TERRESTRIAL LASER SCANNING VERSUS TRADITIONAL FOREST INVENTORY FIRST RESULTS FROM THE POLISH FORESTS

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ABSTRACT:

The goal of this paper was to present the pilot study ongoing in the Polish State Forests on the application of gathering basic forest parameters using the terrestrial laser scanner (TLS) technology. The 3D point cloud was created using scanner based on the "phase-shift" technology. The first part of the paper shows the comparison of two manual methods of TLS data processing, i.e. the directly measurement on the planar image so called - „pixel method" and semi-automatic „pipe method", in the context of the results obtained with traditional forest inventory. The second part of the article refers to author's algorithms, the purpose of which was to make the process of obtained the stand basal area (G) from a scanned tree trunks (also partially scanned) automatic. The first stage of work over algorithms resulted in precise definition of the: location of tree trunks on the inventory plot and such elements: tree basal area (g), stand basal area (G) and BHD.

1. INTRODUCTION

The inventory of forest resources in Europe is based on well-elaborated standards and usually carried out in a very traditional way. To put it in a simple way - the measurement involves getting information on the diameters at breast height (DBH) of the trees, their mean height (H) and density (the number of trees) on circular plots, making statistical sample of respective stratification groups of tree stands. The works on forest inventory are very time-consuming and costly, thus methods and technologies accelerating the work and reducing costs have been looked for. The application of airborne and terrestrial photogrammetry in the forest inventory have been known for decades and the application of VHRS offering a pixel size below 1.0 metre becomes more and more common (de Kok, et al., 2005; de Kok and Wezyk, 2006; Weinacker, et al., 2004). One of dynamically developing technologies in the area of active remote sensing systems is LiDAR, both in the form of airborne laser scanning (ALS) and terrestrial laser scanning (TLS). This technology allows very quick information on the structure of forest in the form of the 3D point cloud, which is processed to gain such taxation features as: the number of trees in the stand, geoposition of individual trunks, diameter at breast height (DBH), crown base height and the height of trees (Aschoff and Spiecker, 2004; Bienert, et al., 2006; Næsset, et al., 2004; Simonse, et al., 2003; Hopkinson, et al., 2004). The purpose of presented paper was the comparison of the TLS technology to traditional forest inventory applied in Poland in the aspect of supporting these methods with modern technologies correcting the quality of elaborations. The paper presents subsequent stages of work over obtaining such parameters as: position of the tree in the 3D space, DBH, tree height and tree/stand basal area (g/G).

2. RESEARCH AREA

The tree stands located in the Forest District of Milicz, central-west Poland (51°27' N; 17°12' N) were selected for the study. In these stands in November 2006, TLS was carried out on 30 circular plots (6 plots located in deciduous forest stands: beech, oak; 24 plots in coniferous stands: Scots pine). In the paper the results from 4 inventory plots are presented (Table 1).

Forest type	Deciduous		Coniferous	
Plot number	3	5	15	19
Forest sub-compartment	140b	140g	232b	220d
Radius [m] / Area [m^2]	12.62 / 500			
Tree species (number)	*Quercus* sp. (12); *Fagus silvatica* (1), *Pinus silvestris* (1)	*Fagus silvatica* (6)	*Pinus silvestris* (21)	*Pinus silvestris* (30)
Mean DBH [cm]	42.7	56.7	22.0	28.5
Mean height [m]	31.2	33.7	20.4	22.5
Age [years]	142	152	107	67

Table 1. Characteristic of selected forest inventory plots (Milicz Forest District PG LP)

Figure 1. Scanner FARO and the 5 spheres on the inventory plot

3. MATERIAL AND METHODS

3.1 Type of scanning

In the paper the method of TLS from 4 scanner locations is presented i.e., first position (S_1) was in the centre of the plot and the following three (S_2, S_3 and S_4) were distributed regularly along the plot. In practice the position of the scanner (so that they could be visible from each other) and reference spheres (k1÷k5), was often problematic, because of the tree trunks and undergrowth. The condition of fitting 4 scans into one point cloud together is clear identification (max. in the distance of 15÷17 m) of at least 3 reference spheres from each scanner position. Scanning of one forest inventory plot from 4 stations, together with preparation work, took about 1 hour and 20 minutes.

