REPLACING SAMPLE PLOTS FOREST INVENTORY BY WHOLE STAND MEASUREMENTS BASED ON LIDAR AND ORTHOPHOTO

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ABSTRACT

Automatic tree counting algorithms based upon image segments form the core of accessing yield per area unit in a standing stock. The Oject Based Image Analysis specifies unique transferable attributes of the crown 'hotspot', which spatial characteristics are encounter over a wide range of aerial photographs, orthophoto's and satellite imagery. With high quality data, including LiDAR height information, a new large scale yield estimation can take place using semi and/or full automatic procedures. The method was tested on two large test area's after development on a variety of data sets within the laboratory of RS and GIS at the faculty of forestry in Cracow

Keywords: Individual tree counting, Automatic inventory, LiDAR, Yield estimation.

1 INTRODUCTION

Models on stand growth normally are derived from coarse inventory data because complete spatial data sets for large forest areas used to be difficult to obtain. Nowadays, such dataset that measures the whole forest complex is, financially as well as practically, within reach. The need for sampling of forest information might therefore lose its dominant position in the inventory procedures developed in the past. The question how traditional methods can be reliably replaced by full measurements is being treated in this paper using measurement of each individual dominant tree within the stand..

2 RETRIEVING CRUCIAL PARAMETERS

Crucial forest stand parameters can be retrieved more and more from remote sensing instead of traditional ground truth measurements. This is noticeable for the taxation parameter like forest stand height obtained from SAR or even better from LiDAR data. Also the counting of individual trees in a forest stand from LiDAR and optical data sets (orthophotos) can replace rough estimations of the tree density as applied in traditional forest inventory. This can not only be done for selected study areas, but also for the complete local or regional forest coverage. Of course terrain elevation and species play a dominant role but for plantation type forest vegetation the practicable applications are mature enough to leave laboratory conditions.

3 CROWN 'HOTSPOT'

In the Laboratory of GIS & RS (Forest Faculty, Agricultural University of Krakow, Poland), experiments on full automatic tree counting from remote sensed data, have been tested on a variety of (historical) data. A crucial features of the tree crown is the 'hotspot' or strong illuminated area of that part of the crown which reflect the light of the sun strongly towards the optical sensor. The term 'hotspot has been used for a different phenomena, the most well known is the center on a single aerial photograph where the sun angle reflect directly into the sensor and over-illuminates landcover on that location inside the photograph. In this paper the term hotspot is used in the sense of Korpela (Korpela, 2006). This 'hotspot'is not the heighest point of the crown but includes or borders the highest crown position. In Gougeon it is known as the local maximum of the crown (Gougeon 2005). The neighboring pixel populations around this hotspot create a nearly full neighborhood of lower intensity values as well as diminishing height values. The unique neighborhood of the crown hotspot allows to extract these regions on a large variety of scanner data.

