AUTOMATIC ESTIMATION OF FOREST INVENTORY PARAMETERS BASED ON LIDAR, MULTI-SPECTRAL AND FOGIS DATA

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ABSTRACT

During the last years the protection of nature has become a very important aspect for interference or structural alterations. It is necessary for all planning, which might have consequences for nature or impairments of nature, to get information about the actual state and the variations of landscape components. A promising field for the extraction of the needed information is the *lidar* (light detection an ranging) remote sensing technology. This technology provides vertical information of the land surface, especially of the vegetation.

In the project NATSCAN introduced here the remote sensing system used consists of a lidar scanner and a RGB/NIR digital line camera. The laser scanner device is a Discrete-return lidar device. It is able to record the first and last pulse of each foot print simultaneously. The NATSCAN project is the succeeding project of HIGHSCAN, in which the University of Freiburg was involved, too. The main objective of the current project is to determine basic variables for forest inventories such as ***tree species***, ***tree height*** and ***crown area***. These parameters are used to estimate further variables like ***tree age***, ***stem diameter***, ***h/d-proportion***, ***timber volume*** and ***tree species distribution***. In order to achieve the above main objectives three important tasks are the delineation of trees, the determination of the tree species and the delineation of stand units. Especially for Middle Europe the determination of tree species is a difficult problem as there exists a variety of different tree species compared to Scandinavian forest types. This problem is still worked on and is not an objective in this article. As further variables for forest inventories tree mean heights and crown cover density will be calculated for each stand unit. These calculations depend on the automatic delineation of single tree crowns.

1. INTRODUCTION

One great aim of the project NATSCAN is to use lidar remote sensing for the extraction of the vertical information of the vegetation and other objects. In the different types of monitoring and inventory systems it is an important part of forest inventories to use part the vertical vegetation structure for planning. Other research fields for example are projects, which calculate the different influences on the nature by different ways of planning or the protection of high voltage power supply lines. For example power supply lines have to have a minimum distance to different objects such as trees, people, cars, buildings, etc. Therefor the lines have to be checked periodically to detect the changes in the area of the supply lines. If trees grow too high, so that the distance from their top to the lowest line is too short, the trees have to be cut. In the past this information was collected manually. In Germany forest inventories are derived every ten years. The forest inventory generally consists of three parts. The first one is involved with the determination of the current state, that means the estimation of tree species, timber volume, stand inventory, increment, etc. The

second one is the supervision of the planning for the last decade. The last one provides the planning for the following decade. In the following forest inventory means in this article the first part of the three steps. This inventory is an expensive system due to the fact that the information in particular of the current state is not extracted automatically. Furthermore as remote sensing data only aerial photos are used to delineate the forest stand units. In a further step the analogue datasets have to be digitalised. Variables like mean tree height, tree species distribution, cover densities, etc. are estimated by field surveys and calculated for each stand unit using statistical methods.
During the last years the interest is growing to decrease the costs of these inventories by reducing the time effort. For these different kinds of inventory systems lidar remote sensing offers great possibilities. With this data type it is possible to get information about the vertical structure of the land surface, especially of the vegetation. Many studies have shown this before. In the project NATSCAN are several approaches for the automatic extraction of the needed information researched. The remote sensing system used is called FALCON and it is developed by TopoSys. It consists of the lidar scanner and a RGB/NIR digital line camera. The laser scanner device is a discrete-return lidar device. It is able to record the first and last pulse of each foot print simultaneously. Within the NATSCAN project an enhanced demonstrator lidar sensor will be developed by TopoSys and tested at Felis. The main advantage of the new system will be a higher spatial resolution and homogenous foot print distribution.

2. MATERIALS

2.1 Study areas

There have been chosen three study areas for the development of the algorithms in the project NATSCAN. The aim was to combine in the study areas as many different characteristics of forest stands as possible. The first area is in the Northwest of the city Freiburg/ Breisgau. It is planar at a height of ca. 200 to 300m above sea level. The tree species distribution and age class distribution is diversified. Furthermore the tree species occur in mixed stands. In contrast to this the second study area is in the Southeast of Freiburg. It is a mountainous area with a height from 500 to 900m above sea level. There occurs the typical mountain mixed forest. But the tree species distribution is diversified, too. While the first two areas are used to develop the algorithms for the forest inventory the third one is used for the extraction of man made objects and the development of algorithms for the inventory system used at power supply lines. The third study area is in the near of the city Engen/ Bodensee. It is mostly planar or slightly mountainous.

2.2 Data sets

In the project NATSCAN are different types of data sets. There are Laser and Multi-spectral data and GIS data. The data sets are collected and used as described in the following.
2.2.1 Laser and Multi-spectral Data. The used Laser scanner device is a discrete return lidar system. It records the first and the last pulse of each laser beam simultaneously. The lidar sensor consists of 127 fan-formed glass fibre cells at the input and at the output side. Another cell is used for the calibration. The angle between the cells amounts 0.2mrad. The laser light is sent off with an angle of 0.1mrad. This means, that the footprint has a diameter of 1m at a flight height of 1000m. The sensor device consists not only of the laserscanner, but contains a digital line scanner. It is able to record RGB and NIR data. Each scan line has 682 pixel at a resolution of 0,55m at 1000m survey height. The wave length of the channels are 440 – 490nm in channel 1, 500 – 580nm in channel 2, 580 – 660nm in channel 3 and 770 – 890nm in channel 4.
2.2.3 FOGIS. The abbreviation FOGIS means “Forstal Geographic Informationsystem Baden-Württemberg”. FOGIS is the digital result of the forest inventory of the government of Baden-Württemberg. As mentioned above for each forestry office this inventory is done every ten years.