3.2 Reference data

The forest inventory campaign was carried out in August 2006 by the company Taxus SI Ltd., based on the methods accepted in the Polish State Forests inventory guidelines (PGLP, 2003). The DBH measurement was carried out in a standard way with the calliper (accuracy 0.001 m) aiming its long arm towards the centre of the plot (this measurement further called reference inventory = Ref. Inv.), i.e., unfortunately exactly the opposite (90°) to the one imaging by scanner. Distances (L) in the polar measurement towards the tree were measured with an ultrasound range finder. The azimuth (Az) was read towards the centres of trunks with a compass (accuracy up to 1°). Due to the irregularity of trunks of the analysed trees, in April 2007 additional reference measurements were carried out by the authors (further called = Ref. 1_AUC), defining for each tree the DBH upright towards each of 4 scanner positions using calliper. At the same time the perimeter of the tree trunk on the height of 1.3 metre from the ground (further called = Ref. 2_AUC) was collected using measuring tape (accuracy 0.001 m). These works, although time-consuming, were necessary to test the usefulness of the FARO scanner fully objectively.

3.3 Hardware and software

In the forest the model LS 880 HE80 of a laser scanner of FARO company was used. It is based of the phase shift technology. Due to this technology up to 250 000 pps can be registered. The beams, in case of full resolution and distance 10.0 m from the scanner are located every 1.5 mm. The time of the scanner's full rotation is about 7 minutes for the resolution of about 1/4. The HE80 model, due to its modular structure, i.e. 4 components installed on a rotating base is very practical. The PC computer and HDD are integrated in the base module and they allow the set-up of the equipment in the office, without the need for a notebook in difficult field conditions. To manage the scans and combine them based on reference spheres, the Faro Scene ver. 4.0 software was applied. This also enables to apply proper filters and make measurements as well as give the geoposition to the point clouds. To achieve this, a static dGPS measurement (300 epoch; reference station: ASG-PL Wroclaw; distance ~50km; Polish Coordinate System PUWG 1992) was carried out for the position of the scanner (Wezyk, 2005). The mean fit scan error of joining 4 point clouds from respective positions of scanners, oscillated for the analysed inventory plots within the range: 2.8÷4.9 mm - long. mismatch and 2.1÷6.3 mm - orthogonal mismatch.

Manual measurements of DBH in FARO Scene, made by the operator between the pixels making the tree trunk in a planar view, were (in a simplified way) called *pixel method* (Figure 2). The other alternative method (further called „pipe method" - Figure 3) involved semi-automatic fitting a cylinder into the tree trunk (on breast height). The distance and angle to tree trunks represented by the clouds of points were defined due to the author's algorithm operating in ArcView (ESRI) environment.

Figure 2. Manual „pixel method" (plot no. 19)

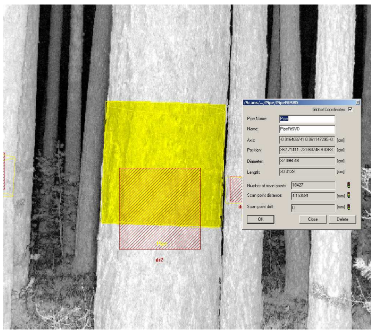

Figure 3. Semi-automatic „pipe method" (plot no. 19)

3.4 Data pre-processing

Advanced data processing (filtration, classification) was carried out by TerraScan and TerraModeler (Terrasolid Ltd.) software importing the cloud of points with added georeference in FARO Scene as XYZ (ASCII) sets. The classification of the point clouds involved generating a correct DTM in the first step, based on so-called *low points routine.* Not always was it a simple task due to so-called *ghost points* occurring below the ground, which should be reclassified. In the next step, points above DTM were put into a *High Vegetation* class (Figure 4). From this class slices were obtained and their thickness was 0.04 m (3D belt 1.28÷1.32 m from the DTM). If this place was covered with another object (e.g. undergrowth) the closest slice above was taken. In the subsequent step the slice was exported as XYZ set to ArcView 3.2 (ESRI) software.

Figure 4. The point cloud after classification (plot no. 5)

3.5 Algorithms

The process of manual fitting ellipses into slices of trunks obtained from the point clouds on BHD height is very time-consuming and it is hard to imagine obtaining this parameter for hundreds or even thousands of inventory plots.

Automatic methods allowing the detection of tree trunks are usually based on the application of Hough transformation (Aschoff and Spiecker, 2004). Fitting geometric figures (ellipse, circle) into trunk slices is also described in detail by Aschoff et al., (2004). The cluster analysis is often used in automatic recognition of tree trunks and extraction of parameters both in case of single scans (covering not more than 180°) of the tree trunk cylinder form, as well as images originating from the integration of several scans on one area (Bienert, et al., 2006).

