

TREE HEIGHT ESTIMATION METHODS FOR TERRESTRIAL LASER SCANNING IN A FOREST RESERVE

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ABSTRACT:

A terrestrial laser scanning survey has been performed on a forest reserve site. This paper represents the processing of the dataset. Two new methods have been developed for tree positioning, which is necessary for height calculation. One of them is the clustering method, the other is the so-called crescent moon method. The stems were modelled, as high as possible, by both methods. Two methods were tested for height estimation. One was a direct method based upon the Digital Surface Model; however a new method was developed to predict the tree-top based upon the modelled trunk and then the nearest local maximum was selected to that predicted point in the DSM. The other was an indirect method, where the modelled stems were described as paraboloids, and the heights were extrapolated. The accuracies of the methods were investigated by means of photogrammetric measurements based on very high-resolution aerial images. Both the clustering and crescent moon methods were appropriate in tree positioning and stem modelling. The height estimation based upon the DSM yielded good results. The extrapolation method was tested for European Larch only. The height in one-third of the cases was estimated by this method within tolerance. This method can be taken into consideration in the case of leaves on scanning in very dense, multi-storey forests.

1. INTRODUCTION

Sixty-eight forest reserves have been established in Hungary to protect and study natural or semi-natural forest ecosystems. Some of these reserves are selected for long-term investigations, and a permanent sampling network has been established. These network points are the geometric base for the collection of different data, such as the forest stand parameters, soil, vegetation and so on (Horváth et al. 2001). Single-tree mapping is not the main objective of these networks, but some of them include stem maps created with conventional instruments, and demand is growing for remote sensing methods producing single tree maps. Terrestrial laser scanning is an available opportunity to automate data acquisition in forests. Several researchers have reported promising results in applicability in forest inventories, e.g. Thies & Spiecker (2004), Aschoff et al. (2004).

Forest Reserve 46, situated next to the Austrian border, was selected for this study. This reserve is a mountainous mixed, almost coeval forest stand with oak, hornbeam, beech, larch and spruce species. The spruces are dying of bark beetle disease.

2. MATERIAL

2.1 TLS data

The terrestrial laser scanning (TLS) was carried out on a permanent sample plot, No. 05-11, in leaf-off state, in April 2006 with a Riegl Z420i instrument. The configuration of the data acquisition can be seen in Figure 1. The scanning was done on the whole upper hemisphere at three different tilting angles, resulting in a vertical range from -40° to 90° with a 0.055° angle resolution. There were three further surveying points from

which the surveys were done toward the sample plot at approx. 180° horizontal, and from -40° to 90° vertical angles with a 0.12° angle resolution. The data acquisition, the registration and the colour coding were performed by the surveying company.

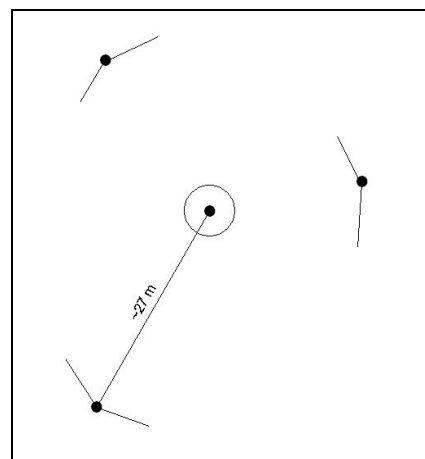


Figure 1. The configuration of the TLS data acquisition

2.2 Aerial images

Very large scale, colour metric aerial photographs were taken in April 2005. The parameters of the photography can be seen in Table 1.

