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Tree stems from terrestrial laser scanner measurements

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Abstract. Terrestrial laser scanner (TLS) measurements were carried out in mature birch, pine, and spruce stands in Järvselja, Estonia. The structure of stands has been previously studied. A simple special clustering procedure is developed for automatic detection of stem positions and estimation of tree stem dimensions from the TLS point cloud. Tree stem diameter at breast height (DBH), vertical profile of stem and size distribution of DBH is estimated with high precision in the pine stand where the second growth tree layer is almost missing. The presence of second growth limits estimating stem dimensions accurately in the birch stand, and the procedure fails in the dense spruce stand of rich undergrowth and low dead branches. In such stands the TLS measurements should be done in dense grid with short-range sounding setup only. The developed procedure is undemanding for computers and can be applied on simple PC-s.

Key words: forest, stand structure, stem shape, lidar measurements.

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Introduction

Quantitative information on trees and stands is required for assessment and management of forests. The stand structure and tree dimension measurements have been labor-intensive, and survey costs set limits to the frequency and amount of in situ data collection (Burkhart & Tomé, 2012). For example Real *et al.* (1989) destructively sampled 1085 trees for development of taper equations for Douglas fir trees. Airborne and terrestrial laser scanners which allow collecting huge amounts of data on a stand structure are now available. Airborne laser scanners have been used to rapidly describe forest structure over large areas (Maltamo *et al.*, 2005; Magnussen *et al.*, 2012). There are examples of estimating timber volume from airborne laser scanner data (Corona *et al.*, 2014) and attempts to estimate tree stem dimensions (Aschoff & Spiecker, 2004; Schilling *et al.*, 2011; Garrity *et al.*, 2012; Chang *et al.*, 2013). Measurements with a terrestrial laser scanner (TLS) can provide more detailed information from where it is possible to estimate forest parameters (see an overview in e.g. Hildebrandt & Iost (2012)). However, new numerical methods are needed to automatically analyse the huge amount of collected data by TLS in a forest without oversimplification causing loss of valuable information. In this

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work, we present a fast and simple clustering method of TLS point cloud for the simultaneous detection of tree positions and stem dimensions in a forest stand. The method was tested in three forest stands in Järvselja, Estonia, using TLS data collected for the further complementing the Järvselja data-base for the validation of forest radiative transfer models by Kuusk *et al*. (2013).

Material and Methods

The study sites

Terrestrial laser scanner measurements were carried out in August 2013 in three 100 m × 100 m mature forest stands at Järvselja, Estonia, 58.3˚ N, 27.3˚ E. These stands have been studied previously and are described in the Järvselja database (Kuusk *et al*., 2009; Kuusk *et al*., 2013). Järvselja forests are typical for the hemiboreal zone – dominant tree species are Scots pine (*Pinus sylvestris* (L.) Karst.), Norway spruce (*Picea abies* (L.)), silver and white birch (*Betula pendula* Roth, *B. pubescens* Ehrh.), aspen (*Populus tremula* L.), common and white alder (*Alnus glutinosa* (L.) Gaertn., *A. incana* (L.) Moench). All these species can grow in pure or mixed stands. Growth conditions range from poor where H_{100} (stand height at the stand age of 100 years) is less than 10 meters to very good where H_{100} can be over 35 meters.

A general description of the stands subject to this study is given in Table 1. A detailed tree level inventory was carried out in the stands in 2007. The stands are located on flat terrain, i.e. there are no topographic effects which need to be taken into account when analysing TLS data.

The birch stand grows on the typical brown gley-soil (*Eutri Mollic Gleysol* – FAO–UNESCO soil classification). Growth conditions are good for forest (H_{100} = 28.7 m). The stand age was 55 years in 2013. Dominating species are silver birch 57%, common alder 29.5%, and aspen 11%. There are two tree layers distinguishable according to the social status of the trees, the lower tree layer is mostly consisting of small-leaved lime *Tilia cordata* (Mill.), *Prunus padus* (L.), and Norway spruce. The total number of trees in the upper and secondary layer is 992. Forest understorey vegetation is dominated by the mixture of several grass species. Moss layer is sparse or missing.