The main purpose of making the algorithm in the discussed project was the need for automatic detection of tree trunks and obtaining the tree/stand basal area (g/G).

The tasks for the algorithm focussed on:

- the definition of the neighbourhood in the point cloud, in the surrounding of 2D or 3D space (filtering, significance definition);
- assignment of points to a concrete tree trunk,
- definition of the angle range for the trunks visible from subsequent scanner positions,
- recognition of tree trunks and definition of their sizes;
- definition of the visibility of trunks (overshadowing by other trees), and
- drawing a probable outline of the trunk in the places without measurement points.

The first step for the algorithm (Algorithm 1) was to define the number of points in the surroundings of the point for plane XY and XYZ. Points with only three neighbours were treated as auxiliary points. The algorithm of automatic definition of the assignment of points (XYZ) to a given trunk is realized by triangulation (TIN) between points and then by the elimination of triangles not fulfilling the initial prerequisites.

As testing parameters the values of triangle's angles and lengths of its sides were accepted. The border value for angles was defined on the level of 10°, while the border value for the length ranged from 0.04 m to 0.08 m. The threshold value for the distance depends on the size of the inventory plot (maximal distance from the scanner), scanning resolution, the number of trees on the plot and their thickness (the influence of the overshadowing).

After classifying the points belonging to one tree trunk, the convex hulls were generated through the points regarded as trunks, then their area, perimeter and the number of internal and border points (making convex hulls) were calculated (Figure 5a).

Respective objects of convex hulls were eliminated based on the attributes according to the following criteria:

- the number of internal points > 3,
- the number of border points > 3,
- polygon perimeter > 0.21991 m (DBH > 7cm),
- area > 0.00385 m^2 (DBH > 7cm).

As a result of the carried out elimination, we obtained the polygons representing tree trunks (Figure 5a, 5b) and objects of a great density of points such as: bushes, branches or undergrowth (Figure 5d). Through the analysis of azimuth and length (Figure 5c, 5e) between the centroid of the object and the point belonging to it - objects other than trees were eliminated. In the case of trees covered by the undergrowth - the closest possible slice of the trunk was taken.

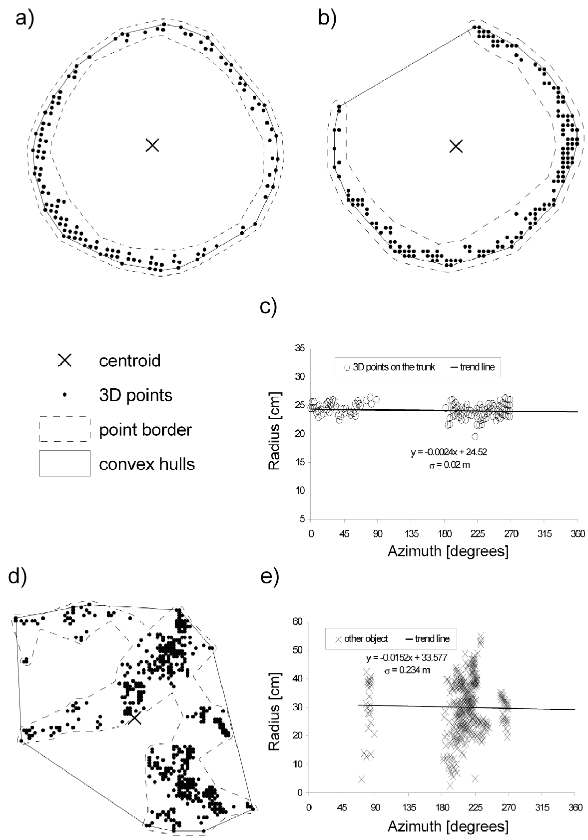

Figure 5. Points belonging to the tree trunk (a), partly to the trunk (b) and regression plots between radius and azimuth (c); not a tree objects (d) and their regression plot between radius and azimuth (e)

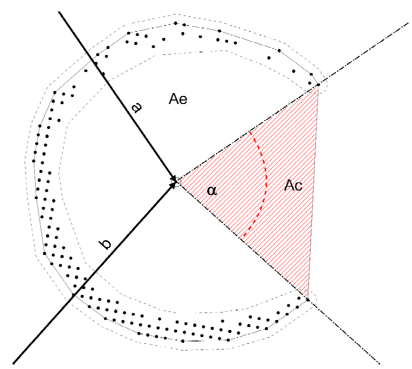

Figure 6. The cross section of tree trunk without a full point cover of TLS: a, b – lines between positions 2 and 4 of the scanner and centroid of the object, A_o; α - central angle describing the missing part of the slice

