FOREST INVENTORY FOR EUCALYPTUS PLANTATIONS BASED ON AIRBORNE LASERSCANNER DATA

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ABSTRACT:

This paper presents the results of a forest inventory for eucalyptus plantations based on airborne laser scanner. Eucalyptus is a very fast growing plant which is mainly used for paper production in Mediterranean climate zones. A 60 km² test site was selected in Portugal, intensive field work and additional data from the forest management provided reference data for the forest inventory with laser scanner data. Since eucalyptus tree crowns within planting rows have a small diameter, the individual trees were modeled by only one parameter – the tree height. The verification of the results from the automatic single tree detection showed a correctness of 93 %. For the estimation of the timber volume for each stand a single tree approach in combination with a stand wise approach was used. The calculation of timber volume for several reference stands with a total size of 75 ha yielded to a correctness of again 93 %. Finally all developed methods were implemented as additional tools in the Joanneum Research image processing toolbox IMPACT. Within IMPACT a processing chain was established which enables an automatic calculation of timber volume for eucalyptus plantations based on a digital terrain model, GIS information of the stands and first pulse laser scanner raw data.

1. INTRODUCTION

1.1 Motivation

In a time of corporate reorganization aiming at process enhancements in efficiency, productivity, cost and optimized resource management, information systems and digital data play a crucial role.
The Paper industry is at the core of this trend. Its business in a competitive context impose multi-dimensional challenges, namely: wide geographical coverage of forest resources; time and space dependent management; environmental interaction, need for accurate and timely data capture, integration and distribution.

Laser scanning technology provides a unique, innovative, accurate and cost effective approach to forest inventory, especially if addressed in a framework of process orientation, multiple datasets integration, information systems integration architecture and massive user access both to data and functionality.
The richness of the resulting data combined with advanced processing, and its ability for GIS integration and performant use, brings the opportunity for optimization in the use of field data collection/inspection resources and supports better informed management decisions.

1.2 Airborne laser scanning

Airborne laser scanning can provide a dense 3D point cloud of the earth surface. The sensor, carried by an aeroplane or helicopter, emitters laser pulses which are reflected by a surface. By measuring the runtime of the signal the distance can be determined. To derive a 3D point, the additional information of the sensor position needs to be known as well as the direction in which the laser pulse has been emitted. This required information can be obtained by a GPS / INS (inertial navigation system) unit (Lohr,Weil,1999).
The emitted laser pulse has a certain footprint size when it reaches the earth surface which depends on the sensor specific beam divergency. If a laser pulse hits the vegetation a part of the signal may be reflected by the top of the vegetation while an other fraction of this pulse may penetrate the vegetation and gets reflected by the terrain. The runtime of the first returning signal fraction can be measured separately from the last returning one. This yields to a distinction between first pulse data which contains mainly vegetation surface information, and last pulse data which contains more information on the terrain.

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Due to a filtering process that separates the non terrain laser hits from the last pulse data, airborne laser scanner data enables the generation of high resolution accurate digital terrain models (DTM).
If a digital surface model (DSM) from first pulse data is subtracted to the corresponding DTM, all objects (e.g. vegetation and buildings) covering the terrain are extracted and then contain height above ground information.

As several studies like the EU-project HIGHSCAN have shown(Schardt ed.al,2002, Persson ed.al,2002), it is now possible to use these data for the derivation of forest parameters like tree height, timber volume or dominant height. Due the high resolution of the laser scanner data, individual trees can be detected and modelled (Brandtberg ed.al, 2003). To obtain accurate forest parameters a correct segmentation of tree crowns is crucial which has turned out to be a non trivial task (Pyysalo and Hyyppä, 2002).

The correct estimation of timber volume has a strong impact on the resource management of the paper industry. Therefore a labour intensive forest inventory based on statistical approaches with permanent sample plots needs to be carried out at regular time intervals. Local deviations of the growing conditions may not be considered by this way and cause strong deviations of the final result.

In mediterranean climate zones the fast growing eucalyptus is mostly used to cover the needs of the paper industry. The results of an investigation to what extent laser scanning can contribute to forest inventory in eucalyptus plantations(eucalyptus globulus) are presented in this paper.

