

COMBINING LIDAR- AND GIS DATA FOR THE EXTRACTION OF FOREST INVENTORY PARAMETERS

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ABSTRACT

During the last decade 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 and ranging) remote sensing technology. This technology provides vertical information of the land surface, especially of the vegetation.

In this approach the automatic extraction of information is based on the combined analysis of lidar- and GIS-data. 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 main objective of the current project, called NATSCAN, 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. The paper will focus on the automatic delineation of the tree crown shapes, the automatic recognition of forest stand units and the calculation of the mean tree height of the highest trees in each stand unit and the calculation of the crown cover density in each unit.

1. INTRODUCTION

One great aim of the project NATSCAN is to use lidar remote sensing for the extraction of the object heights such as tree heights or generally the height of the vegetation. The height is an important variable in the different types of monitoring and inventory systems. It is a basic parameter for planning. A further aim is to extract other variables which can be derived from the lidar data. Another field of the project deals with the protection of high voltage power supply lines. The conclusion in this research field is drawn depending on the information which are extracted from the lidar data, too. For example power supply lines have to have a minimum distance to different objects such as trees, people, cars, buildings, etc. Therefore the lines have to be checked periodically to detect the changes in the area of the supply lines. If varying objects like trees reach a special height 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 and tree species distribution, timber volume, stand inventory, increment, etc. The second one is the supervision of the execution 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 of the current state in particular is measured manually. Furthermore 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 has grown 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. Many studies have shown this suitability before. But still there is a lack of applications. In the project NATSCAN are several approaches for the automatic extraction of the needed information researched. Within the 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. The study areas should combine 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 about 250m 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 South-east of Freiburg. It is a mountainous area with a height from 500 to 900m above sea level. There occurs the typical mountain mixed forest. The tree species distribution is diversified, too. The third area has been chosen for the extraction of man made objects and the development of algorithms for the inventory system used at power supply lines. It is near by the city Engen/ Lake Constance and it is mostly planar or slightly mountainous.

2.2 Data sets

In the project different types of data sets are used – laser-, multi-spectral- and GIS-data. The data sets are collected and used as described in the following.

2.2.1 LASER AND MULTI-SPECTRAL DATA

The lidar and multi-spectral data used are recorded during spring and summer 2002 by TopoSys with their FALCON system. 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 2mrad. The laser light is sent off with an angle of 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 laser scanner, 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 “Forestal Geographic Information System Baden-Wuerttemberg”. FOGIS is the digital result of the forest inventory of the government of Baden-Wuerttemberg. For each forestry office this inventory is done every decade. The results of the field surveys are drawn in maps, which are digitised with a special FOGIS-software based on ArcInfo©. The GIS-geometries are relayed to a special data base, which contains the information about tree species, tree age, tree height, stem diameter, standing volume, etc. The forest inventory is the execution control of the last ten years and declares the planning for the following decade.

3. METHODS

3.1 Single tree delineation

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. The delineation of single trees or groups of trees is done in a sequential manner.

So far the procedures developed are based on the rasterised digital surface model (**DSM**) and the digital terrain model (**DTM**). For the development the HALCON image processing software has been used. It is a developing system mainly used in the area of machine vision applications and 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.

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 normalised digital surface model (nDSM) by subtracting the DTM from the DSM. This step should only be used 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 produce falsified results.

Thereafter the forest area is classified into “old growth” and “young growth” regions. As threshold conducted the tree height. Trees which are higher than 22m, especially broad-leafed 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.