The results of the field surveys are drawn in maps, which are digitalised with a special FOGIS-software. To the GIS-geometries belongs a special data base, which contains the information about tree species, tree age, tree height, stem diameter, standing volume, etc. Furthermore the forest inventory declares the planning for the following ten years.

3. METHODS

3.1 Single Tree Delineation

The delineation of single trees or groups of trees is processed in a sequential manner. So far the procedures developed are based on the rasterised digital surface model (DSM) and digital terrain model (DTM). For the development the HALCON image processing software has been used in great extend. HALCON is a developing system mainly used in the area of machine vision applications. It consists of a huge library of image processing routines, which can be integrated into own software developments based on C, C++ or COM. Additionally it provides the developer with a case tool called Hdevelop.
The extraction of single trees in very dense forest areas is compared to the estimation of man-made objects an even more difficult task as nature is chaotic: no right angles, no plan surfaces, no distinct delimitation between objects exist.

3.1.1 Normalized digital surface model [nDSM] and the smoothing model [snDSM]

The first step in the processing chain is the calculation of the normalized digital surface model (**nDSM**) by subtracting the DTM from the DSM. This step should only be usesd in areas where no extreme topography occurs, otherwise the surface, which in fact represents the canopy of the trees, is changed and the tree delineation will not work correctly.
Thereafter the forest area is classified into “old growth” and “young growth” regions. As threshold conduced the tree height. Trees which are higher than 20m, especially broad-leafeded trees, have quite large height variations in their crown topography. The variations can in a later step be used to distinguish between broad-leafed and coniferous trees . In this basic state, where the interest is concentrated on the delineation of single trees or groups of trees, these variations worsen the desired results of the delineation processes.
Figures 1a,b show the DSM and DTM delivered by TopoSys and figure 1c the calculated nDSM. The nDSM has been grouped into two domains “young growth” and “old growth”. The “old growth” domain has been filtered by a Gaussian filter with a large sigma to smooth the rough tree canopies to avoid an “over-segmentation” by the following pouring algorithm. In the “young growth” domain none or only a very “mild smoothing” has been done, otherwise tree crowns would be spuriously merged. After the filtering processes the domains have been merged to the smoothed nDSM (snDSM), see figure 2.

3.1.2 Pouring – the raindrop model

A pouring algorithm is used to estimate both tree tops and corresponding “light crown boundaries” in the snDSM. The pouring algorithm is provided by the HALCON software and works similar to a watershed algorithm. It assumes the input data describing a “mountain range”. Firstly the local maxima are calculated. Gray-values, i.e. tree heights, which have larger values than their 4-connective neighbours are marked as maxima. Secondly, starting from these maxima an expansion is done until the valley-bottoms are reached, like raindrops running downhill in all possible directions. This part of the algorithm continues as long as the examined points found are smaller or equal. Thereby some points of the valley-bottom can belong to several maxima. In a final step these unsure points are assigned by a uniform expansion of all affected regions, see figure 3.

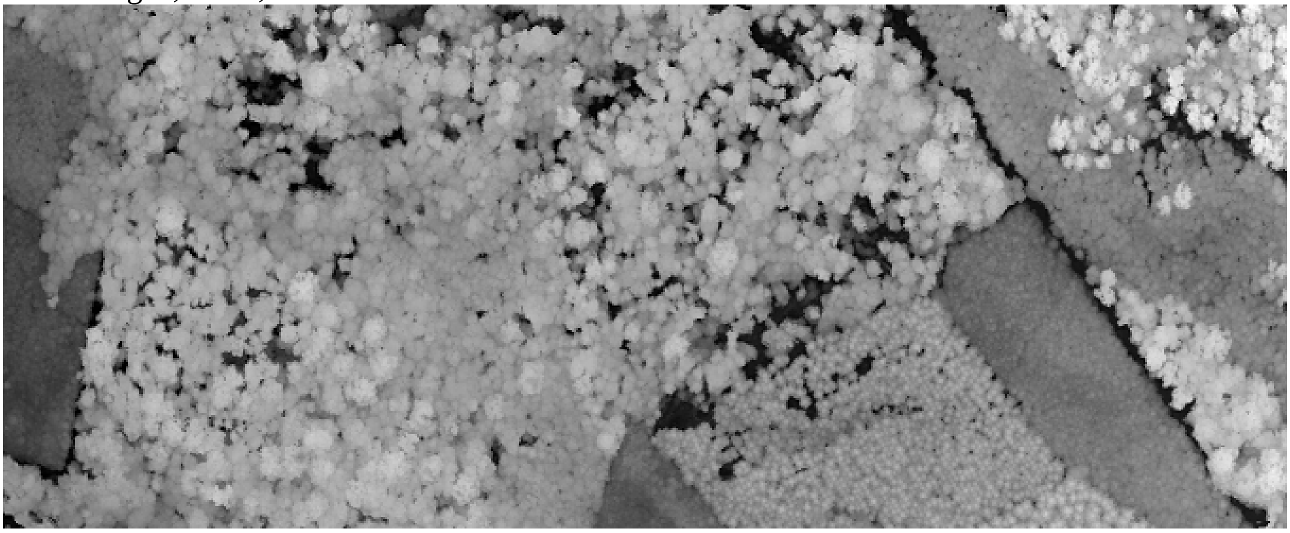

Figure 1a: *Shows the* ***DSM*** *from the test site West of Freiburg (South Germany) (TopoSys)*

