Woody biovolume extraction from laser scanned trees

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Abstract

Biomass extraction from indiviual trees measured by terrestrial laser scanning is a valuable tool for forestry and for orchard plantations to extract the economic and ecological parameters of trees.

The focus of this paper is to extract the woody biovolume from laser scanned trees based on the SkelTre-Skeleton, which is a skeletal structure description. State of the art research proposed skeletons to extract parameters like branch length and branch diameters from trees on the basis of the SkelTre-Skeleton (Bucksch et al. 2010), from trerrestrial LiDAR measurements. In this paper we report on the fully automatic and purely laser-scan derived biovolume extraction of two collected evaluation scenarios:

1.) six leafless orchard apple trees

2.) two European beech trees in a forest

Validation measurements on 6 apple trees comprise the lengths and diameters of all branch segments of their canopies, but not their specific weight so that biovolumes can be compared. The beech tree biovolumes are derived from an allometric relation of tree height, breast height diameter and the known density of the beech wood (Rademacher et al. 2009)

We apply this method in order to assess the biovolume fractions of branch diameter classes in the tree crowns of 3m high apple trees as well as those of 20m high beech trees in the leafless stage in winter. The results show that for the six apple trees the difference in biovolume between automatic and field measurement is 1.18 litres on average. For the beech trees huge differences were derived demanding better field data to draw actual conclusions from it.

1. Introduction

Biomass itself is an important parameter for economic assessment of a forest, since it gives the amount of wood available for fueling or other purely mass-based purposes. Other purposes like wood as building material or source of chemical compounds may require qualitative information on top of this, especially the available amount of wood in specific branch diameter classes. Beyond this, even the distribution of biomass in space may play a role e.g. for the physiological description of light use and transpiration of the trees that determines their ecological function.

The acquisition of detailed data on trees is possible by using a terrestrial laser scanner. New studies show that the diameter and the length of branches are extractable by utilizing a skeletonization (Bucksch and Fleck 2010). Length and diameters of all woody axes are sufficient to determine the woody biovolume of a tree. From the biovolume the biomass can be derived under the assumption of a known density of the wood. The results of this paper give an insight into the amount of biovolume captured by a laser scanner which is calculated on the basis of the skeletal structure extracted by the SkelTre-Algorithm (Bucksch et al. 2010).

We asses the biomass in two main scenarios. The first scenario uses apple trees growing on an orchard plantation. This first scenario contains leafless trees with dense crowns of approximately 3 meters height. The second scenario focuses on mature beech trees scanned in a forest before budbreak in spring.

Related work

Until now the majority of biomass estimations are carried out by airborne systems(e.g. Popescu 2007, Drake et al. 2002). We refer to a review of current techniques used to assess the forest structure with terrestrial laser scanning given by Van Leeuwen et al. (2010) . They also cover the topic of individual tree assessment..

We give in this section a few example studies, which investigate the biomass or tree parameters on an individual tree level close to the context of this paper.

Fleck et al. (2004) used a terrestrial laser scanner to reconstruct the structure of a tree manually in order to predict the physiological properties of a tree. Rossell et al. (2004) described a manual approach to quantify the tree parameters in orchards by using a CAD software and slices through the point cloud. They were able to derive the crop load and tree parameters by mounting the laser scanner on a vehicle. Parker et al (2004) determined the above ground biomass in forests on the basis of terrestrial laser scans and stated that the vertical structure in terrestrial laser scans is consistent with the one found in the field measurements.

Typical for most studies on individual trees is the estimation of tree parameters like diameters of trunk and branches, tree height or crown width with a high degree of accuracy(e.g. Thies et al. 2004, Henning and Radtke 2006).

The best comparable study to this paper is the one by Lefsky and Mc Hale (2008) who determined the biovolume of a complex branching systems of trees by representing the lidar measurments in a 3-dimensional voxel grid. The voxel grid was exploited to derive the biovolume of the tree. Further the sampling pattern of the sensor was taken into account by Lefsky and Mc Hale (2008), in order to derive estimates for the fine branches. A further motivation can be found in (Strahler et al. 2008), who suggested that laser scanning can serve as platform for biomass extraction from individual trees without using allometric relationships.

Our approach automatically calculates the woody biomass of an individual tree and does not use allometric relations. Mostly the evaluation of individual trees stops at the extraction of tree parameters, which can be used in conjunction with allometry to caculate the biomass. Our technique allows to determine the biomass without using allometric relationships and caculates the biomass directly from the point cloud on the basis of an extracted skeleton.

