Large Area Forest Inventory And Management Using Remote Sensing Data Combining Single Tree and Stand Level in a 4D-GIS-System

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Abstract

Traditionally, forest inventory is carried out with the help of rather simple tools like a relascope and incomplex procedures like the variable radius sampling method. But it is well known that this work can be supported with new approaches in the GIS sector, which are based on airborne remote sensing data. While spectral and texture information can be used to estimate tree species, laser scanners can deliver the third dimension – the information about tree height, volume and count.

In this paper we present a novel approach to automatically calculate forest inventory data on a single tree level, as well as a stand wise level. These algorithms are more than independent tools - as one can be used to increase the quality of the results of the other and vice versa: While the results of the stand-based approach are used as a calibration source for the single tree level, the results of the single tree delineation help to improve tree species determination. With additional ground truth information this results in a set of self parameterizing algorithms which are the basis for our new large area forest inventory approach.

The algorithms and ideas presented in this paper were successfully implemented and tested on two test-sites in North Rhine-Westphalia (Germany) with a total area of about 400km² each. The final goal is to provide forest inventory data for the entire forest in North-Rhine Westphalia (approx. 9.000 km² and 240 million trees whose diameter breast height is bigger than 20 cm) resulting in a new 4D- (space and time) GIS information system for the forest.

Introduction

These days information about forestry units mainly consists of stand descriptions within the forest inventory, while information on a single-tree-level is only available for rare test-sites. But even the rather simplistic census that leads to the stand-wise data is time-consuming and expensive. Well-trained experts work on-site with relascopes, yield-tables, clinometers and GPS-devices. The time available to collect all information about a forestry unit is getting shorter, because the districts in the responsibility of one surveyor are getting larger.

With the increased availability of remote sensing data, it becomes possible to support this work with novel concepts in the forestry GIS sector. While spectral and texture information can be used to estimate tree species [1], laser scanners can deliver the third dimension – the information about height, volume and quantities. Individual trees can be extracted and annotated with their key attributes like height, position and crown-diameter. Other parameters like diameter at breast height and volume are related to this information. This information can be used to prepare a forest inventory that contains information on a single-tree level, as well as on the level of forestry units. The work of the forest surveyor in the field can be supported by this information and he can concentrate on other parameters like diseases and game damage, which are not detectable from remote sensing data.

In the “Virtual Forest” project we develop a next-generation geo-information-system which is no longer limited to two dimensions. The “4D-GIS” of the Virtual Forest supports three spatial dimensions and keeps track about changes over time. All algorithms presented here were successfully implemented in the “Virtual Forest” software and tested on two test-sites in North Rhine-Westphalia (Germany). The final goal of the project is to provide a forest inventory database for the entire forest in North-Rhine Westphalia (approx. 9.000 km² and 240 million trees whose diameter breast height is bigger than 20 cm).

The paper is organized as follows: First we will introduce a volumetric approach for single tree delineation and discuss how to extract attributes of the individual tree of the available remote sensing data. In the second part of the paper we will describe algorithms for a stand-wise level.

Single-Tree delineation

A LIDAR differential model (DM, also known as canopy height model CHM and normalized digital surface model nDSM) is a two and a half dimensional representation of the height of the vegetation. We introduced a volumetric algorithm to identify individual trees in this data which is equal to the task to decide whether a local maximum is caused by a tree-top or a lateral branch. While other approaches like the watershed algorithm only use the basal area of a potential tree-top for its decision, we choose a volumetric approach based that considers the volume of a peak pointing out of the canopy. Figure 1 illustrates the workflow of the volumetric approach with a sectional drawing through the 3D DM. The first image shows some trees and the sectional drawing above them. In the subsequent images we turned the sectional drawing upside down with the most significant points – the maximum heights in the original data that may represent tree-tops – as local minima of the graph. The inverted graph makes it easier to imagine the volumetric algorithm as a simulation of a water-flow.

