METHODS FOR THE AUTOMATIC ESTIMATION OF FOREST ATTRIBUTES FROM AERIAL IMAGERY

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ABSTRACT

This study focuses on the derivation of forest attributes from different types of aerial images. Traditional CIR images and new digital Ultracam data were used. From the CIR images a digital surface model was calculated. This model and an accurate DTM derived from laser scanner data provided the basis for calculating vegetation height. While the results for homogeneous stands were acceptable, poor results were obtained for heterogeneous stands due to the fact that the height model does not represent the vertical structures of these stands. The age of the forest stands can be estimated from the vegetation height taking into account growing conditions. An algorithm was applied to extract stem numbers for each stand based on the age and brightness distribution of the orthophoto derived. The stem number results obtained from the CIR images are still relatively poor, which might be due to changes of stand structure over the six years that passed between the time of image and reference recording. Further investigations should thus be performed using ground truth and image data taken at the same time. In order to distinguish between spruce and pine trees, a method was developed based on the characteristic two-dimensional crown shape of the two tree species. The results are very promising, especially when using Ultracam data. The results derived show that more than 75 % of the dominant reference trees representing the natural age classes “middle” and “old timber” can be detected correctly using only a single and very simple morphological feature. Further accuracy enhancements can be expected from employing a larger number and/or more complex features as well as from combining the shape characteristics with the spectral properties of the segmented crowns. Additional accuracy tests are, however, necessary to check the commission errors and the applicability of the algorithm to sub-dominant and suppressed trees. A different method needs to be developed to distinguish younger trees, as their crowns do not yet have a characteristic shape.

Keywords: Aerial photos, digital imagery, stem number, tree height, species differentiation, automated extraction.

1 INTRODUCTION

Forests cover nearly half of Austria’s surface area. They are not only a major economic factor, but also a recreational area, an important protection against natural disasters and a reliable indicator of climate change. The multiple benefits that derive from a forest in a particular region depend on the geographic, climatic and demographic situation of that area. This is why information about forest parameters is necessary to help decision makers take the right measures to ensure the ecological and economic health of forest stands today and in future. However, this information is not available everywhere. Especially Austria with its high percentage of small structured forest property has large areas of scarcely cultivated and insufficiently mapped forest. The study was therefore aimed at automatically extracting forest information from aerial images in order to lower the cost of traditional information assessment, such as field work. Two different types of imagery were available for the investigated test site in Styria (Austria): traditional CIR images and digital images from the Ultracam large-format digital camera. The forest attributes “tree height”, “stem number” and “tree type” were derived at stand level using the IMPACT image processing software developed at the Institute of Digital Image Processing. The study was partly financed by the “Factory of Tomorrow” initiative of the Austrian Ministry for Transport, Innovation and Technology (BMVIT) and was part of a dissertation granted by DOC-FFORTE [WOMEN IN RESEARCH AND TECHNOLOGY], a program of the Austrian Academy of Sciences.

2 DATA CHARACTERISTICS

Two different aerial image types were available for the “Burgau” test site, which is located in the south-east of Austria: traditional colour infrared (CIR) images from 1998 scanned at a spatial resolution of 20 cm and digital imagery from the large-format digital camera Ultracam dating from 2004. In the latter flight campaign, the spatial resolution was 15 cm for the panchromatic and approx. 45 cm for the four multispectral bands. A detailed technical description of the camera and data characteristics can be found in [1]. Figure 1 compares the two data sets in a small subset of the test area. For the Ultracam data, the producer’s pre-fused product “high-resolution CIR image” is displayed in order to ensure comparability with the traditional image (both: band 1 = infrared, band 2 = red, band 3 = green).

Figure 1. Left: traditional CIR image (1998); right: high-resolution digital CIR image taken with Ultracam (2004)

Fig. 1 shows that the new digital data provide more detailed information due to the higher spatial resolution. The small spruce trees in the upper part of the image can easily be differentiated visually, but are hardly distinguishable in the CIR image. These two images provided the basis for investigating the potential of aerial imagery for forest parameter extraction.

