EVALUATION OF AIRBORNE LASER SCANNING DATA FOR TREE PARAMETERS AND TERRAIN MODELLING IN FOREST ENVIRONMENT

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Abstract

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The aim of this article is to analyse possibilities of airborne laser scanning (ALS) data utilization in forestry, especially for the purposes of terrain modelling and for forest inventory (determination of forest height, diameter breast height and volume – DBH). The accuracy of ALS data in forestry was tested on the area of 1.5 ha. On this area the topography and location of all trees as well as their heights were surveyed in detail by means of total station. Firstly, the altitudinal accuracy of ALS for the creation of digital elevation model (DEM) was evaluated, based on the comparison with relief measurement. The research also evaluated different data sources from various types of scanners with a different point density per m². Further, we compared tree heights determined from ALS data by different ways of interpolation into canopy height model (CHM) with the surveyed data, following calculations of DBH (diameter breast height) and tree volume based on the regressions. The results show sufficient data accuracy for the creation of DEM. Concerning tree height determination, the data is also useful although the accuracy is slightly lower, there is a slight undervaluation of the tree heights. Concerning using high point density data at full waveform scanner it is also possible to detect skidding tracks and micro-relief details. Anyway we did not find sufficient accuracy for DBH and tree volume at the scale of individual trees, but ALS data still gives better results for tree height, DBH and timber volume for larger forest stands than usual inventory.

airborne laser scanning, tree height assessment, digital elevation model, canopy height model, TerraScan

1 INTRODUCTION

The system of airborne laser scanning (ALS) or generally LIDAR (*light detection and ranging*) is based on the principle of the analysis of laser pulses which are emitted from an aircraft, moving at a certain distance from the scanned object. At the same time for each laser pulse emitted from a source its current position in the space is recorded by means of differential GPS and inertial navigation unit (INU). The laser pulse hits an object and it is reflected in the form of an echo back to the sensor and the distance it travelled is measured. The pulse is reflected from each area surface of an object which creates an echo string – from the highest (closest to the sensor) area surfaces to the lowest ones, in order to create a dense field of geographic coordinates in places where laser pulses were reflected from the surface (Baltsavias, 1999).

Airborne laser scanners emit short laser impulses (ca. 10 ns) with the wave length of mostly 1040–1060 nm and divergence < 1 mrad towards the earth's surface in a plane perpendicular to the flight direction. Depending on the flight height, a reasonable diameter of footprint of laser on the earth surface may vary from 10 cm to as much as 4 m. The field of vision throughout the flight depending on the scanner type varies from 45° to 75°. ALS can be used both by day or night, in cloudy weather or where there is a thin coat of snow. However, it is not possible to be used when it is raining or snowing.

Laser scanning imposes high demands on processing possibilities of available technology as there is a large amount of data at high accuracy of scanning. The gained data (point cloud) is usually processed by two basic methods: filtration (its task is to separate points corresponding to a required object) and classification (where individual surfaces are separated). These processes may be automatic or semi-automatic; a fully automatic filtration and classification does not always provide the best results. It is used in zonal and global filters while the biggest differences are between types of land cover representing urban area and continuous vegetation (Jacobsen and Lohmann, 2003).

In forestry ALS is used especially for three types of tasks:

● creation of digital model of canopy surface

● tree identification

● measurement of tree parameters.

By using ALS technology different forestry activities can be carried out faster and in a more effective way (Akay *et al.*, 2009; Enßle *et* Weinacker, 2010). When creating datasets in woody areas laser pulses may reflect from different layers of vegetative cover covering the highest vegetation level (first return), middle level (second and following returns) and earth ground (the last return). Based on the first and last returns it is possible to guess some parameters of forest such as forest border (Smreček and Sačkov, 2013), individual trees or plant cover (Holopainen and Hyyppä, 2003) such as canopy surface, tree height or canopy density (Heurich *et al.*, 2003; Maltamo *et al.*, 2004). A more recent approach when investigating tree and cover features is using information from returns of full-waveform ALS, that means not only from discrete returns and their intensities (Heinzel and Koch, 2011). By using the last return, DEM of high quality can be interpolated with spatial resolution of about 1 m and height accuracy of ca. 0.1 to 0.20 m (Reutebuch *et al.*, 2003). Such DEM may help to design new terrain classifications of harvesting technology with regard to possibilities of harvesting systems or design and to optimise forest road network (Akay and Sessions 2005) and increase the functionality of Spatial Decision Support Systems (SDSS) in forestry (Kuhmaier *et* Stampfer, 2010).

