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Individual Tree Parameters Estimation from Terrestrial Laser Scanner Data

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Abstract. Tree models and information on the various characteristics of trees and forests are required for forest management, city models, carbon accounting and the management of assets. In order to get precise characteristics and information, tree modelling must be done at individual tree level as it represents the interaction process between trees. For sustainable forest management, more information is needed, however, the traditional methods of investigating forest parameters such as, tree height, diameter at breast height, crown diameter, stem curve and stem mapping or tree location are complex and labour-intensive. Light detection and ranging (LiDAR) has been proposed as a suitable technique for mapping of forest biomass. LiDAR can be operated in airborne configuration (Airborne laser scanning) or in a terrestrial setup. Terrestrial Laser Scanner measures forests from below canopy and offers a much more detailed description of the individual trees. The aim of this study is to derive the essential tree parameters for estimation of biomass from terrestrial LiDAR data. Tree height, diameter at breast height, crown diameter, stem curve and tree locations were extracted from Terrestrial Laser Scanner point clouds.

Keywords: terrestrial laser scanning, tree parameters, light detection and ranging (LiDAR).

Conference topic: Technologies of geodesy and cadastre.

Introduction

Three-dimensional laser measurement systems play a significant role in the rapidly developing world, particularly in facilitating the process of measuring large objects requiring high precision. This technology allows to collect spatial information about the object, remotely, without physical contact and at very high speeds (Barber *et al.* 2008). These systems make work more productive and faster, reducing the time and cost collecting information around us in just a few minutes. Therefore these systems are used more and more in various fields as surveying, construction, deformation monitoring, earthwork calculations and etc. (Staiger 2003). Beyond interactive measurement in 3D point clouds, techniques for the automatic detection of objects and the determination of geometric parameters form a high priority research issue. With the quality of 3D point clouds generated by laser scanners and the automation potential in data processing, terrestrial laser scanning is also becoming a useful tool for forest inventory (Kelbe *et al.* 2013). In this paper the possible application of terrestrial laser scanning for forestry applications is investigated. Inventory and parameterization of individual trees in orchards and forests are of large interest because of the potential of economical maximization of orchard production and the sustainable management of forests (Urano, Omasa 2003; Srinivasan *et al.* 2015). The tree parameters considered in this study are of geometric type: tree height, diameter at breast height, crown diameter, stem curve and stem mapping including the diameter of the trunk crown diameter are to be determined. (Pfeifer *et al*. 2004) These parameters are of interest due to ecological reasons (management of environmental influences, etc.) and economic reasons (timber volume estimation for wood production, etc.).

The overall aim of this study is to retrieve forest structural parameters at individual tree level using LiDAR data sets acquired with TLS.

Test site and data collection

As test area we selected a small group of eight trees with DBH greater than 6 cm. The trees were measured conventionally and using TLS. The reference data was measured with a total station (position and height) and a tape (measurements in DBH).

The scans were conducted using Leica ScanStation C10 (Fig. 1), a high point density 3D laser scanner, which emits visible green light pulses (532 nm) with a scan rate of 50,000 pulses per second. Single point accuracies of 4 mm for distance measurement and 6 mm for positional measurement from 1 to 50 m can be achieved with this scanner. The maximum field-of-view is 360° horizontal and 270° vertical.

Fig. 1. Leica ScanStation C10

The trees were scanned from three stations (directions) to avoid laser shadows and to measure trees from different sides. Targets were used to match the data from the different scans and to orientate the point clouds in a georeferenced coordinate system (Fig. 2). These targets were placed in such a way so that they are visible in all of the scans. At least three scanned targets per station were necessary to register a scan.

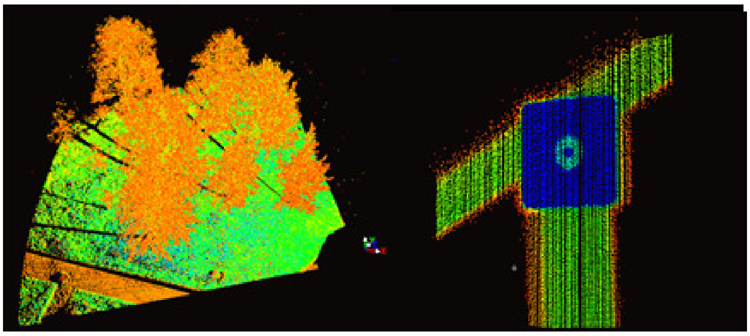

Fig. 2. Scanned data from single station and scanned target

For georeferencing the point clouds targets were measured with a total station and connected to the Lithuanian coordinate system LKS-94. All scans were accurately co-registered and the trees were mapped from this merged multi-scan point cloud (Fig. 3). Registration (georeferencing) was performed using Leica Cyclone software, and registration accuracies were not exceeding 2 millimetres between scans. Registered point cloud consisted of 8062221 points, but after cleaning and filtering the excessive amount of unnecessary points was reduced to 1317822 points. The georeferenced data was exported as text file for further processing Forest 3D software.