Study areas

In case of the apple trees the study was mainly conducted in apple orchards of the Annapolis Valley, Nova Scotia, Canada close to the city of Kentville (45°4'39'' N, 64°29'45''W). The six investigated apple trees (*Malus* x *domestica* Borkh. 'Honeycrisp') were located in two orchards that belong to the test sites of the Atlantic Food and Horticulture Research Centre (Fleck et al. 2010). Three apple trees grew on a trellis system and the other three trees stood as single trees in rows. The orientation of the rows is from North to South with a tree spacing of 3m within each row and a spacing of 5m between rows. Trees of comparable height were located next to the investigated trees. The manually measured trunk diameters ranged from 3.9cm to 8.1cm. The tree height of the six apple trees varied from 1.27m to 3.03m.

In case of the beech trees the study was carried out in a forest stand in Hundelshausen (51° 18′ N, 9° 51′ O) in Germany close to the city of Göttingen. The two investigated beech trees (*Fagus sylvatica* L.) were selected in a nutrient rich area of the forest. The manually measured trunk diameters at breast height (DBH) ranged from 21.6cm to 50.8cm. The tree height of the beeches varied from 20.1m to 23.4m.

Figure 1: *On the left one of the scanned apple trees (Apple 4) and on the right one of the scanned beech trees (Beech 2). Undersampling in the upper crown of the beech tree is visible.*

2. Methods

Field measurement

The six apple trees were scanned with the Imager 5006 laser scanner of Zoller and Froehlich. They were registered with the Neptan based software ZF-LaserControl. Each tree was scanned from 4 positions in 2 different heights to overcome occlusion effects. The branches of each tree were numbered for reconstructing the branch hierarchy and their length was measured following the elongation direction of the branch. The diameter of each branch was measured at its base and tip, about 1cm before the node or end bud. The diameters of branches were measured with a calliper in two directions and averaged. If both diameter measurements were more than 1mm apart, a third diameter measurement was taken and the average of three measurements was taken. Branch diameters thicker than 5cm were derived from circumference measurements with a meter tape assuming the trunk or main branch to have a circular cross-section. An example of a registered apple tree is shown in Figure 1 on the left.

The two beech trees were scanned with a Faro Photon system and registered with the Software Faro scene based on fixed targets on the surrounding trees. Each tree was recorded by 6 single scans. Targets were also placed 10 m above the floor in the surrounding tree crowns to assure a homogeneous distribution of targets for registration of the 20m high trees. An example of a registered beech tree is shown in Figure 1 on the right.

The biovolumes of the beech trees were estimated by calculating the biomass as described in Rademacher et al. (2009). Assuming a specific weight of 0.74 kg/l for the wood of beech trees the biovolume was obtained on the basis of the diameter at breast height (DBH). The formula for calculating the biovolume is therefore given as:

$$volume = \frac{0.001074 * DBH - 0.141885}{0.74}$$

Automatic measurement

Branch diameters and length were derived with the method of Bucksch and Fleck (2010). This method segments the tree into individual branches and utilizes the distances to the skeleton to determine the diameter of each individual branch. First a skeleton, as shown in Figure 2, represented as a graph is extracted from the point cloud. This graph is assumed to be centered within the point cloud representing the tree. A graph contains vertices connected by edges. For every point cloud point the distance to the closest edge is taken. The cylinder length is given by the extracted branch length and the cylinder diameter as the maximum closest to the median of a binned histogram of the scan point distances to the branches represented by the segmented skeleton.

We calculate for every branch the volume of the half cone based on the diameters extracted at the branch base and branch end. For branches where only one diameter was extractable the cylindrical volume was taken. This case of one diameter can occur on finer branches when the branch end is strongly undersampled.