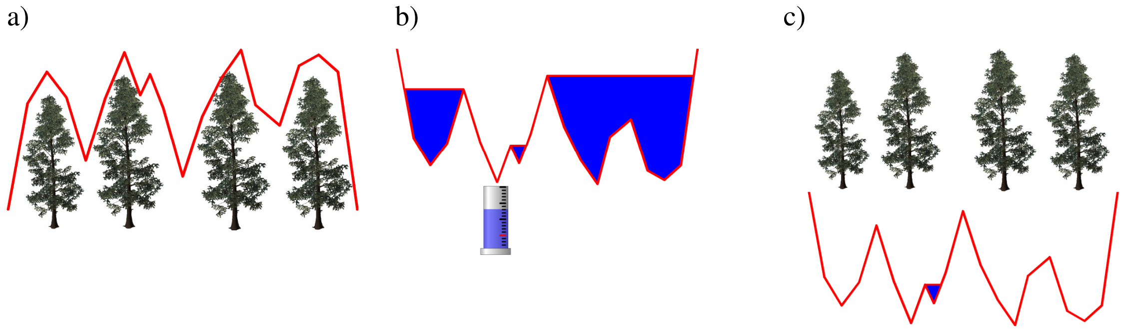

Figure 1: Single Tree Detection in LIDAR data. a) Trees and LIDAR Information, c) Volumetric Algorithm – First Cycle, d) Last Cycle

To get volumetric information we figuratively spoken fill the DM with water. Then, in each cycle, we puncture the point having the highest water-pressure acting on it and measure the amount of water streaming out of this opening. (Fig. 1b) This volume is composed out of the volume of the peak itself and a basal volume below the peak and the adjacent peaks which are dominated by this peak. The interesting feature is that the resulting volume emphasizes peaks that are dominant in the surrounding. For each opening receiving a volume higher than a user-specified threshold, a tree is generated in the map using the x and y position of the puncture - which is always the highest point within its peak –, and the z value taken from the FDTM. The tree is annotated with its height which can read out of the DM. Fig. 1c shows a situation where only one peak is left. The remaining volume is below the threshold so there will be no tree generated at this position.

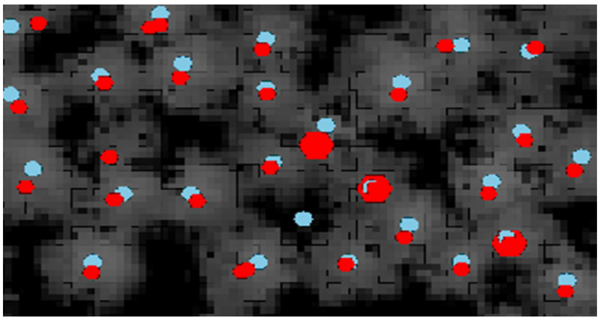

Figure 2: Detection result of the volumetric approach (blue) in comparison to a terrestrial census (red)

In contrast to the well known 2D approach, the volumetric approach adds another dimension to the data used for calculation and makes it easier to decide whether a peak is a tree or just a branch of a tree. The algorithm reaches a detection rate of up to 95 percent in coniferous units ready to harvest on a DM that was calculated out of 4 to 6 measured laser points per square meter. Figure 2 shows a comparison of the detection result and the result of a manual, terrestrial census. In this example one tree was not detected by the algorithm while another tree was missed by the surveyor.

Attributes of the individual tree

It is well-known that LIDAR models underestimate tree heights especially in coniferous forests. [3] This happens mainly due to the fact that is quite unlikely that the topmost part of the tree reflects enough light to be detected by the receiver in the laser-scanner. In comparison to terrestrial measurement with a high-precision and high-resolution 3d-laserscanner which is capable of reproducing the topmost sprout, the height from the airborne scanner was underestimated by about 30cm. This difference is in the same order compared to differences that may occur with handheld clinometers, which are used for terrestrial measurement. (Roessler, 2000) While LIDAR detection underestimates the height, the clinometer method overestimates the tree height. While the position, height and crown-diameter are measurable from remote sensing data, other parameters like the diameter at breast height (DBH) and stem-volume are occluded and can only be calculated from the know attributes.

