USING AIRBORNE LASER SCANNER DATA IN FORESTRY MANAGEMENT: A NOVEL APPROACH TO SINGLE TREE DELINEATION

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ABSTRACT:

Lately, laser scanning even of huge areas has become economically sensible due to new airborne laser-scanners delivering higher resolutions and measurement frequency. In this paper we will describe a novel approach for single tree delineation based on airborne laser-scanner-data for use in forestry applications. This currently leads into the development a forestry management tool as a part of a new three-dimensional geoinformation system (3D-GIS).
By enhancing the well-known watershed-algorithm by adding a third dimension, we developed a novel volumetric approach, which is able to accurately — and robustly — detect positions and dimensions of the individual trees in a forest. Each tree's "business card" is then stored in a database, the "Virtual Forest" which serves as the integration platform for a new single-tree-based forestry management system currently being developed in Northrhine-Westfalia, Germany. Combining the single-tree-data with known statistical methods, the system will provide the user with a detailed view on forestry units, on single trees or on the complete forest within an administrative district. The presented algorithms and methods were integrated into our 3D-GIS and successfully tested in a 82km² test-area close to Arnsberg, Germany.

1. INTRODUCTION

In recent years, laser-scanner technology has responded to the demands of the market by increasing resolution and measurement-frequency. Today's devices are capable of performing up to 150.000 measurements per second at helicopter flight level (Leica) or up to 100.000 measurements per second at airplane flight-level (Riegl). Multiple echoes or even a full-waveform recording provide information not limited to the surface of a forest (fig. 1). Lower levels are also monitored. Using the first echo it is possible to calculate a digital surface model (DSM), an (interpolated) grid-based representation of the vegetation surface. On the other hand the last received echo can be processed into a digital terrain model (DTM). The DTM calculated this way might contain remains of vegetation as well as buildings and other objects that are not penetrable by laser. By removing this perturbation and by interpolating the resulting gaps a so-called filled digital terrain model (FDTM) is calculated. The difference between the DSM and the FDTM is called differential model (DM). It is the DM that is actually used to locate and parameterise individual trees.

Adding high-resolution aerial photos it is possible to calculate "true-ortho-photos", which are free of paralactic distortions. In true-ortho-photos the roof of a building covers exactly the buildings footprint. The image looks like every pixel was taken with a perpendicular optical axis.

This paper introduces our new single tree delineation algorithm which takes the differential model or true-ortho-photos as input data. The results of the algorithm using DM-data and true-ortho-photos will be compared later in this paper.

2. PROCESSING OF THE DATA

2.1 Data Acquisition

All examples in this paper are based on data recorded in spring 2004 and summer 2005 using a Toposys Falcon II scanner (Schnadt, 2004, Toposys). The data shows the area around "Glindfeld", a small town located close to Winterberg, Germany. The size of the recorded area was about 82km². The dominating tree species in the forestry units used for examination of the presented algorithm is spruce, but there were also other coniferous species like Douglas Fir and European Larch.

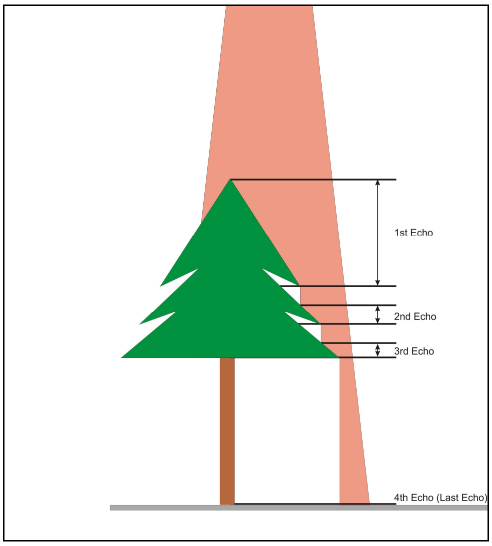

Figure 1. Multiple Echoes in LIDAR Data Recording

The resolution of the LIDAR data was specified to be one point per square-meter, the true-ortho-photos were specified to have a resolution of four pixels per square-meter.

Furthermore, a smaller area was recorded with a nominal resolution of 4 points per square meter.

The pointcloud of the first echo has been rastered into a digital surface model grid (DSM), while the last echo has been converted into a digital terrain model raster (DTM). Due to the limited penetrability of the canopy, there may be (small) regions where no ground echo occurred. For these points the last echo is identical with the first echo. During the process of the DTM generation a semi-automatic filter was applied by the data provider in order to eliminate trees and bushes as well as artificial objects like buildings and bridges. This leads to a DTM representation with gaps. The DTM with interpolated gaps is referred as filled digital terrain model (FDTM). The difference between the DSM and the FDTM is a differential model (DM, also known as canopy height model CHM or normalized digital surface model nDSM).