For trees not having points on fragment of the trunk (Figure 5b) – the correcting algorithm (Algorithm 2) was applied, based on the sector relayed on to central angle α. This algorithm acts in two ways based on the analysis of the interface based on the analysis of the length and the number of points on the perimeter of the convex hulls and the analysis of mutual situation of the objects and the positions of the scanner (Figure 6).

The area of the detected tree trunk by Algorithm 1 can be defined as:

$$A_o = A_e + A_c \quad (1)$$

where: A_e – part of trunk cross section with correct area,
A_c – part of trunk cross section of an underestimated area.

The algorithm removed the determined part A_c to replace it by the corrected area (A_{cor}), calculated from the ratio between a full angle (360°) and angle α as well as the respective areas (Figure 6).

The correction values (A_{cor}) are expressed by the formula:

$$A_{cor} = A_e * \frac{2\Pi}{\alpha} \quad (2)$$

The total tree basal area (g_t) is defined as:

$$g_t = A_e + A_{cor} \quad (3)$$

The majority of functioning algorithms for automatic calculation of the basal area of the trunk propose fitting of a circle (Aschoff, et al., 2004,), cylinder (Bienert, et al., 2006, Hopkinson, et al., 2004) or Hough's transformation (Aschoff and Spiecker, 2004) assuming that a circle can approximately represent a trunk. In case of the listed algorithms the mean difference in the relation to the reference measurement DBH ranges from 1÷2 cm. Additionally the algorithm based on Hough transformation requires the conversion of vector data TLS (points XY) into raster. In algorithms based on the fitting of a cylinder, its height is connected with the size of the trees DBH. The larger DBH – the bigger height of the cylinder, thus it is necessary to make the mean base of cylinder. The proposed in this article algorithm is first of all based on a correct definition of the basal area of individual trees (g), from which DBH value could be calculated back as one of basic tree and stand parameters. The studies over the algorithm (Algorithm 1 and Algorithm 2) have been continued and the algorithm is gradually being improved.

4. RESULTS

4.1 The number of trees

Depending on the scanner position (S_1÷S_4), the number of tree trunks on the reference plot, possible to be interpreted as full slices or their fragments, can be different. In case of plot 19 from the central position (S_1) one tree trunk could not be seen and two other were partially covered, which was stated only on the stage of detail work on the comparison with Ref. Inv. Making manual measurements with the pixel and pipe method is strictly dependent on full identification of tree trunk. The percentage of trees visible for manual measurement in plot number 19, ranges from 63.3% to maximal 90.0% from individual scanner positions. This has its consequences in calculating the stand basal area (Table 2).

4.2 Polar measurement

The process of getting slices of tree trunks leads to automatic gaining information on the centroid of the trunk and, this way, making a precise map of trees on the forest inventory plot (Figure 7).

