ORIGINAL ARTICLE

Accuracy of tree height estimation based on LIDAR data analysis

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Abstract

Some modern remote sensing technologies, including LIDAR (LIght Detection And Ranging), have significantly developed recently. Laser scanners mounted on the airborne platform make it possible to collect very precise information over large areas, including tree and stand heights. A literature review shows that the model-based method of tree height determination underestimates this parameter in comparison to field measurements. The objective of the study was to analyze accuracy of the automatic height estimation of Scots pine stands, based on the airborne laser scanning data and the example of the Milicz Forest District. Applied algorithm of the stand segmentation into individual trees gave systematic and significant underestimation of the number of trees. The minimum tree height was estimated with a large negative error reaching up to several meters. The maximum mean and top heights were determined more precisely, with a small negative error of a few percent. The sum of tree heights was determined with an error exceeding 40%, which is caused mostly by the error in estimation of the number of trees.

Keywords

laser scanning, forest inventory, point cloud, segmentation

Introduction

Various data about forests, especially those including the information on features and structure of individual stands is recorded during the preparation of a forest management plan. Dendrometry and geomatics have to provide improved methods of forest mensuration to support this process. Recently, some modern remote sensing technologies, including LIDAR (LIght Detection And Ranging), have significantly developed (Lefsky et al. 2002). Laser scanners mounted on the airborne platform make it possible to collect very precise information about a single tree (Naesset and Bjerknes 2001; Maltamo *et al.* 2004) over large areas (Naesset 2004; Tickle *et al.* 2006). To begin with, these data is subject to the first filtration and processing by the company that performs the flight. Then, with regard to the customer's demand, a cloud of points can be recalculated from WGS-84 (World Geodetic System) frame into whichever coordinate system.

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Main products of airborne laser scanning (ALS) include raw data, which is usually provided as first and last echoes, as well as digital elevation and surface models (DEMs and DSMs, respectively). Data resolution depends on the flight altitude and velocity, footprint size, and frequency of the laser beams sent towards the surface.

A literature review shows that DEMs-based method of tree height determination underestimates this parameter in comparison to field measurements (Buddenbaum and Seeling 2006; Coops *et al.* 2004; Stereńczak *et al.* 2008; Yu *et al.* 2004a, 2004b). The reason of that is often, among other factors, an overestimation of the elevation by DEM and its underestimation by DSM, as a result of LIDAR data interpolation (Wack and Stelzl 2005; Będkowski and Stereńczak 2008). Thus, when in the next stage of data processing we subtract the values of the corresponding pixels of DSM and DEM (receiving CHM – Crown Height Model), the result will differ from the real height of the object. However, according to the above-mentioned authors this difference should not exceed some percent.

This study was a part of a larger project which aimed at selecting useful in forestry methods of remote recording of the state of forest. It also concerned elaboration of the forest inventory method that would make possible not only determination of the current state of forest, but also preparation of forecast for resource development.

The objective of the present paper was to analyze the accuracy of height estimation of Scots pine (*Pinus silvestris* L.) stands using the example of the Milicz Forest District. The paper presents the results of application of the tree crown segmentation as well as the analysis of the accuracy of tree and stand height estimation based on segmented crowns.

Methods and material

Scanning flight took place on 2 and 3 May, 2007, and was performed by TopoSys Ltd. with Falcon II system (Tab. 1). Information about the first (FE) and last (LE) echoed signals was recorded during the flight.

LIDAR data was applied to obtain DEM and DSM. The interpolation algorithm is based on the active contour theory. At first, a raster whose basic area size depends on the point density was created. DEM and DSM filtering was performed at the next stage based on the previously established rasters. After DTM and DSM generation, the Crown Height Model (CHM) was derived by subtracting DTM pixel values from DSM pixels values. CHM was used for single *P. silvestris* tree detection.

Tab. 1. Falcon II system parameters with the characteristics of data collected for the project

Sensor type	Pulsed fiber scanner
Wave length	1560 nm
Pulse length	5 nsec
Scan rate	83 kHz
Scan with	14.3°
Data recording	first (FE) and last (LE) pulse
Flight height	700 m
Size of footprint	0.7 cm

Previous experience has proven that 0.5 m raster resolution is optimal for single tree detection (Stereńczak et al. 2008). CHM segmentation was performed in HALCON (MVTec) software. The *pouring* algorithm (Koch et al. 2006; Weinacker et al. 2004b), that determines a crown range by "pouring", was used. The algorithm was elaborated at the University of Freiburg. More detailed description of algorithm performance can be found in Weinacker et al. (2004a).

In the present study, different methods of crown selection, filter parameters and crown delineation were used. Only *P. silvestris* trees belonging to upper forest layer were taken into account. Generally, the algorithm treats trees as single mountains. Tree crowns were processed as similar to water flowing from the hill. The pixel with local maximum height was a starting point for the analysis. In the present case, 8 neighboring pixels were analyzed to check a direction of pouring crowns. The algorithm processed each crown and formed a segment until pixels lied on the slope or until it met a neighboring segment. For each formed crown segment, height values were analyzed and processed. Pixels with the height under the top crown level, e.g. belonging to lower vegetation, were extracted, so that the crown shape was conveyed more precisely (Fig. 1). Single segments were counted and treated as the number of trees in each stand. Tree automatically received tree parameters: the height and number were compared to data received in the field.