Parameters	Value
Date	2 April 2005
Camera	Wild RC-20
Film type	KODAK AEROCROME III
Focal length	153.1 mm
FHAG	~600 m
GSD	4 cm

Table 1. Parameters of the aerial photography

3. METHODS

3.1 Creating Surface Models

The processing of the surface models was done based upon all four scanning positions (Figure 1). The first, and very important step, of the data-processing was the creation of the digital terrain model (DTM). The DTM was processed based upon an iterative, coarse to fine method. The points with the absolute minimum heights were selected within a cell, and then the first coarse triangulated irregular network (TIN) model was created. Then the heights relative to the previous DTM were calculated, and the points with the minimum relative heights were selected within a double resolution cell. In the raw data some points situated below the terrain surface were found to be faulty. A filtering method based upon the derivatives of the surface was applied, but some manual selections were also left. Finally the points situated on the terrain were selected and a TIN model was created.

The processing of the Digital Surface Model (DSM) was simpler, because there were no points above the tree-canopy surface. An iterative coarse to fine method was applied here as well, but always the absolute highest points were selected within the cell. A minimum curvature raster model was interpolated from the 'bumpy' selected points.

3.2 Stem modelling

Two new methods, a statistical and a geometric approach, were developed to automatically detect the position of single trees, and furthermore the stem position and size at each height layer. Both modelling methods initiate the process with the determination of a tree's position and diameter, based upon the selected points at breast heights (Figure 2).

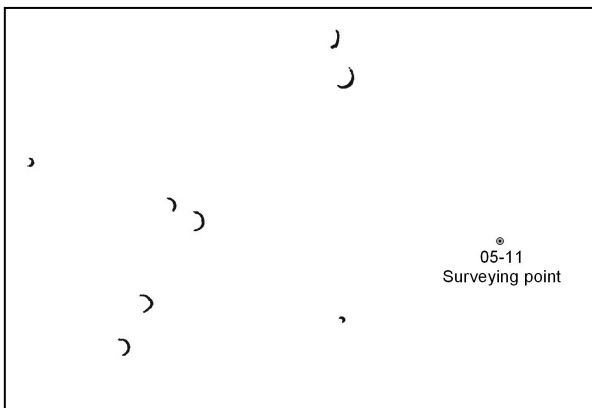


Figure 2. The shape of the points at breast heights

These processes were iterated for the selected points in slices of different height section above the terrain in both processes, but the processes differ from each other. The first approach was a statistical clustering method with a combination of a circle fitting by means of least square adjustments. The second approach was a geometric method utilising the crescent form of the points, which determines the position and diameter in one step. This method was called the crescent moon (CM) method.

3.2.1 Clustering

The point cloud was sliced for the clustering, with a surface parallel to the DTM from 1 to 18 metres above the ground by 1-metre steps. The thickness of the slices were 10 cm up to 5 meters, then it increased 10 cm for every 5 meters in elevation, because of the declining exposure of stems and the rising covering effect of neighbouring foliage.

The measurements reflected from stems form groups at each height layer, as seen in Figure 2. Grouping points of a dataset based on a similarity criterion was possible with clustering methods. Points that were measured from the same stem were much closer to each other than points measured from different stems, and thus points that were reflected from the same cross-section are represented by one cluster. The similarity was defined as the distance from the clusters' centroid. The number of clusters was usually not known at the beginning of the process. However, an interval for the approximate cluster size could be given, because the minimal and maximal diameter of trees on the sample plot could be roughly estimated. Let d_{max} denote the maximal diameter for all of the clusters. In our work d_{max} was 1.0 m. That also means the minimal distance between stems has to be larger than d_{max} , otherwise the clusters will be merged (Figure 3).

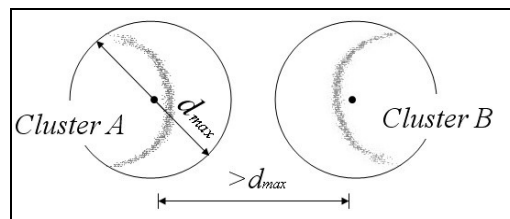


Figure 3. Rules of clustering

The algorithm worked iteratively. It read the points sequentially from a list. The actual point is labelled to the nearest cluster if it is closer than d_{max} , otherwise the point will be the centroid of a new cluster. At the end of the cycle the centroids were recalculated, and the clusters whose centroids were closer than d_{max} were merged. The iteration was continued until the changes in the coordinates of cluster centroids exceeded a given limit. After the last iteration the clusters containing fewer than 20 measurements were deleted, because these were usually bushes, branches, or other small objects.