3.1 THE ROLE OF SHADOW

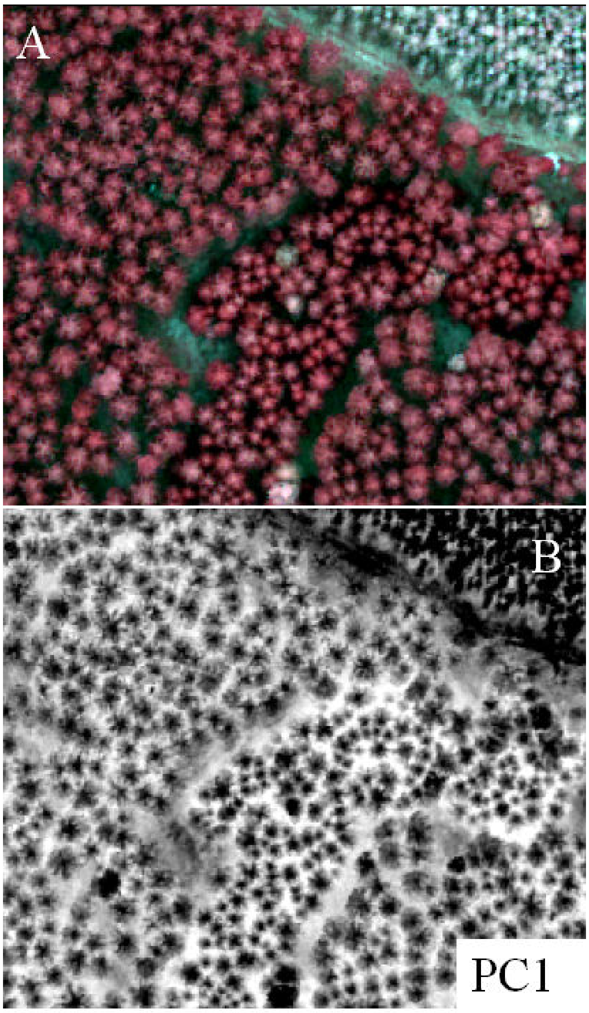
Besides the Watershed technique (Diedershagen et.al., 2003, Rossmann et. al , 2007) The ITC technique of Gougeon (Gougeon, 2005) can be regarded as the main-stream principle of tree counting algorithms. An advantage for object neighborhoods (in Oject Based Image Analysis) compared with the ITC technique is that a shadow matrix is helpful but not such a necessity as it is for the ITC technique. If shadow is not prominent, crown centers still are more brighter than surrounding neighborhood objects. In practice the 11 bit color infrared line scanners with a higher than 50 cm resolution deliver the best result for this and is making full automatic crown tree counting possible. Semi automatic procedures can than still be applied to imagery with lower bit-depths and lower resolutions. The next step in transforming this OBIA using the principles of the Cognition Network Language (Tiede et.al, 2005) method to a fully operational workflow is a larger pilot study covering large variety of stands and a much larger amount of trees up to several thousand hectares.

3.2 FIELD INVENTORY

Parallel to the inventory parameters from aerial remote sensing, in the test area of Chojna (NW Poland), the taxation parameter of single trees and forest stands are collected and based on the standardized forest inventory method in the field. These inventories from the field are time consuming and expensive but also a necessary step to calculate differences between semi automated algorithms and the traditional inventory based on sampling plots. The results can lead to an automatic forest inventory method through different steps. First an optimization of sampling can be retrieved form the experimental results. Further, strategies for linking data to full inventory parameters over semi and/or fully automated OBIA procedures can be developed according to the results for different forest stand parameters.

3.3 THE 'HOTSPOT

The ‚Hotspot‘ on the crown is a brighter area facing the sun. After amplifying this pixel-group using a negative principal component (Figure 1B) to isolate the centers, it‘s neighborhood after segmentation is unique for tree crowns. The hotspot is always nearly completely surrounded by crown objects with a lower brightness value and therefore a larger value in the negative PC1. Figure 1C is the core image of this study. It shows the standard spatial behavior of the brighter part of the crown, the hotspot' in relation to it's neighborhood. Here the visualization shows a segmented image in black and white displaying their relative brightness values of objects (not pixels !) visualized towards their neighboring objects having higher gray values in the negative PC1. The hotspots or maximum brightness of image objects (pixelgroups) are ' surrounded by brighter pc1-neighbor objects' inside the negative PC1 image from Figure 1B. The crowns of trees higher than 12 meters become white spots surrounded by darker grey neigbouring



Figures 1 A and 1 B:One of the subsets of a standard 8 bit CIR image over a coniferous forest area. Figure 1B, the negative principle component of figure 1A.

This phenomena of the 'hotspot' and it's unique neighborhood is universal for CIR, RGB and Multispectral VHRS satellite data. The final export is a point dataset of centroids of the brightest objects shown in Figure 1C and can incorporate height information in the table from nDSM values. In the figure 1D they selected centroids are displayed as white triangels. Although it is possible to use the single points as a basis for area delineation using a TIN (Triangular Network) grouping trees of similar height, the delineation might always be arbitrary to the observer. The calculation however based upon the grouping of trees with similar heights will deliver statistical results which are not based upon disputable boundaries but indisputable tree positions.

