The use of terrestrial and airborne LIDAR technology in forest inventory

O uso da tecnologia LIDAR aerotransportado e terrestre no inventário fl orestal

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Abstract

Paper describes Polish experiences with the use of terrestrial and airborne LIDAR in forestry and especially in forest inventory. Two types of airborne scanners (TopoSys and Optech) were used to visualise two different test sites: one located on flat terrain and another in the mountains. For terrestrial scanning FARO LS880 laser equipment was used. LIDAR data were related to precise forest inventory parameters of stands and trees.

Key words: airborne LIDAR; terrestrial LIDAR; forestry; forest inventory.

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Resumo

O artigo descreve a experiência polonesa com o uso do LIDAR terrestre e aerotransportado na atividade florestal e especialmente no inventário florestal. Dois tipos de imageadores aéreos (*TopoSys* e *Optech*) foram usados para visualizar duas diferentes áreas testes: uma está localizada em terreno plano e a outra em terreno montanhoso. No escaneamento terrestre foi usado o equipamento FARO. Os dados LIDAR foram relacionados com parâmetros precisos de inventário florestal de talhões e de árvores.

Palavras-chave: LIDAR aéreo; LIDAR terrestre; engenharia florestal; inventário florestal.Introduction

There have been many papers published on the forest and environment inventory performed with the laser technology. Laser (*Light Amplification by Stimulated Emissions of Radiation*), also referred to as optical amplifier, is a device generating or amplifying electromagnetic radiation in the range from ultraviolet to infrared.

LIDAR (*LIght Detection And Ranging*) is an active system of the remote data collection that utilises amplified light beam (laser). The beam is sent towards the object and then reflected from it as well as dispersed. The return signal is recorded and analysed. Analysis of the properties of the returning light beam enables to characterize the objects from which the beam is reflected. Measurement of time between the sending and the return of the beam is used to determine the distance from the source of radiation to the object.

LIDAR usually utilises radiation of near and mid infrared portion of spectrum that is sent in a form of a constant or pulsing beam. Environmental research uses mainly airborne pulsing lasers with the frequency of 5000-150000 pulses per second. The beam is slower than the light by 0,03%. Typical range of scanning covers the angle from 1 to 75°, but the best range for forest research is from 10 to 20°. It provides maximum penetration of the laser beam into the stand and covers the depiction belt of 100-200 m in width with respect to the flight height. Terrestrial trace of the laser pulse (referred to as a footprint) characterizes diameter of 5-100 cm.

The number of points covering specific area changes in relation to the height and velocity of flight. The higher the flight - the larger the radius of the footprint. Maximum field resolution is 10-20 cm (dense sampling is necessary to achieve that), vertical accuracy equals ± 10-20 cm, and horizontal accuracy - ± 11-15 cm.

During the airborne scanning, determination of the co-ordinates of measured objects consists in the measurement of: the aircraft position with the use of Differential Global Positioning System (DGPS), its orientation with the use of Inertial Measurement Unit (IMU). Distance between the sensor and the ground surface was calculated based on the time that passed between the sending of the laser impulse (light speed) and the registration of the return signal.

In order to receive the most precise picture of the scanned object, some companies (e.g. TopoSys) introduced vibrating sensors (Falcon) thanks to which the line of registration on the ground surface was lengthened. As a result one has denser sampling and increased number of information obtained in this way. Applied resolution of point ranges from 1 per 4 m^2 to 100 per 1 m^2, and number of registered return signals of laser radiation expands from 2 (the first and the last one) up to the full-wave registration.

As far as terrestrial LIDAR is concerned, the scanner used for measurements in forest areas should characterize with the following parameters: maximum range up to 100 m, minimum registration frequency equalling 10 000 points per second, maximum registration area (optimum values: 360° horizontally and at least 300° vertically) as well as accuracy not worse than 10 mm.