There is a hypothesis that ALS technology provides opportunities to improve the efficiency of sourcing stands to be harvested, above all by improving the quantification of tree volume on the planned clearcut on the basis of digital elevation model (DEM) and digital surface model (DSM) or in forest stands usually called canopy height model (CHM). From these datasets it should be possible to extract information about basic tree parameters such as tree heights, DBH or tree volume based on regressions. Currently the information about trees in forest (especially about volume of wood) is based only on the datasets from forest management plans (FMP) thus only aggregated information for the

stand level is usually available, whereas information about individual trees is missing. The analysis of ALS allows to acquire more specific information about individual trees with higher precision at least in the parameter of tree height. Quantitatively and qualitatively ALS brings a new view on data acquired primarily from forest ecosystems. It is the already mentioned DEM and CHM, as well as the dendrometric tree or stand properties (especially concerning DBH, height and volume of trees, canopy closure, canopy density etc.). Quality and accuracy of gained information is related to the procedures of data processing of ALS. This concerns especially filtration and classification of measured data as well as variety of interpolation of filtered (and classified) data into DEM or DSM (Klimánek, 2006; Cibulka and Mikita, 2011). The ratio of positional and elevation errors normally reaches ranges 2:1 to 5:1. At the slope of relief up to 30° the elevation accuracy is always higher than at digital photogrammetric methods, while the positional accuracy is always significantly worse than the elevation one (Šíma, 2009).

Current results of applied research show a large variety of tested parameters. For instance the most often evaluated parameter – the tree height – ranges in accuracy about 1 m (Leeuwen and Nieuwenhuis 2010). When finding out the DBH, the reached accuracies ranged from 0.025 to 0.065 m (Korpela *et al.*, 2007; Holopainen *et al.*, 2009; Holopainen, 2011). It is possible to detect standing volume with accuracy from 5 % up to 35 % (Maltamo *et al.*, 2009; Tonolli *et al.*, 2010; Vauhkonen *et al.*, 2009). All these values are linked to vertical and horizontal structure of the growth, terrain slope and point cloud density of ALS. ALS data is also used as back-up datasets when classifying tree species. The data classification concerning coniferous and deciduous vegetation only reaches high correctness at classification by dichotomy (Liang *et al.*, 2007).

When classifying woody species the data is different for leaved and non-leaved forests. High classification correctness (over 90 %) is reached when both types of data are used: when using data from periods off vegetation season, the accuracy of classification is higher – ca. 85 % as opposed to 75 % in the vegetation period (Sooyoung *et al.*, 2009). A clear factor is that in forest stands with rich structure we fail to identify all individual trees, only 35 % to 45 % individuals (Kvak *et al.*, 2007; Monnet *et al.*, 2010).

Current ALS application in the conditions of forest stands depends on scanning parameters (flight height and flight speed) as well as on terrain properties (Lim *et al.*, 2008). Normally these parameters are taken into account so that in "normal" conditions of wooded areas there was a density of 3–5 points per 1 m² where the average accuracy is reached in the position of 0.3 m and at height of 0.15 m. ALS technology clearly enhances economical efficiency of gained data which when covering the whole area of inventory surveys (in the

range of hundreds of thousands of hectares) may, in ideal conditions, bring about savings of up to 40 % of sources as opposed to terrestrial methods.

2 MATERIALS AND METHODS

Evaluation of ALS data accuracy for the purposes of DEM and CHM creation was carried out on the area of the Křtiny Training Forest Enterprise (TFE) near the city of Brno (see Fig. 1). For the evaluation, data from company GEODIS Brno s.r.o. from two different flight campaigns was used while using different flight scanners. Both scannings were carried out during a vegetation period. The first ALS was done in 2009 by discrete return scanner Leica ALS50-II from flight altitude of 1395 m with average density of 4.3 points per square meter. The second ALS was performed in 2011 by means of full waveform scanner RIEGL LMS – Q680i. The resultant point cloud was created by means of scanner testing by company GEODIS Brno by combination of several cross flights from different flight altitudes (see Tab. I) with resultant average density of 125.6 points per square meter. Table I shows the ALS point density on the researched plot from both scanners.

