AUTOMATIC SEGMENTATION AND CHARACTERISATION OF FOREST STAND PARAMETERS USING AIRBORNE LIDAR DATA, MULTISPECTRAL AND FOGIS DATA

Oliver Diedershagen*, Barbara Koch*, Holger Weinacker*

*Department of Remote Sensing and Land Information Systems.
Institute of Forestry Economics. University Freiburg.
Tennenbacher-Str.4, 79106 Freiburg, Germany

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ABSTRACT:

Inventories and monitoring systems are important tools for sustainable forest management and for the protection of nature in general. In order to make appropriate management plans, it is important to obtain information about the actual state of the environment and the extent of possible changes. Up until now, forest inventories have been based on terrestrial surveys that often integrate material from aerial photographs. These terrestrial surveys, however, are time consuming and thus very expensive. This also makes the repetition of these inventories at regular intervals very difficult. It is therefore necessary to automate these methods and to analyse the use of other remote sensing datasets. One possible method for automatic object recognition might be the use of airborne laser scanner data, which permits the extraction of 3-D information. Several publications have shown that inventory parameters can be collected on a single tree or complete stand basis from lidar data (NÆSSET, E. 1997; NÆSSET ET ALL 2001; NÆSSET ET ALL 2003). This paper deals with the automatic segmentation and characterisation of forest stand units. The procedure presented uses 3-D information from a combined laser-line scanner system. Forest stands are automatically delineated using lidar datasets, and the mean tree height and crown cover density is then calculated for each stand unit. Furthermore, the multi-spectral data can be used to extract information on the tree species and the mixture distribution. This paper presents an effective method of automatically detecting stand boundaries.

1. INTRODUCTION

Forest inventories are conducted every ten years in Germany. As an instrument for medium-term planning they are divided in three components. The first concerns the monitoring of harvesting procedures, the second involves the collection of data, such as growing stock, increment, tree height, tree species distribution etc.; while the third concerns planning for the next decade. The term forest inventory usually refers to the second component, the data collection. Estimations of forest parameters generally correspond to the smallest forest units, the forest stands. The boundaries of these stands are drawn manually from analogue maps and / or digital orthophotos, and are then digitised. This approach is time consuming and erroneous. In order to decrease the costs of public and private forest management tasks, and to accelerate the stand delineation process, the use of advanced technologies is becoming more of a necessity. Due to the fact that lidar data offers the advantage of providing 3-D information, the use of this data type appears to be an interesting approach to obtaining forest information in an automated, and thus cost-efficient way. Laser scanner data has been previously used in a number of forest inventories, especially in Scandinavian countries (HYYPPÄ, J.; et al. 2001; NÆSSET, E. 1997, 2001; NÆSSET et al 2003; PYYSALO, U. & HYYPPÄ, H. 2002). Many studies have shown the applicability of lidar data in the field of forest management (HYYPPÄ, J.; et al. 2001; LEFSKY, M et al 1999, 2002; LIM, K. Et al. 2002; NÆSSET, E. 1997,2001; NÆSSET ET ALL 2003; PYYSALO, U. & HYYPPÄ, H. 2002; SCHARDT, M. et al. 2002). An approach to automatic delineation and characterisation of forest stands by laser scanner data is presented in this article. Furthermore, the assignment of multi-spectral data and GIS information is discussed. The approach presented in this paper is part of the NATSCAN project focussing research primarily on landscape elements and forests.

2. MATERIALS AND METHODS

2.1 Study areas

Three study areas have been selected for investigation within the project, and two of these were used for the automatic stand delineation. These test sites are located near the town of Freiburg/ Breisgau. In order to fulfil the requirement of combining different forest stand characteristics, one area is located in the northwest (Figure 1) and the other one in the southeast (Figure 2) of Freiburg. The first site is a mostly planar area in the Rhine Valley at an altitude of between 200 and 300m above sea level. The site is dominated by a variety of broadleaf trees species and a range of different age class distributions.

The second test site is located in the mountainous region of the Black Forest with an altitude between 500 and 900m above sea level. This area is represented by mixed forest stands typical of mountainous areas in the region.

2.2 Data sets

A variety of datasets have been made available for this study, including laser and multi-spectral data, as well as GIS information from an existing forest information system called FOGIS.

Figure 1: Test site Mooswald (blue arrow) in the northwest of Freiburg, Brsg. Approx. 20 ha.