In recent years General Directorate of Polish State Forests as well as EU program InterReg have financed research that allowed determination of the range of application of laser scanning in forestry. Studies presented in this paper have been carried out by Faculties of Forestry at Warsaw University of Life Sciences - SGGW and Poznan University of Life Sciences as well as Swieradow Forest District and University of Applied Science in Eberswalde (Germany) in cooperation with Department of Remote Sensing and Landscape Information Systems (FeLIS) of the Albert-Ludwig-University in Freiburg (Germany) and TreeMetrics Ltd. from Cork (Ireland).

Research was especially focused on the determination of vertical and horizontal structure of the stands as well as on automatic inventory of trees parameters, and also on modelling of floods and soil erosion. The paper presents a summary of so-far results of research in above mentioned fields.

Data and Methods

The research was carried out mainly in Swieradow and Szklarska Poreba Forest Districts (Sound Ecology Promotion Complex “Western Sudety Mountains”) as well as in Milicz, Gryfino and Slawno Forest Districts. Two types of LIDAR scanning (airborne and terrestrial) were used. Applied equipment included following software: TreesVis (FeLIS), Halcon (MVTec Software GmbH), AutoStem (TreeMetrics), ERDAS Imagine, ArcGIS (ESRI) as well as Quick Terrain Modeler (Applied Imagery).

Airborne scanning

Airborne laser scanning for both research areas was performed with the use of different scanners, which determined parameters of collected data (Table 1).

During the preparation phase of the work the reference terrestrial study plots were established (250 in Milicz and 50 in Western Sudety Mts.). In the next step we generated digital surface model of land cover (DSM) with the resolution of 0,25, 0,5 and 1 m, digital terrain model (DTM) with 1 m resolution and differential model (nDSM) with the resolution of 0,25, 0,5 and 1 m.

Table 1. Parameters of the airborne scanning for the research areas

Parameter	Milicz Forest District	Western Sudety Mts.
Scanner	TopoSys (Falcon System)	Optech ALTM 3100
Spectral range	1540 nm	1047 nm
Scanning angle	14,3° (+/-7°)	18°
Flight height	700 m	700 m
Laser footprint size	0,7 m	0,21 m
Sampling density	5-7 points per m^2	4 points per m^2
Number of reflections (echoes)	2	4

Segmentation of the stands into homogenous groups was performed on the basis of raw data from the first and the last reflections that were used to generate the differential model, analyse the stand structure, determine number of trees per area and assign the species as well as on the basis of digital R-G-B-IR photos that were used in verification.

Terrestrial scanning

FARO LS880 laser was applied in terrestrial scanning. The main parameter of this device are as follows: maximum range: 74 m, frequency: 120 kHz, linear error: 3 mm per 10 m, laser wave length: 785 nm, spot size on exit: 3 mm, vertical scanning angle: 320 degrees, horizontal scanning angle: 360 degrees.

Scanning on each study plot (permanent or temporary inventory plots) was performed from 1, 3 or 4 locations (figure 1). Obtaining a few scans from one plot allows creating full 3D image. Beside the basic scanning, the digital photos were taken with camera integrated with the laser scanner (camera: Nikon D70s, lens: Nikkor AF DX 10,5 mm f/2,8G ED). As a result, beside the cloud of points, a series of photos were obtained, which allowed preparing photo-realistic 3D model for analysed area (figure 2).

Figure 1. Test plot model created on the basis of the cloud of points registered from four locations of scanner