To compare the usage of ALS data, three research plots of the area of 1.5 ha were surveyed. The plots are situated 10 km north of Brno with altitudes ranging from 470 to 520 meters. This concerned three square flat-relief lots with 70-year-old forest stands and one rectangle plot in a steep ravine with an 82-year-old forest stand. On all plots the tree species composition was very similar – with the predominance of beech (50 %), spruce (25 %) and fir (25 %), with average height of about 25 meters. Geodetic surveying of the plot was done by combination of measurement by total station

Topcon GPT – 9003M and GNSS Topcon Hiper Pro in the Czech coordinate system S-JTSK. To improve accuracy of results of GNSS measurements RTK (Real Time Kinematic) corrections were used from the CZEPOS reference station network. Altogether the position and altitude of 600 trees was surveyed.

Surveying of heights and DBHs of these trees was performed by electronic altimeters TruPulse 360B and with forestry calliper. Tree heights were measured from a suitable place so that the top and foot of the tree were well visible from this spot. Minimum standoff distance from the tree equalled to the estimated tree height. To guarantee more accuracy the height of each tree was measured three times – each time from a different direction and the resultant height was calculated as the arithmetic average of the three values. Measuring results from the total station were converted to the point shapefile layer with attributes of a measured height for each tree.

2.1 ALS data processing

ALS data was provided in the format LAS 1.2. For use in GIS it was further processed in software TerraScan (Microstation V8i extension).

Software TerraScan is primarily intended for the classification and filtration of point clouds from air and terrestrial scanning and besides the filtration of first and other returns and the detection of ground points it also enables the detection of low, medium and high vegetation, hard surfaces, buildings or electric power line. The output is represented by classified points in LAS format.

The final classification result in the LAS file of ground and first return set of points was converted in ArcGIS 10.1 and 3D Analyst extension by tool LAS to Multipoint which converts LAS format to a point shapefile, which can further be
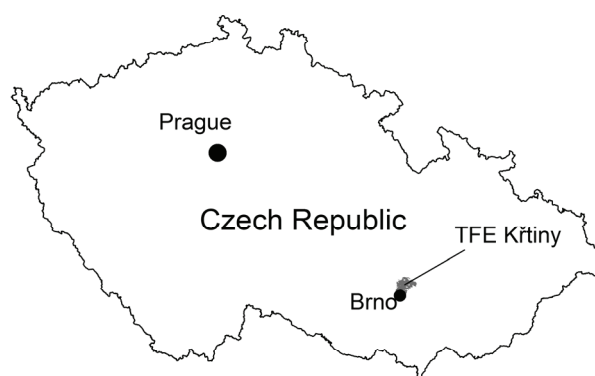
1: *Location of TFE Křtiny*

I: *Point density on research plot from different laser scanners (FR – First return points, gr – ground points, all – all returns)*