In addition to optical images, laser scanner data (DSM, DTM, vegetation height) from 1999 were also available for the test site. Many investigations carried out in the past have shown that the accuracy of laser scanner data is very high. These data were therefore used as a solid reference for the verification of the photogrammetric height measurements. The results of a detailed field campaign carried out in summer 2004 were used as ground truth to calculate the parameter “stem numbers” from the yield table. Reference trees were digitised on screen for each image type separately to verify the results of single tree classification.

3 VEGETATION HEIGHT

Photogrammetry and laser scanning are the most commonly used methods for deriving vegetation height. As laser scanning is still expensive, the focus of this study was on automatic photogrammetric measurements. The first step thus consisted in the derivation of the digital crown surface model (DSM), which - in combination with an accurate digital terrain model (DTM) - was used to calculate vegetation height.

2.1 DERIVATION OF VEGETATION HEIGHT

Two different software packages were tested for the derivation of the DSM from CIR images: Intergraph and RSG (Remote Sensing Software Package Graz). A detailed description of algorithms and achievable accuracies can be found in [2]. The comparison showed that the RSG model is more suitable, because it better preserves vertical structures within the crown surface. A further important result of the above mentioned studies is that it is not possible to model single trees (within the forest) three-dimensionally. The calculation of a mean stand surface only is possible. A digital terrain model is needed in addition to the crown surface model to obtain the tree/stand height. For this purpose, the accuracy of the official Austrian DTM with a ground resolution of 10m was investigated. The comparison of this DTM with a DTM derived from laser scanner data showed errors of 10 m and more [see 2] for forested areas. It can thus be stated that the official Austrian DTM is not accurate enough for the calculation of vegetation height and could therefore not be used for this purpose. The filtered last pulse data (DTM) of a laser scanner campaign conducted in 1999 were used instead. The model's accuracy was checked by more than a hundred terrestrial GPS and geodetic measurements and varies between 18 and 45 cm. For a detailed description of the filter algorithm applied to DTM derivation, see [3].

Methods for calculating "mean" stand height had been developed in previous studies [4] and included different calculations:

- the "real" mean (of all values),
- the mean of all values greater than 0 (negative values might be possible as well) and
- the mean of the highest 50 % (75 %) of the values ($mean_{50/75}$).

The $mean_{50}$ value best fitted the "mean stem height" from the yield table. It showed a correlation coefficient of 0.9 and was, therefore, used for all further calculations.

2.2 ACCURACY ASSESSMENT

The $mean_{50}$ from the CIR images was compared to the $mean_{50}$ of the laser scanner data. The correlation accuracy for quite homogeneous stands was sufficient (R^2 = 0.8852, see Fig. 2), while results for heterogeneous stands differed significantly from the ones derived by means of laser scanning. The overall R^2 including these heterogeneous stands was 0.7164.

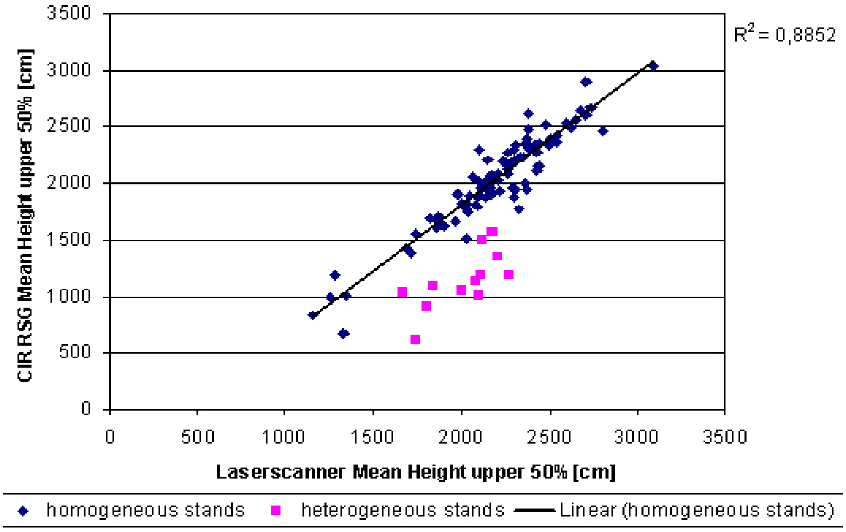

Figure 2. Result of mean stand height: CIR image heights from 1998 plotted vs. laser scanner heights from 1999

3 ESTIMATION OF STEM NUMBERS

The stem number has been the subject of detailed investigation over the past few years. There are two possibilities of stem number estimation: from optical data only or from the combination of optical data with surface or vegetation height models.