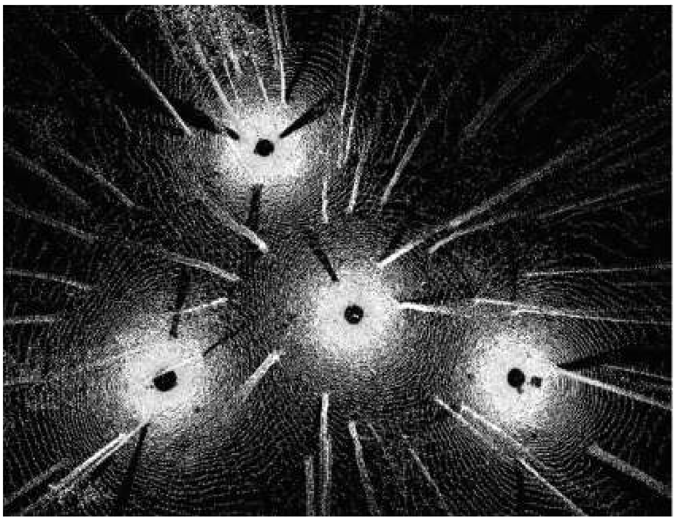


Figure 2. Fragment of forest stand LIDAR image based on the cloud of points and LIDAR image with photography superimposed

Intensity image, that is a panoramic picture of the area (360° horizontally and 320° vertically), comprises one of the data types obtained during the laser scanning. Hence the image is projected, it can be used among others to measure the distance from the scanner to the individual points as well as among points themselves. Such image was used for measurement of dbh and height of individual trees. Intensity image and 3D model were the bases for determination of tree species and its precise localization at the study plot. That allows identification of individual trees and hence comparison of measurement results from scans to the referential data.

Results

Airborne scanning

Data from airborne laser scanning (figure 3) were used for automatic determination of trees height (figure 4) and number of trees. Applied method is based on 2.5D model, so only upper stand layer was considered in the analysis.

Additionally, an experiment on determination of ranges of homogenous parts of the stands was carried out. Method elaborated by Koch et al. (2006) was applied for that purpose. The only modification concerns the way of stand classification into conifers and deciduous on the basis of NDVI index and red band of airborne digital image.

Data collected on 242 trees were used to compare the results of the height determination from LIDAR field measurements. They come from 23 study plots where Scots pine (*Pinus sylvestris* L.) was the dominant species. Only trees obtained during automatic segmentation and combined with those measured in the forest (determination coefficient $R^2 > 0{,}8$) were selected for the analysis (figure 5).

Mean tree height from terrestrial measurements (21,07 m) is 1,55 m (7,4%) smaller than the average height determined for the same trees basing on differential terrain model obtained from LIDAR data. Maximum difference of individual tree height equalled 28%.

Such relationship between the results of the height determination is quite

Figure 3. DTM with 1 m resolution (brown) and DSM with 0,5 m resolution (green)

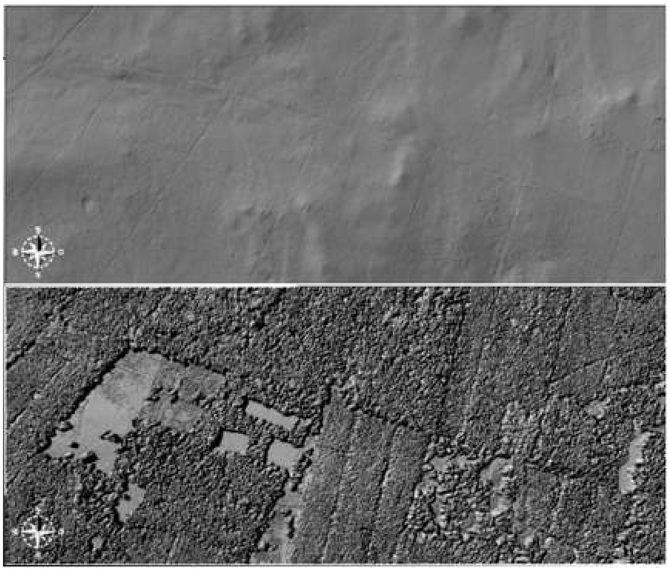


Figure 4. Example of trees height determination by comparison of DSM (green line) and DTM (brown line)