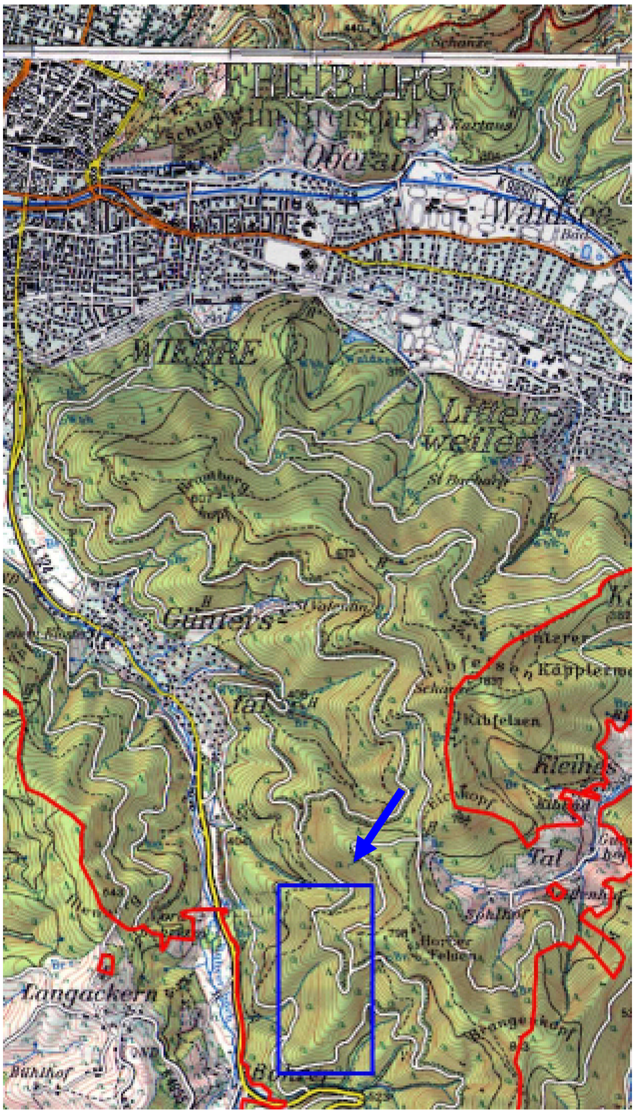


Figure 2: Test site Black Forest (blue arrow) in the southwest of Freiburg, Brsg. Approx. 70 ha.

2.2.1 Laser and multi-spectral data: The small footprint laser scanner device used for the lidar data collection is called FALCON and was developed by TopoSys. FALCON is a discrete return lidar device, which records the first and the last pulse of each laser beam simultaneously. The lidar sensor consists of 127 fan-formed fibreglass cells at both the input and output sides of the device. Another cell is used for calibration. The angle between the cells amounts to 2mrad. The laser light is emitted with an angle of 1mrad, which means that the footprint has a diameter of 1m at a flight height of 1000m. The sensor device consists not only of the laser scanner, but also contains a digital line scanner. The line scanner records data in the visible and near infrared region of the electromagnetic spectrum. A corresponding rgb/cir dataset is therefore available for every lidar flight strip.

2.2.2 Geographic Forest Information System: FOGIS is the digital geographic information system used by the Baden-Württemberg Forest Administration. FOGIS is a software tool for digitisation and analysis of the geometric data based on ESRI ArcInfo®. The stand boundaries are digitised with this software and connected with the database, which contains the results from the field surveys. This database includes all the information required for forest management planning.

2.2.3 Software: ERDAS Imagine software is used for the classification steps and fuzzy convolution applications. The segmentation steps outlined below were conducted with the MVTec Halcon software package. For further information, please refer to the applicable software manuals or visit www.mvtec.de or www.gis.leica-geosystems.com.

2.3 Methodology

2.3.1 Stand Unit Delineation: In forestry practice, forest stands are usually extracted manually from aerial images. The stands are differentiated according to their height structure, the structure of the canopy and the tree species. Furthermore, the stand boundaries also depend on historical factors. Therefore, in some cases, these boundaries are not comprehensible (Figure 3 B). Due to the fact that lidar data provides 3-D object information, it is obvious that lidar data can be applied for stand delineation - especially for an automatic approach.