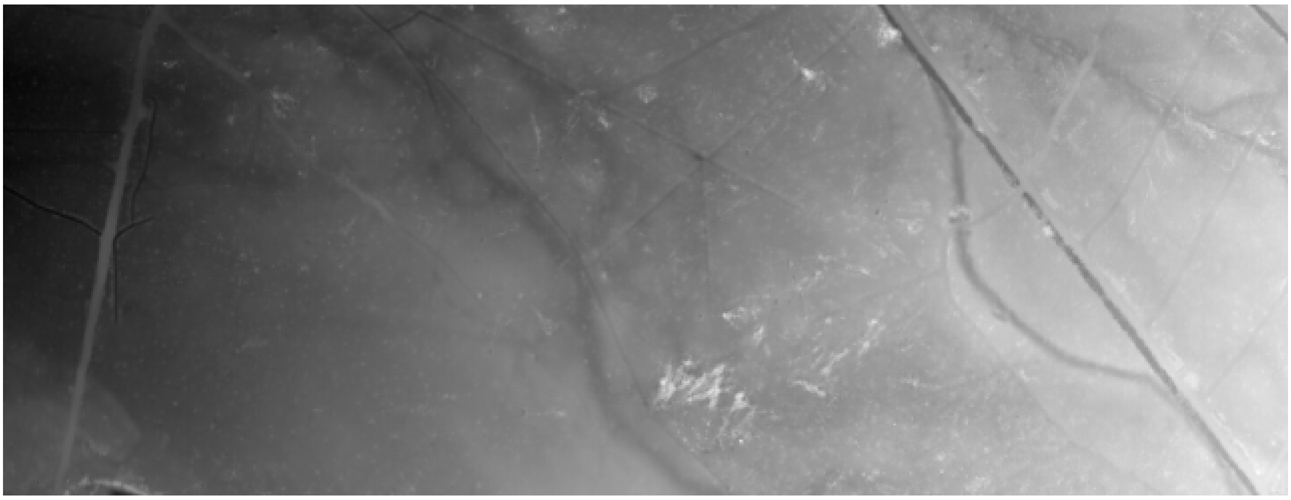

Figure 1b: *Shows the* ***DTM*** *from the test site West of Freiburg (South Germany) (TopoSys)*

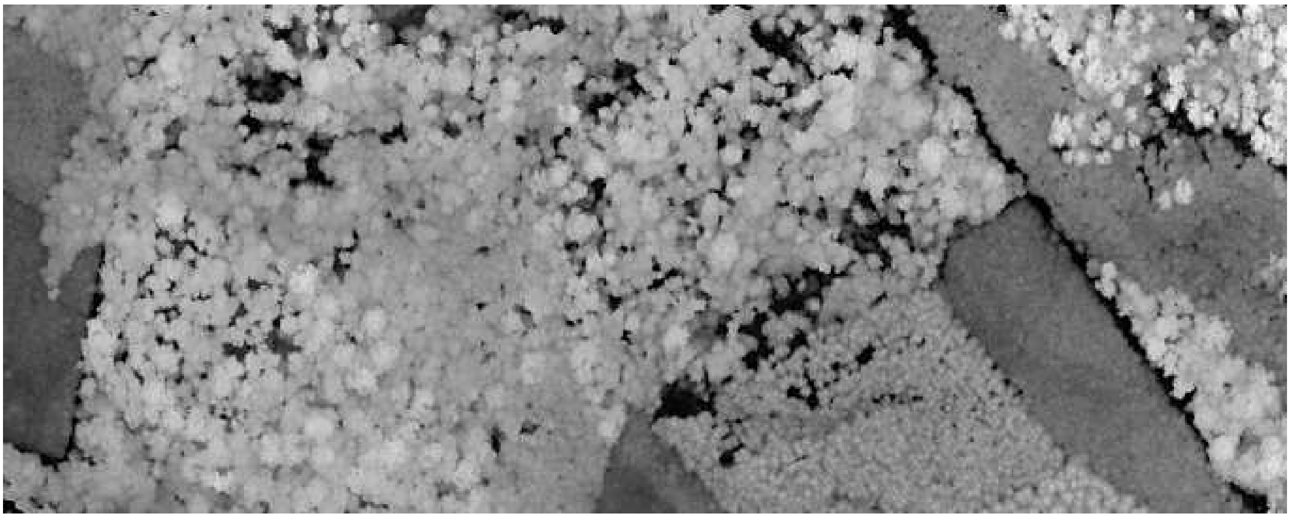

Figure 1c: *Subtracting the DTM from the DSM the normalised DSM (**nDSM**) is calculated. Tree heights can by measured directly in this modell. The data in the DSM, DTM and nDSM have 16bit format. Therefore an altitude range of 655,36m, where each gray-value represents 1 cm in reality, can be represented.*