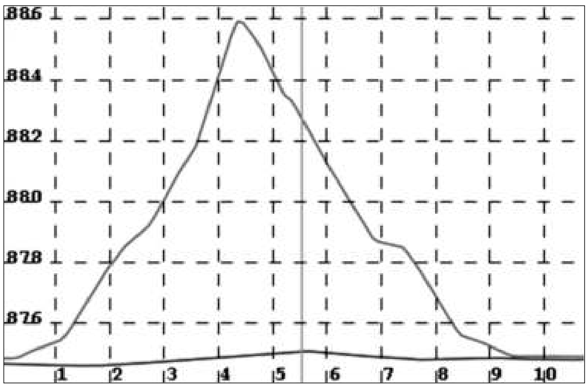
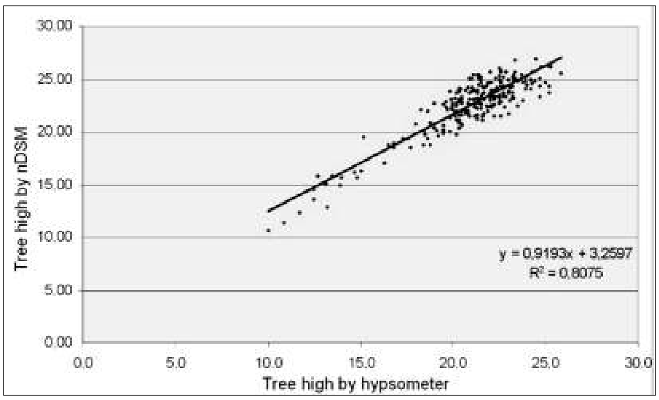


Figure 5. Correlation of height of trees measured in forest and on the basis of nDSM



peculiar. Literature reveals that it is LIDAR data that produces lower tree-heights in comparison to data from terrestrial reference measurements (Buddenbaum, Seeling, 2006; Coops et al., 2004; Heurich, Weinacker, 2004; Maltamo et al., 2004). As far as the presented research is concerned the situation is opposite. It is strange because values of the height were read from the model which already itself is a kind of generalization of the described area and which rather smoothen its shape. Additionally, in case of forests, DTM overvalues the "z" value for individual pixel because of dense understory and small number of LIDAR points reaching the bottom of the forest. To sum up, every pixel of the elaborated differential terrain model should have the height at least several dozen cm lower than the real value of the terrain height. The reason of this situation may be in systematic error appearing in the LIDAR data or errors occurring during terrestrial inventory.

Algorithm that searches for local maxima (Dorren et al., 2006) was applied to determine the number of trees. Height layers of 5 m were distinguished in the differential model and filtered twice using Gaussian filter. Specific feature of this algorithm is that it allows analysing only the upper layer of the stand, which is described by nDSM.

In the first turn, 25 study plots with Scots pine, oak (*Quercus sp.*) and European beech (*Fagus sylvatica* L.) as the dominant species were analysed. Applied algorithm found 396 out of 517 trees growing on these plots, which constituted 77% of their total number. Considering the age of the stands (from 33 to 152 years) this result can be recognized as satisfactory.

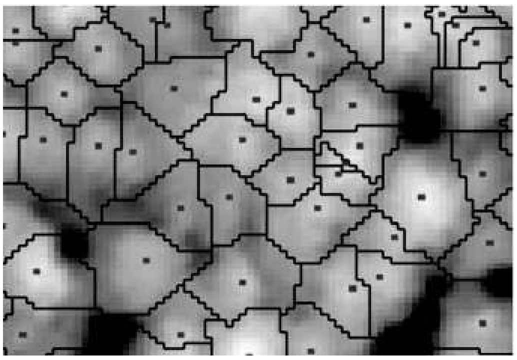
The next step was to analyse only the older (>50 years) Scots pine stands. Algorithm found automatically 218 out of 255 trees, which amounts for 86% of all trees. Also in this case the result was found satisfactory. During the determination of the number of trees, the *growing algorithm* was applied to elaborate the crown-ranges (figure 6). This algorithm builds the crown all around the stem until it meets crowns of neighbour trees.

The method was not found to be the proper one as it does not take into account individual variability of the crowns. There are attempts to substitute the *growing algorithm* with the *pouring* one (Sterenczak et al. 2008). Weinacker et al. (2004) show, that currently it is the best way to determine the range of the trees.