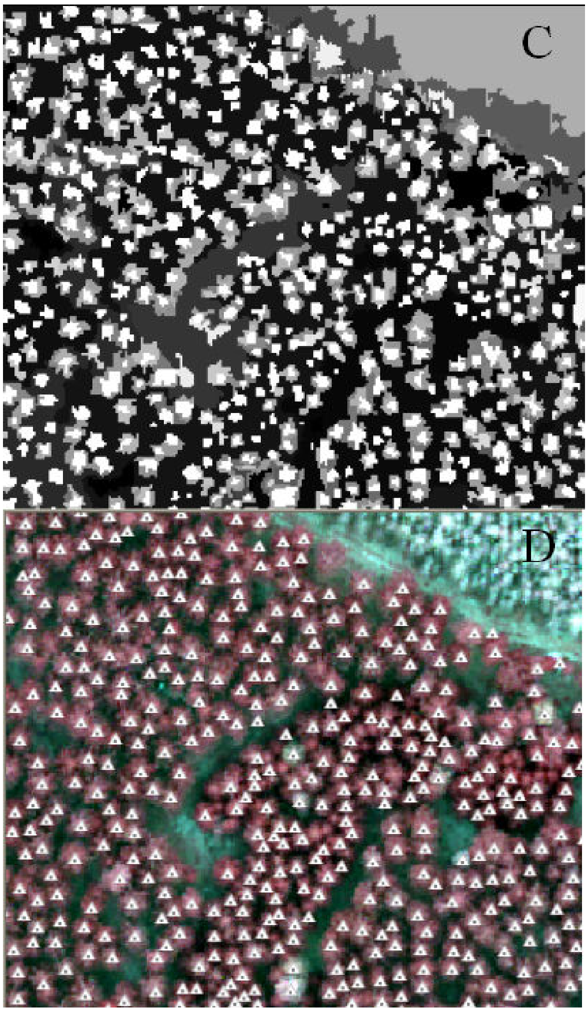


Figure 1C, a visualization of the brightness towards neigbouring objects with the center of the crown as the brightest spot inside an OBIA analysis here from Definiens Developer version 6. Figure **1D**, The export of pointdata, a single white triangle per dominant tree.

Table 1. A selection of 15 Stands on a 35 Km²area in Chojna-Poland for which full inventory data was collected to test the deviation of automatic extracted trees.

Height category	Amount of trees found by OBIA versus full terrain inventory
10	0.041096
15	0.492386
20	0.744698
20	0.793638
15	0.540728
15	0.611785
20	0.935185
20	0.854938
25	0.966667
25	0.892793
20	0.842742
25	1.146974
25	1.172911
30	1.073227
30	0.83524

3.4 HEIGHT OVER 12 METERS

After recognizing that under 12 meters tree height, the OBIA method made no sense on the applied optical data of CIR 50 cm with 8bit resolution, the estimated amount of trees for 14 stands in Table 1 was 85,02 % in comparison with a full inventory. It does not mean that 12 meter and lower is not a catergory on which indivividual tree count is possible, but the amount of data quality should increase if this height class is important.

4 APPLYING YIELD TABLES

The measurements of tree heights for homogeneous tree-groups as well as for individual trees in non-homogeneous stands should now be coupled with the comprehensive knowledge in existing yield and management models for homogeneous forest areas. Assuming, that the yield and management models are equally valid for small homogeneous groups as well as for uniform even aged stands, the automatic measurement of homogeneous tree groups or even individual trees under certain stand conditions, might provide enough information for an accurate calculation of the most important stand parameters. In another 250 ha large test area processed by landConsult.de, on 90 stands a total of 55450 trees were detected and measured. For instance a 1.21 Hectare homogeneous group in a selected stand (Table 2) would give a result of 530 solid cubic meters of standing crop (cbm).

Table 2. A stand with ID 187. Containing 230Trees/Ha, with an average height of the 100 highest trees per ha of 39.06 Meter and 0.72 crown coverage. Age and species is given for this stand. The corresponding yield table (linked by the stand age and the top height) for this stand gives the stand volume of 734 cbm/ha (VfmD/ha). The 0.72 is the ratio between the area of the tree crowns and the total area. In total with 230trees/Ha an estimated 530 cbm/ha can be assigned.