Table 1. Description of three forest stands in the Järvselja database (Kuusk *et al*., 2013). *A* is stand age in years, *N* is number of trees in the 1 ha stand, *H* is dominant species height, m, *LAI* is allometric leaf area index, q_{ca} is canopy cover and *CrC* is crown cover.

Tabel 1. Puistute kirjeldused Järvselja andmebaasist (Kuusk et al., 2013). A on puistu vanus, N on puistu tihedus (puid ha^{-1}), H on enamuspuuliigi kõrgus, m, LAI on allomeetriaseosest hinnatud lehepinnaindeks, q_{ca} on võrastiku katvus ja CrC on võrade liitus.

Stand *Puistu*	*A*	*N*	*H*	*LAI*	q_{ca}	*CrC*
Birch *Kaasik*	49	992	27	3.93	0.80	1.09
Pine *Männik*	124	1122	16	1.86	0.74	0.79
Spruce *Kuusik*	59	1689	23	4.36	0.90	1.2

The pine stand grows on the transitional bog. The soil is deep (> 1.3 m) *Sphagnum* peat. The growth conditions are poor as indicated by H_{100} = 13.1 m in the forest inventory database. In 2013 the stand height was 15.6 meters, the stand was 130 years old, and stand density was 1122 trees per hectare, 1115 of which belong to the upper layer. Forest understorey vegetation is composed of *Ledum palustre* L., sparse *Eriophorum vaginatum* L., and continuous *Sphagnum* spp. moss layer.

The spruce stand grows on a *Gleyi Ferric Podzol* site. However, the growth conditions are rather good (H_{100} = 29.1 m) because of drainage. The stand age was 65 years in 2013. There are two tree layers distinguishable according to the social status of the trees. Average height in the first (upper) layer is 23.2 meters and there are 774 trees per hectare. Stand density in the second (lower) layer is 915 trees per hectare and the height of trees ranges from 3.5 to 20 meters. Canopy cover is high (0.89) and, therefore, forest understorey vegetation is either partially missing or consists only of mosses such as *Hylocomium splendens* (Hedw.) B., S. et G. or *Pleurozium schreberi* (Brid.) Mitt.

The stands were extensively measured for use as a validation dataset for heterogeneous canopy reflectance models in summer 2007 (Kuusk *et al.*, 2013). Exact positions of all trees with the trunk diameter at the reference level 1.3 m (DBH) larger than 4 cm were mapped using a Nikon DTM-332 Total Station. The trees were calipered using the electronic calliper Masser Racal (Savcor Group Ltd., OY, FIN-50100 Mikkeli, Finland), and the average of two perpendicular trunk diameter measurements was used as the DBH estimate. In order to create allometric models of the tree height and crown dimensions a series of sample trees were measured. Tree height h, height to live crown base h_{lcb} and two perpendicular crown diameters d_{cr} were measured on each of the sample trees. Based on measured dimensions of sample trees the allometric models of tree height, crown length, and crown radius were created, and using these allometric models the tree height and crown dimensions of every tree were calculated in the Järvselja database (Kuusk *et al.*, 2013).

There is a time difference of six years between the TLS measurements and the forestry mensuration of the stands. The stands are mature, especially the pine stand, and changes in the stand structure are slow, therefore repeated measurements of tree stem diameters were not carried out during TLS measurements. The increase in the stem diameter is accounted for by stem growth models (Tappo, 1982).

Instruments

Laser data were collected using a terrestrial laser scanner Leica ScanStation C10. The main technical specifications of the TLS instrument are as follows (Leica Geosystems AG, 2011):

- Scanning range of 0.5–300 meters (from a surface with 90% reflectivity index).
- Horizontal scanning range of 360˚, vertical scanning range at least 270˚.
- Frequency of scanning up to 50000 Hz.
- Laser beam visible, green, wavelength of 532 nm.
- Size of the laser beam not more than 7 mm at the distance of 50 m.
- Accuracy of individual scanning point distance at the distance of up to 50 m: 4 mm (one sigma).
- Accuracy of individual scanning point 3D position at the distance of up to 50 m: 6 mm (one sigma).
- Estimated accuracy of statistical modeling of the point cloud: 2 mm.
- Accuracy of target measurements up to a distance of 50 m: 2 mm (one sigma).