The experiment with the application of the method that determines homogenous parts of the stand in Polish conditions gave satisfactory results. Thanks to its implementation, much richer information about spatial structure of individual compartments was obtained. Vector model of the data that has so far been used in Poland does not give such a possibility of the presentation of stand inner diversity. Taking into consideration the intention of approximate Polish forestry to close-to-nature management, the required information about single compartment parameters will be richer and richer. It may cause the search for new kind of information presented in a form of raster or vector layer. It seems that implementation of the method proposed by Koch et al. (2006) will win the recognition of forestry practice.

Apart from the analysis of tree and stand parameters, airborne scanning data

Figure 6. Range of crowns generated on the basis of airborne scanning data



were used also in modelling of flood and soil erosion phenomena (Balazy et al., 2008). In the context of the number of floods that have increased in recent years, the possibility of the damage analysis basing on the DTM combined with the ortophoto layer gains the special meaning. It gives the basis not only to assess the range of the flood wave, but also to visualise specific parts of the stands (or even single trees) that will be in danger of flooding and damage (figure 7).

A bit more complicated analysis deal with designing of hydrological constructions e.g. protection dam (figure 8). Whereas the spatial analyses concerning among others occurrence of soil types, slope and sun expositions of the terrain were applied to determination of erosion risk, location of Stone pine (*Pinus cembra*) plantation as well as optimal course of ski-trail in Izerskie Mountains range (figure 9).

Terrestrial scanning

Terrestrial laser scanning was performed, among others, on study plot localized in Slawno Forest District. Comparison of the LIDAR and reference measurements shows that laser based data is underestimated in relation of both dbh and height measurements (Table. 2). In case of dbh the mean difference is 2,4 cm and as far as height is concerned – 2,7 m (Zawila-Niedzwiecki et al., 2007). It has to be stressed that these differences may result from errors or inaccuracy of measurements both in the field and on

Figure 7. Visualisation of the flood in the selected part of the Swieradow Forest District

Figure 8. The use of DTM for designing of protection dam in Swieradow Forest District

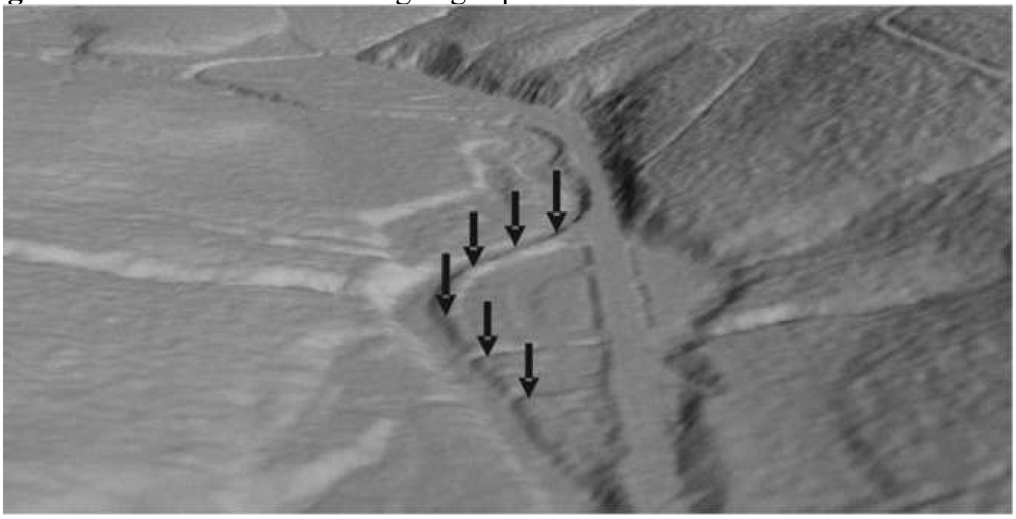


Figure 9. Analysis of susceptibility to erosion in the area of planned ski-trail on Stog Izerski Mt.