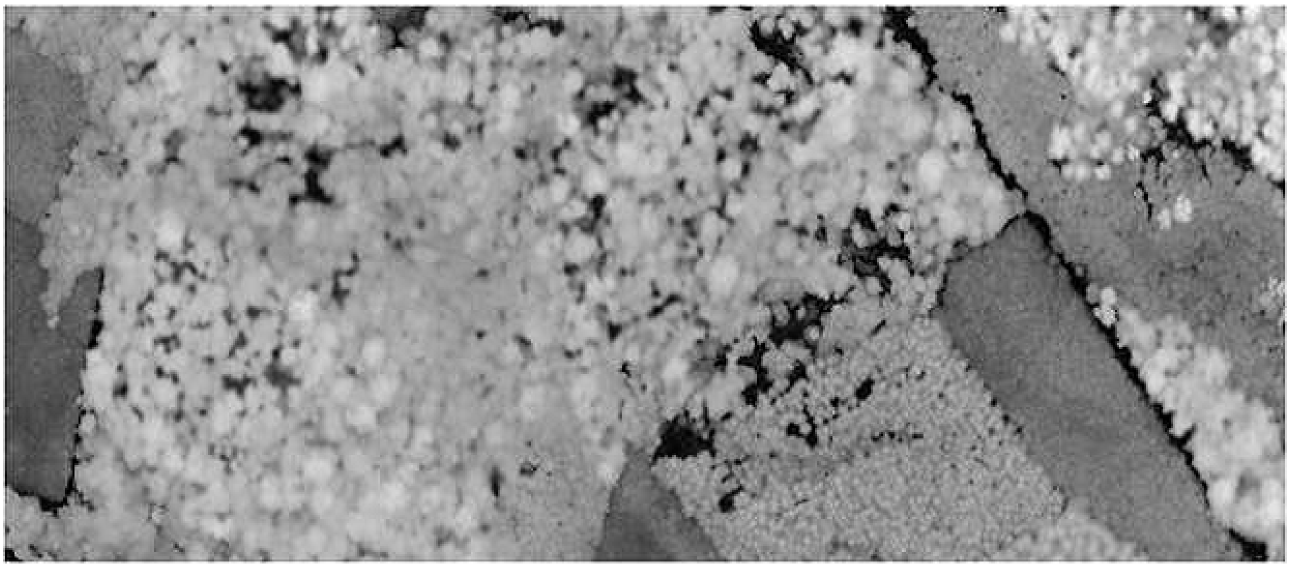

***Figure 2: snDSM** - Areas with tree heights less than 20m are classified as "young growth" and where the heights are greater than 20m are "old growth". The nDSM has been smoothed by a Gaussian filter with different sigma, depending whether it is "old growth" or "young growth".*

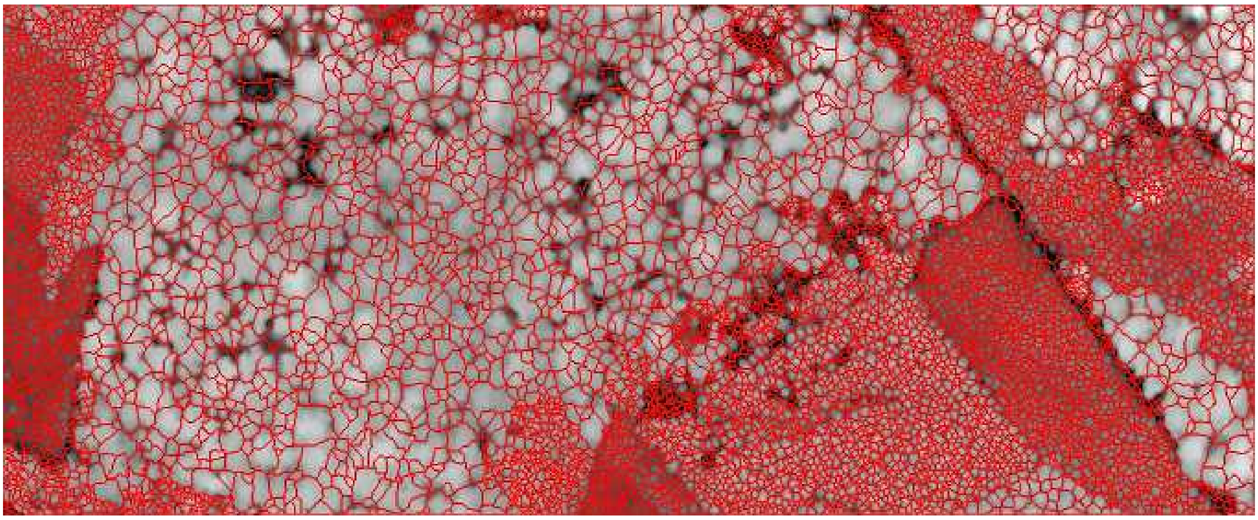

***Figure 3:** Result of the **Pouring** algorithm. The algorithm does not stop at the tree border, but at the bottom-valleys, which e.g. can be the real surface or a small tree with a more or less flat crown standing between two or more large ones.*