Plot parameters	Leica FR	Riegl FR	Leica gr	Riegl gr	Leica all	Riegl all
Point density	1.46	50.99	0.1	1.49	4.3	125.62
Number of points	6 194	249 941	429	51 412	18 230	615 798
Area of plot (m²)	4 239	4 902	4 239	4 902	4 239	4 902
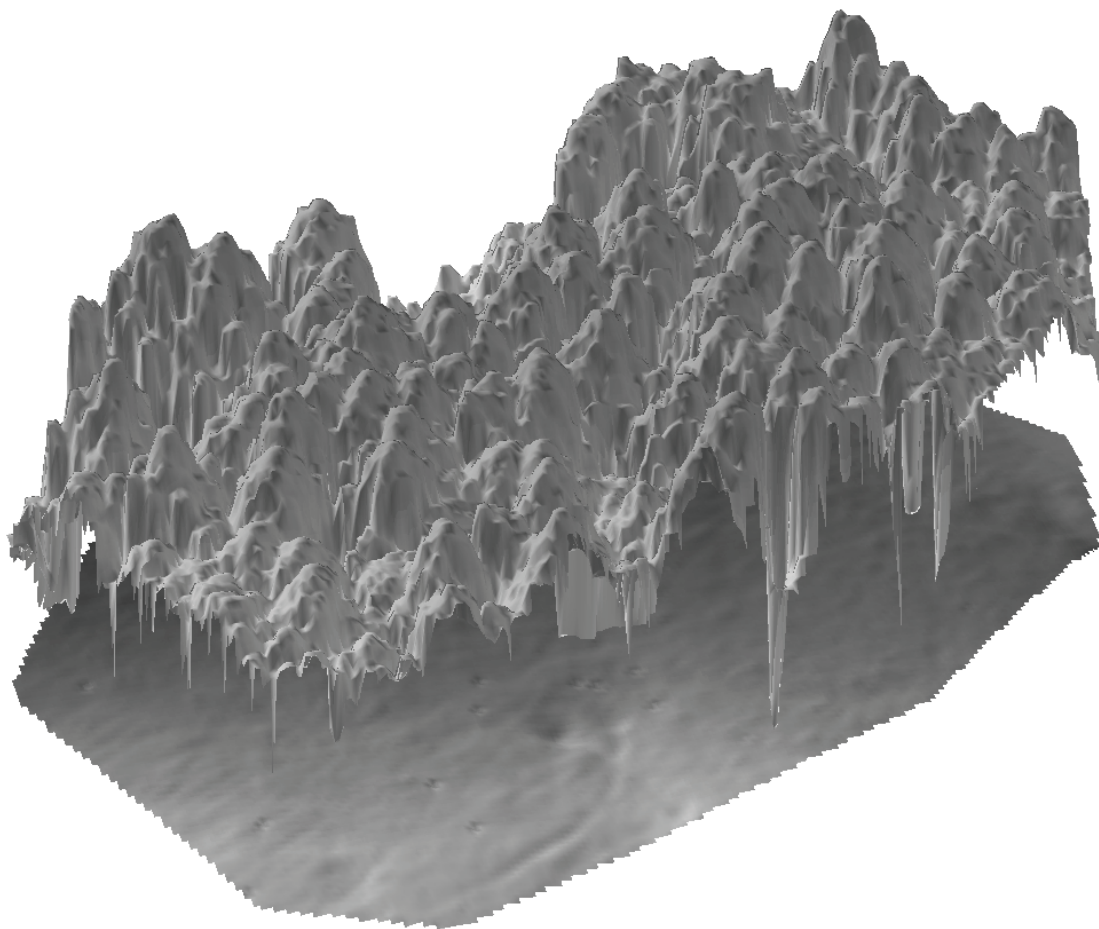
2: *Digital elevation model and digital surface model of one of the research plots*

interpolated to rasters of DEM or CHM. Firstly for point interpolation was used the linear Natural Neighbor interpolation and later Focal Statistics and Point Statistics tools of ArcGIS. The function performed on the input was maximum statistics of all values encountered in circle neighbourhood of each raster cell. Other interpolation methods (i.e. Spline or IDW) were not examined because in case of such dense point data the differences between interpolation methods are insignificant (Cibulka *et* Mikita, 2011). Firstly the accuracy evaluation of the used data sources and interpolation methods was carried out and subsequently were tested different cell sizes and different ranges for focal filtration.

Tree identification was conduct by watershed segmentation (Edson, 2011). Watershed segmentation determines tree top locations by inverting the CHM and finding local minima as tree tops. Heights of detected trees were extracted from difference of CHM and DEM and subsequently compared with closest measured trees. The last method of ALS data accuracy evaluation is the attribution of the closest point of ALS to the treetop of the surveyed tree in 3D space (tool Spatial Join – Intersect 3D) with maximum distance first up to 1 m and later up to 2 m.

2.2 Tree parameters extraction

We further tried extraction of other tree parameters such as diameter breast height (DBH) and tree volume. Calculations of these parameters were based on regressions created by our own analysis from source data of measured trees. For DBH calculation adjusted Michajlov's function (1) was used.

$$DBH = 12.2901/[3.777 - \ln(h - 1.3)] \qquad (1)$$

(h…tree height, DBH).

Subsequently volumes of individual trees based on Slovak tree volume model (Petráš *et* Pajtík 1991) were computed. Due to the dominance of beech on the research plots equation and coefficients for beech tree (2) was used.

$$V = (0.542013 - 0.31183/h + 44.3274/h^2 - 235.97/ \\ /DBH - 0,00107117 * h/DBH - 0.0000186004* \\ *h^2/DBH - 0.0000008806277*h* DBH^2 - \\ - 0.00000000599567*h* DBH^3) *(\pi*DBH/40000) * h$$
(V… tree volume). $\qquad (2)$