Terrestrial laser measurements

The regular grid of LAI-2000 measurements in the stands (Kuusk *et al.*, 2013) was used for the TLS measurements, (Table 2). TLS surveying angle was 360˚ (full circle) horizontally and about 270 degrees vertically (omitting only a sector with a radius of about 2 meters underneath the instrument). TLS data resolution was set to 8 × 8 cm at the distance of 100 meters on a perpendicular surface. Since the scanner spreads out measuring beams radially from its location, the point cloud can be as dense as 4 × 4 mm at the distance of 5 meters. On the other hand, there are data gaps in the sectors that are shadowed by the first object (leaf or a tree stem) on the path of the laser beam.

Special targets were used to merge individual scans into a common point cloud in plot coordinates. The maximum error in relative scanner positions was only 7 mm for the pine stand. Due to the use of previously known LAI point positions, it was 10 cm and 17 cm for the spruce and birch stands, respectively. Relative positions of individual scan points within a scan correspond to the instrument's accuracy. Therefore larger errors in scanner positions in the birch and spruce stand may affect data processing where data from multiple stations overlap.

Table 2. The grid of positions used for terrestrial laser measurements in test stands.

Tabel 2. Laserskanneri asukohtade skeem puistutes.

Point ID *Punkti ID*	Position (x, y), m *Asukoht (x, y), m*
L1	(20, 20)
L2	(20, 50)
L3	(20, 80)
L4	(50, 20)
L5	(50, 50)
L6	(50, 80)
L7	(80, 20)
L8	(80, 50)
L9	(80, 80)

The vertical distribution of laser hits allows estimating stand height. In stands with little second growth the crown length of upper storey trees and the height of live crown base is also visible (Figure 1). That is the case in the pine stand. In the birch stand two layers of tree crowns can be distinguished. The overlapping of tree crowns of the upper and second layer does not allow estimating crown length of each layer separately. In the spruce stand the estimation of the crown length is also problematic due to second growth birches and large number of living or dead low branches on spruce trees.

Laser hits in the range $(x, y, z) = (0–100, 0–100, 1.0–z_{max})$ were used. Here distances are measured in meters, the maximum height z_{max} corresponds to the mean crown base height in the stand. In order to reduce the size and inhomogeneity of the point cloud, a discrete space of $dx = dy = 0.01$ m, $dz = 0.1$ m was used. Multiple laser hits in a voxel do not add information about the stand structure, therefore multiple hits were accounted only once. This way we analysed the voxels of 1 cm × 1 cm × 10 cm, and separated the voxels which have laser hits and which have not. The horizontal resolution of the discrete space 1 cm was found to be sufficient for further processing to yield estimates comparable to precision of calliper measurements.

The vertical resolution 10 cm is sufficient for the description of stem diameter profiles. Such discretization does not need any special calculations nor the analysis of the point cloud structure, it is carried out using Fortran formats of writing intermediate results. Thus millions of divisions and multiplications and comparisons of real data which are needed if using smaller discretization steps, are avoided. The size of the point cloud was decreased by about five times, and the inhomogeneity of the point cloud was reduced substantially. There were voxels which had a single laser hit, and some voxels near the TLS instrument which had more than 4000 hits. A fragment of the point cloud in the pine stand in the discrete space $(dx, dy, dz) = (0.01, 0.01, 0.1)$ is shown in Figure 2.