2. FOREST INVENTORY

2.1 Test site and data acquisition

The main test site is located in the vicinity of Monte do Prado / Portugal, has a total size of 60 km² and contains a forest area of 38 km². The terrain contains plains as well as mountainous parts. At the plantations the terrain has been leveled artificially in two meter wide bands that follow the terrain at the same height like contour lines. The height difference of these bands depend on the slop of the terrain and range from 10 cm to about 100 cm. Each band contains one planting row of eucalyptus with a tree every 1.5 to 2 meters(see figure 1).

Figure 1: photo of eucalyptus planting rows at test site Monte do Prado – plot 3

The data capture was carried out by the Toposys airborne laser scanner in first and last pulse mode. Since Toposys used the Toposys I sensor each mode was flown separately with a survey altitude of about 850 m above ground level. Simultaneously image data were gathered by means of the Toposys line scanner. The average point density is 5 points/m² with the typical point distribution of the used sensor.

2.2 Field work

To verify the results of the DTM and the forest parameters a field campaign was performed. For that purpose 4 plots in the size of about 30m x 40m where defined which contained several planting rows of eucalyptus. For the external orientation of the surveyed ground points and tree positions it was also necessary to create a GPS net since the density of marked survey points within the test site Monte do Prado was very low. Besides a total of 600 terrain points about 100 trees were registered with position, tree height and diameter at breast height (dbh). Based on these forest parameters the timber volume of each tree can be calculated. Furthermore the local forest management, Alianca Florestal, provided data of additional several hundred trees and timber volume from forest inventories and harvesting.

2.3 Generation of the DTM

As mentioned before a DTM of the test site is required to extract height above ground information of the vegetation. Therefore the last pulse data needs to be filtered to remove all non terrain data. The applied filtering technique was first developed by Joanneum Research within the EU project HIGHSCAN and has been continually modified and improved(Wack and Wimmer, 2002).

Based on a rasterization of the data, which allows the usage of fast digital image processing methods, the algorithm combines a hierarchical approach and a weighing function for the detection of non terrain raster elements. The weighing function considers the terrain shape as well as the distribution of the data points within a raster element. The hierarchical approach generates DTMs with 9, 3 and finally 1 meter resolution. This technique helps to remove large buildings or areas with dense vegetation.
The 60 km² DTM with 1 meter resolution (figure 2) was generated without tiling and the verification of the results are presented in table 1.

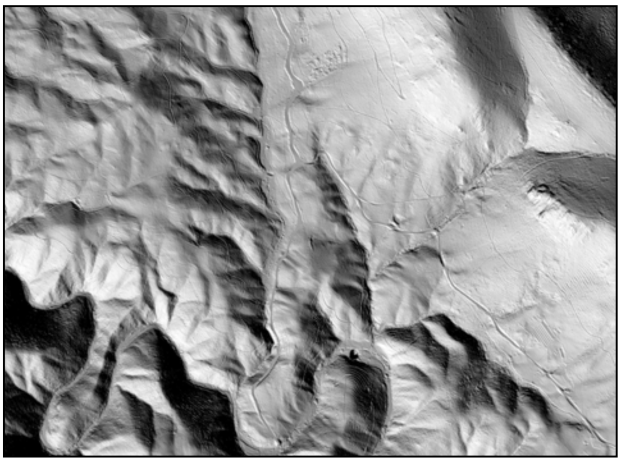


Figure 2: part of the Monte do Prado DTM with 1m resolution

Plot	points	Mean error[cm]	Stdev[cm]
I	210	14,9	17,6
II	176	13,7	24,5
III	107	8,1	16,1
IV	109	17,36	17,4

Table 1: DTM verification results

2.4 Single tree detection

A DSM of plot 4 shows (figure 3) that the modeling of single trees from a tree crown segmentation is very difficult. The tree crowns of trees with heights of 15 meters can have a diameter of only 1 meter. Since the Toposys scan pattern shows profile lines with a distance of about 1.8 meters across flight direction tree crowns can not be modeled in a sufficient way.
Therefore only tree tops were detected within the 3D point cloud of the DSM subtracted by the DTM. To enable the usage of fast neighbourhood operations the raw data were rastered at a resolution of 0.2 meters.