The grey values of the pixels from lidar images correspond to height values, with brighter grey values matching larger height values. A Digtital Surface Model DSM and a Digital Terrain Model DTM are also usually calculated from lidar data. In order to achieve the extraction of the stands according to their height, a normalised DSM must be first calculated. This is achieved by subtracting the DTM from the DSM. The segmentation attempt to extract stand units was derived from an image taken at the Mooswald test site. The image was successively classified and filtered according to tree heights with filter masks of various sizes. The first part of the approach is based on simple classification functions using the software ERDAS Imagine. The theory behind this is to divide the forests into higher and lower sections, as it is easier to characterise these groups separately. The grey value range is consequently reduced from 65,536 potential grey values to five grey value classes. This is achieved by applying several classification functions to the nDSM. First of all, an unsupervised classification is used. The software uses the ISODATA algorithm, which stands for "Iterative Self-Organising Data Analysis Technique". The procedure iteratively performs an entire classification. The term "Self-Organising" describes the method in which the clusters inherent in the data are ordered. The clusters are created using the minimum distance formula. Further information can be taken from the ERDAS Field Guide.

The number of five grey value classes is specified as default for the classification. Thus the image is reduced to five grey values after classification. Qualitative analysis has shown that five grey value classes provide the best results for the segmentation process that follows. A supervised classification is then applied to the new image using the minimum distance classifier. After that, a fuzzy convolution function reduces the speckle effects of mixed pixels by considering the grey values of a centre pixel and those of its neighbours. If too many neighbouring pixels belong to a different class, the class of the centre pixel is changed to the class of the neighbouring pixels. The size of the filter mask used is 7x7 pixels.

The image can now be divided into two parts according to the upper and lower parts of the forest, and is segmented at a fixed threshold. Because of the classification, this threshold provides the same results in different test sites. The two parts are now handled separately by creating two new images. For this creation the grey values of the nDSM are used. After a histogram linearisation of the two images is conducted to spread the grey value range, the same classification process is started again. As in the first iteration, five grey value classes delivered the best result for subsequent stand extraction.

The final stand delineation is achieved by segmenting the new classification results with fixed thresholds. In some cases it was necessary to use a filter to suppress speckle effects. The segmentation result is improved using morphological operators such as opening and closing, which closes the gaps and holes at a specified extent.

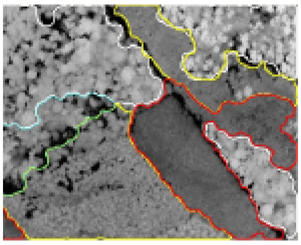
2.3.2 Mean stand height: A mean stand height for each stand unit is calculated depending on the single tree crowns (HEYDER 2003). The extraction of the single tree crowns is based on an algorithm that was developed and improved at the Department of Remote Sensing and Landscape Information Systems (HEYDER 2003). The corresponding tree height is estimated for each tree crown. A mean stand height is then calculated for every stand unit from these values. The stand height was previously one of three important variables for developing the yield tables used for forestry planning.

2.3.3 Crown density: Another important variable is the crown density of each stand, which is also dependant on the delineation of single trees. The area of the tree crown is calculated for each individual tree. The crown density is the result of the total tree crown area in relation to the area of the forest stand. This variable provides important information about the stand density.

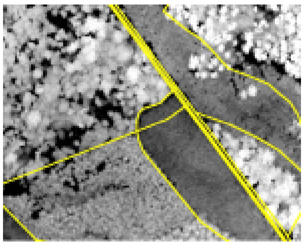
3. RESULTS

3.1 Stand delineation

Visual comparison of the segmentation results with the local government's manually delineated stand boundaries show that the procedure provides good results. In some cases the algorithm worked better, but in several cases the algorithm did not divide the stands in the same way a human interpreter would. The following figures show some examples of the delineation results and comparisons with FOGIS data.



A



B

Figure 3: Subset of the segmentation result from the test site Mooswald (A) in comparison with the FOGIS delineation (B).