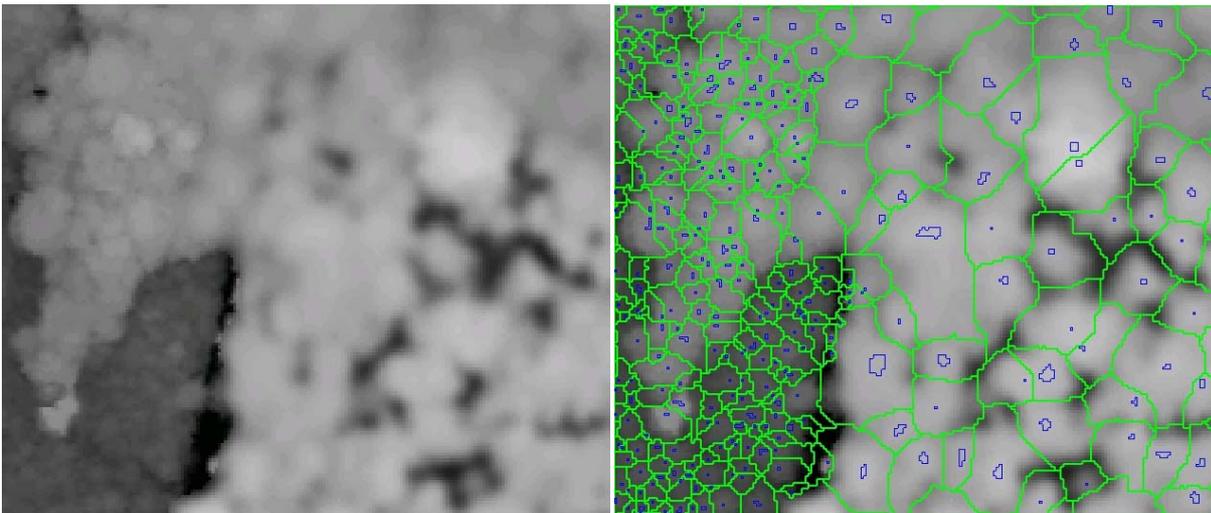
Figures 1a,b show the DSM and DTM and figure 1c the calculated nDSM. The nDSM has been grouped into two domains “young growth” and “old growth”. The “old growth” domain has been filtered by a Gaussian filter with a large sigma to smooth the rough tree canopies to avoid an “over-segmentation” by the following 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 2a.

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 2b.



Figures 1: 1a) shows the **DSM** from the test site West of Freiburg (South Germany); 1b) shows the **DTM** and 1c) shows the normalised DSM (**nDSM**), calculated by subtracting the DTM from the DSM. Tree heights can be measured directly in this model.



Figures 2: 2a) **snDSM** – Areas with tree heights less than 22m are classified as “young growth” and where the heights are greater than 22m are “old growth”. The **nDSM** has been smoothed by Gaussian filter with different sigma, depending whether it is “old growth” or young growth”. 2b) Result of the **Pouring** algorithm. The green border lines show the created tree regions and the small blue ones the pouring maxima regions. The algorithm does not stop at the tree border, but at the bottom-valleys, which e.g. can be the real surface or small trees with a more or less flat crown standing between two or more large trees.

3.1.3 FORM PARAMETERS AND MUTUAL RELATIONS

There still exists a lot of mismatched, merged or not recognised 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 introduced:

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 an choosable “area threshold”, depending on the tree height are assumed not to be separate trees, but part of an adjacent tree. These regions are merged with that neighbouring tree having the longest “border line” in common.

Anisometry (Ratio of radius r_a and r_b): 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 (DSM) as the highest points in the 4-connectivity or 8-connectivity neighbourhood. Otherwise no merging takes place

Compactness: The compactness of the extracted tree regions is examined. It is defined as the ratio between the squared circumference and $4 \cdot \pi \cdot \text{area}$. A circle has a compactness of 1.0. The value becomes smaller in case that the corresponding shape differs 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, two morphological operators. 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 “distance threshold” again depending on the tree height the two adjacent regions are merged. The result of this process is shown in figure 3.