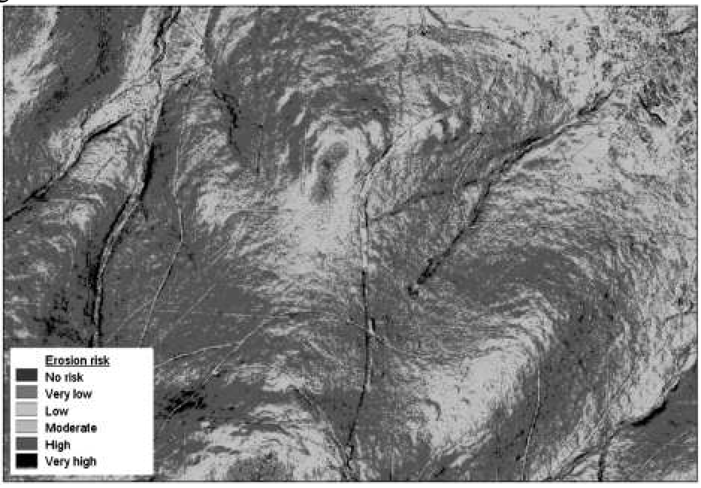


Table 2. Track record from laser scanning versus reference data

Number of tree	Species	Ground measurements		Laser scanning		Difference	
		dbh [cm]	height [m]	dbh *[cm]*	height *[m]*	dbh *[cm]*	height *[m]*
1	Beech	45,5	31,0	43,5	27,4	2,0	3,6
2	Fir	27,1	25,0	26	23,2	1,1	1,8
3	Spruce	60,5	35,0	56,7	32,4	3,8	2,6
4	Fir	55,4	36,0	53,3	32,3	2,1	3,7
5	Beech	34,1	32,0	31,6	28,0	2,5	4,0
…	…	…	…	…	…	…	…
74	Pine	44,6	37,0	43,1	35,8	1,5	1,2
Average (of all trees)						2,4	2,7

scans. Both methods may be encumbered with some error related to subjectivity of the measurements. As can be seen on figures 10 and 11, there is great convergence of results, which allows expecting that further improvement of the method may result in form of precise and reliable information about individual trees and the whole stand.

Much higher accordance of measurement assigned as reference (performed with calliper) with the results of laser scanning was received on the study plot in Gryfino Forest District (figure 12). Some 100 beeches in three stands were assigned to measurements. Average difference between traditional

Figure 10. Comparison of dbh measurements in Slawno Forest District (blue line – callipers, red line – scanner)

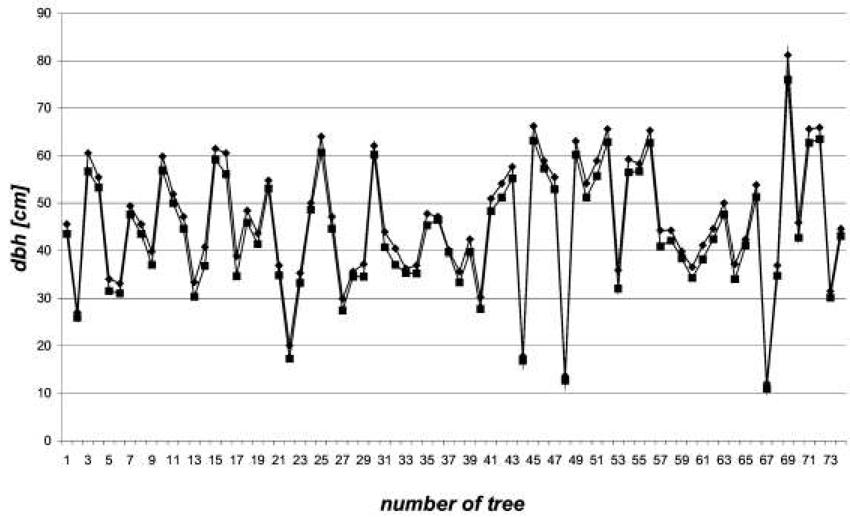


Figure 11. Comparison of height measurements in Slawno Forest District (blue line – hypsometer, red line – scanner)