3.2.2 Crescent Moon Method

This method utilises the more or less regular crescent moon (CM) shape of the selected points (Király et al. 2007). Starting from the surveying point, the first step was to find the nearest point. Next a test was applied to find whether the point was a CM point or a single or scattered point. The routine calculated a fitting circle in the first case, based upon three cardinal points of the shape (Figure 4). The points were sorted by the horizontal angle as seen from the surveying point. The means

were calculated for the points situated at the minimum, the mean and the maximum angle with a tolerance for the three points defining the circle.

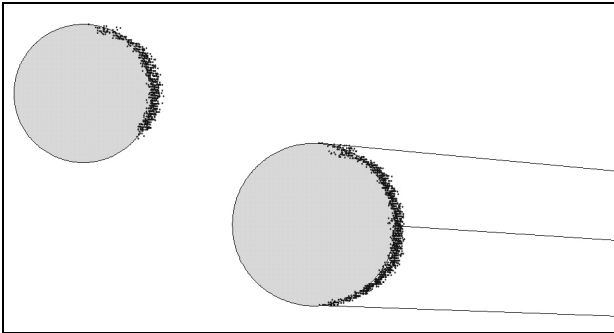


Figure 4. Fitting a circle to a crescent moon shape

When the fitting was successful and the calculated diameter at breast height (DBH) was within a tolerance, then the tree's position and DBH were recorded, the selected points – whether scattered or CM points – were deleted, and the routine was continued.

The next step of this method was the slicing. This was applied downwards from breast height to the ground, and upwards from the breast height to as high as possible by 10-cm steps. Some constraints can be defined based upon the diameter difference and the centre translation. At times the fitting was unsuccessful because of noisy points or branches, but the method allowed us to leave these slices out, and to continue normally when a successful fitting occurred.

3.2.3 Stem modelling from the fitted circles

A model of the stems could be produced based upon the circles from either of the above-mentioned methods. The model was suitable for volume calculations, demonstrations and so on (Figure 5).

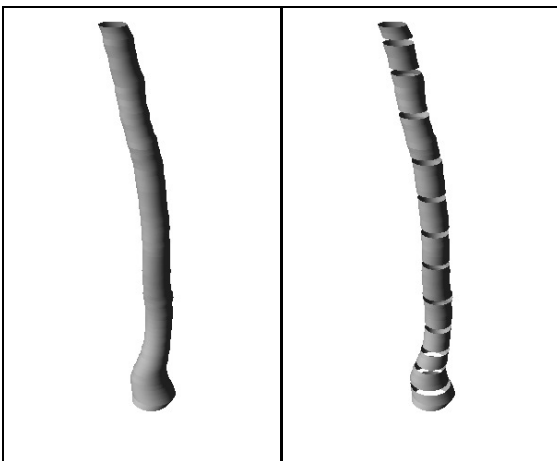


Figure 5. Two different representations of a stem model produced by the CM method

3.3 Calculating tree height by Terrestrial Laser Scanning

3.3.1 Stem form extrapolation

The lower halves of the trunks were well defined by the several fitted circles in leaves-off conditions. So one can assume that the upper half could be extrapolated to estimate the tree height.