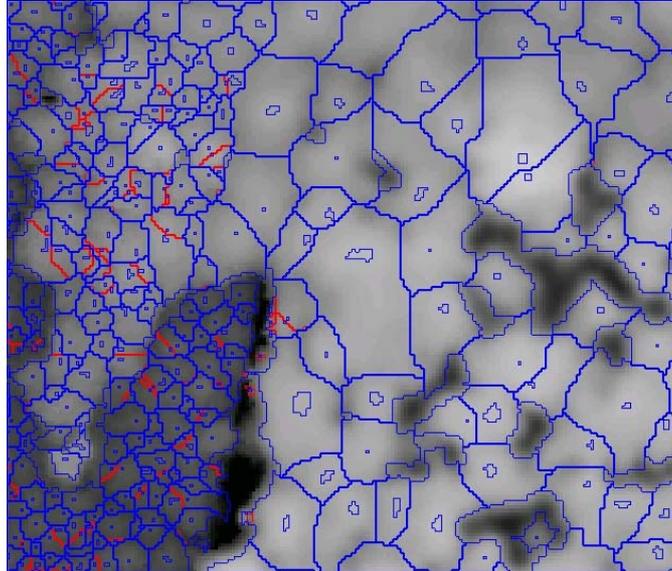


Figure 3: Merging Algorithm - The regions calculated by the pouring algorithm are changed. The blue border lines show the corrected and the red ones the part of the border lines, which have been originally calculated by the pouring algorithm.

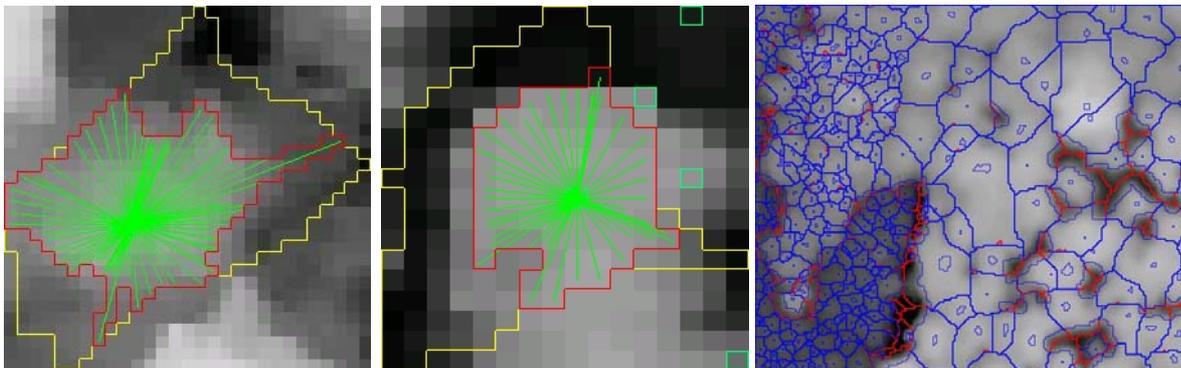


Figure 4: Ray-algorithm - 4a,b) show two examples, where the regions created by the pouring algorithm are reduced, based on a slope criteria. 4c) shows the final result after the ray algorithm. The blue border lines show the new corrected and the red ones the part of the border lines, which have been calculated by the merging algorithm.

3.1.4 RAY-ALGORITHM

The enhanced tree area can still contain parts of the real surface or include small trees which have a more or less flat crown and stand between the large trees. This is caused by the fact, that the pouring algorithm executes until all bottom lines in the whole image are found. Therefore the border lines do not always represent the border of the trees. This means that several tree crowns are estimated too large. Therefore the “ray-search algorithm” is included and it 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 rays between the maxima and a special amount of border points.
- Along each ray the difference in elevation is calculated within distinct arbitrary chooseable steps. A difference in elevation of $-2.0\text{m}/0.5\text{m}$ was empirically chosen as threshold, but can be adapted based on the tree height.
- If the calculated elevation is negative and smaller than the 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 by calculating the new border polygon based on retained border points and the new ones.

The ray-search algorithm is proceeded for all tree regions. Two test regions and the final result is shown in figure 4.