As regards the first category, Pinz [5]detected so called "blobs", i. e. brighter parts in an aerial image, as early as 1994. In the following years, a lot of algorithms were developed aiming to count the trees and/or to delineate the tree crowns. Some papers on this topic were published, e.g., by [6], [7], [8], [9] or [10]. The results vary considerably, most of the algorithms show very good accuracies under ideal conditions, as for example for plantations, but their applicability to natural forests has so far been investigated only for a few of the algorithms. The precondition for all calculations is the assumption, that a tree is brighter than its surroundings. This idea is also used in the method presented in chapter 3.1.

The second category was mainly developed using laser scanning data (e. g. [11], [12], [13]) or incorporating DSMs from photogrammetric measurements of optical data [14] or interferometric measurements of SAR data [15]. They mainly deal with high resolution DSMs, where single trees can be detected and counted directly.

3.1. METHOD

As already mentioned, the DSM derived from the CIR images could not be used for single tree recognition, because the derived surface was too smooth. Another approach based on brightness values of the infrared band was therefore applied. In optical imagery, the location of the brightest part within a crown depends on its position within the aerial image. Nonetheless, if every tree is represented by one intensity maximum, the number of trees can be assessed by counting the number of the detected maxima. In many cases, however, one crown is represented by more than one maximum. For this reason the minimum distance between the detected maxima should be integrated into the filtering process. In order to define this distance, an empirical regression analysis was used to calculate the mean distance in dependence of tree age. Based on comparable stand conditions and the knowledge of tree species, the age of the forest can be roughly estimated from the mean stand height derived.

3.2. RESULTS

The stem numbers, which served as ground truth for quality control, were estimated by means of yield tables based on the stand condition as well as age and stand density recorded in a forest inventory carried out in 2004. As the reference data were taken 6 years after CIR image acquisition, areas of apparent re-, de- and afforestation were excluded from the accuracy check. As expected, extreme errors occurred in the calculation of stem numbers of multi-layer stands due to the results of mean height calculation. Two reasons for these errors were identified: Firstly, suppressed trees, which have much more influence on the stem number of the whole stand than older trees, are not sufficiently represented in the $mean_{50}$. Secondly, sub-dominant or suppressed trees are often not illuminated and thus do not show any intensity maxima. Therefore, these stands were also excluded from the accuracy check.

Errors also occur when calculating stem numbers of very young homogeneous stands of up to approx. 30 years of age, as individual trees are not visible due to the extremely high stem density and, therefore, groups of trees are represented by only one maximum. This phenomenon has also been reported in [8]. The following diagram shows the results of stem number calculation for the 23 remaining stands.

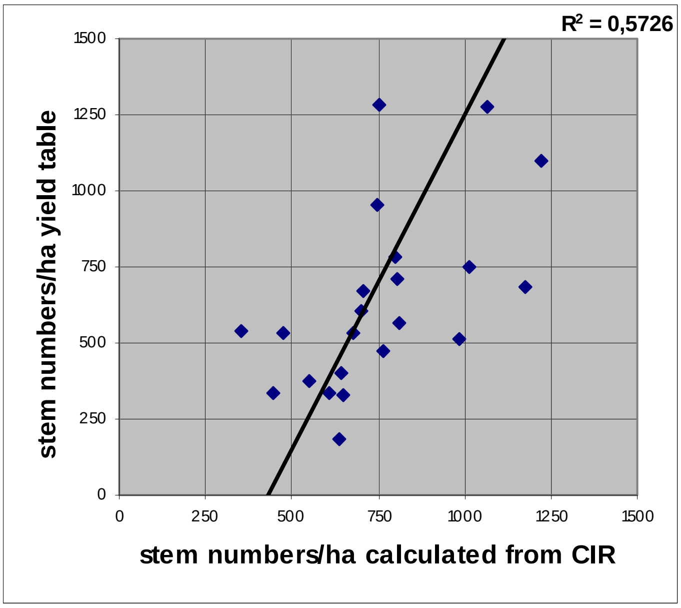

Figure 3: Stem number/ha for each stand calculated from CIR images plotted vs. yield table figures