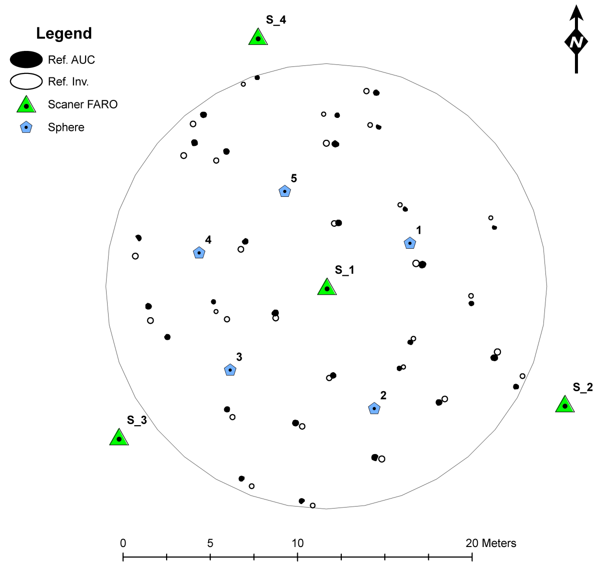

Figure 7. Map of tree trunks on the plot no. 19

Compared to traditional forest inventory, a constant angular shifting was observed (about 4°) resulting from the application of different instruments to measure azimuth from the centre of the plot to the tree trunk, as well as the situation of a survey pole northwards at the moment of scanning. So-called „gross errors" were relatively rare. They occurred e.g. during completing the paper forms in the "distance to the trunk" field (e.g. in case of plot 19, tree no. 21; the error was ca. 3.5m). The error in marking the north and inaccurate reading can cause the change of the position of the tree trunk to about 0.80÷1.0 m, on the border of the reference plot (radius = 12.62 m). Taking that the errors in the localization of respective laser points on the tree trunks can reach 1÷2 cm – this is still 50 to 100 times less than the accuracy of dGPS measurement (RMS 1.0÷1.5 m) under the forest canopy (Wezyk, 2005).

4.3 Tree DBH

The carried out statistic analysis of the measurements for all the scanner positions - i.e. for 141 visible pines, 36 oaks and 22 beech trees – showed that manual "pixel" and "pipe methods" provide precise results. A very clear relationship ($R^2 > 0.946$) between DBH defined with the "pixel method" and Ref. AUC is presented below (Figure 8).

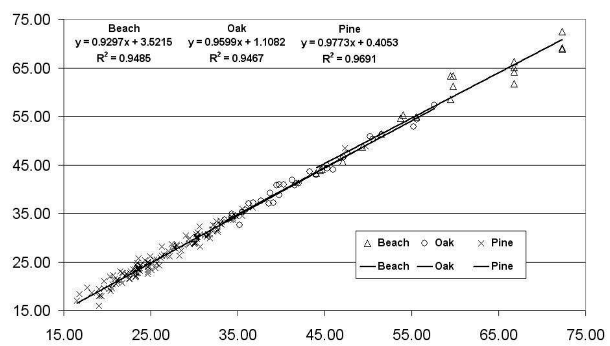

Figure 8. Regression plot of manual (Ref. 1_AUC) versus TLS DBH [cm] estimates (all trees from inventory plots)

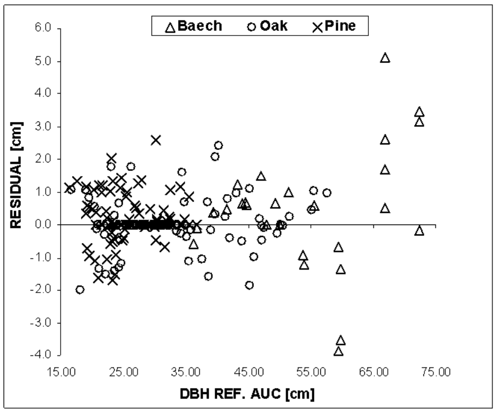

Figure 9. Residual plot for DBH from TLS of all the analysed trees

4.4 Tree height

After the application of several levels of data filtering to get rid of so-called *air points* and *ghost points*, the classification of point clouds was made. The height of tree was defined in a *High Vegetation* class in the TerraScan (Terrasolid) software. Compared to Ref. Inv., the TLS measurement of deciduous tree stands and the interpretation of point clouds turned out to be slightly underestimated. The arithmetic error if the reading of the highest points belonging to the canopy of deciduous trees was +0.44 m (beach -0.01 m; oak +0.61 m), an absolute mean error was about 1.10 m (beach 0.59 m; oak 1.30 m). Due to the late season in the tree crown remained about 15÷20% leaves, which on one hand enabled deep penetration with a laser beam, on the other hand the lack of leaves above 30 meters made small twigs not clearly seen target by the scanner. The beech stand, because of small density could be better measured by both methods, probably because of this the results were better. In case of coniferous tree stands the arithmetic mean of the height measurement was +0.35 m, which indicated a slight overestimation of the reading of the obtained points compared to Ref. Inv. The absolute mean value for these pine stands was 0.79 m.

4.5 Methods of the automatic definition of the tree (g) and stand basal area (G)

As a result of the application of two algorithms (Algorithm 1 and Algorithm 2; Table 2) in a fully automatic way, the information on stand basal area (G m^2 ha^-1) was obtained and compared to the results got from forest inventory (Ref. Inv.) and manual measurement in planar view of point cloud as well (methods: *pixel and pipe*).
The results clearly indicate that the accuracy of the automatic measurement with the application of Algorithm 2, in the coniferous stands (plots no. 15 and 19) gives mean error on the level of 0.26% (Table 2) in the situation when a traditional inventory measurement differs by about 2.88%. For the deciduous stands the mean values of the error in defining stand basal area (G) with Algorithm 2 are respectively 1.63% and, compared to Ref. Inv. (5.19%), are also several times smaller. Both manual measurements methods: *pixel and pipe* give much worse results, because every time they only refer to one direction of calliper.
The application of the Algorithm 2 correcting the area of the slice with incomplete cover of TLS points, very significantly reduced the error of the tree basal area (g) in deciduous tree stands, from about 3.5 times to several dozens of times in the case of Scots pine stands (Table 3).