For practical usage of the whole method for tree identification and tree height, DBH and volume
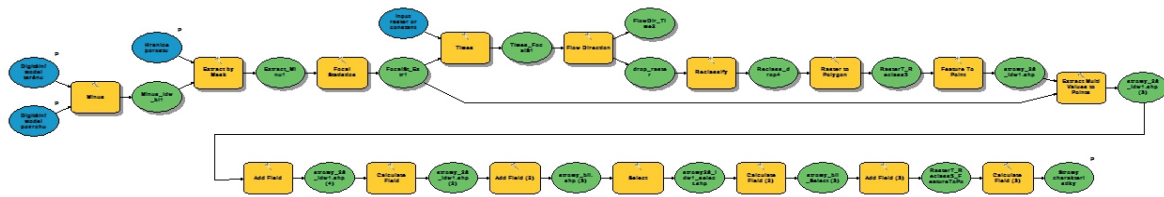
3: *Model diagram in ArcGIS 10.1 for tree parameters calculation*

extraction model for ArcGIS was created. On the basis of CHM, DEM and clearcut area the model calculates selected parameters and in tables directly gives information about individual trees and the whole clearcut area (see model diagram Fig. 3). The results were again compared with measured trees and the success of the created tool was further tested on an 8-hectare beech forest (mean DBH 30 cm, mean height 27 m) and resultant summary tree volume was compared with data of Forest management plan (FMP).

3 RESULTS AND DISCUSSION

Results in the form of differences between real (surveyed) and calculated tree parameters from ALS data were elaborated into tables. For each dataset

was computed maximum and minimum value from a statistic set, systematic error (Mean), standard error (Standard Deviation) and Root Mean Square Error (RMSE), which comprises of both Mean and Standard Deviation.

In the first step the accuracy of the calculation of elevation above sea level in the terrain was evaluated (see Tab. II). From the results of processing DEM from ALS data it is clear that as opposed to geodetic surveying, there is quite a large systematic error (Mean) – circa 0.5 m, while the standard error is about 0.1 m. Systematic error can be partly caused by for example GNSS setting at airplane or by wrong calculation of elevations at the grid of geodetic points for measurement. Concerning full waveform scanner Riegl the resultant DEM is so detailed that even ruts on the roads are well visible and thus based on visual evaluation it is possible to differentiate places of skidding tracks.

When comparing heights of surveyed trees with heights gained by processing ALS data, it was found out that when comparing all trees the overall accuracy of determining heights is almost at all chosen methods very low – ranging from 5.4 to 7.8 meters with similar results at both used data sources (see Tabs. III and IV). This inaccuracy is especially due to a number of trees with lower heights, whose tops cannot be detected from ALS data because they are covered by canopies of higher trees.

II: *Comparison of calculated DEMs: Leica – Ground point generated by Terra Scan from Leica dataset and interpolated to DEM by Natural Neighbor interpolation, Riegl – Ground point from Riegl dataset*

DEM vertical precision	Leica_TS	Riegl_TS
Count:	600	600
Minimum (m):	−1.588	−1.238
Maximum (m):	−0.926	−0.756
Mean (m):	−0.623	−0.42
St. Dev. (m):	0.127	0.088
RMSE (m):	0.636	0.429

III: *Comparison of tree heights with Riegl dataset - pm1_3 - Point Statistic Tool, 1 m cell size, 3×3 cells neighborhood, pm05_3 - 0,5 m cell size, 3×3 cells, pm01_3 - 0,1 m cell size, 3×3 cells, pm01_05 - 0,1 m cell size, 5×5 cells, nat1 - Natural Neighbor interpolation, 1 m cell size, nat1_f - 1 m cell size, filtered by Focal Statistic, nat05 - Natural Neighbor, 0,5 m cell size, nat05_f - 0,5 m cell size, filtered by Focal Statistic, top1 – closest treetops, 1 m cell size, top05 - 0,5 m cell size, top01 – 0,1 m cell size*