The stems of trees can be approximated by a conoid-type geometric body of revolutions in general. For conoids the relative area of cross section is denotable with a power function of the relative length measured from the top. While the middle part of individual stems can usually be described as paraboloid, there is a linear relationship between the cross-section area and cross-section height that can be modelled with linear regression. The extrapolated value of the regression function at zero cross-section area predicts the individual tree height (Figure 6). The area of cross sections can be calculated by fitting circles onto them. In our study site the larch (*Larix decidua*) had the longest stem without branches, so only these trees were sampled. In a pre-processing step the deformed or noisy clusters were eliminated by visual inspection. Only those trees were evaluated upon which at least 10 circles could be fitted. In the next step the regression model was established for each individual tree. In spite of the manual elimination of irregular clusters, extreme diameters sometimes occurred that erroneously affected the regression models. Therefore a second filtering step was necessary, where the detection of outliers took place during an iterative regression. In every step the standard deviation of residuals (S_{xy}) was calculated, and if there was a diameter with a larger residual than $2 \cdot S_{xy}$ then it was deleted. Finally the intersection with the abscissa was calculated.

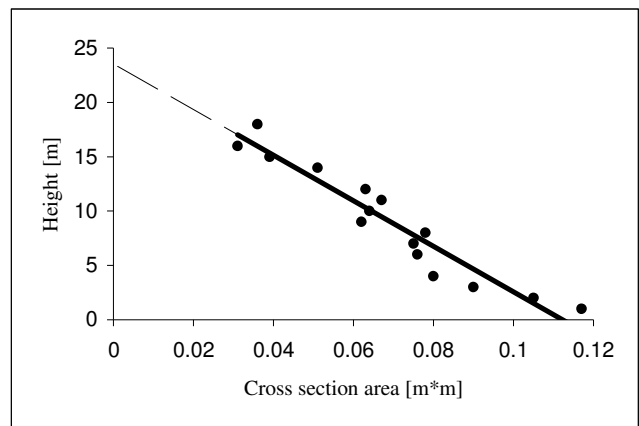


Figure 6. Estimated tree height versus cross section area

3.3.2 Calculating tree height using DSM

Tree height estimation can be done with the direct application of the digital surface model in the case of leaves-off scanning. The most problematic point in this method is finding the appropriate treetops on the DSM.

Accepting that the tree-tops are local maxima in the DSM, the task is to find the appropriate local maxima on the DSM. An inverse watershed modelling was applied to detect the local maxima (Gougeon 1995, and Király 1998).

The most obvious method is to find the nearest local maxima to the bottom of the tree in XY direction; however, this often causes mismatching. A new method was developed for predicting the treetop based upon the already modelled trunk. The modelled trunk was described as simple function of the heights. Then the predicted treetop was calculated based upon this function and the height estimated by the method above. The nearest local maximum was selected to that predicted point for the height calculation.

3.4 Reference Measurements

3.4.1 Field Measurements

A 30 m radius full circle sample with 208 trees was surveyed with total station around the sample point. Species and DBH were determined as attributes.

3.4.2 Photogrammetric Measurements on aerial images

The aerial images were evaluated using a digital photogrammetric workstation. The control points were measured by geodetic GPS surveys. The σ of the inner and relative orientations of the photos are less than 4 μ m. The RMS of the absolute orientation is better than 0.3 m. The primary mean error of Z measurements is -0.45 m. The 3D measurements on the oriented model were done manually. The measured larches were already grown green, so pointing the tip was usually effortless.

4. RESULTS AND DISCUSSION

The detection of the trees is a crucial point in automatic algorithms. There were 169 trees visible (or partly visible) from the sample point and 158 were sampled by more than 20 laser hits.

The efficiency of the modified sequential clustering in stem detection was examined visually and by means of spatial analysis in GIS software. This method clustered 158 stems altogether. The stem points were successfully clustered in 142 cases (89 %). The clustering merged two slight stems together in 4 cases. There were also 8 faulty clusters because of branches and noise. The main advantage of clustering is that it can handle point clouds from more than one scanning position in the same way. Although it is an easy and fast algorithm, it does not take account of shapes and is still unable to separate several stems if their outermost points are closer than the maximal cluster size. Noise reduction should be improved.