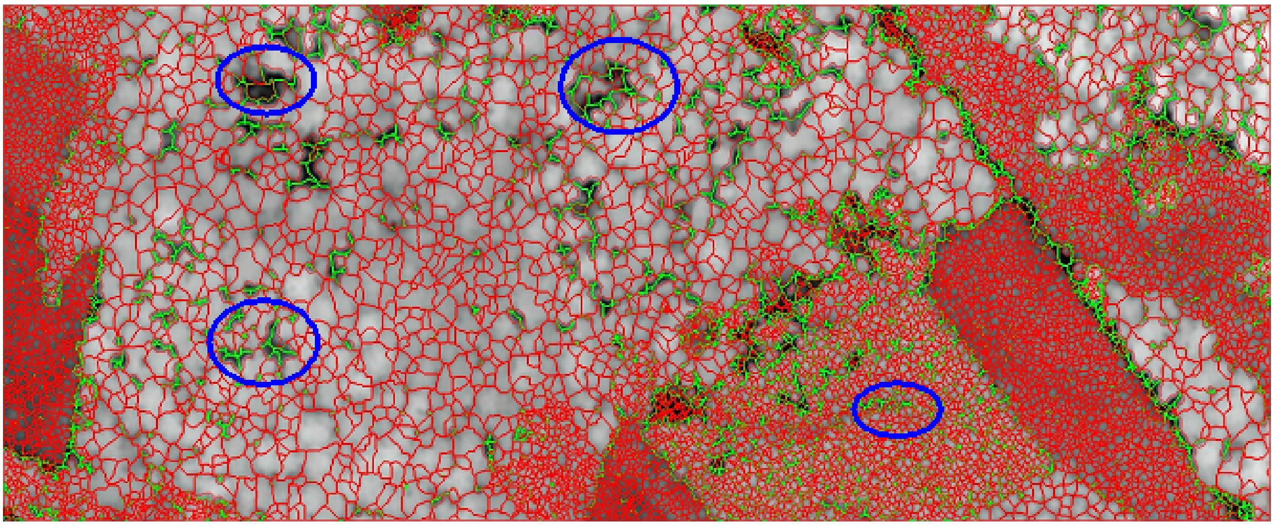

***Figure 4: Ray-algorithm**: The regions calculated by the pouring algorithm are changed. The red border lines show the corrected and the green ones the part of the border lines, which have been originally calculated by the pouring algorithm.*

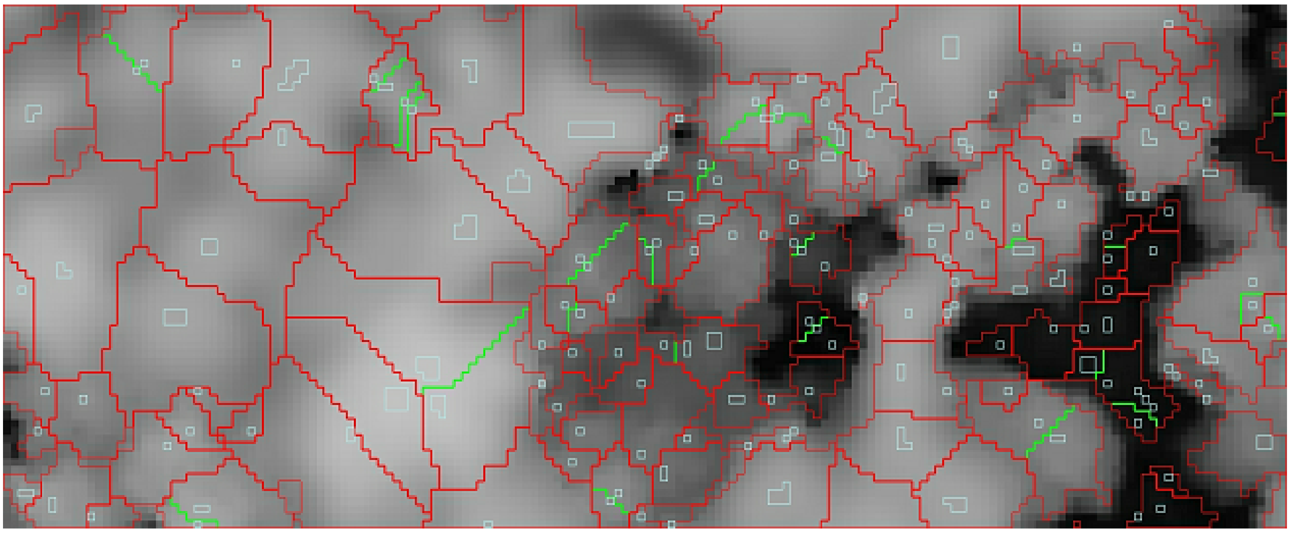

Figure 5: *Regions are merged, where the distance between the tops is less than 3 pixel, corresponding to 1.5m in reality.*