all trees	pm1_3	pm05_3	pm01_3	pm01_5	nat1	nat1_f	nat05	nat05_f	top1	top05	top01
Mean (m):	−5.27	−4.247	−2.128	−2.83	0.938	−3.399	0.914	−2.886	−2.015	−2.436	−3.183
St.Dev.(m):	5.804	5.444	5.691	5.578	6.304	5.547	6.261	5.413	5.079	4.948	4.997
RMSE (m):	7.84	6.905	6.076	6.255	6.373	6.506	6.327	6.134	5.464	5.515	5.925
trees higher than 25 m	pm1_3	pm05_3	pm01_3	pm01_5	nat1	nat1_f	nat05	nat05_f	top1	top05	top01
Mean (m):	−1.272	−0.732	0.83	0.369	4.461	0.305	4.479	0.497	0.139	−0.171	−0.615
St.Dev.(m):	1.876	1.89	3.331	2.705	4.455	1.867	4.723	2.015	1.932	1.569	1.52
RMSE (m):	2.267	2.027	3.433	2.73	6.305	1.892	6.509	2.075	1.937	1.578	1.64
trees higher than 20 m	pm1_3	pm05_3	pm01_3	pm01_5	nat1	nat1_f	nat05	nat05_f	top1	top05	top01
Mean (m):	−2.971	−2.233	−0.319	−0.959	2.821	−1.293	2.725	−0.921	−0.824	−1.081	−1.583
St.Dev.(m):	3.605	3.452	4.029	3.77	5.112	3.538	5.304	3.442	3.605	3.126	2.961
RMSE (m):	4.671	4.111	4.042	3.89	5.839	3.767	5.963	3.563	3.698	3.308	3.358

IV: *Comparison of tree heights with Leica dataset – FRLA1 – First return by LIDAR Analyst Extension from Leica scanner dataset, 1 m cell size, FRLA05 – 0.5 m cell size*

all trees	pm1_3	pm05_3	nat1	nat1_f	nat05	nat05_f	top1	top05
Mean (m):	–4.944	–3.488	–1.603	–4.229	–1.436	–3.457	–4.151	–3.694
St. Dev. (m):	5.988	5.934	5.423	5.883	5.686	5.792	6.093	6.267
RMSE (m):	7.765	6.883	5.655	7.245	5.865	6.745	7.373	7.275
trees higher than 25 m	pm1_3	pm05_3	nat1	nat1_f	nat05	nat05_f	top1	top05
Mean (m):	–0.733	0.467	2.047	–0.083	2.396	0.524	–0.261	–0.159
St.Dev. (m):	1.875	2.315	2.564	1.818	2.921	2.064	1.35	1.574
RMSE (m):	2.013	2.361	3.281	1.82	3.778	2.129	1..375	1.582
trees higher than 20 m	pm1_3	pm05_3	nat1	nat1_fo	nat05	nat05_f	top1	top05
Mean (m):	–2.506	–1.248	0.265	–1.912	0.47	–1.249	–2.381	–1.767
St.Dev. (m):	3.662	3.79	3.853	3.705	4.205	3.759	4.359	3.961
RMSE (m):	4.438	3.99	3.862	4.17	4.231	3.961	4.967	4.337

V: *Comparison of tree heights by intersection of treetops in 3D space*

Intersect3D precision	Riegl 1m	Riegl 2m	Leica 1m	Leica 2m
Mean (m):	0.082	0.276	–0.003	0.234
St. Dev. (m):	0.399	0.805	0.396	0.902
RMSE (m):	0.407	0.852	0.396	0.933

Subsequently only trees higher than 20 meters and then trees higher than 25 meters were included into the evaluation. As can be seen from Tabs. III and IV, the best results are reached when comparing trees above 25 m high, however, the statistic set diminishes to 81 individuals. At methods comparing treetops the number is always lower due to greater distance of treetops from the surveyed tree trunks. This effect is caused by trunk sweep (crooked shape) when even a small inclination of the tree at the height of 25 meters has a significant impact on the position of the treetop. That is why the best results are reached when comparing heights of detected treetops with RMSE 1.578 meter while using Riegl dataset and 1.375 meter at Leica dataset at trees above 25 meters high. Other methods show more or less random results regardless of defined environment or pixel size. In the case of DBH and tree volume extraction we didn't have survey data for evaluation. In comparison with FMP it could be said that the calculated parameters correspond to it and can give high precision information about cut forest stand.

Considerable impact on the accuracy of the resultant model of the vegetation surface and consequently also on the detected tree heights has the cell size of the CHM raster. According to the results, the most suitable and the most accurate method of CHM creation is the method of direct interpolation. When using data with common data density about 3–5 points per m² the optimal pixel size is 1m. When using data with density higher than 10 points per m² it is optimal to use 0.5 meter cell size. At smaller cell size there is excessive information and for example for the identification of treetops it is necessary to smooth the data subsequently. At the identification of individual trees, although this concerned forest stand with rich spatial structure, good-quality results were reached ranging from 60 % of identified trees at Leica dataset up to 80 % at Riegl dataset.