The CM method found 196 single trees from 169 ('116 %'), of which 166 were accurate (98 %). This method definitely over-detected the branches and noise, but was often successful with less than 20 hits. The over-detection can be reduced by the checking of the successfully detected stems. The stem modelling was not so successful; approximately half of the detected trees were modelled to at least 10 metres. The branches and junctions are difficult to model automatically with this method. The prediction of treetops worked well; the right crown was found in more than 95 % of the cases. The height calculation of this method depends on the quality of the DSM. This is the point where the height estimation from extrapolation can play a role: e.g., summer scanning with a high veil layer.

Twenty-seven larches were detected only with at least ten fitted circles along the stem, from thirty-nine total in the study area. The mean error of the prediction is 1.6 metres, which means significant underestimation. This presumably arises from the error of the model when the tops of trees are more conical than paraboloid formed. The main problem with the fitting cone is that accurate diameters above the two-third level of tree height are necessary. At such a height it is not possible to filter stem points with the methods presented here, due to the complexity of branches and crowns. We can say only in 9 cases (33%) that the accuracy of the prediction is comparable to the conventional field instruments, and gross errors often occurred (Table 2).

ID	H_photo	H_DSM	H_par	Diff_DSM	Diff_par
7	25.1	26.8	19.5	1.8	-5.6
11	25.7	26.8	25.0	1.0	-0.7
13	28.8	29.5	21.9	0.7	-6.9
20	26.1	28.9	25.6	2.7	-0.5
23	25.1	28.1	21.9	3.0	-3.2
24	27.2	27.4	30.5	0.2	3.3
25	26.6	28.2	18.8	1.6	-7.8
34	25.3	25.0	16.4	-0.3	-8.9
43	22.6	24.2	27.6	1.6	5.0
47	26.7	26.9	25.1	0.2	-1.6
53	26.5	27.3	22.3	0.8	-4.2
56	28.7	30.6	29.6	2.0	0.9
63	28.3	28.9	28.7	0.5	0.4
82	29.0	27.6	23.7	-1.4	-5.3
91	24.4	26.2	24.0	1.8	-0.4
93	28.1	28.3	23.8	0.1	-4.3
97	27.3	28.1	19.6	0.9	-7.7
99	31.1	28.1	25.6	-3.0	-5.5
100	24.8	25.7	23.0	1.0	-1.8
104	26.1	26.1	21.0	0.0	-5.1
108	28.8	28.7	24.8	-0.1	-4.0
111	27.3	26.3	25.0	-1.0	-2.3
134	25.5	26.2	25.3	0.7	-0.2
137	28.0	27.6	25.9	-0.5	-2.1
143	26.9	27.4	33.1	0.6	6.2
156	27.9	27.7	24.8	-0.2	-3.1
202	28.1	27.2	29.2	-0.9	1.1
Min				-3.0	-8.9
Max				3.0	6.2
Mean				0.5	-2.4
RMSE				1.4	4.4

Table 2. Results of the different height calculations

5. CONCLUSION

Two new methods were developed for positioning tree trunks automatically, and these methods are also suitable for positioning and measuring the slices of the stems. The right locations and directions are essential for height estimation. Both methods proved their suitability.

Height calculation based upon the DSM is not novel, but the algorithm predicting the tree top based upon the stem model is. It worked very well, although the method should be improved for curly trunks. Irrespective of the precision of the tree top, the accuracy of this method is based upon the accuracy of the DSM. The data acquisition in our study was adequate for DSM generation, but this is not always the case. Therefore, a new method was created calculating the height based upon the extrapolation of the stems. The accuracy of this method is not really adequate for practical tree height determination at this stage. With more precise filtering the upper third part of the stem should be sampled and an additional body of revolution (e.g., a cone) should be fitted.

6. REFERENCES

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