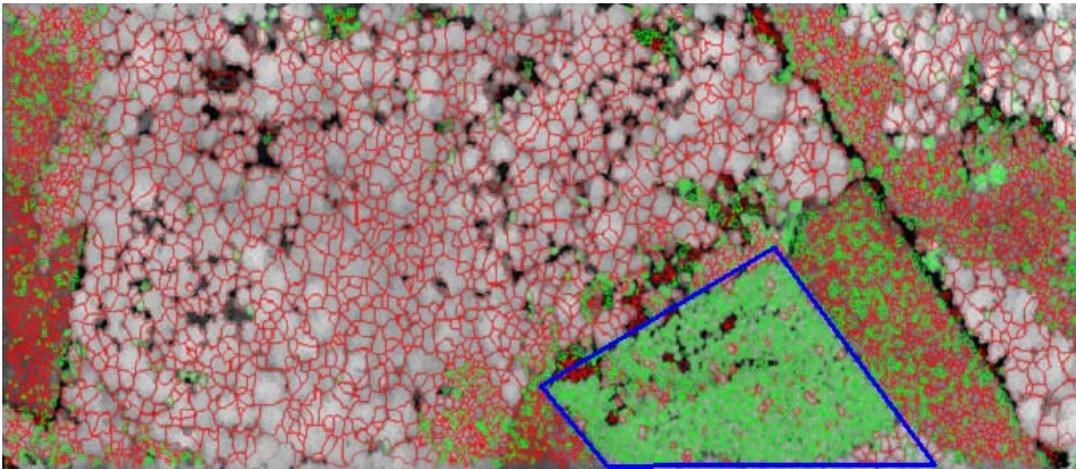


Figure 5: The classification of the two main forest groups broad-leafed trees and conifers is based on the ratio between “light crown height” to “light crown area”. The green bordered regions are classified as conifers and the red ones as broad-leafed trees. The blue bordered region is a conifer area extracted from FOGIS.

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-leafed trees and conifers 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-leafed trees do not occur. 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 final result of all processing steps concerning tree delineation based only on laser data is presented in figure 5.

3.3 Estimation of stand characteristics

3.3.1 STAND UNIT DELINEATION

As mentioned above first of all a nDSM has been calculated. After that every pixel value expresses the object height and here the tree height respectively. The image is filtered in different ways for the extraction of the different stand units. This is done under the assumption, that stand units could be differentiated by their height characteristics. The different closeness of the canopy should lead to characteristic criteria, which can be used for the segmentation. 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 using the original tree height with a segmentation at a threshold at 15m. This is possible due to the fact that young forest stands have a homogenous canopy, which is mostly closed. This is the only step using a real tree height. All other segmentations are calculated after the use of a special filter. Every filter emphasises the according criteria of the extracted stand unit. For one step a mean smoothing filter is used which is able to smooth in a defined range of gray values. The filter mask has a size of 15 x 15 pixels. This is useful to extract stand units that are dominated from broad-leaved trees with a height above 25m. Another filter calculates the local deviation. This is very capable to detect stand units with a homogenous texture like young planted coniferous trees. The uniform character of this stand type can be easily used for the segmentation. After the extraction of a stand unit, the delineated area is cut of the original image. Thus once detected the stand unit doesn't influence the following segmentation steps. The figure 6 shows the result of the automatic delineation of the stand units. With the used algorithm it is possible to divide the image in the different stand units.

3.3.2 MEAN STAND HEIGHT

Depending on the single tree delineation a mean stand height for each stand unit is calculated. The automatic delineated crown shapes represent the dominant trees in each stand unit. Their heights are used to calculate a mean stand height of the dominant species. The single tree shapes are extracted as described above. For every tree crown shape the maximum gray value is recorded assuming that this value is the top of the tree. Furthermore the position of every maximum value is extracted, too. Thus an index of every stand unit is assigned to every maximum height value, which belongs to the corresponding stand unit. Using this index it is possible to calculate the mean height for every stand unit. Furthermore the values can be visualised by their position to verify, whether they really represent the tree tops or not.

3.3.3 CROWN DENSITY

The calculation of the crown density in each stand unit depends on the single tree delineation, too. First the area of every stand unit and second the area of every crown shape is calculated. Thereafter the shapes of the crowns and the stand units are clipped. The crown covered area is set in ratio to the area of the corresponding 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

The FOGIS delineation is provided using ortho aerial images. It is done by visual interpretation and is proofed by field surveys. However figure 7 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 figure 7 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 caused 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. This is increased the greater the used filter mask is.