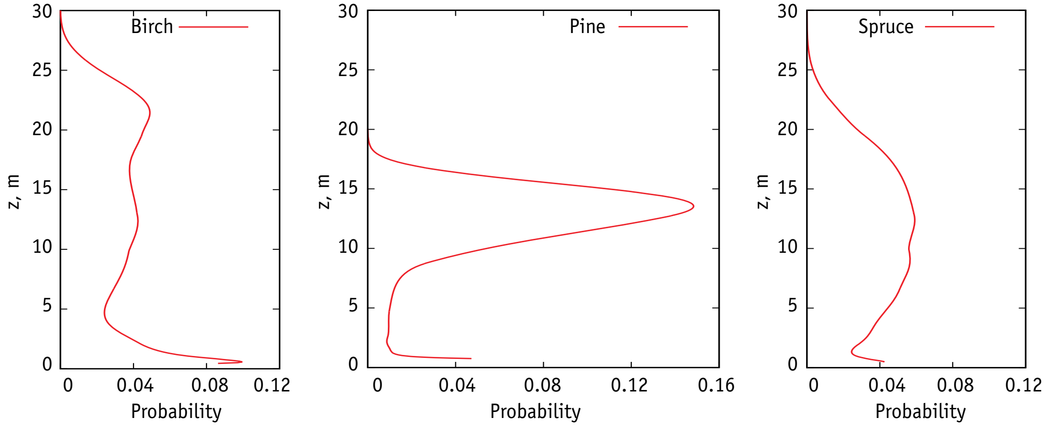

Figure 1. Vertical profiles of laser hits in the birch, pine, and spruce stands.

Joonis 1. Lidaripeegelduste kõrgusjaotused kolmes katsepuistus.

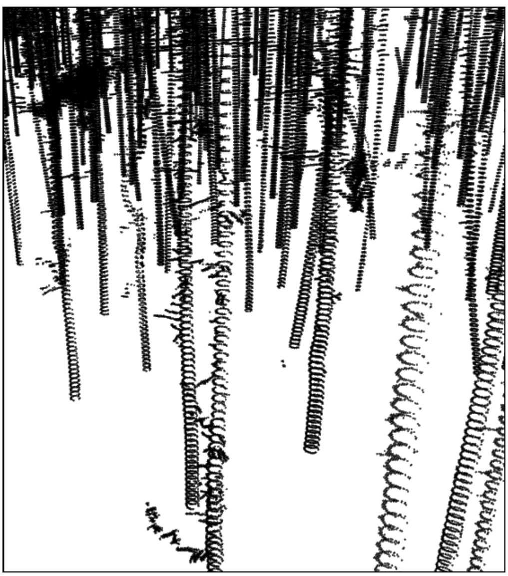

Figure 2. A fragment of the point cloud in the discrete space in the pine stand.

Joonis 2. Fragment lidaripeegelduste andmestikust männikus peale algse punktipilve diskreetsesse ruumi teisendamist.

Stem detection from point cloud

A special 3D clustering procedure was developed for finding tree stems in the predefined height range z_{min}–z_{max} (1.0–8.5 m) in the point cloud. First, 2D clusters were searched in the lower slice z_1 = 1.0 m. The procedure is straight-forward. First, the first point is considered a cluster centre. If a point is found which is closer to the first point than the search radius then the point is included in the cluster, the new barycentre is calculated, and for the next point the distance from the new cluster centre is checked. The maximum horizontal extent of a cluster is determined by the given search radius. Every point which belongs to a cluster is marked, belonging to other clusters is not checked.

The second step was to detect characteristic circular patterns corresponding to possible tree stems in each 2D cluster (Figure 3). A circle is fitted to the 2D cluster. Three distant points at the cluster perimeter are used for finding the initial circle. Then the radius and position of the circle are varied so that the distance of cluster points to the circle perimeter is minimized using the Powell's method of multidimensional minimization (Press *et al.*, 1992). Obviously any other minimization procedure will give a similar result. The temptation to use the barycentre of the cluster as the initial circle centre results in often fails of the circle fitting in case of one-sided observations of the stem. The fitted circle gives the preliminary estimate of the stem diameter. If the fitting of a circle fails or the circle diameter exceeds the given size limit (clusters of a few laser hits almost in line), or there are laser hits close to the "stem" centre, the cluster is omitted. The clusters that have only one or two points are omitted too. The 2D clustering in the first layer produces the preliminary list of tree positions (circle centres) and stem diameters at the level z_1.