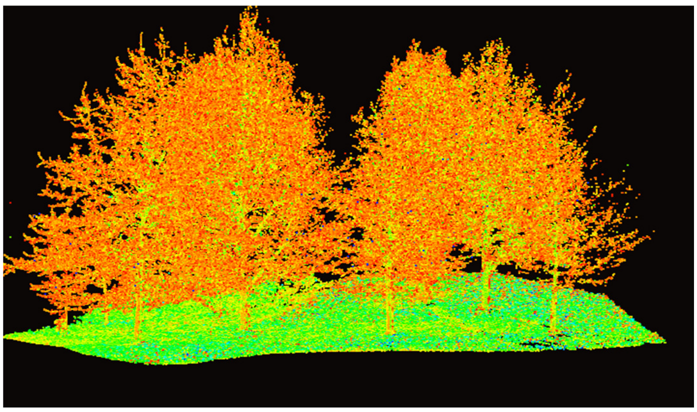

Fig. 3. Registered and georeferenced point cloud

Individual tree parameters estimation and results

The main individual tree parameters we want to estimate are: diameter at breast height (DBH), tree height (TH), stem curve (SC), Tree planar projection (TPP) and tree position (Fig. 4) (Moskal, Zheng 2012).

Tree height (TH) – the distance between the ground and highest point of the tree.

Diameter at breast height (DBH) – the main and most important parameter of the tree that provides information about the structure of the tree, its condition and development. It is described as a straight line passing through the center of the circle. As standard, the diameter is measured at breast height i.e. 1.3 meters. Also, the diameter can be measured with or without bark.

Stem curve (SC) – The stem centers and diameters calculated by fitted circles in various heights above the tree position (0.65 m,1.3 m, 2 m, 3 m, etc.).

Tree position (TP) – this parameter indicates the exact coordinate of the tree position on the ground.

Tree planar projection (TPP) – polygon with the smallest possible area (concave) or shortest possible boundary (convex) containing all points in tree cloud orthogonally projected at the horizontal plain.

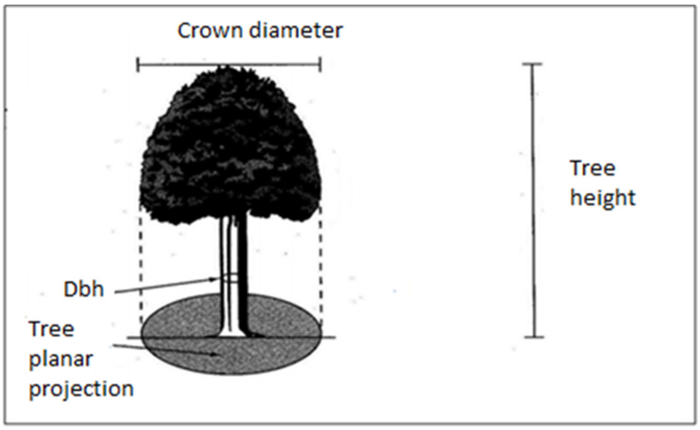

Fig. 4. Main individual tree parameters

The first thing we need to do is to perform a terrain segmentation (ground separation from the point cloud) or DTM creation, because this ground level is used in other individual tree parameter (tree height, DBH) estimation.

We tried two approaches to generate terrain: from octree and from voxels.

In octree approach input cloud is divided into cubes. Cubes which contain points and have the lowest z-value (height) are considered as the "ground cubes". Terrain is then defined by the points in the ground cubes. This means that all the points in ground cubes are considered as terrain and contrary to voxelization there is no reduction of points and no generalization. In voxel approach input point cloud will be reduced into voxels and centroids of voxels (i.e. points with average coordinates from all original points within individual voxels) with the lowest z-values will define the terrain. With increasing voxel size increases also overestimation of terrain height (z-value of centroids is affected by more points which lie above the terrain) (Krucek *et al.* 2015). With right voxel or cube sizes (it depends on density and other parameters of the point cloud) both approaches showed comparable results, however an optical test is still essential after finishing the automatic derivation of DTM. This test can be carried out on the drawn points. Points that are obviously not part of the surface can be manually removed from the selection. A digital terrain model with a grid size of 30 x 30 cm is calculated with the selected points (Fig. 5).