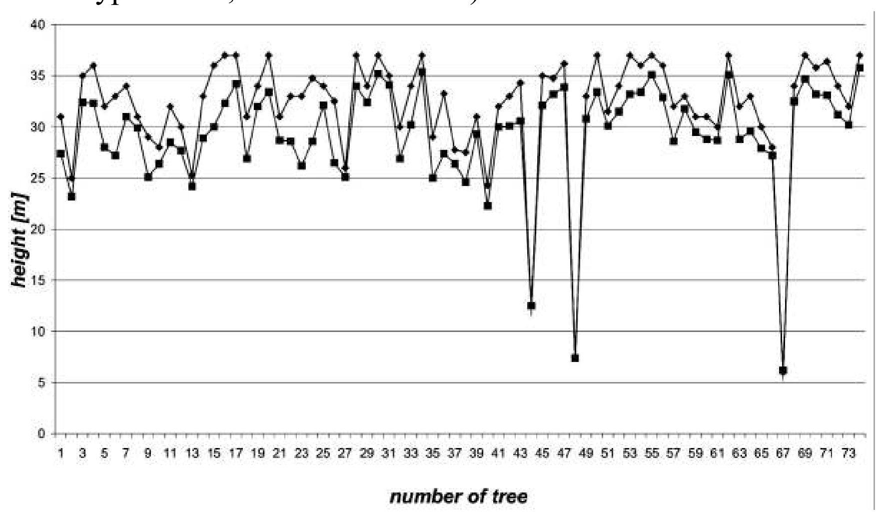
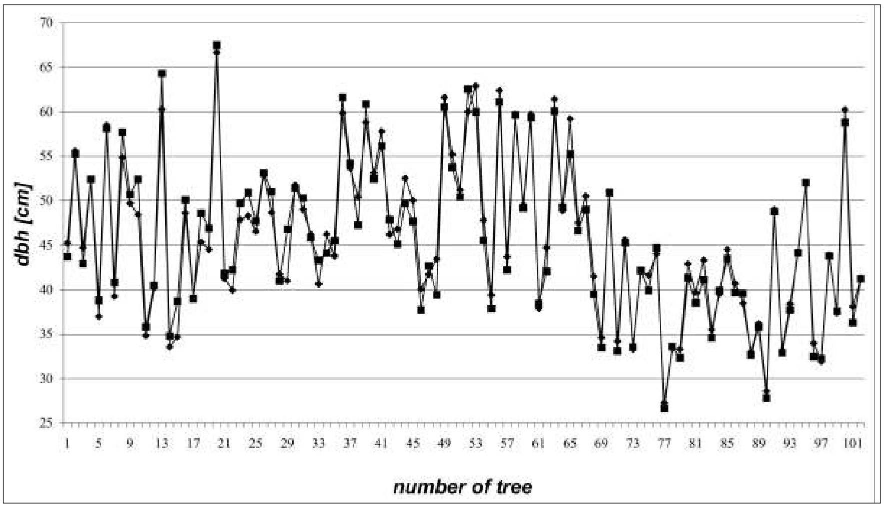


Figure 12. Comparison of dbh measurements in Gryfino Forest District (blue line – callipers, red line – scanner)



measurement (callipers) and the scanner was 0,07 cm (Wencel et al., 2007).

Undoubtedly, structure of bark of the measured trees was of great importance. In case of European beech, especially by the analysis of intensity image, it is easy to identify pixels depicting a tree and its surrounding.

Conclusions

Results of the presented studies allowed stating that laser scanning is useful not only for development of digital terrain model and land cover model, but also for determination of a number of stand and forest parameters as well as for forest management activity.

Presented here examples of implementation of the most modern geomatics technologies in forest analyses allow us to conclude that synergic use of various techniques enables precise modelling of environmental conditions, forest state and processes occurring in them.

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