The overlapping high-resolution photos captured by a rgb-ir line-scanner were projected on the DSM. The result is a set of "true-ortho-photos", which are free of paralactic distortions.

2.2 LIDAR Processing

A popular way for single-tree-delineation in LIDAR maps is the use of the watershed-algorithm. (Diedershagen, 2003) With a standard watershed-algorithm the z-axis of the three dimensional data is only used to generate gradients and calculate affiliations, resulting in a set of areas, each annotated with its size. So the size of the region would be the only criterion to decide whether a region represents a tree or a branch of a tree. We decided to look at the volume of a peak pointing out of the canopy, rather than restricting the investigation to 2-D simplifications.

By increasing the amount of raindrops simulated in the watershed-algorithm up to a level that floods the whole canopy, this algorithm can easily be modified to work on three-dimensional data. To illustrate the volumetric algorithm we will use a sectional drawing — a cut through a three-dimensional DM. Fig. 2a shows several trees and the canopy above them. To make it easier to associate this drawing with rainfall and water-flow, we turned the canopy upside down in the subsequent images with the most significant points – the maximum heights in the original data that may represent tree-tops – as local minima of the graph. Fig. 2b illustrates the idea of a standard watershed algorithm. Water is poured across the area uniformly. The water-flow is simulated and the amount of arriving water is measured at all local minima. The amount of water is equivalent to the area covered by the peak.

To get the volumetric information, we fill the DM with water. Then, in each cycle, we puncture the point with the highest water-pressure acting on it and measure the amount of water flowing out of this opening. (Fig. 2c) The result is a value, which is always greater than or equal to the real volume of the peak. The interesting feature is that the result is far away from the real volume for the most extreme points (for the most likely treetops) but very close to the real volume for the critical peaks that are hard to decide. For each opening which receives a volume greater than a user-specified threshold a tree is generated in the map. The tree is annotated with its height that can be read out of the DM. Fig. 2d shows a situation where only one peak is left. The remaining volume is below the threshold, so no tree will be generated at this position.

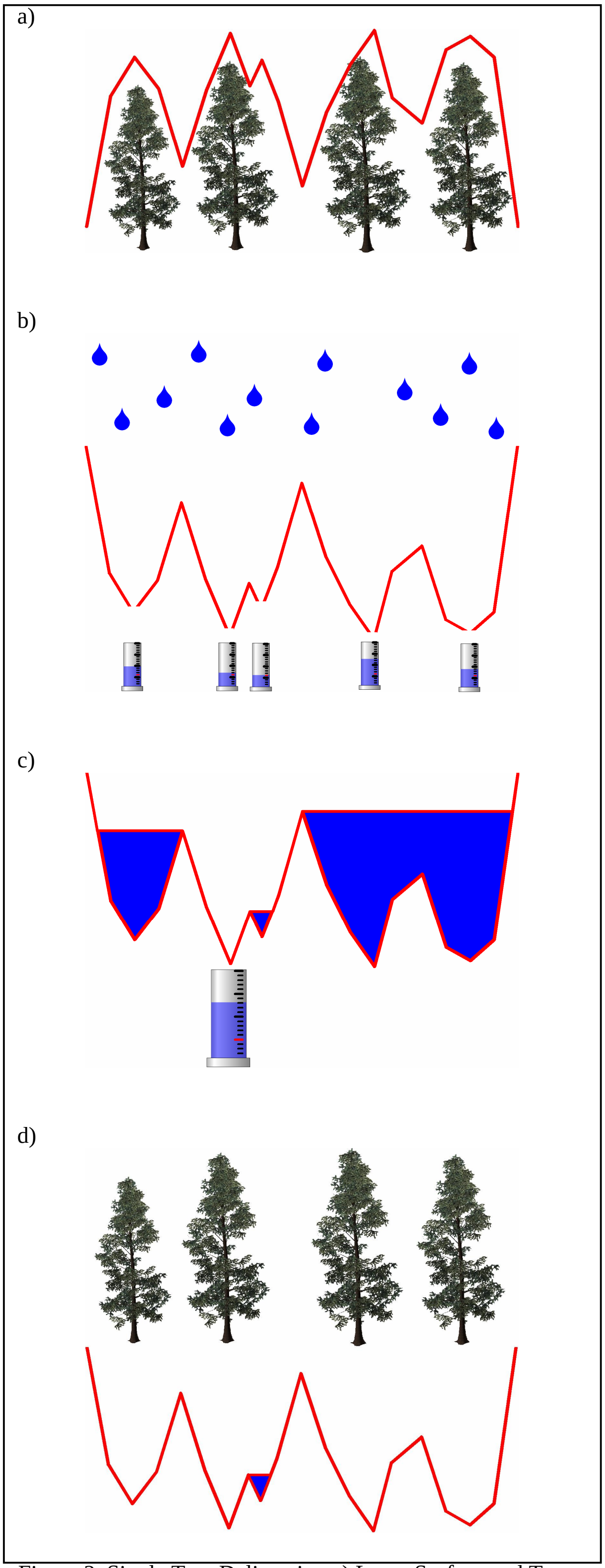

Figure 2. Single Tree Delineation a) Laser-Surface and Trees, b) Watershed-Algorithm, c) Volumetric Algorithm, d) Last Decision for the Volumetric Algorithm