The low accuracy (R^2 = 0.57) might be due to changes that occurred in the six year period between image and ground truth recording and that were not obvious, e.g. thinnings. Additionally, the stem numbers from the yield table are average figures and might be not representative of the study area.

Furthermore, the algorithm still has some weaknesses and further investigations are needed to improve the results.

4 TREE SPECIES DIFFERENTIATION

Tree species classification using very high resolution imagery is mainly based on the spectral values of the pixels (traditional pixel-based classification) or on statistical values of objects obtained from segments (object-based classification). Good results for species classification have been reported in various papers, which, however, usually deal with single aerial photos. When analysing areas covered by more than one image, however, it must be taken into consideration that the statistics of training areas collected in one image might not be transferable to neighbouring images. The method developed is thus based more on structural features than on radiometric properties. For example, the star-like shape of a spruce crown in comparison to the compact form of a pine crown could be used as a criterion for differentiation. Figure 3 shows two characteristic crowns of the species under investigation, left columns depicting the subsets from the traditional aerial images and the right two columns showing the same trees in the Ultracam data.

Some limitations must, however, be taken into account: first, it is only true for natural age classes older than thicket, because younger trees do not yet have the distinct crown shape. Second, tree shape varies depending on the viewing angle. The subset used should therefore not be too far away from the nadir point. Using a similar approach, Erikson [16] successfully processed data up to a maximum viewing angle of 25.22°.

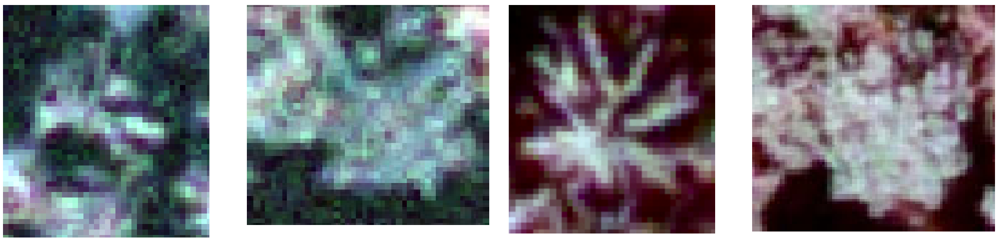

Figure 3. (a) spruce and (b) pine in traditional CIR image (1998); the same trees, (c) spruce, (d) pine, mapped by the digital camera (Ultracam, 2004)

Only few authors actually deal with the recognition of tree types based on shape features. One example is Persson et al. [17], who worked on “rotational symmetries”. Another very recent method, which uses the same approach as this paper was presented by Erikson [16]. The main differences can be found in the method of seed finding and in the morphological measures.

4.1. METHOD

The method developed is based on a “seeded region growing” algorithm (SRG). The seeds are found in a similar way as in the stem number calculation already described. A method with fixed seed distances was used resulting in two different seed files: The first file was calculated with a minimum distance of 300 cm, which is best suitable for spruce trees and the second one with a minimum distance of 600 cm, which is best suitable for pine trees. Seeds representing deciduous trees were eliminated by using threshold operations. In a next step, two SRG operations using the same parameter setting were performed based on the corrected seed files resulting in two different segmentations (referred to here as SRG 300 and SRG 600). It was found out that the parameters must be adjusted according to the radiometric characteristics of the images (CIR and Ultracam).