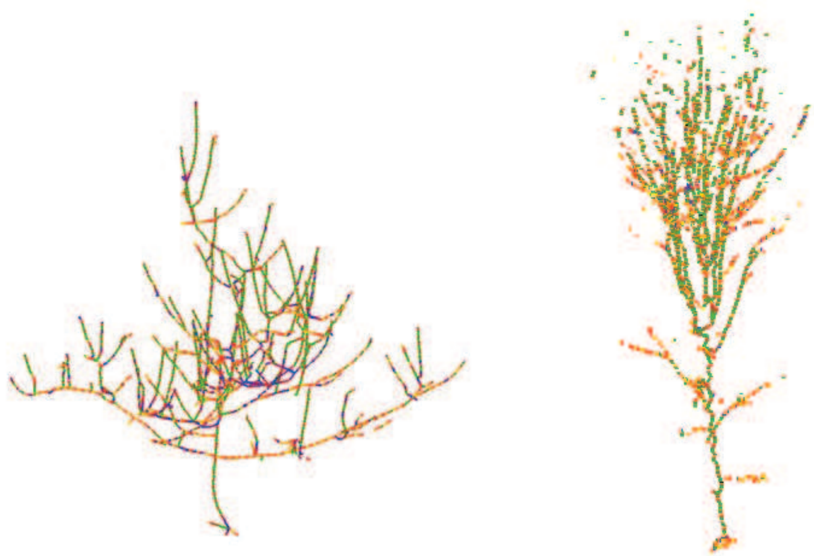

Figure 2: *Example Skeletons of an appletree (Apple 4) on the left and a beech tree on the right (Beech 2)*

It was shown in (Bucksch and Fleck 2010), which utilized the same six apple trees as this study, that the frequency distributions of the branch diameters show excellent correlation with manual measured field data while the detectable branch length is shorter than the manually measured one. For very thin branches (<1.5cm diameter) an insufficient amount of points for estimating the diameter was obtained. Because of that we assumed a constant diameter for all branches represented in the skeleton where no diameter could be obtained. In case of the six apple trees we assumed 1cm diameter. For the beech trees we assumed 5cm, because the distance between scanner and crown is much bigger than for the apple tree. This larger distance causes undersampling to be present on thicker branches (compare Figure 1 and Figure 2). These constant factors were applied to the difference between the total detected skeleton length and the skeleton length resulting in an estimated diameter. Noise can cause the skeletonization to fail and results in diameter estimations for finer branches in the upper crown much larger than the estimated trunk diameter. For this reason we rejected volume measurements bigger than the stem diameter.

3. Results

In Table 1 a one-to-one comparison of the collected field data and the automatic measurements is shown. The influence of the branch segmentation is minor. The results for the six apple trees show that the estimated biomass varies on average by 1.18 liters from the field measurements. The reason for the less good biomass extraction for apple can be found in the fact that a major branch was removed by pruning between laser and field measurement. For all apple trees the detected overall length of the branching system was between 60% and 85% of the manually measured length.

For the forest scenario no reliable biovolume estimation could be found. Though the used allometric relationship for beech is based on extensive measurements that were extremely well correlated (Rademacher et al. 2009), it cannot be excluded that it was not appropriate for the beech trees in our study, since allometric relationships are highly site specific and may vary substantially between regions. Also the estimated specific weight may not necessarily be accurate, especially for the fine branches of the investigated beech trees. The scanned beech trees were harvested after scanning and their biovoume was additionally assessed using randomized branch sampling (RBS). The results of this assessment were not yet available for this summary, but will be reported on the conference.

Table 1: Comparison of the obtained biomass by manual field and automatic measurement. The measurements were corrected by assuming a 1cm diameter for the apple trees and 5cm for the beech trees where no diameter was estimatable.

Tree	Biovolume automatic measurement (uncorrected / corrected) in litres	Biovolume field measurement in litres and difference to the automatic measurement
Apple 1	8.5 / 11.8	10.3 (-1.5)
Apple 2	3.4/ 6.4	8.3 (+1.9)
Apple 3	1.2 / 2.4	2.8 (+0.4)
Apple 4	5.2 / 5.6	7.0 (+1.4)
Apple 5	18.6 / 20.4	18.7 (-1.7)
Apple 6	10.4 / 13.2	13.0 (-0.2)
Beech 1	939 / 1102	1446.0 (+344.0)
Beech 2	1394 / 1568	2740.0 (+1172.0)

4. Conclusions

From these prelimary results we conclude that skeletonization can be used to determine the biovolume of an individual tree. On average a differce of 1.18 litres to the manual measurement was found. Still, the results on forest trees have to be evaluated against manual field measurements that are carried out at the North-West German Forest Research Station. Further research will aim on the possibility to extract the branch diameters more robustly.

We found that the results of the biomass estimation on the apple trees may be further improved by investigating he influence of the resolution parameter in the skeleton extraction process.

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