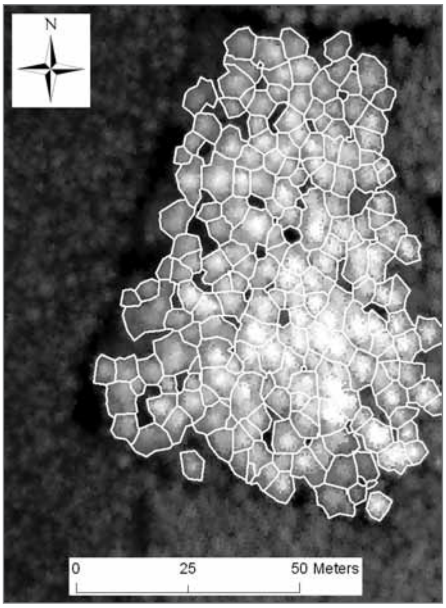

Fig. 1. Visualization of segmentation results for the whole stand (white – individual crowns)

Seven Scots pine (*P. sylvestris*) stands with clear borders were selected for verification of the accuracy of tree and stand height estimation. Characteristics of the analyzed plots are presented in Tab. 2. Each of these plots was localized on site. All tree diameters at the breast height (DBH) and several heights used to elaborate the height-diameter curve were measured on each plot. DBHs were measured using calipers (0.001 m accuracy), and height was determined with the Vertex altimeter (0.1 m accuracy).

Height curve for each stand was smoothed with the least squares method, and Näslund curve was applied as the model of relationship between the height and DBH. The height of each tree in every observed forest stand was calculated with the use of these models. Based on the field data the following parameters were determined: the number of trees in the stand, mean stand height and arithmetic mean of tree heights. Two top heights, defined as the arithmetic mean of heights of 100 tallest trees per hectare and as the mean height of the 100 largest trees per hectare, the sum of the heights and height variability were calculated. The results were recorded in the database that was subject to further analyses.

Data obtained from the point cloud processing and terrestrial measurements served to determine the accuracy of estimation of the number of trees in the stand, minimum, maximum and mean stand height, the top height defined as the height of 100 tallest trees per hectare, and the sum of the heights. Absolute and relative percentage errors were calculated as well.

Results

The first part of Tab. 2 presents reference data, the second – the results of segmentation of the point cloud and the corresponding errors.

Tab. 2. Sample plots characteristics, results of automatic segmentation of point cloud and error analysis for individual features

1	2	3	4	5	6	7	8
Sample plots							
Location	175b	160m	159k	142i	163f	146t	276j
Area	2.53	1.30	0.89	0.58	2.00	0.90	0.60
Terrestrial measurement (reference)							
Number of trees	918	810	296	244	680	470	325
h_min	17.2	20.9	21.8	26.3	20.1	21.4	21.6
h_max	37.2	27.9	34.1	28.1	25.8	30.8	26.8
h_m	27.5	25.2	28.2	26.8	23.3	26.0	24.4
h_g	29.2	25.5	29.0	26.8	23.6	26.7	24.8
hm_100	31.6	26.5	30.5	26.9	24.23	29.1	25.7
hg_100	32.2	26.6	30.8	26.9	24.4	28.45	25.8

1	2	3	4	5	6	7	8
sum_h	25259.1	20392.2	8341.5	6527.6	15821.5	12195.9	7929.2
stddev_h	3.33	0.94	2.04	0.15	0.91	1.50	0.92
devfac_h	12.10	3.73	7.24	0.56	3.91	5.78	3.77
Automatic segmentation							
Number of trees	747	496	246	190	645	308	237
h_min	5.51	17.49	12.92	19.35	9.33	6.02	15.67
h_max	34.22	28.13	30.85	30.54	27.32	29.42	28.78
h_m	26.38	23.96	26.20	26.16	21.48	24.12	24.82
hm_100	30.15	25.95	28.15	28.42	23.83	26.46	27.24
sum_h	19706.34	11885.56	6444.89	4969.99	13855.50	7427.82	5882.24
stddev_h	3.65	1.77	2.36	2.01	2.53	2.58	2.27
devfac_h	13.84	7.39	9.01	7.68	11.78	10.70	9.15
Absolute error							
Number of trees	–171	–314	–50	–54	–35	–162	–88
h_min	–11.71	–3.42	–8.90	–6.98	–10.75	–15.38	–5.90
h_max	–2.99	0.20	–3.21	2.45	1.53	–1.36	2.00
h_m	–1.14	–1.22	–1.98	–0.59	–1.79	–1.83	0.42
hm_100	–1.48	–0.57	–2.33	1.49	–0.45	–2.59	1.52
sum_h	–5552.73	–8506.67	–1896.57	–1557.56	–1966.0	–4768.09	–2047.0
Relative percentage error							
Number of trees	–18.63	–38.77	–16.89	–22.13	–5.15	–34.47	–27.08
h_min	–68.00	–16.36	–40.79	–26.51	–53.54	–71.87	–27.35
h_max	–8.04	0.72	–9.42	8.72	5.93	–4.42	7.47
h_m	–4.14	–4.85	–7.03	–2.21	–7.69	–7.05	1.72
hm_100	–4.68	–2.15	–7.64	5.53	–1.85	–8.92	5.91
sum_h	–21.98	–41.72	–22.74	–23.86	–12.43	–39.10	–25.82