Plot no.	Method	G [m^2 ha^{-1}]	Percentage of difference to Ref. 2_AUC
3	Ref. 2_AUC	42.1638	
	Ref. Inv.	42.0877	0.18%
	Pixel	40.5036	3.94%
	Pipe	40.9054	2.98%
	Algorithm 1	39.3390	6.70%
	Algorithm 2	41.3680	1.89%
5	Ref. 2_AUC	26.2230	
	Ref. Inv.	24.5319	6.45%
	Pixel	18.8020	28.30%
	Pipe	15.8495	39.56%
	Algorithm 1	25.4210	3.06%
	Algorithm 2	25.8640	1.37%
15	Ref. 2_AUC	17.1722	
	Ref. Inv.	16.6284	3.17%
	Pixel	15.6010	9.15%
	Pipe	15.5777	9.29%
	Algorithm 1	16.7250	2.60%
	Algorithm 2	17.1780	-0.03%
19	Ref. 2_AUC	40.8747	
	Ref. Inv.	39.8160	2.59%
	Pixel	34.8210	14.81%
	Pipe	35.0043	14.36%
	Algorithm 1	39.6220	3.06%
	Algorithm 2	41.0760	-0.49%

Table 2. The accuracy of the determination of stand basal area (G) of the forest inventory plots using different methods (Milicz Forest District).

Tree species	Method	Sum of tree basal area (g)	Percentage of difference to Ref. 2_AUC
European Beach	Ref. 2_AUC	1.4647	
	Ref. Inv.	1.3885	5.20%
	Pixel	1.0928	25.39%
	Pipe	0.9383	35.94%
	Algorithm 1	1.4006	4.38%
	Algorithm 2	1.4463	1.26%
Oak	Ref. 2_AUC	1.7649	
	Ref. Inv.	1.7398	1.42%
	Pixel	1.6858	4.49%
	Pipe	1.7235	2.35%
	Algorithm 1	1.6492	6.56%
	Algorithm 2	1.7270	2.15%
Scots pine	Ref. 2_AUC	3.0920	
	Ref. Inv.	3.0249	2.17%
	Pixel	2.7078	12.43%
	Pipe	2.7050	12.52%
	Algorithm 1	3.0056	2.79%
	Algorithm 2	3.1009	-0.29%

Table 3. The accuracy of the tree basal area (g) determination with different methods for respective tree species (Milicz Forest District)

5. CONCLUSIONS

The obtained results allow the statement that the application of TLS technology in the forest inventory work is already possible. Manual measurements of the point clouds using dedicated software give very good results, however only when the tree trunk is fully visible for the scanner.
Comparison or benchmarks of the TLS with the traditional forest inventory methods make sense only when the same parameter is gathered in right way. The perimeter of the irregular tree trunk on the DBH height is the best reference in case of using TLS.
The fact that such work is time-consuming made these methods applicable in e.g. observation of areas or monitoring and modelling the growth of trees and tree stands, but not very successful when it is necessary to make automatic data-gaining in the area of hundreds or thousands of hectares.
Further planned work of the research team is aimed at defining the possibilities of limiting the number of scanner positions and (at the same time) the improvement of the algorithm reconstructing missing fragments of tree trunk slices. However, the improvements require the following stages: data pre-processing (filtering) and their classification. The errors of the automatic determination of stand basal area (G) reach level of only a few percent. The application of algorithms in the automatic calculation of tree basal area (g) and stand basal area (G) significantly shortens the time of full data processing and provides high correctness of the results. This can contribute to the verification of present legal regulations and guidelines describing the standards of calculation the wood biomass of the stands.
At present high accuracy TLS data are hardly used in standard forest inventory. As long as the concept of „precise forestry" is not applied in practice, scanners will be regarded too expensive and unnecessary tools.
Finally, TLS seems to be a tool for objective obtaining of information on the forest structure, although fully automatic use of data will only be possible in the near future.

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