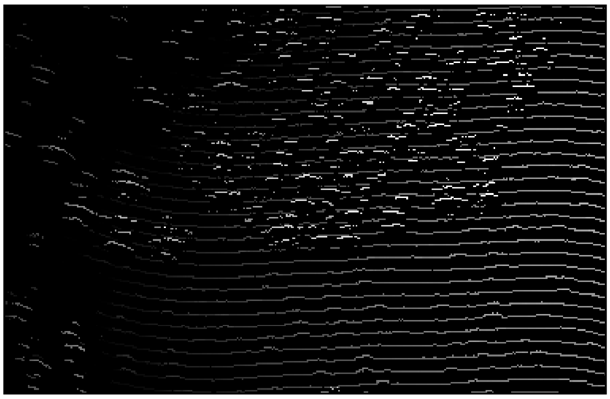


Figure 3: DSM of plot 4 with 20 cm resolution

The developed method for a tree detection works in several steps. First a difference image DSM minus DTM is required to obtain the tree heights. Based on this image an algorithm looks for all non zero values and creates a sorted list dependent on the point height above ground. Starting with the highest point it defines a area around this point where no other data points will be accepted. This way the algorithm removes most of the points. This process serves as a data thinning to accelerate the subsequent operations.

In a second step a tree height specific filtering takes place. The algorithm creates again a sorted list of the remaining points. Starting of with the highest point of the list, a maximum possible crown diameter is calculated depending on the tree height. The used diameter can be scaled depending on local growing conditions or eucalyptus species. This circle defines the area where all data points need to be checked whether they belong to the tree, which will cause their elimination from the sorted list, or they are part of a neighbouring tree.
An inner circle around the tree top can be defined as a fraction of the outer circle which defines an area where no other points will be accepted. These points will again be removed from the sorted list. To filter all points between the inner and outer circle a cone can be defined as an input parameter which serves as a rough model of the tree crown. If a point is located within the cone it will be removed from the list (figure 4).

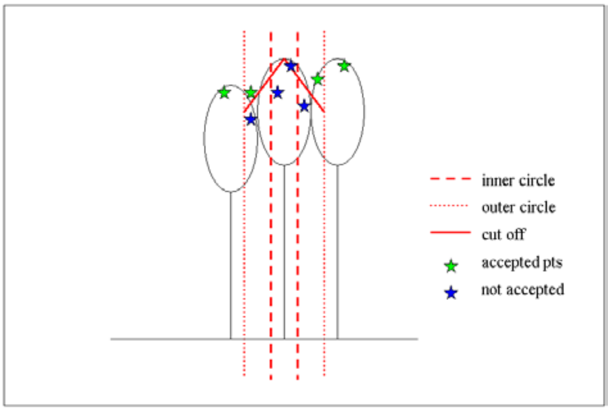


Figure 4: single tree detection

Using this algorithm almost all data points that are not representing a tree top can be eliminated. Since this method works over the hole image with the same set up it is not possible to consider special situations. If trees are located next to open plans like roads their branches have got more space and light and will therefore grow more towards these open spaces. These trees have slightly different shape in comparison to trees growing in the middle of planting rows. As a result of that situation some of these trees next to open plans will be defined by more than one tree top.
To overcome this problem the vegetation areas next to open plans can be masked and filtered once more by the algorithm just mentioned before. This time an other parameter set up is used to consider the different growth behaviour of such trees. The trees are now represented by only one tree top.

This method for the single tree detection was applied for every of the four plots at the test site Monte do Prado. During the field work the positions of 113 trees were surveyed which served now as a reverence for the verification of the tree detection results(table 2).

Plot	Reference trees	Correctly detected	undetected trees	erroneous detections
1	29	27	2	1
2	24	21	3	2
3	47	45	2	6
4	13	12	1	-
Total	113	105	8	9

Table 2: Verification of the tree detection

As a result a total of 105 trees out of 113 (correctness of 93 %) trees could be detected correctly. Eight trees could not be detected. The main reason for that is a situation where low trees are located next to dominant ones and therefore stay rather small. Although planted at the same time these trees show height differences of up to 8 meters in relation to the dominant neighbouring trees. An other reason for undetected trees can be a skew growth of a tree, the crown ends up being right next to an other one and can not be separated anymore.