The volumetric approach introduces an additional dimension to the data used for the calculation and makes it easier to decide whether a peak is a tree or just a branch of a tree. This is especially valuable for our test-data because the z-axis of the rasterized LIDAR data features a resolution of 1cm compared to the 1m-resolution of the x- and y-axis.

Especially for coniferous forests, the detection results using the volumetric approach were significantly better compared to the ones of the standard watershed algorithm applied to the same data. Not surprisingly it turned out that the results for the four points per square meter data were better than the ones for the 1m data.

Figure 3. RGB True-Ortho-Photo and Image after Colour-Tone-Based Brightness Reduction

2.3 Arial Photo Processing

While analysing the source of the LIDAR DM, the point-cloud recorded by the laser-scanner, we encountered some gaps in the coverage, which led us to the question whether homogeneity of the source data is also important for the detection results. The true-ortho-photos are stored at a resolution of four pixels per square meter. So they are comparable to the high-resolution LIDAR data as far as resolution is concerned. But the true-ortho-photos have a better homogeneity compared to the LIDAR data so they are a good candidate for the comparison. In order to transfer the volumetric watershed idea to the ortho-photos, we simply associated brightness-levels of the photos with an artificial height and *directly applied the same volumetric algorithm to the images*. The results were amazingly promising.

A minor problem was, that in addition to the trees, a few artificial landmarks like white road markings were "detected". We implemented a colour-tone-depending brightness-reduction-filter (fig. 3). The filter takes four channels (R, G, B and IR) as its input. Each pixel in the destination image is mixed of the rgb-values of the source and a defined brown colour. The ratio between the source and the constant brown colour is determined by the values of the four input channels. Basically it can be said that bright objects with a colour different to all typical green-tones are reduced in brightness by adding the brown colour. In the resulting image, we chose the green-channel of the RGB image – obviously a sensible choice for trees – for detection. At the first glance, this data looks very similar to a greyscale representation of the LIDAR-data. We associated height-levels with brightness-levels in the green-channel and applied the volumetric algorithm described above to this data in order to find the tree-positions. The true-ortho-photos are geo-referenced so we read the height of each detected tree out of the DM again.

The detection rate was significantly improved compared to the volumetric approach on LIDAR-data. In older forestry units, close to their harvesting age, we achieved detection rates of about 95%.

2.4 Extraction of Forestry Attributes

In addition to the position and the height of an individual tree, attributes like diameter at breast height (DBH) and timber volume are interesting when judging the value of the log. In addition to the height of a tree, the diameter (of the visible part) of its crown can also be calculated using the DM by performing a gradient descent for all detected trees. Note that this must be done simultaneously for all trees in order to divide areas that are reachable by gradient descent from several trees centres correctly between the adjacent crowns.
The DBH was the most important characteristic of a tree in former times and is still very important for the forester. According to (Hyyppä, 1999), the DBH can be calculated using the height and crown-diameter of a tree by:

$$DBH = aL + bh + g$$

In this equation α, β, and γ are parameters depending on the local situation of the tree. L is the crown-diameter and h represents the height. The parameters α, β and γ can be calculated using regression formulas and measured data triplets DBH, L and h.

Other important attributes like the timber volume of a stem can be derived by using the DBH and the height of the tree or other known attributes. In (Kramer, 1995) and (Landesanstalt, 1989) the authors specify – ordered by tree-species – the relation between several attributes of an average tree. Knowing the DBH, the height of the tree and the quality of the habitat, it is possible to estimate the other attributes of the tree that are relevant in forestry management.

2.5 Implementation

The described algorithms were integrated into the VEROSIM 3D GIS, a software solution for virtual reality systems and GIS. The threshold needed for the decision in the volumetric algorithm is set interactively by using a slider (fig. 4). The varying results, depending on the threshold, are displayed in real-time in order to help the user to find the correct value for each forest unit. Older units will require higher thresholds because smaller peaks will most likely represent only branches whereas a peak with the same volume in a younger unit will most likely be a treetop.