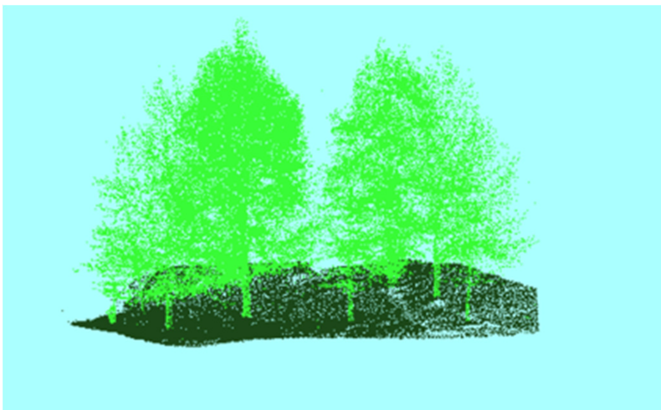

Fig. 5. Terrain segmentation

The second step is segmentation of individual trees. It was done manually because of the relatively small number of trees in a data set, however algorithms for automatic individual tree segmentation also exists (Hosoi, Omasa 2006). After this stage each individual tree has its own point cloud for further parameter estimation.

Tree base position (TP) is a key parameter providing a baseline for computation of other tree parameters such as DBH, tree height and stem curve and affects also the visualization of convex/concave tree projection. Previously obtained terrain (DTM) cloud for estimation of the Z coordinate of the tree base was used. For obtaining tree position randomized Hough transformation (RHT) method was used (Simonse *et al.* 2003). This algorithm computes tree position using centers of two circles fitted by RHT to the stem at 1.3 and 0.65 m above the DTM. The RHT position is then defined by the point, where vector heading from upper circle center thru lower circle center intersects the horizontal plain defined by median Z value of the selected number of closest points on the DTM cloud (Krucek *et al.* 2015). Comparison of the reference data (Total station) and the results from the laser scan show minimum deviation of 1,7 cm and maximum of 9,8 cm in tree position estimates with an standard deviation of 2,8 cm.

The diameter at breast height (DBH) is computed from the subset of points of the tree cloud. Using the digital terrain model a search for circles as a model of tree cross-sections has been implemented. To find these circles all coordinates in a layer with a height between 1.25 and 1.35 meters above terrain were extracted from the point cloud. The randomized Hough transformation (RHT) approach used to calculate DBH. Thickest determined tree trunk is 29.4 cm in diameter, and the smallest – 6.2 cm (Fig. 6)

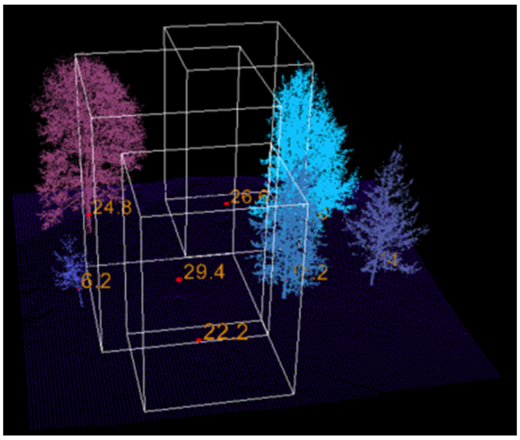

Fig. 6. Estimated DBH values

Reference DBH measurements were carried out using measuring tape. Diameter at breast height can be determined fairly accurately – encircling the trunk with tape and calculating the diameter of the trunk with a circumference by the formula (1):

$$d = \frac{C}{\pi}, \quad (1)$$

where: d – diameter; C – length of the circle; π – 3,14;

The comparison between both methods is presented in Table 1.

Table 1. DBH Comparison

Tree Nr.	DBH from tape measurements, cm	DBH from TLS data, cm	Difference, cm (deviation in %)
1.	14.1	12.8	1,3 (9,2)
2.	26.4	24.8	1,6 (6,1)
3.	18.7	17.2	1,5 (8,0)
4.	28.3	26.6	1,7 (6,0)
5.	25.3	23.8	1,5 (5,9)
6.	23.3	22.2	1,1 (4,7)
7.	30.7	29.4	1,3 (4,2)
8.	6.5	6.2	0,3 (4,6)
		Average	1.29 (6.1)

These results are quite promising and differences are quite small. From the results in the table it is noticable, that RHT algorithm tends to undeestimate the DBH by 6.1%. Aslo it is worth to stress that for lower scan resolutions and longer ranges, DBH estimation accuracies might decrease due to reduced point density.