Hyyppä [4] states a correlation between crown-diameter, height and DBH:

$$DBH = \alpha L + \beta h + \gamma \qquad (1)$$

where L specifies the crown diameter whereas h is the stem height. α, β and γ are local parameters depending on the tree species. This value also determines the basal area of a tree.

The volume of a stem can be calculated based on its DBH and a taper curve which was parameterized for the species. BDATPro [5] or the Pain-function [6] define several taper curves. Kleinn [7] examined the connection between the DBH and taper curve and the volume of a stem. In his test units he reached a mean difference of only 1,4m³/ha for beech and 7.5m³/ha for spruce.

Stand-wise inventory

In North Rhine-Westphalia and other German states units are mainly described by the parameters "stock density" and "proportion of mixture" and for each species the triple out of age, dominant height and yield class and the timber volume as a dependent value.

The proportion of mixture can be calculated out of the tree species map which was generated out of the spectral data of the unit, while the stock density is related (not equal!) to the percentage of sheltered area in the unit.

Internal tests by the Landesbetrieb Wald und Holz (agency for forest and wood of the state of North-Rhine-Westphalia) have shown, that the dominant height which is usually defined as the average height of the 100 strongest trees (H100) may also be approximated in the following way: The forestry unit is divided in individual grid cells (30m x 30m). In each grid cell we determine the point with the maximum height (per species). The weighted average of all these height values can be used instead of the H100.

The second important attribute to characterize the tree of one species in a forestry unit is either the age of the trees or the yield class. In all state owned and some private owned units the age is known and can be read out of the previous forest inventory. For these units the yield class as the third information of the triple can be read out of the yield tables. In other units the yield class can be estimated. A site classification [8], which is available for all units in North-Rhine-Westphalia, delivers information about hydrology and trophic level. The yield class depends on these characteristics and can be estimated with this information.

Other parameters like timber volume, number of stems and DBH can be found in the yield tables, when the stock density and the triplet out of age, height and yield class are known.

The stand-wise inventory can be calculated without the immense density of LIDAR information that is required for the calculation of individual trees. While an inventory on an individual tree level requires at least 4 to 6 measured points per square meter, an inventory on a stand-wise level can be calculated when about one measured point per square meter is available.

Conclusion

The single-tree delineation shown in this paper was implemented in the VEROSIM® 4D-GIS and tested on three test areas with a total of approximately 800km². We have already populated a number of forestry units with a total of more than 1.000.000 trees. During these tests it turned out that the detection rate is very high – up to 95 percent – in homogenous coniferous units ready to harvest. For younger coniferous units the results are still good, although the detection-rate falls below 90 percent. Very young units (Christmas trees) are still difficult to measure. Even with the human eye it is often not possible to count the trees in a height-representation of the DM because the density of the points measured by the laser is still not adequate and the laser footprint is still too larger in these units.

In broadleaf units the situation changes from unit to unit. There are units where a human operator as well as the algorithm is able to recognize individual trees from the DM. In other units the surface just looks like a giant cauliflower, where it is not possible to see borders between adjacent crowns. The algorithm cannot deliver reliable information in units like this. We are currently working on new approaches for these units, that will consider full-waveform-information and/or available background information on the unit for the delineation of single trees. Until these algorithms become available only the stand-wise solution can provide data on these units.

The stand-wise approach can also be used as a calibration source for the individual-tree inventory. The threshold used in the volumetric algorithm depends on the structure of the unit, on tree species, age and height as well as on the number of stems in the unit. Currently we set the threshold in an interactive way. The value can be controlled with a slider in the GUI and the operator ensures that the values matches the scene. Information which was generated by the stand-wise approach can help to calculate a possible value for the threshold. The number of stems and the timber volume calculated by this approach can be matched with the information on individual tree level. With nested intervals this leads to an estimated threshold which can be used either as a starting point for the interactive method or as the threshold for a fully automated census. On the other hand the (manually calibrated) census on individual tree level delivers tons of information about growth of the species in the unit. Subsequent censuses of the same unit may be used to recalibrate the current yield tables, which are based on data from the beginning of the last century and to generate yield tables for species where currently no information is available.

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