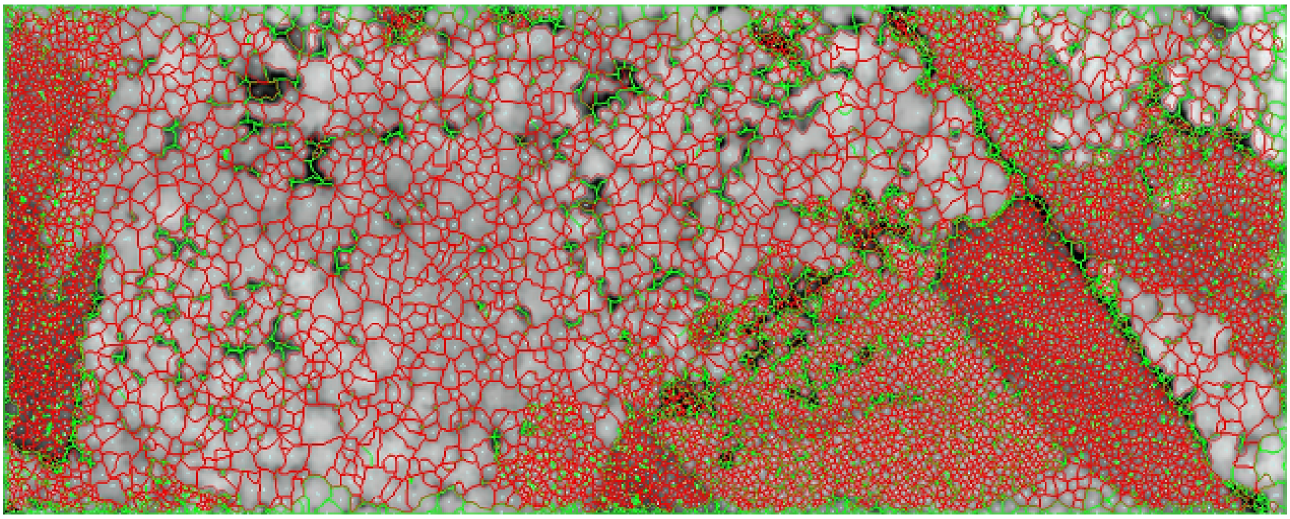

Figure 6: *Final result of the tree delineation after all programming steps (green after pouring, red after all following steps)*

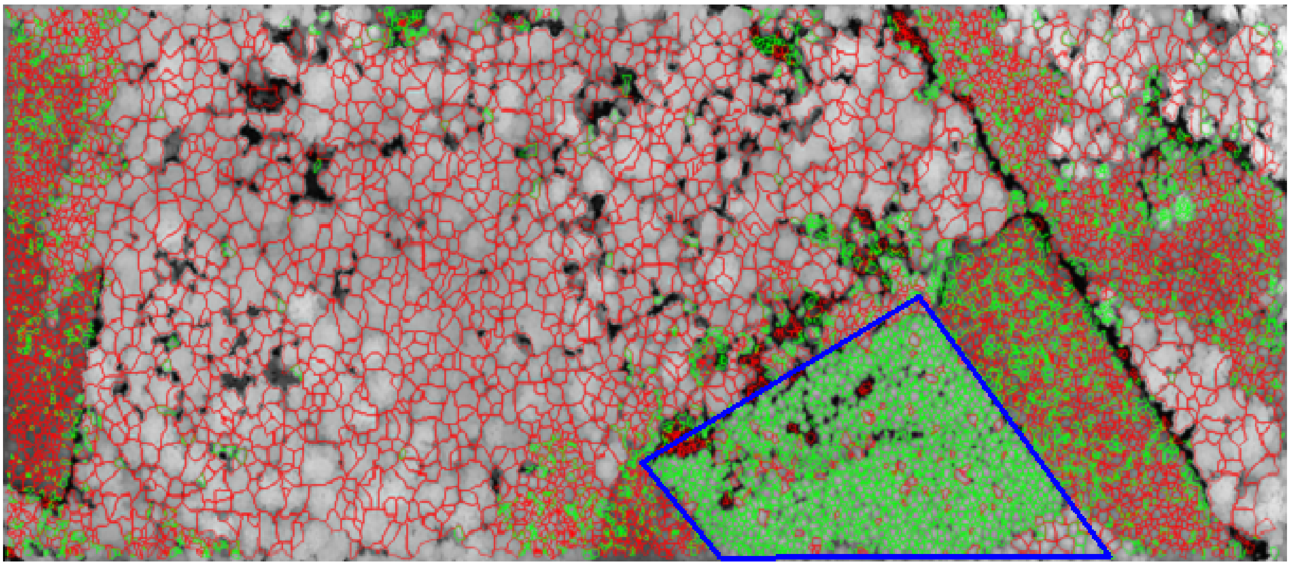

Figure 7: The classification of the two main forest groups broad-leafed trees and conifers is based on the ratio between "light crown height" to "light crown area". The green bordered regions are classified as conifers and the red ones as broad-leafed trees. The blue bordered region is a conifesr area extracted from FOGIS.

3.1.3 Ray-algorithm

The pouring algorithm executes until all bottom lines in the whole image are found. These bottom lines do not always represent the border lines of the trees, instead the lines can include parts of the real surface or they can lie on small trees with a more or less flat crown, which stand between large trees. This means that several tree crowns are estimated too large. Therefore a “ray-search-algorithm” is included.

The ray-algorithm works as following:

- Choosing approximate tree tops
  It is assumed, that the maxima extracted by the pouring algorithm represent the tops of the trees. These points are the starting positions of the algorithm.
- Calculation of the rays
  Virtual rays between the maxima and a special amount of border points are established.
- Estimation of new border points of the tree crown
  On each ray the difference in elevation is calculated within distinct arbitrary chooseable steps along the ray. A difference in elevation of -1.5m/0.5m was empirically chosen as threshold.
  If the calculated value is negative and smaller than this threshold, the position on the ray is marked as a new border point. Otherwise the original border point, which is the end point of the examined ray, will be retained.
- Creation of the new tree crown
  The resulting polygon of all newly calculated and retained border points is the new border line of the tree.