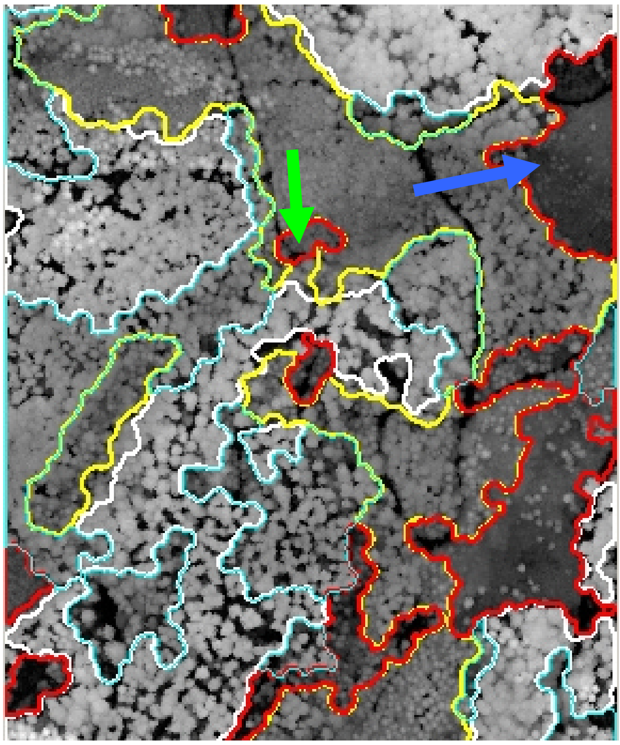


Figure 4: Subset of the segmentation result from the test site Black Forest. This figure shows the problems of the automatic delineation.

4. DISCUSSION

The quality of the resulting automatic delineation is dependent on the structure of the forest. If the canopy structure is largely homogeneous, the algorithm works well (Figure 3 A). However in heterogeneous forests, such as the Black Forest test site, (Figure 4) several errors or inaccuracies occur. Some stands are delineated well (blue arrow), while other stands are separated although they belong to the same stand (green arrow). One cause for these errors is the different types of gaps and holes within the stands. Furthermore, the range of vertical structures within one stand composed of the same tree species can also introduce errors. In another example, two neighbouring stands of the same height, but different tree species are not delineated. The algorithm cannot divide these two stands based on their heights alone. While it is obvious to a human interpreter where these boundaries should be drawn, the automatic algorithm is not able to correctly differentiate these. It is always necessary to check the delineation result and to improve it manually by fusing falsely delineated stands or delineating further boundaries.

By reducing the number of grey values used for the classification, the algorithm is transferable to images from other test sites without changing the parameters. The values of these classes are always the same when the number of classes is also chosen equally.

A possible improvement to the algorithm could be to combine lidar and multi-spectral data. This could be helpful for differentiating neighbouring stands that have a similar height but different tree species. However, due to the fact that most forests in Germany are composed of mixed tree species, this may not be practical. In many cases the same tree species are mixed in similar combinations, which can complicate automatic stand delineation.

Multi-spectral data, however, will be helpful in characterising the final stands and can be used to classify stand types according to tree species.

Old yield tables are often still used for forest inventories, despite inherent inaccuracies in the forest parameters that are estimated. Lidar data offers an excellent opportunity to estimate these parameters faster and more precisely. Important forest variables can be extracted for single trees and also for entire forest stands.

Another approach to automatic stand delineation could be based on single tree delineation, whereby a single tree is compared with its neighbours. If the trees do not differentiate too much from each other, they will be merged into a single region. This procedure is then repeated until the region area is stable and the next single tree is compared with its neighbours, until all single trees are accounted for. Initial attempts with this new algorithm provide promising results, however, the development is still in progress.

5. CONCLUSIONS

The algorithm presented in this article provides good results for automatic stand delineation, however, the results are erroneous and inaccurate. As a result, each segmentation must be checked and improved where necessary. The procedure automatically provides suggestions as to how these boundaries should be drawn, which decreases the time required for visual interpretation. One disadvantage is that line management of the automatic delineation delivers corrugated lines according to the shape of the tree crowns. This must be improved.

The combination of lidar data with multi-spectral data will not improve the delineation result, however, it will assist with the classification of each stand. The precise 3-D information from the lidar data and the tree species information deliver the basic information for many important forest variables.

The algorithm is not applicable for a self-contained forest inventory. Nevertheless, the procedure is much faster than visual interpretation and is not influenced by the subjectivity of the interpreter. This procedure can be considered a cost efficient tool. A field survey, however, must be implemented in order to defend the accuracy of the described method. Furthermore, the procedure must be tested at other test sites in order to prove the transferability.

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FURTHER INFORMATION

If you have questions or are interested in this subject, please do not hesitate to contact us at:

ferninfo@felis.uni-freiburg.de
oliver.diedershagen@felis.uni-freiburg.de
holger.weinacker@felis.uni-freiburg.de

Information about the software can be found at:

MVTEC SOFTWARE GMBH (2003): PRODUCT HALCON - HTTP://WWW.MVTEC.DE/HALCON/

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