In the layer above the first layer 2D clusters are searched around the circle centres in the first layer and the coordinates of the stem axis at level z_2 are found. Afterwards, laser hits in this layer not involved in clusters are checked for belonging to new 2D clusters similar to the slice z_1 and new potential stems are added to the list of trees. In this manner the whole z–range of the point cloud is analysed and 2D clusters belonging to a tree stem form a 3D cluster. If there are no hits in a layer in the given distance from the tree stem axis in the previous layer or the approximation by a circle fails the tree coordinates are still kept in the list of trees and the last successful estimate of the tree position is used in upper layers. There will be some gaps in the stem diameter profiles. A 3D cluster of laser hits was considered a tree stem if there was at least 12 successful approximations by circles in the height range 1.0–6.0 m. On the bifurcating tree stems the result of building the 3D cluster is not determined. Following one branch or terminating the cluster are both possible. Such stem profiles have random fluctuations and may have some gaps. The vertical profiles of stem diameters were smoothed by spline approximation (de Boor, 2001) (Figure 4). Some more details on the procedure and computer code are reported in the Appendix 1.

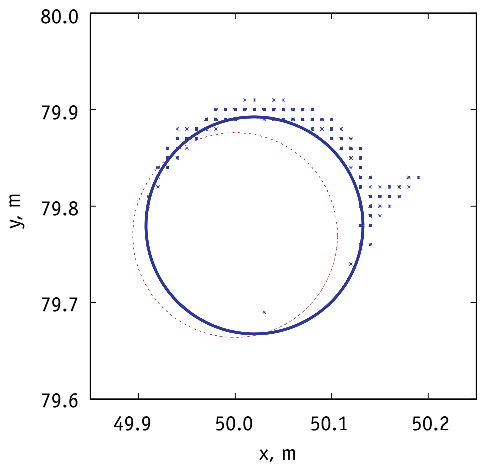

Figure 3. Estimating the stem diameter by fitting a circle (bold line) to the slice of laser hits (dots). The thin dotted line depicts the tree stem in the Järvselja database.

Joonis 3. Lidaripilve sobitatud puu tüve ristlõiget kujutav ring (paks joon) ja sama puu mõõdetud andmed Järvselja andmebaasist (kriipsjoon).

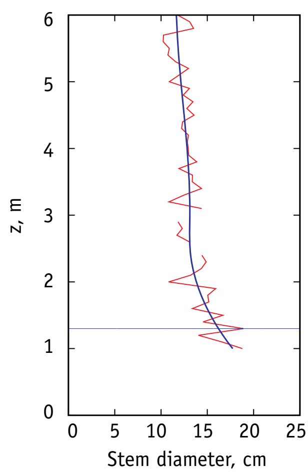

Figure 4. A noisy vertical profile of the stem diameter, smoothed by spline approximation. The horizontal line at z = 1.3 m marks the height of stem diameter measurements in field.

Joonis 4. Hajuvast punktipilvest saadud puutüve profiil lähendatuna splainiga. Horisontaaljoon tähistab rinnasdiameetri mõõtmiskohta z = 1.3 m.

Results

Pine stand

The Järvselja data-base lists 1115 pine trees, 6 small birches and a small spruce in the pine stand. The point cloud analysis procedure discovered 1149 clusters, 1057 of which correspond to the trees in the data-base. Some trees were dead and fallen down in the stand since building the data-base. A few small trees which were found could be missing in the data-base, but obviously there are some fake stems – these clusters consist of laser hits to bushes and tree branches. The mean distance of stem positions in the data-base and corresponding estimated positions from laser hits is 9 cm, the maximum discrepancy in a tree position 35 cm could be caused by the toppling of a tree.

The estimated DBH values are in good accordance with the data on the pine stand in the Järvselja data-base. Figure 5 shows the estimated DBH against the measured DBH in the pine stand. Correlation of these two data sets is high, $r^2 = 0.965$. Some outlier cases in Figure 5 are the trees near the plot boundaries, measurements of which are one-sided, and/or trees which have few lidar hits due to occlusion by other trees. Excluding these outliers from the analysis does not change neither correlation coefficient nor regression slope and offset.

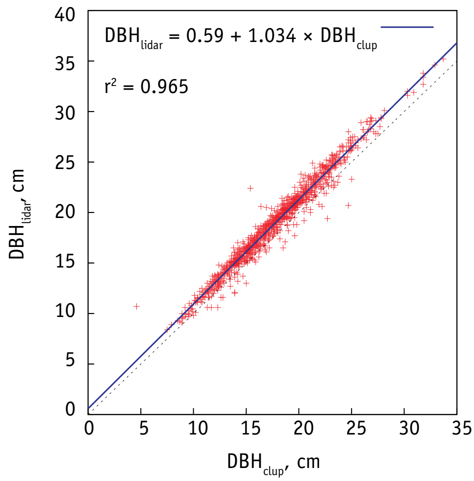

Figure 5. DBH of trees in the pine stand calipered in 2007 and estimated from TLS measurements in 2013. Dotted line is the 1:1 line.