Where: h_min – height of the smallest tree in the stand upper layer; h_max – height of the tallest tree in the stand; h_m – mean stand height; h_g – arithmetic mean of tree heights; hm_100 – top height (an arithmetic mean of heights of 100 the tallest trees per ha); hg_100 – top height (mean height of 100 the largest trees the per ha); sum_h – sum of heights in the stand; stddev_h – standard deviation of tree heights; devfac_h – coefficient of variation of tree heights.

The applied algorithm of stand segmentation into individual trees is characteristic of systematic underestimation of the number of trees, ranging from some to several dozen percent. The relative percentage error of estimation the number of trees for analyzed plots was 23.35% on average (almost 77% of trees was properly identified).

The minimum tree height is estimated with a large negative error reaching up to several meters (over 70%). In turn, the maximum height is determined more precisely. The extreme values of absolute errors were –2.99 and +2.00 m for negative and positive errors, respectively. The mean absolute error was –0.82 m. Mean stand height is estimated with a small negative error that somewhat reaches more than 7% (almost 5% on the average), i.e. the maximum height underestimation being about 2 m (1.25 m on the average). Similar accuracy was received for the top height. The maximum relative error amounts to 9% (less than 2 m). In turn, the sum of heights is determined with the error exceeding 40%, which is first of all connected to the error in estimation of tree number.

Discussion

The present results are comparable to those obtained in various research centers. Mean accuracy of the estimation of tree number is 77%, which is comparable to other studies that analyzed stand upper canopy layer (Coops et al. 2004; Heurich and Weinacker 2004; Holmgren and Persson 2004). Due to the fact that the algorithm is able to analyze only the top stand layer, the described method is dedicated only to the one-layer stands. The methods for LIDAR data stratification which allows their application in analyses of individual layers have not been invented so far.

Analyzed stands are typical silvicultural Scots pine (*P. silvestris*) stands growing on Poland's lowlands. In addition, the algorithm is still in the development phase, thus it is not its ultimate form. Results repetition is the most crucial task in such research, and further work will focus on this issue. If statistically similar segmentation results were obtained for specific groups of stands, it would be possible to determine corrections that should be made in order to estimate correctly e.g. the number of trees per hectare.

The tree and stand height received from application of the automatic procedures is, as suspected, underestimated. First of all, this relates to application of the DEM and DSM for estimation of the tree height. In general, application of the models interpolated from LIDAR data indicates such results. Accuracy improvement may be probably expected when the direct segmentation of point cloud is applied rather than interpolated models. However, the segmentation of points cloud requires advanced algorithms and new tools. Work on them will be performed during further research. The parameters of data from the LIDAR flight are another element affecting the accuracy of obtained results. The presented analysis was applied to point clouds with 5 points/m^2 density and only the first and last echoes were recorded. Nowadays, there are available new systems of scanners that are able to record higher numbers of reflections or the full waveform (Reitberger et al. 2006). These systems make it possible to obtain higher accuracy.

The results for typical silvicultural stands presented in this paper are, in our opinion, satisfactory – above all they were obtained as a result of application of replicable automatic algorithm. Even though the data is encumbered by the systematic error, its practical application is possible in relation to reference field data, e.g. in the inventory method including permanent control study plots (Miścicki 2000) or in the support for currently applied periodical inventory (IUL 2003).

It is worth to point out that many papers concerning the described issue present the segmentation in very loose spruce stands or plantations, which, in turn, leads to the results almost as good as reference measurements (Kiraly and Brolly 2006; Wack et al. 2003). The presented analysis did not focus on the stands which would be easy for analyses, (e.g. distinguished stands), but on typical silvicultural objects.

Conclusions

In the light of presented research, the automation of measurement of the number and height of trees and the horizontal crown range as well as the automation of detection of stand gaps and linear open areas or dominant trees and the course of forest roads turn to be possible on the basis of airborne laser scanning. The results may not be satisfactory in many cases; however we should bare in mind some limitations of practical use of LIDAR. These include stand density and complex stand species and spatial structure. Therefore, it is not possible to analyze the structure in all stands. Much depends on the applied scanning system and used equipment. However, it seems that the most important advantages of the presented method are objectivity, replicability and automation.

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