Tree height parameter estimation is quite straightforward. It is vertical distance from tree position (lowest point) to the highest point in a single tree point cloud. In the test area the height of the trees ranged from 5.38 m to 13.9 m (Fig. 7). Comparison of the reference data (Total station) and the results from the laser scan show minimum deviation of 8.7 cm and maximum of 14,2 cm in tree height estimates with an standard deviation of 5,4 cm. The estimated tree heights are 1,1% higher than those measured conventionally.

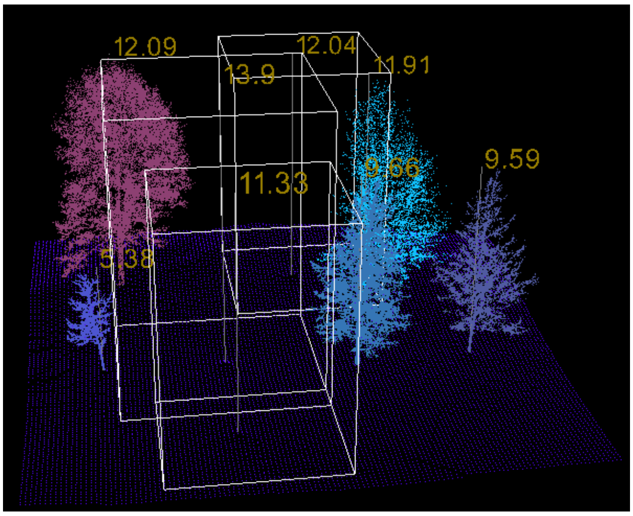

Fig. 7. Estimated tree heights

Tree planar projection (convex) - a parameter representing the area of convex hull of the tree cloud orthogonally projected to the horizontal plane in the tree base (Fig. 8). The calculation is based on the Gift wrapping algorithm (Rosén *et al.* 2014).

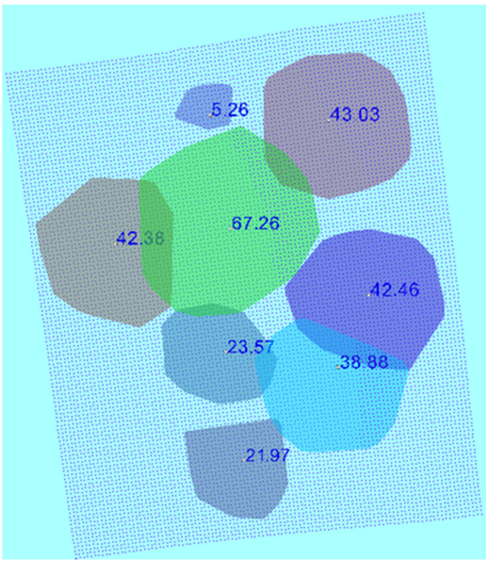

Fig. 8. Tree convex projection

The stem diameters are computed as circles using Randomized Hough transformation from 7 cm high slices of the tree cloud. They are displayed as 7 cm high cylinders defined by the RHT fitted circles (Krucek *et al.* 2015). The algorithm starts with computing first the stem diameter at 0.65 m above the ground, then at 1.3m and 2m above the ground and then continues computing diameters with 1 m spacing until the new diameter is two times wider than both previous two diameters (Fig. 9).

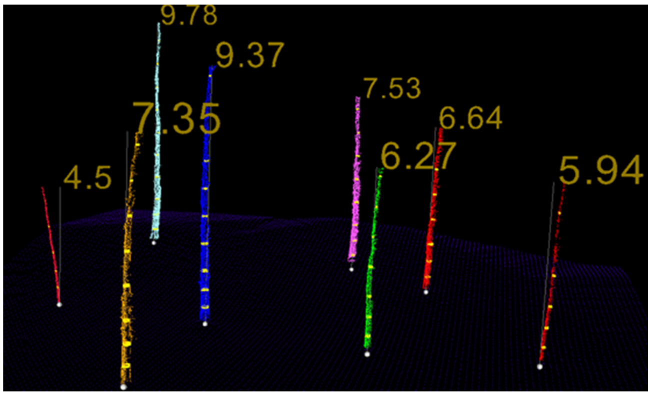

Fig. 9. Estimated stem curves

The table below summarizes estimated individual tree parameters of 8 trees from the point cloud of 1317822 points (Table 2):

Table 2. Estimated individual tree parameters

Tree No.	Height, m (deviation in % from reference)	DBH) cm (deviation in % from reference)	Convex tree projection, m^2
1.	9.6 (0.9)	12.80 (9.21)	21.973
2.	12.09 (0.94)	24.80 (6.06)	43.029
3.	9.66 (1.07)	17.20 (8.02)	23.568
4.	12.04 (1.17)	26.60 (6.0)	42.456
5.	11.91 (1.15)	23.80 (5.93)	38.883
6.	11.33 (1.18)	22.20 (4.72)	42.375
7.	13.9 (0.84)	29.40 (4.23)	67.265
8.	5.38 (1.5)	6.20 (4.62)	5.265

Estimated tree heights ranges from 5.38 m to 13.9 m. Convex tree projection – ranges from 5.26 m^2 to 67.26 m^2. The diameters at breast height ranges from 6.2 cm to 29.4 cm.