The reason for an erroneous detection is the underestimation of the crown size which can be controlled by the input parameters of the tree detecting algorithm.
A horizontal shift between detected tree tops and surveyed tree position can have several reasons:

- an uncertainty in the position coordinates of the laser scanner points and the surveyed tree positions
- trees grown in a skew manner
- since an airborne laser scanner produces a quasi randomly distributed 3D point cloud a laser pulse does not necessarily hit a tree at its very top - deviations of up to a half of the scan line distances can occur.

Since eucalyptus trees are planted very near to each other it is possible that some are not even hit once by a laser pulse because the scan lines can be up to 1.8 meters apart from each other. The overlap area of neighbouring strips helps in scaling down the data gaps.
Furthermore a combined use of first and last pulse data for all the calculations concerning vegetation was investigated. In general the last pulse data penetrates the vegetation to a certain extent and do not contain information on the vegetation surface. But if the vegetation has a very high density also last pulse data may supplement the DSM in areas with no data. To study the influence of the additional use of last pulse data all calculations at the plots were carried out once more with both first and last pulse data. A comparison of the final results did not show any differences what yields to the conclusion that the additional use of last pulse data for the detection of tree tops is not suggestive.

To verify the tree heights from airborne laser scanner data (maximum values of DSM minus DTM) the height of several trees were measured by a VERTEX instrument. The accuracy of these heights are estimated to be in the range of about 0.5 meters. Within the plots 82 tree heights were measured in that way and compared with the results of laser scanner data(table 3).

Trees	mean error[m]	Standard deviation [m]
82	0.69	1.24

Table 3: Verification of the tree heights from laser scanner data

Some larger earth mounds were located right beneath the trees which did not appear in the terrain model since there was no terrain data of that region. As a result such tree heights got slightly overestimated. If the tree top was not directly hit by laser pulses the heights were underestimated. Both of these aspects cause a standard deviation of 1.24 m.

2.5 Timber volume

As mentioned before a statistical approach based on sample plots gets used to estimate the timber volume of an entire stand. A sample plot has an area of about 20x20m. Within such a plot all trees are registered with height and dbh (diameter at breast hight) and the timber volume per hectare can be calculated what yields to a direct estimation of the timber volume for the entire stand.
Airborne laser scanning is able to provide information on all the trees within a stand. In the case of eucalyptus it is the tree height, for other species like spruce or fir each tree can be modeled and a crown diameter extracted, here the point density is not such a limiting factor. By estimating the dbh based on this information the timber volume of each tree can be calculated and summed up for all trees of a stand

The formulas used by the foresters to calculate the timber volume of eucalyptus for individual trees is shown below:

$$Vt = 0.00770178 + 0.0000326355 * dbh^2 * H$$
$$Vm = - 0.00751134 + 0.0000288163 * dbh^2 * H \quad (1)$$

Vt...........timber volume with bark
Vm.........timber volume without bark
dbh.......diameter at breast height
H.............tree height

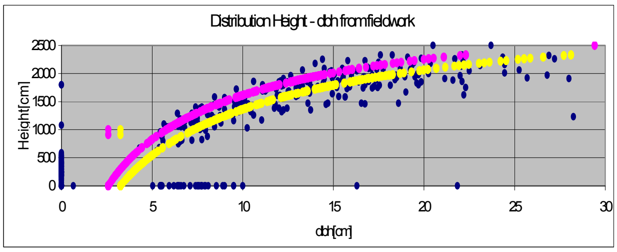
In case of the eucalyptus plantations only the tree height of each tree is available which is not enough information to get to a good estimation of the dbh. Therefore a formula (2) was provided by the forest management, Alianca Florestal, which defines a relation between the individual trees and stand wise information. A stand wise information can be the size of the stand, the tree species, age class and dominant tree height to estimate the timber volume of a stand. For eucalyptus the dominant height was defined as the average height of 20 % of the dominant trees.

$$H = c+9.195 * \log H^d - 0.304 *dbh + 1.432*H^d + 0.31*\log A*H^d \quad (2)$$

c……..-7.57
H^d…….dominant tree height of a stand
dbh.......diameter at breast height
A……..area of the stem at breast height – a function of dbh
H….....tree height

Since H^d can be calculated based on the results of the single tree detection and H (individual tree height) is the direct output of this operation, the dbh can be expressed as a function of these two parameters.
A transformation of the equation (2) yields to a logarithmic equation that can be solved numerically by iteration for each tree of a stand.