To optimise the results of the SRG process, an allocation file (based on the Euclidean distance) was integrated to avoid unnaturally elongated tree crowns. This is particularly required if the crowns are not well separated. This procedure only leads to satisfactory results if the seed lies in the centre of the crown and if only one seed is detected within a crown. Otherwise the SRG would split up the crown. To solve this problem, procedures “dragging” the seeds to the centre of the crown need to be applied.

To improve the SRG results, further post-processing was necessary in order to drop small islands (<1m²) within the crowns (see Fig. 4d – dark dots). The results of the method are illustrated by way of example in Figure 4 (same trees as in Fig. 3). The Figure shows that the depicted spruce and pine trees are delineated quite well in both images. Furthermore it can clearly be seen that the external border of pines is much smoother and less jagged than the border of spruce trees.

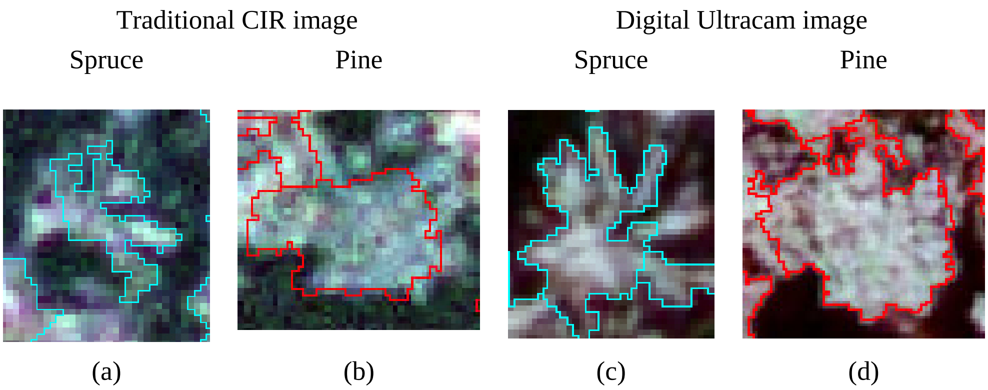

Figure 4. Example results (outlines) of SRG process: (a) spruce and (b) pine in traditional CIR image (1998); (c) spruce, (d) pine mapped by the digital camera (Ultracam, 2004)

After crown delineation, the segments were classified based on their shape characteristics. The area/perimeter ratio, which is the simplest morphological feature, was calculated and a threshold operation performed. The spruces were classified in the SRG result from SRG 300 using an area/perimeter threshold of < 0.5 and the pines in the SRG result from SRG 600 using an area/perimeter threshold of > 0.43. After this simple classification, the two layers were combined. Intersections (rules for both tree types true) were classified as pines, because the pine classification rule is stricter and therefore more reliable.

4.2. RESULTS

The accuracy check was based on dominant trees selected by means of visual interpretation of the image data. For each selected reference tree, a point was digitised at the centre of each crown (see Fig. 5).