Joonis 5. Männikus 2007. aastal puudele mõõdetud rinnasdiameetri DBH_{clup} ja 2013. aastal lidarmõõtmistest hinnatud rinnasdiameetri DBH_{lidar} seos.

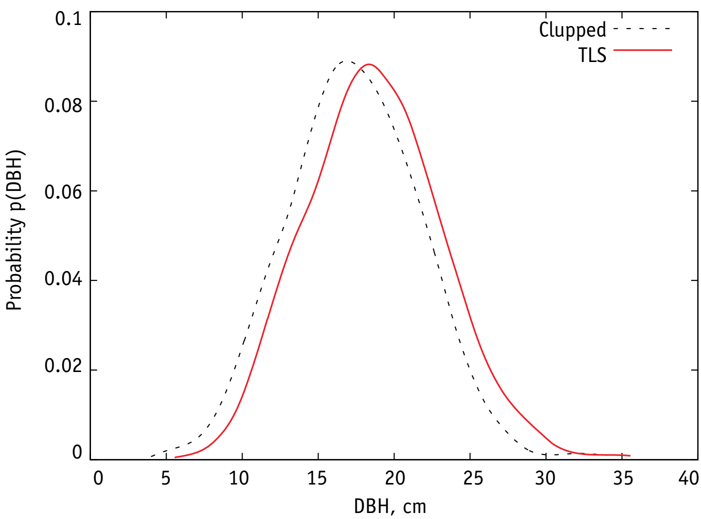

Figure 6. Size distribution of DBH values from caliper (Clupped) and TLS measurements in the pine stand.

Joonis 6. Lidarmõõtmistest (TLS) ning kluppimisel saadud puude rinnasdiameetrite jaotused männikus.

The estimated mean DBH exceeds the calipered value by 7% (12 mm). The time difference of six years between calipering and TLS measurements causes the increase of the DBH of the pine stand by about 6 mm (Tappo, 1982). Thus, the procedure overestimates the mean DBH of the stand by 3–4%. The distributions of the calipered and estimated DBH values are very similar except the TLS estimates are shifted by 12 mm, (Figure 6). The Kolmogorov–Smirnov test indicates that, reduced to the same mean value and equal standard deviation, the estimates of DBH have equal distributions, $p = 0.988$. Figure 7 shows the vertical profile of stem diameter estimated from TLS data. At high levels the lower part of tree crowns adds noise to TLS data which increases the scatter of diameter estimates.

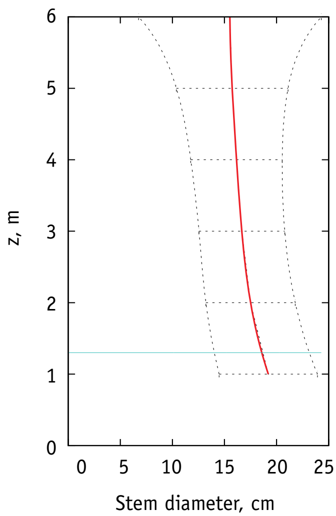

Figure 7. The mean vertical profile of the stem diameter in the pine stand. Thin dotted lines show the standard deviation.

Joonis 7. Lidarandmetest arvutatud keskmine tüveprofiil ja standardhälve (kriipsjoon) männikus.

The birch and spruce stands

The second growth in the birch stand and numerous dead branches at low height levels in the spruce stand add noise to the point cloud and disturb stem detection in these stands. Therefore the stem detection procedure was run only in the centre part of the stands $(x, y) = (25–75, 25–75)$, where TLS hits cover a larger part of the tree stem perimeter. In the birch stand, the number of trees in this sub-plot is 292, the clustering procedure finds 184 clusters, 140 of which correspond to real trees and 44 are fake stems. Correlation of calipered and estimated DBH is still rather high, $r^2 = 0.60$ but the mean stem diameter is overestimated by 14%. Obviously, the stems could be found better during leafless season when the second growth is more transparent and does not obscure tree stems so much. The estimation of DBH in the dense spruce stand is even more problematic. In the centre part of the stand $(x, y) = (25–75, 25–75)$ there are 484 trees. The clustering procedure found 184 clusters, only 99 of which correspond to tree stems and the estimated DBH exceeds the calipered value by 60%. Correlation of the calipered and estimated DBH is in the spruce stand weak, $r^2 = 0.12$.