After some tests with several hundred sample trees at the area of Monte do Prado a correctional term was added to the equation to adapt the formula to local growing conditions (figure 5).



- estimated dbh based on formula(under estimation-upper line)
- estimated dbh based on corrected formula

Figure 5: Distribution of tree height and dbh from field work

2.6 Software

All newly developed methods were implemented as C++ tools in IMPACT, a Joanneum Research image processing tool box. For an automatic processing all new tools were combined with already existing tools in a script. By executing the script the timber volume of the defined stands can be derived automatically. The processing chain can be summarized in the following way:

- import additional data from GIS of the forest management - to do stand wise calculations information on the stands is required. Therefore an arcinfo program was developed to extract the boundaries of each stand

- by making use of the GIS data the matching part of the previously derived DTM was cut out and the DSM calculated from laser scanner data. The difference image of DTM and DSM represents the relevant laser pulse hits on the vegetation surface

- single tree detection

- application of the timber volume formulas

- final output: dominant height, list of all trees with height, estimated dbh and timber volume

2.7 Results

To verify the results of the forest inventory, Alianca Florestal provided data of this forest inventory using a statistical approach with sampling plots for 6 stands with a total size of 75 ha. Based on the information of 18 sample plots the timber volume of all stands was estimated to be 100 m^3 / ha.
Furthermore the exact amount of timber volume from harvesting the involved stands was also known. The total timber volume was 5349.05m^3 without bark, which corresponds to a timber volume of about 71 m^3 / ha.
In this case the statistical approach overestimates the timber volume by about 40 %. This overestimation may be caused by the selection of sampling plots which did not represent the character of the entire stand very well.

The results achieved with the developed methods based on airborne laser scanner are shown in table 4. The total timber volume without bark was estimated with 4964,14 m^3 or 66 m^3/ha. Therefore the estimated volume have a correctness of 93% which corresponds to results achieved by Persson ed.al (2002).

The underestimation of the volume may result from a time gap of several months between the laser scan data acquisition and the harvesting of the stands. After a growing period of 12 years Eucalyptus reach a height of about 20m and can be harvested. This fast growing behaviour results in an increase of the timber volume within a short period of time.

In combination with the numerical output a visualization can help to compare the different stands. The Eucalyptus at all involved stands was planted at the same time but can differ in their growing behaviour (figure 6).

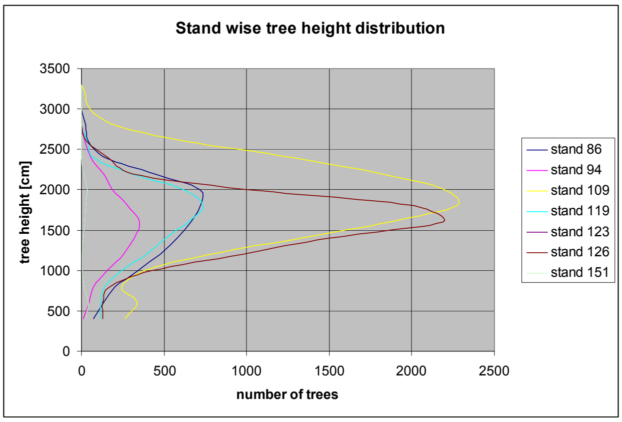


Figure 6: Stand wise tree height distribution

2.8 Additional investigations concerning scrub detection

To test if the detection of scrub beneath the Eucalyptus is possible, a DSM was calculated with first and last pulse data of stand 119. By subtracting the DTM from the DSM, heights of the data points above ground are generated. For a better visualisation of the scrub, all data points higher than 350 cm above ground were removed since scrub does not grow any higher then that. A comparison with the DSM before thresholding shows dense scrub where the tree density is low and the ground gets more sunlight. Beneath the tree crowns only few data are available on the scrub. On the one side hardly any laser pulses are able to penetrate the tree crowns to provide some data and on the other side investigations during field work showed that scrub barely grows under such circumstances. Closely related to this observation is the clear structure of the scrub distribution that can be seen. Directly related to the varying scrub density is the growing behaviour of the Eucalyptus that changes significantly within the stand. The trees at the western side of