The ray-algorithm is proceeded for all tree regions. The result is shown in figure 4.

3.1.4 Form Parameters and Mutual Relations

There still exists a lot of mismatched, merged or not recognized trees, e.g. a substantial amount of regions which are too small or have shapes which are impossible for being trees.

To enhance the result the following parameters and relations have been tested:

- Removal of border trees
- Minimal area
- Minimal distance between tree tops based on pouring region maxima
- Ratio of radius (anisometry for the shape selection)
- Compactness

Removal of border trees: Trees lying at the image border are dissected and falsify the calculation. Therefore they are extracted and suppressed.

Minimal area: All regions consisting of equal or less than 9 pixels [2.25m²] are assumed not to be separate trees, but part of an adjacent tree. These regions are merged with the neighbouring tree having the longest “border line” in common.

Anisometry (Ratio of radius ra and rb): The parameter **anisometry** describes the ratio of two estimated radii lying perpendicular to each other in the two main directions of the region. For a circle this value is 1.0. If this ratio is too large, which means that the region has a very long but narrow shape, it is improbable that this region represents a tree. If there is no plateau in the region it is merged to the adjacent region with the most similar orientation. Plateaus are calculated in the unfiltered 16bit image (**snDSM**) as the highest points in the 4-connectivity neighbourhood. Otherwise no merging takes place

Compactness: Here the **compactness** of the extracted tree regions is examined. It is defined as the ratio between the squared circumference and 4*pi*area. A circle has a compactness of 1.0. The value becomes smaller in case that the corresponding shape differse more and more from a circle. It is assumed that a tree crown has more or less the shape of a circle or ellipse. Depending on the shape of single tree the delineation is improved either by opening or closing. Overlapping regions are separated.

Minimal distance between tree tops (pouring maxima): Finally, the distance between tree tops of neighbouring regions is examined. In case that the distance is less than 1.5m the two adjacent regions are merged. The result of this process is shown in figure 5. The final results of all processing steps are presented in figure 6.

3.2 Classification of broad-leafed trees and conifers by the ratio “light crown height ” versus “light crown area”

Up to now just one criterion for the classification of the two main groups of trees – broad-leafeded trees and conifers, based on laser data, has been investigated. It is the ratio “light crown height” to “light crown area”. The ratio becomes larger for conifers than for broad-leafed trees. Unfortunately this is not true for young broad-leafed trees as they almost have the same shape as conifers. Therefore the ratio should only be used in areas, where young broad-leafeded trees do not occur. But as the aim is to distinguish between the two groups, all areas with young trees should be excluded from the investigation concerning this criterion. The result achieved in our test area is shown in figure 7.

3.3 Estimation of stand characteristics

3.3.1 Stand Unit Delineation. The pixels of the screened lidar data express the object heights by gray values. As mentioned above first of all a normalized DSM is calculated. Then the image is filtered and segmented in different ways to extract the different stand units. It is assumed, that stand units could be differentiated by their height characteristics. Every segmented region is cut out to avoid multiple segmentations. Without that it would lead to errors or interferences. Every following segmentation step is operated at the newly reduced image. The easiest step is segmentation with a threshold at 15m. This is possible due to the fact that young forest stands have a homogenous canopy, which is mostly closed. In a following step a local deviation filter is used. This is very helpful to extract young coniferous stands that are higher than 15m. Using a special filter in the higher gray values the highest stand units are segmented. By a filter mask size of 15 x 15 the sp-effect can be much reduced. It is a great filter mask size because the highest stand units consist normally of the oldest trees. That means that the canopy is not homogenous because of the possibility, that there are holes in the canopy. Using a great filter mask this effect can be suppressed. Similar to this the image is segmented step by step. In all segmentation steps stand units are extracted that possess similar characteristics. The figure 8 shows the segmentation result for the study area in the Northwest of Freiburg.

3.3.2 Mean stand height. Depending on the single tree delineation a mean stand height for each stand unit is calculated. Due to the fact that the delineated crown shapes represent the canopy in each stand unit their heights are used to calculate a mean stand height. The single tree heights are extracted as described above. In the past the stand height was one of three important variables to use the yield tables for forestry planning.

3.3.3 Crown density. The calculation of the crown density in each stand unit depends on the single tree delineation, too. For each stand unit the covered area of the tree crowns is calculated. The result is set in ratio to the area of the stand unit. The result is the crown density in each stand unit. With this parameter it is possible to draw conclusions to the stand density.

3.4 Comparison between GIS and automatic delineation

For the comparison of the FOGIS delineation and the automatic extraction of the stand units it has to be mentioned, that the FOGIS delineation is provided using ortho aerial images. This delineation is done by visual interpretation and is proofed by field surveys. However figure 9 shows that the

FOGIS data contains errors. The courses for these errors are on the one hand errors done by the interpreter and on the other hand errors during the digitalisation. The arrows mark two points, where the line management is not comprehensible. Furthermore the figure shows one important aspect. The automatic delineation could be done well only depending on the height information of forest stands. It is possible to use the screened lidar data to extract stand unit boundaries automatically. Indeed it has to be said, that the automatic line management is not as straight as the one of a human interpreter. This is coursed by the fact that the automatic delineation depends on the boundaries of the tree crowns. This means that the older the trees in the stand unit are the more frayed is the line management.