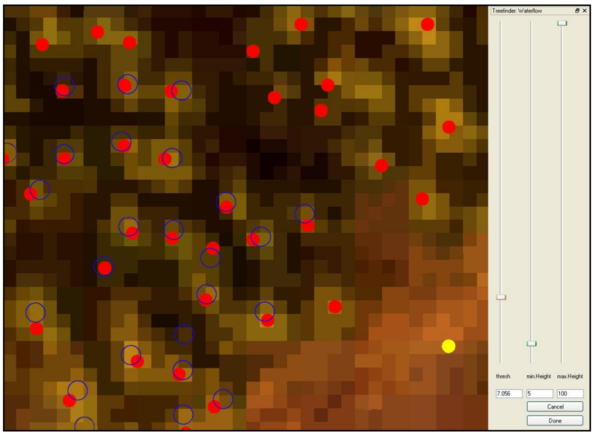

Figure 4. Detection Results and User Interface

2.6 Results

It turned out, that not only resolution but also homogeneity of the data improves the quality of the single tree delineation. Although the detection rate gets better using the additional visual information as explained above, LIDAR-data will mostly deliver better tree-positions. On the other hand RGB and CIR fotos depend on the actual lighting situation. At noon, the treetops will be the brightest point of a tree giving correct results. If the image was taken during the later afternoon, the lower sun will light one side of a tree moving the “optically detected centre” of the brightest part of a tree away from its treetop. Within the 82km² test-area, we found several places were lightning conditions made it hard to recognize trees – even for a human.

3. ONGOING WORK

The results shown in this paper are a first step towards the “Virtual Forest”, a database containing each individual tree in Northrhine-Westfalia. We already delineated a number of forestry units with a total of about 120.000 trees (Fig. 5). During this work we discovered several points which will need ongoing work and attention.

- It turned out that the detection quality is best on homogeneous high-resolution data. Promising sensors that seem to be capable of delivering the required resolution at a homogenous point-distribution are DLR’s HRSC stereo-camera (Scholten, 1999), using an appropriate algorithm for stereo matching, as well as the latest rotating and oscillating mirror laser-scanners. We will implement import-filters for this data and evaluate its quality for single-tree delineation using the volumetric algorithm presented in this paper.

- The boundaries of the units used for detection of the 120,000 trees were based on current administrative units that consider ownership and historical borders as well as forestry office districts. In many units we found several species of trees or a huge spectrum of sizes. It became apparent that different classes of trees also need different parameters for the detection. In order to support the single-tree-delineation, we will integrate an algorithm that separates current units or even the whole forest into biologically reasonable areas that contain a homogeneous tree structure.

- Some of the formulas used for the calculation of the individual tree’s attributes base on statistical data. The Hyyppä-formula uses constants α, β and γ as a description of the habitat. It turned out that the variance of these parameters is rather high. A promising approach to adapt the parameters to an area is to combine airborne measured data with terrestrial measurements. We will develop new methods to extract the DBH and position of individual trees from terrestrial laser-scanner data and match the positions of these trees with the ones detected in the airborne LIDAR data in order to get sample sets of completely characterized trees. These trees will serve as an input to a mathematical regression tool that can be used to determine the local parameters.

- Other modules will be added to the Virtual Forest GIS. Some of these modules will be: Classifying the tree species out of aerial and satellite images, segmenting a forest into units with similar structure and species, calculating terrain attributes for each unit, simulating forest growth and calculating the profit of a harvesting action.

Figure 5. View into the Virtual Forest

4. CONCLUSIONS

By using the novel volumetric approach the detection rate was significantly improved compared to the well-known watershed-algorithm. The algorithm works well on LIDAR data as well as on a combination of aerial photos (which deliver tree positions) and laser-scanner-data (for the determination of the tree-height). It works best on homogeneous high-resolution data.

Additional attributes of the individual tree were estimated using the DBH formula invented by Hyyppä and Inkinen and statistical relations between DBH and other attributes of a tree.

We stored the complete single-tree data set, the tree’s “business card”, in a geo-database. The user is now able to select trees in the database using SQL-statements or a database GUI. Using this tool a forester is able to react on requests of the timber market faster and more efficiently, because it becomes possible to determine exact locations in the forest where the customer-ordered number of trees of a given species with a certain height and diameter can be harvested. The database is used as a warehouse management system for the natural warehouse forest.

The tree attributes generated by the presented combination of algorithms make up the most significant part of the data a forester needs to collect to evaluate and to further develop forestry units. Thus, there is a strong demand to make our forest-optimized 3D-GIS available as a standard tool for foresters in NRW.

By passing the gathered information to other modules of the 3D-GIS, it will be possible to project the development of the forest into the future in a kind of “time-machine” (Klemmt, 2004) and to be able to exactly calculate the cost and gain of a thinning.

The generated virtual forests can also be used on harvester simulators during the training of new drivers to give them an impression of the areas they will work in (Fig. 6).

Recapitulating, one can state that the volumetric approach for single-tree delineation in the VEROSIM 3D-GIS is a foundation for many different new applications in forestry management.

Figure 6. Forest Machine Simulation in the Virtual Forest

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