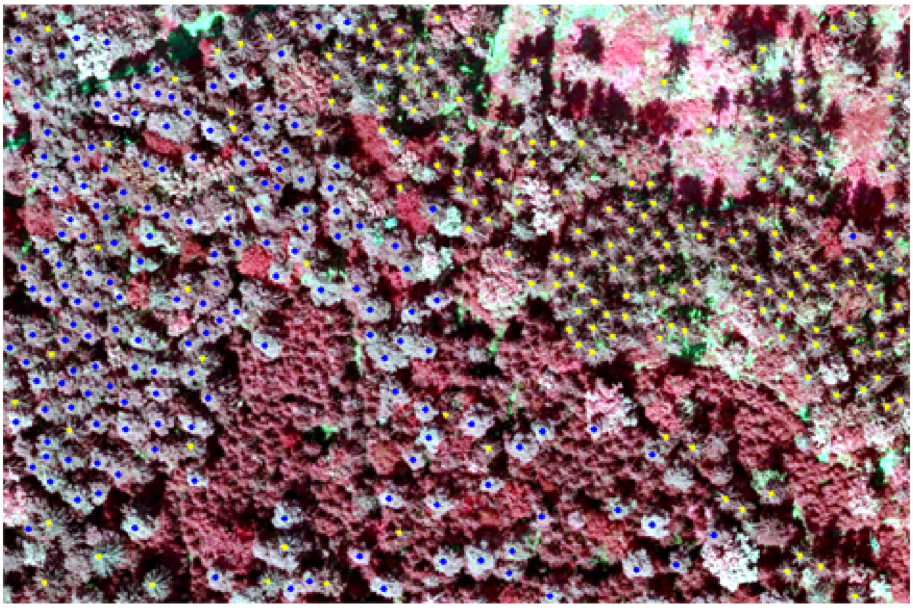

Figure 5: Test area (Ultracam data) with reference trees (blue dots = pines; yellow stars = spruces)

The reference tree points were intersected with the combined classification image and the numbers of correctly identified trees, misclassified trees and completely missed trees were counted. If a crown was split into sub-segments (see e.g. Fig. 4c) and a reference tree point was located within a correctly classified sub-segment, consequently this tree was counted as correctly classified. Commission errors could not be evaluated, because the reference trees represent only a selection of trees. The results of the verification are displayed in Table 1.

Table 1. Results of the spruce – pine segregation process

	Tree type	No. reference trees	Correctly identified		Misclassified		Omission	
			No.	[%]	No.	[%]	No.	[%]
CIR	spruce	216	144	66.67	47	21.76	25	11.57
	pine	233	135	57.94	48	20.60	50	21.46
Ultracam	spruce	183	139	75.96	13	7.10	31	16.94
	pine	173	131	75.72	16	9.25	26	15.03

As expected, the results for the Ultracam data are far better, because tree crowns are displayed more distinctly due to the higher resolution. The omission errors are nearly the same for both image types due to the same procedure of seed generation, while the number of misclassified trees is three times higher for the CIR image. As shown in other papers [6, 8], higher resolution leads to a significant improvement in single tree detection. This can also be confirmed by this study. It must be mentioned, however, that the accuracy check was based only on dominant, clearly visible older trees. Further checks need to include also sub-dominant and suppressed trees – as far as they are visible in the image. Additionally, commission errors need to be evaluated and a procedure to distinguish younger spruce and pine trees needs to be developed. First tests employing texture calculations have already shown some promising results.

6 SUMMARY AND OUTLOOK

In this study different forest parameters were estimated based on CIR and digital Ultracam images. The mean stand height was calculated using a photogrammetric DSM derived from CIR images and an accurate digital terrain model derived from laser scanner data. The mean stand height was calculated with an adequate accuracy, except for heterogeneous stands characterised by a marked vertical structure. The results for the estimation of stem numbers proved to be less satisfactory. The segregation of spruce and pine was performed successfully in both image types, but the Ultracam results showed higher accuracies. The final results for the Ultracam data showed a classification accuracy of nearly 76 % for the reference trees. Other morphological measurements and the spectral properties of the segments should be tested to further improve accuracy. Additionally, the influence of viewing angle on the shape characteristics of trees need to be investigated. In general, further adjustments and optimisation are still necessary to obtain more applicable results. Nonetheless, the method proposed is a further step towards extending the application of remote sensing data in forest management.

REFERENCES

1 Kalliany, R., Pfahler, G. and Meixner, H. 2004: Neue Perspektiven in der Fotogrammetrie durch eine innovative großformatige digitale Lufbildkamera. *Proc. of CORP2004*, Vienna, pp. --.

2 Schardt, M., Hruby, W., Hirschmugl, M., Franke, M. and Wack, R. 2004: Comparison of Aerial Photographs and Laser Scanning Data as Methods for Obtaining 3D Forest Stand Parameters. *Proc. of NATSCAN*, Freiburg, Germany, pp.--.

3 Ziegler, M.; Wimmer, A. and Wack, R. 2001: DTM generation by means of airborne laser scanner data – an advanced method for forested areas. *Proc. of the 5th Conference on Optical 3-D Measurement Techniques* Vienna, pp. 97 - 102.

4 Hirschmugl, M. Schardt, M. and Hruby, W. 2004: Machbarkeitskonzept zur großflächigen Implementierung von Informationssystemen auf GIS-Basis in Waldverbänden, Unpubl. Project Report, Technical University of Graz, Graz, 72 p.