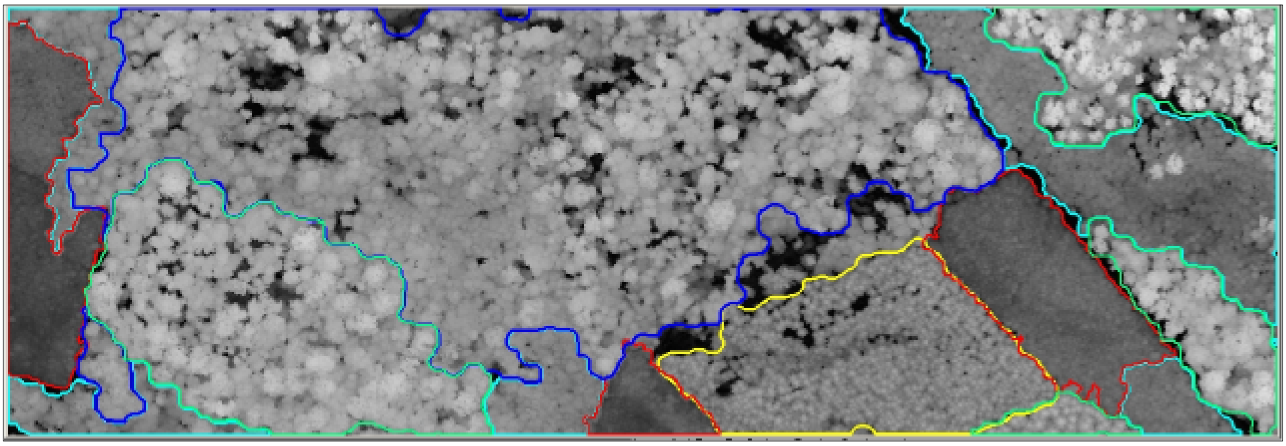

Figure 8: *Result of the stand unit delineation*

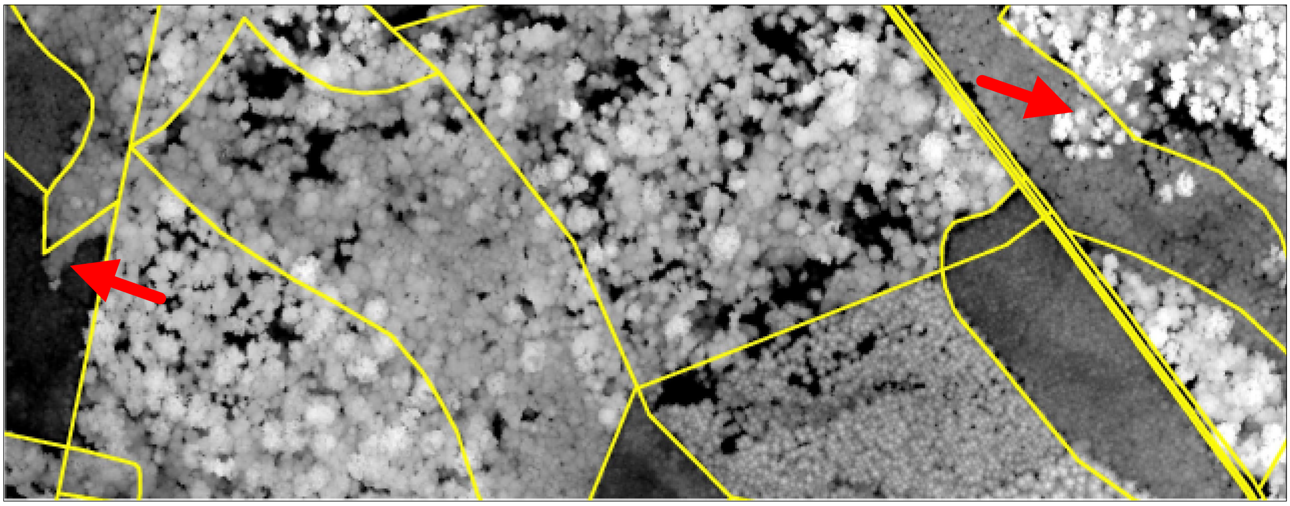

Figure 9: *FOGIS Delineation. The red arrows mark two examples for errors in the line management. In comparison to figure 8, it becomes apparent that the algorithm for the automatic stand unit extraction works well. (FOGIS data from the government of Baden-Württemberg)*

4. DISCUSSIONS

A hundred percent correct solution will never be reachable in our opinion, especially with an automatic inventory method. In several cases it is not possible for an interpreter to determine from top view, whether a scanned object describes a single tree or a part of a tree crown. It is obvious that in such a case a computer detect anything more. However, compared to the methods used for forest inventory, the laser-based methods will satisfy the requirements both in a faster and more economic way, if it is possible that the estimated results are reliable within a defined limit. The question is, how reliable is the reference data. For forest inventories often the old yield tables are used. Many studies have shown, that these tables are uncertain to estimate the timber volume. The results of the laser scanner data deviate from the forest inventory inevitably. Therefore a special field survey has been implemented. But the parameters of this survey still have to be calculated so that so far no exact reference exists.

5. ACKNOWLEDGEMENTS

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