Stand	187
Ha	1.21
Number of Trees	278
Number/Ha	230
Crowncover	0.72
Height of 100 max	39.06
Mean-Height	34.53
Min Height	2.48
Max Height	48.10
StDev-Height	7.28
Var-Height	53.1

4.1 HOMOGENEOUS VERSUS HETEROGENEOUS

After defining single trees and their height, local homogeneous groups can be selected. The trees within such a groups that are not effected by the border position should behave like completely surrounded by peers. This implies a full stress on competition for light. The homogeneous stands are based on the assumption to apply light competition to favor height growth. There seems to be no reason this principal remains for the individual trees surrounded by trees of the same height regardless if the total stand is homogeneous or heterogeneous.

Therefore the yield tables which are derived from homogeneous stands can be applied for the smaller plots of trees who are under similar light competition as trees among plantation conditions. As the height for individual trees are known, an estimation still can be made taking the relative height of the neighborhood into account giving a bonus for border-tree which are higher and a malus for lower trees. Based upon single tree selection, local homogeneous groups and especially the trees inside these groups are under similar light competition levels as trees in larger homogeneous stands (plantations). Although the border effect should not be neglected, the amount of trees in direct light competition within smaller groups with neighbors of similar height should approach conditions for homogeneous stands. Therefore, the area valid for standard tables for yield and management can therefore be estimated.

5 DISCUSSION

The tree counting algorithm in polish conditions prove that 85 % and higher are values to be encountered as normal using the detection of 'hotspots' per tree crown. Especially if height values for the forest stands increase, the amount of correct found numbers is more likely.

With this knowledge in mind, the focus turns not to the total amount of trees in a stand, but to the representative 100 highest individuals in a hectare. Here with proper high quality data a more than 90% correct selection of highest trees is more likely than those hundred would have been found by going in the terrain. The LiDAR measurements should and are reliable if the terrain is not too steep. Than these 100 highest trees truly represent the stands population.Representative populations is the core assumption of assessing forest data. Therefore, having more than 85% count, the degree of representativity can be derived as well from the hight distribution histrogramm. Deviations among single tree heights, it is large height variances should be a warning here. Then additional information from species and age are still needed to select the proper yield table values.

5.1 DELINIATION

In the end, yield tables are very much based on area information and require area delineation. By registering each tree however, management decisions can be applied to a selection of individual trees in a group. Delineation than loses it's importance and might considerably change the way forest inventory takes place. However existing information on behavior in homogeneous groups should be used as much as possible to explain the predicted behavior of single trees surrounded by peers.

The behavior of border trees of the group deviate in a bonus or malus way, which requires a lot more knowledge on individual tree modeling. It is not that such a route is too complex to go. Especially if wood prices make it worth to consider individual tree management versus stand management.

5.2 FAVOURABLE CONDITIONS

Tree species and age play an important role for a successful automatic inventory. Old coniferous stands are easier to handle than young broadleaved stands. Due to the amount of test plots and a few thousands of individual tree crowns, the conditions for optimal results as well as the limitations can be demonstrated. Volume estimation is more accurate for forest plantations than it is for "semi-natural stands", associated with a larger diversity of tree heights, crown area, stem diameter and species composition. The practical application of the long gathered knowledge of yield and management models must be adapted to the premises of a modern forest management based on natural conditions. This requires an optimal use of full measurements over complete forest areas on a (sub-) national scale.

6.CONCLUDING REMARKS

Individual tree counting over large areas with thousands of trees can be demonstrated. The typical spatial relationship of the core of the tree hotspot towards it's neighborhood provides a standard transferable feature which allows the development of full autonomous or robotic vision in tree counting. The case offers itself as a role model for further full autonomy in remote sensing with knowing a class can be extracted if it has a fingerprint like spatial characteristic. The usefulness of relating volumes over local groups and/or individual trees is discussed as well as the crucial crown area estimation. The crown area as used in Table 2 is directly from LiDAR Height information and might besides being practical not the most optimal way to defi8ne this parameter. From the 3 basic parameters - tree height, location (x, y) and crown area, only the last one remains a difficult parameter to be retrieved from existing data types. But even without being able to precisely calculate the area of individual tree crowns, the automatic counting of treetops in combination with individual tree heights and the overall tree density - all parameters retrieved from a detailed LiDAR model delivers enough data for an accurate and cost-effective forest inventory.

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