Conclusions

Estimation of tree characteristics from terrestrial laser scanner data described in this paper allows an automatic identification of trees positions, stem curve, tree height, tree projection and the DBH (as well as additional diameters in variable tree heights). However some manual interaction and visual tests are required to verify or correct automatic determination of some parameters. That might be difficult and time consuming while working with big data sets.

Comparison of the reference data (Total station) with the results from the laser scan shows minimum deviation of 8.7 cm and maximum of 14,2 cm in tree height estimates. The estimated tree heights are 1,1% higher than those measured conventionally. The reason of this underestimation might be laser beam reflections from tree branches and leaves, resulting distorted data.

Comparison of the reference data (tape measurements) with the results from the laser scan shows minimum deviation of 0,3 cm and maximum of 1,7 cm in DBH estimates (average 1,29 cm). From the results in the table it is noticeable, that RHT algorithm tends to underestimate the DBH by 6.1%.

Analyzed methods and algorithms might be improved, the RGB color information and intensity data might be added to the 3D geometry data. This might improve filter methods and also facilitate the determination of other forest inventory parameters.

It can be expected that at the current stage inventories with terrestrial laser scanners will offer the opportunity to determine timber quality of standing trees with high accuracy.

References

Barber, D.; Mills, J.; Smith-Voysey, S. 2008. Geometric validation of a ground-based mobile laser scanning system, *ISPRS Journal of Photogrammetry and Remote Sensing* 63(1): 128–141. https://doi.org/10.1016/j.isprsjprs.2007.07.005

Hosoi, F.; Omasa, K. 2006. Voxel-based 3D modeling of individual trees for estimating leaf area density using high-resolution portable scanning lidar, *IEEE Transactions on Geoscience and Remote Sensing* 44: 3610–3618. https://doi.org/10.1109/TGRS.2006.881743

Kelbe, D.; Romanczyk, P.; van Aardt, J.; Cawse-Nicholson, K. 2013. Reconstruction of 3D tree stem models from low-cost terrestrial laser scanner data. *SPIE Defense, Security, and Sensing*, 873106–873106.

Krucek, M.; Trochta, J.; Kral, K. 2015. *A tool for processing of pointclouds acquired by terrestrial laser scanning in forests*. 3D Forest User Guide [online], [cited 10 November 2016]. Available from Internet: http://www.3dforest.eu/

Moskal, L. M.; Zheng, G. 2012. Retrieving forest inventory variables ith terrestrial laser scanning (TLS) in urban heterogeneous forest, *Remote Sensing* 4(1): 1–20.

Pfeifer, N.; Gorte, B.; Winterhalder, D. 2004. Automatic reconstruction of single trees from terrestrial laser scanner data, in *Proceedings of 20th ISPRS Congress*, Istanbul: ISPRS, 114–119.

Rosén, E.; Jansson, E.; Brundin, M. 2014. Implementation of a fast and efficient concave hull algorithm [online], Project Report, Uppsala University [cited 22 November 2016]. Available from Internet: http://www.it.uu.se/edu/course/homepage/projektTDB/ht13/project10/ Project-10-report.pdf

Simonse, M.; Aschoff, T.; Spiecker, H.; Thies, M. 2003 (September). Automatic determination of forest inventory parameters using terrestrial laser scanning, in *Proceedings of the scandlaser scientific workshop on airborne laser scanning of forests*, 252–258.

Srinivasan, S.; Popescu, S. C.; Eriksson, M.; Sheridan, R. D.; Ku, N. W. 2015. Terrestrial laser scanning as an effective tool to retrieve tree level height, crown width, and stem diameter, *Remote Sensing* 7(2): 1877–1896. https://doi.org/10.3390/rs70201877

Staiger, R. 2003. Terrestrial Laser Scanning Technology, Systems and Applications, *TS12 Positioning and Measurement Technologies and Practices* 12(3).

Urano, Y.; Omasa, K. 2003. Accurate estimation of forest stand parameters in Japanese cedar woods using a portable scanning lidar, in *Proceedings of IAWPS2003*, Daejeon, Korea, 403–407.