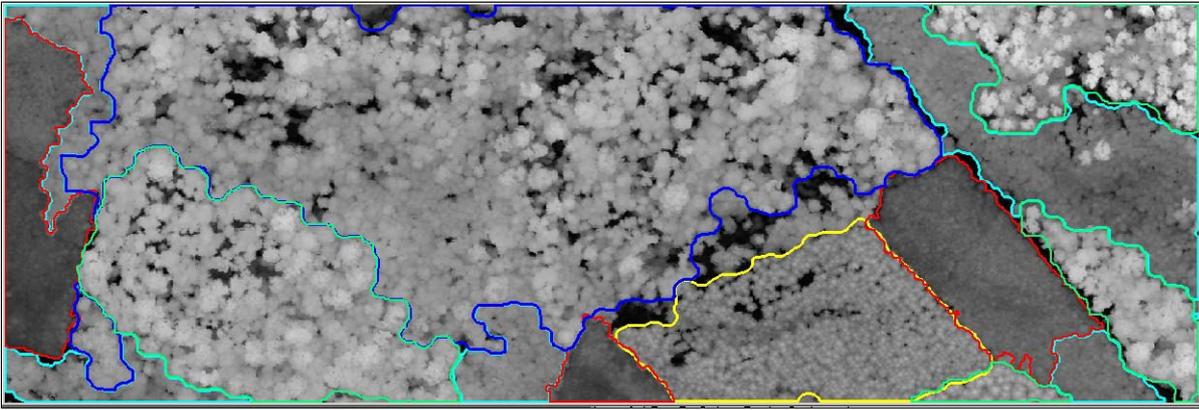


Figure 6: Result of the stand unit delineation.

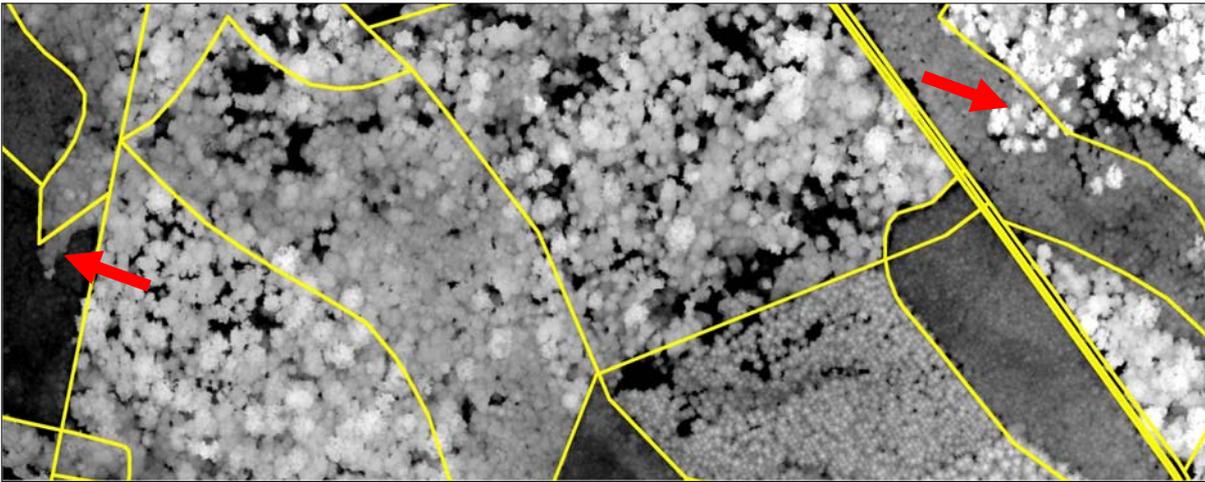


Figure 7: FOGIS Delineation. The red arrows mark two examples for errors in the line management. In comparison to figure 6, it becomes apparent that the algorithm for the automatic stand unit extraction works well. (FOGIS data from the government of Baden-Wuerttemberg).

4. DISCUSSIONS

A hundred percent correct solution will never be reachable in our opinion, especially with an automatic inventory method. In several cases this is not possible either 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. The most significant problem occurs at the extraction of the single tree crowns. Especially in forest stands that consists mainly of older broad-leaved trees it is difficult to detect the right crown shape. Very often one great tree crown is divided in three or four big branches. Every branch is detected as a single crown and sometimes it is not possible for a human to identify the right crown shape. 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. 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.

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