stand nr.	size [ha]	trees	trees / ha	volume with bark	Volume without bark	basal area	mean dbh [cm]	H^d [m]	Volume / ha with bark	Volume / ha without bark
86	9,55	4562	478	774,99	619,01	9,55	14,5	22,3	81,15	64,82
94	3,87	1887	488	293,41	232,06	9,16	14,0	21,6	75,82	59,96
109	32,4	13680	422	3.019,17	2.470,08	10,07	16,0	24,6	93,18	76,24
119	8,19	3933	480	632,88	502,52	9,32	14,4	21,7	77,27	61,36
123	0,26	193	742	25,93	20,13	12,16	12,4	21,0	99,73	77,42
126	19,86	9016	454	1.385,79	1.094,58	8,78	14,5	20,7	69,78	55,11
151	0,91	475	522	36,98	25,85	5,62	9,5	17,6	40,64	28,41
Total/average	75,04	33746	450	6.169,14	4.964,23	-----	-----	-----	82,21	66,15

Table 4: results of the forest inventory based on laser scanning

the stand are much weaker, this might be due to a different soil quality or the steeper terrain in this area. However it is possible to visualize the scrub distribution and density in Eucalyptus plantations what can be a helpful information source for forest fire prevention(figure7).

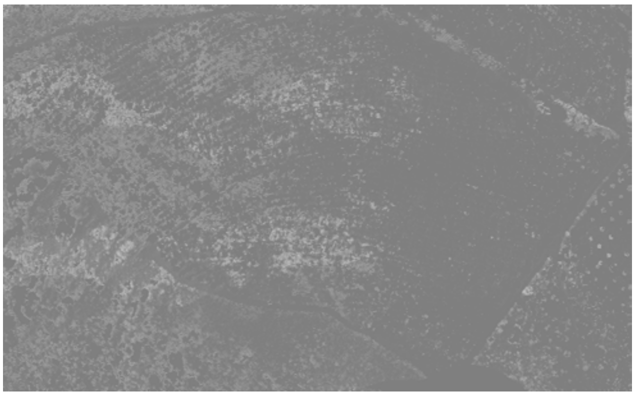


Figure 7a: stand 119 / resolution 20 cm / heights of data points between 0 cm and 3.5m above ground.(0 – dark / 3.5m light)

Figure 7b: stand 119 / resolution 20 cm / heights of data points between 3.5 m and 23m above ground.(3.5m – dark / 23m light) Amongst the trees are lighter and darker sections which simpl mark the area of overlapping stripes. The tree height at this area does not change.

2.9 Conclusion

The results of this study show that laser scanning is able to provide data which can be used to achieve reliable forest inventory results for eucalyptus plantations. Due to the small diameter of tree crowns the modeling of individual trees is very limited. A single tree detection provided the number of trees per stand with individual heights. Based on this information it was possible to find relations which allowed the estimation of the dbh for each tree. In combination with the tree heights it was now possible to estimate the timber volume for each stand. The verification of the results showed a correctness of 93 %. An explanation for this deviation may be the time gap between laser scanner data acquisition and harvesting where the reference timber volume was determined by the saw mill and the underestimation of the detected trees .

All developed methods were implemented as part of the Joanneum Research image processing tool box IMPACT. An automatic calculation of the timber volume could be established using GIS data for the stands, laser raw data and a DTM as an input. To improve the method further inventories at different sites are required to test if the set up of the algorithm is a generally valid approach which is able to produce reliable results for different age classes and growing conditions.

The results of statistical approaches with sample plots can not be used as reference for a verification since this data has a lower accuracy then the approach based on laser scanning. Therefore a intensive field campaign is required unless the eucalyptus is harvested soon after the laser scanner data capture.

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