Discussion

The suggested rather primitive clustering method allowed both to find trees and to estimate not only DBH of trees but also the vertical profile of stem diameter in stands where no disturbing secondary growth and low branches on stems were present. The TLS measurements were planned to supplement the existing Järvselja database (Kuusk *et al.*, 2013), therefore the grid of LAI-2000 measurements was used which is not optimal for finding and measuring trees by TLS measurements in the whole 100 × 100 m plot. Anyway, 95 % of stems were detected in the pine stand and the precision of estimating DBH of stems is high. The time difference of six years between calipering and TLS measurements is not a source of errors in the stand of 124 years age, the growth tables for the compensation of DBH increment by Tappo

(1982) have been tested for decades and are in permanent use in forestry mensuration. The results of DBH estimation in the whole stand are comparable to the special measurements on a small number of trees (less than 30 trees in five tests) by Maas *et al.* (2008). The study by Tansey *et al.* (2009) was carried out in a pine stand similar to our pine stand. All trees were detected in a 23 × 21 m plot surrounded by four scan positions. DBH was estimated on 8 trees only.

The study by Calders *et al.* (2015) was carried out in an eucalypt stand on two plots of 40 m radius. The stand density of the study plots was three times less than in our pine stand. Five scanner positions – one in the plot centre and four at the perimeter were used. The results of tree detection are not reported, DBH and stem diameter profile was measured on 65 harvested trees. The correlation of the TLS-derived and field measured DBH is equal to our result, the slope of the regression line was 0.98, so the deviation from the 1:1 line is almost equal to our result, but DBH was underestimated a little. In our stem detection procedure we did not use the signal intensity. The tangent hits of stems have lower intensity, thus excluding week reflections from the point cloud could decrease the overestimation of DBH in our procedure.

In the birch stand of rich deciduous undergrowth distant tree stems are obscured. Better results could be reached using measurements in a leafless season, using more and specially selected scan positions, and limiting scan distance to shorter ranges.

In the dense spruce stand of rich deciduous undergrowth some different measurement scheme and more complex filtration of point cloud and more complex clustering procedure are required.

Conclusions

Terrestrial laser scanner is an effective tool for collecting data on forest structure. The developed software tools allowed to find exact tree positions and to estimate the vertical profile of stem diameter in a forest stand with limited understorey vegetation. In the pine stand where the second growth is missing, good results were reached by TLS measurements at the regular grid of 30 m. Errors of the estimated distribution of stem diameter at breast height do not exceed 5% and correlation between the calliper measurements and estimates using TLS data is high. The vertical profile of stem diameter is estimated between ground and the base of live crown which allows estimating timber volume. Scattering of stem diameter estimates increases near the crown base. In the stands with broadleaf understorey vegetation the laser measurements should be carried out in leafless conditions. In dense spruce stands the procedure is not usable. Low dead branches add so much noise to the point cloud that the suggested clustering procedure fails.

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Appendix 1. Computer code.
Lisa 1.

The developed clustering routines for the processing of TLS data are written in Fortran using publicly available special programs (minimization in multidimensions, spline approximation). Data processing was carried out on a Linux PC I7-2600, 3.4 GHz, 8 GB RAM, using system tools (concatenate, sort), a simple Fortran program Grid for extracting the laser hits in the given region from the initial point cloud, and converting point coordinates to a discrete space, and the special 3D clustering program Clmpxyz in Fortran for finding tree stems in the pre-processed point cloud. Compiling the special Fortran programs is very fast, therefore most of the program parameters are fixed in the source code – the limits of the analysed volume and the criteria for approving or rejecting clusters – and the only free input parameter of the Clmpxyz is the search radius. 2D clusters are rejected if there is less than 3 points in a cluster. If the square root distance of cluster points from the fitted circle perimeter is large then the most distant point from the circle centre is excluded and the circle is fitted again. This procedure is repeated until the change in the circle radius is substantial; up to 20% of points can be excluded from the 2D cluster. The whole 2D cluster is rejected if the radius of the fitted circle exceeds the given limit or there are laser hits too close to the centre of the fitted circle. Additionally, a 2D cluster is excluded from the 3D cluster if its radius is too far from the median radius of the 3D cluster. The whole 3D cluster is rejected if it contains less than 12 2D clusters. All these criteria are fixed in the code; however they can be easily changed if the experience of using the procedure increases.