When comparing the used data sources, scanner Riegl with higher density of points reaches higher accuracy, especially at DEM calculation where more points hit bare surface; in case of modelling tree heights the results are very similar and from scanner Leica we found out even better results. A negative effect might have been also caused by systematic error ca. 0.5 meter at detection of DEM, which would lower the overall error when detecting heights. The very best results, however, were reached by the method of comparing the closest points of ALS points from treetops in 3D space (see Tab. V), where the height accuracy reached under 0.5 meter. At the visual evaluation of point cloud and interpolated surfaces the hypothesis was proved that as a result of data interpolation there always occurs undervaluation of CHM heights as opposed to raw ALS data.

4 CONCLUSIONS

Despite the mentioned criticism it can be stated that ALS data is a good-quality source of information for detailed mapping of both terrain and vegetation and with further development it will find practical use also in forestry management, for example for determining average height of

forest stands or standing volume and its species. Even at average density of 125 points per m² in most cases in the profile section it is not possible to manually measure DBH. Calculation of other tree parameters such as DBH and tree volume is available by regression models. Precision of such models is mostly dependent on suitability of DBH and tree volume models and it could be clearly formulated that they are still missing for the area of the Czech Republic for main tree species and its implementation should be one of significant goals of forest research. The created ArcGIS 10.1 tool for automatic tree identification, tree height, DBH and volume extraction can be very useful for forest management after optimization.

The ALS data will also find its practical use for the location of skid tracks and for optimising harvesting technologies depending on ruggedness of terrain. The most perspective way of determining qualitative and quantitative tree and growth mensurational properties seems to be a combination of terrestrial methods and ALS or at least a combination of ALS and multi-spectral image data with high resolution.

SUMMARY

Airborne laser scanning brings, both qualitatively and quantitatively, a new view on data gained primarily from the environment of forest ecosystems. From ALS data it is possible to generate accurate digital terrain models and digital surface models. By combining these, it is possible to estimate basic dendrometric tree and growth properties such as height, tree volume, canopy, crop density or overall standing volume. ALS data accuracy in forestry was tested on the area of 0.5 ha. On this area was surveyed the position of all trees by total station, tree heights and the topography of the area. The research also evaluated different data sources from different types of scanners with different point density per m² and different used software for processing ALS data. In the first step the height accuracy of ALS for the creation of DEM was evaluated, based on comparing terrain measurement of the relief. Consequently tree heights, determined from ALS data by different ways of data interpolation, were compared with the surveyed data. The results show high accuracy of determining altitude above sea level for DEM with RMSE being about 0.5 m. Concerning determination of heights at CHM, the RMSE at best results ranges from 5.5 m up to 1.4 m.

Accurate elevation source in the form of digital terrain models enhances the possibilities for better harvesting technology selection and application but it can be also used in a number of other supporting forestry practices, such as forest mapping. From the digital surface model by means of GIS tools, it is possible to automatically identify treetops and in consequence to determine the amount of trees for area unit and by computing the difference between CHM and DEM to determine tree heights. Although ALS data has been studied for a long time, its practical application is still limited. This is especially due to high costs for data provision as well as due to as yet a rather small density of points for common scanning. To gain higher density of point it is necessary to either use non-standard carrier such as a helicopter or airplane with slow and low flight or a so-called cross flight, which further increases costs for provision. The results of the research on the researched area show that for a common forestry applications such as determining number of trees and determining their heights even standard scanning with density of 3–5 points per m² show sufficient accuracy and enables to gain good-quality model of the vegetation for this purpose. As opposed to the conventional ways of forest inventory by forestry altimeters it can be said that the method reaches good-quality results with a slight undervaluation of the height and the overall amount of trees. In the case of DBH and tree volume calculation good results for practical usage in forest inventory can be reached. The optimal cell size for interpolation of ALS data with common data density of about 3–5 points per m² is 1m, when using data with density higher than 10 points per m² it is 0.5 meter. Larger cell size does not bring significantly better results; on the contrary, it is necessary to smooth the created surface. The basic problem for absolute evaluating accuracy of CHM is the discrepancy of the treetop position surveyed by common geodetic methods and the treetop determined from ALS data which is given by the crookedness of the tree stem and the difference of the position of the foot of the stem and its top. The most perspective way of finding out qualitative and quantitative mensurational tree and growth properties by means of remote sensing data remains the combination of terrestrial methods and ALS or at least a combination of ALS and multispectral image data with high resolution.

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