5 Pinz, A. 1994: Bildverstehen. Verlag Springer, Wien – New York. 235 S.

6 Gougeon, F. A. 1995: A Crown-Following Approach to the Automatic Delineation of Individual Tree Crowns in High Spatial Resolution Aerial Images. Canadian Journal of Remote Sensing 21, Special Issue on Aerial Optical Remote Sensing. S. 274 – 282.

7 St.-Onge, B. and Cavayas, F. 1997: Automated Forest Structure Mapping from High Resolution Imagery Based on Directional Semivariogram Estimates. Remote Sensing of Environment 61. pp. 82 – 95.

8 Leckie, D.; Burnett, C.; Nelson, T.; Jay, C.; Walsworth, N.; Gougeon, F. and Cloney, E. 1999: Forest parameter extraction through computer-based analysis of high resolution imagery. In *Proc. Fourth Int. Airborne Rem. Sens. Conf. and Exh. / 21st 1Can. Symp. Rem. Sensing*, Vol. II. Ottawa, Canada, June 21-24, 1999, pp. 205-213.

9 Culvenor, D. S. (2002): TIDA: an Algorithm for the Delineation of Tree Crowns in High Spatial Resolution Remotely Sensed Imagery. In: Computers & Geosiences, Vol. 28, Issue 1, pp. 33 – 44.

10 Wang, L., Gong, P. and Biging, G. S. 2002: Automated Individual Tree Crown Delineation and Treetop Detection in high-spatial resolution Aerial Imagery, *Proc. of the UCGIS Summer Assembly* 26. – 30. 06. 02 Athens, Georgia, available at: http://www.cobblestoneconcepts.com/ucgis2summer2002/wang/wang.htm.

11 Schardt M., Konrad H., Hyyppä J., Ruppert G., Hyyppä H., Ziegler M., Wimmer A. & Hofrichter J., 2000: Assessment of forest attributes and single-tree segmentation by means of laser scanning. *Proc. of SPIE*, AEROSENSE, Orlando/Florida.

12 Maltamo M., Eerikäinen K., Pitkänen J., Hyyppä J. & Vehmas M. 2003: Combination of Single Tree Laser Scanning and Theoretical Distribution Functions in the Estimation of Plot Volume and Number of Stems. *Proc. of the SCANDLASER Scientific Workshop on Airborne Laser Scanning of Forests*, Umeå/Sweden, S. 198 –211.

13 Hyyppä J., Hyyppä, H., Maltamo M., Yu X.W., Ahokas E., Pyyssalo U. 2003: Laser scanning of forest resources – some of the finnish experience, *Proc. of the SCANDLASER Scientific Workshop on Airborne Laser Scanning of Forests*, Umeå/Sweden, S. 53 – 59.

14 Adler, P. 2001: Einsatz digitaler Photogrammetrie zur Beschreibung von Waldbeständen – am Beispiel der digitalen photogrammetrischen Erfassung der Level 2 Flächen Baden-Württembergs. Dissertation at the Albert-Ludwigs-University Freiburg im Breisgau. 148 p.

15 Nugroho, M., Hoekman, D. H. and De Kok, R. 2002: Analysis of the Forests Spatial Structure using SAR and Ikonos Data. *Proc. of the ForestSAT Symposium*, 5th – 9th August 2002, Edinburgh, available at: http://www.definiens-imaging.com/documents/publications/Nugroho3.pdf

16 Erikson, Mats. 2004: Species Classification of Individually Segmented Tree Crowns in High-Resolution Aerial Images Using Radiometric and Morphologic Image Measures. Remote Sensing of Environment 91, pp. 469 – 477.

17 Persson, Å., Holmgren, J. and Söderman, U. 2003: Detection, Measurements and Species Classification of Individual Trees for Forest Inventory and Visualization, *Proc. of the SCANDLASER Scientific Workshop on Airborne Laser Scanning of Forests*, Umeå/Sweden, S. 223 – 234.