As the point clouds are huge, the programs are processing disk files line by line instead of trying to allocate memory for these files. Therefore the size of PC RAM does not limit the size of the point cloud under processing. The initial point cloud in the pine stand had 175 M laser hits, the file size was 6.0 GB. In the given box (x, y, z) = (0–100, 0–100, 1.0–8.5) there were 34.7 M hits, the discretization of the space of laser hits reduced the size of the point cloud five times. Total processing time was 11 min, 92% of which was pre-processing using system tools and reformatting point cloud data. The detection and extraction of tree stems in the pre-processed point cloud required only about 8% of the time.

Puude asukohtade ja tüve mõõtmete leidmine maapealse laserskaneerimisega

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Kokkuvõte

Välja on töötatud lihtne protseduur puude leidmiseks ning puutüvede rinnasdiameetri ja tüve diameetri vertikaalse profiili leidmiseks. Protseduuri kasutati Järvselja andmebaasis (Kuusk *et al*., 2013) kirjeldatud kolmes puistus (tabel 1) tehtud laserskaneerimisandmete analüüsil. Andmetöötlus põhines punktipilvest puutüvesid kirjeldavate klastrite leidmisel ning neile puutüve ristlõiget kujutava ringi sobitamises (joonised 2–4). Lasermõõtmised tehti nendes 100 × 100 m puistutes LAI-2000 mõõtmisteks ja poolsfäärifotode jaoks kasutatud 30-meetrise sammuga regulaarsel võrgul (tabel 2). Niisuguse paigutusega mõõtmisskeem ei ole optimaalne kogu puistu puude asukohtade ja rinnasdiameetrite leidmiseks, sest puistu äärtele lähemal kui 20 m olevaid puid sondeeriti ainult ühest küljest. Ka on mõõtmispunktide kaugus üksteisest nii suur, et osa tüvesid võib jääda lidarile lähemal olevate puutüvede varju. Sellest hoolimata leiti männikus, kus ei ole alusmetsa segamas, 95% tüvedest, puude asukohad erinesid tahhümeetriga mõõdetud asukohtadest keskmiselt 9 cm, maksimaalne erinevus 35 cm võib olla põhjustatud puu viltuvajumisest, sest lidarimõõtmised tehti kuus aastat pärast tahhümeetriga mõõtmisi. Peale kuueaastase juurdekasvu arvestamist olid klupitud ja lidarmõõtmiste rinnasdiameetri jaotused väga ühesugused, korrelatsioon väga hea. Keskmine rinnasdiameeter lidarmõõtmistest ületab kluppimise tulemust 3–4% (joonis 5). Tüve diameetrit saab hinnata maapinnast kuni võra aluseni (joonis 7). Nähtavust piirava alusmetsa puudumise korral saab selle meetodiga loendada puud ning mõõta rinnaspindala väga kiiresti ja täpselt. Kaasikus segas nähtavust lehtpuude võsa. Niisuguses puistus peaks mõõtmisi tegema siis, kui puudel ei ole lehti ning arvatavasti on laserskaneerimist vaja teha rohkemates kohtades ning limiteerida lasersondeerimise ulatust. Kuusik on väga tihe, umbes 1600 puud hektaril. Rohked surnud oksad madalal tüve küljes ja järelkasv tekitavad laserskaneerimise andmetes nii palju müra, et nii lihtsa protseduuriga jäävad tulemused väga tagasihoidlikuks. Vaja on kasutada teistsugust mõõtmisskeemi, punktipilve spetsiaalset filtreerimist ning tõhusamaid klastrite otsimise protseduure.

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