineation shows an overall accuracy of 43.87 % when comparing perfect and good matches of isols to the total number of refs and 56.95 % compared to the total number of isols. After spectral correction of certain polygons the overall accuracy is 51.29 % (isols from refs) and 60.37 % (isols from isols) (see Table 3).

Table 3: Statistics for the single tree delineation (Germany)

	Perfect match	**Good match**	**Grouped**	**Split**	**Comission error**	**Not detected**	**Total number of isols**	**Total number of refs**
LiDAR delineation	165	89	95	95	2	16	446	579
After spectral enhancement	213	84	79	90	6	31	492	579

From the statistics an improvement of 7.42 % can be calculated when comparing the number of matches with the number of reference trees. Considering the low accuracy of the LiDAR polygons and the fact that only certain polygons are corrected this is a remarkable number. The low accuracy of LiDAR delineation reflects the study of Heurich (2006) who describes an average accuracy of 40 % with similar delineation algorithms in the Bavarian forest. Difficulties are made by dense forest stands and interlocking tree crowns as they occur in temperate mixed forest. Since the spectral improvement is applied to the LiDAR delineation it cannot completely change the result but it is a good tool for corrections.

Further development should be invested in finding new approaches for the LiDAR based delineation algorithm. Spectral correction could be improved by finding more stable features for class separation. Maybe the spectral and the LiDAR data can be directly combined in one process.

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