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IDENTIFICATION OF INDIVIDUAL TREES AND GROUPS OF TREES IN THE LANDSCAPE USING AIRBORNE LASER SCANNING DATA

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Abstract. In the work, a fully automatic approach for vegetation delineation using ALS data is presented. Nowadays, in Slovakia, aerial images and satellite scenes are used for this purpose. For vegetation identification, the measurement of local transparency and roughness directly in 3D point cloud was used. The aim was the identification of groups of trees with area bigger than 0.1 ha and individual trees. On the experimental area, 33 polygons representing groups of trees and 120 individual trees were identified. For groups of trees the accuracy of identification was 100%. For comparison, an area with reference polygons, which were manually vectorised by the operator on the orthophotos with spatial resolution 30 cm, was used. The average difference in the area was –0.26%, with standard deviation ±8.17%. The distance of borders of reference polygons and polygons derived from ALS data was also compared, average distance for border parts that fall inside the reference polygons was 2.24 m with standard deviation of ±2.8 m. The average distance for borders parts that fall outside of the reference polygons was 1.84 m with standard deviation ±2.04 m. The accuracy of individual trees identification was 98%.

Keywords: airborne laser scanning, remote sensing, OPALS, vegetation mapping, trees delineation, vegetation boundary.

Introduction

The development of airborne laser scanning (ALS) took place during the 1970s and 1980s, and suitable scanning mechanisms were derived during the 1990s. ALS has been developed extremely rapidly and is now in widespread use. The chronology of forestry-focused scientific research using ALS can be found in Hyyppä *et al*. (2009).

Airborne laser scanning is an active method of remote sensing (RS) which measures the time of laser pulse between the sensor and target. The ALS instruments operate on the principle of RADAR (Radio Detection and Ranging); therefore the acronym LiDAR (Light Detection and Ranging) is used for ALS (Jenn 2005). The scanning is carried out through a series of profile measurements in a direction perpendicular to the flight line. The position and elevation of a mesh of points called a point cloud is generated (Petrie, Toth 2009). High point density of ALS allows the creation of highly accurate digital surface models (DSM), and digital terrain models (DTM) (Hollaus *et al*. 2005). The ALS can be considered as the most accurate method for mapping land surface by RS; it provides rapid and dense collection of data points up to subdecimeter measurement precision (Gallay *et al*. 2012). The big advantage of ALS, according to applications in forestry, is the partial penetration of laser pulses through the canopy cover.

Part of forestry mapping is mapping forest borders – forest delineation. In Slovak conditions forest mapping is mostly done by photogrammetry; mapping is done on 41% of the area of the Slovak Republic. Terrain survey is used if the detail is not visible from aerial images, or for improving measured detail. It is not possible to get information about objects under the forest canopy with photogrammetry methods. Photogrammetry is also sensitive to weather conditions (cloud, fog) and time of flights (orientation and length of shadows). Also ALS is sensitive to some weather condition (dense fog). The data also includes a shadow effect, behind impenetrable objects where there is no reflection of laser pulse. Forest delineation is commonly a large area application (Eysn *et al.* 2012). Forest delineation is done from aerial images or satellite images, and is nowadays done from aerial or satellite images using a different approach. Shadow is a limitation factor for these data types. The operator affects manual forest delineation, and it is likely that on big areas many mistakes could occur. Airborne laser scanning (ALS) is a good tool for forest delineation. Operator's errors are excluded due to the high automation of ALS data processing. ALS also allows forest delineation on big homogeneous forest areas. The option of forest delineation using ALS is shown in Straub *et al.* (2008) and Eysn *et al.* (2012).

This article describes the methodology for vegetation delineation using ALS data. Tree groups used for delineation do not meet any of the forest definition, therefore we use "vegetation delineation". The methodology is based on the measurement of local transparency and roughness directly in the 3D point cloud. The main input is the echo ratio map describing the object transparency for laser pulses. For the evaluation, manually vectorised vegetation borders and points representing individual trees were used.

1. Methodology

1.1. Dataset

ALS data were provided by the vendor, covering the University Forest Enterprise of the Technical University in Zvolen, Slovakia, in September 2012. The airborne laser scanner employed was Riegl L-680i, with a flight altitude of 700 m and a 50° field of view, PRR 320 kHz and SR 122 Hz. The resulting RMSE of absolute data position is 0.047 m. The ALS data provided by the vendor were filtered into the ground points (representing DTM) and non-ground points (representing vegetation, buildings and other objects). The dataset representing the non-ground points was used for the purposes of this article. The average point density of laser points was 21.6 points per m^2. The DTM and DSM were created in the software Microstation V8 with application TerraScan by the vendor.

The images were provided by the vendor, covering the University Forest Enterprise of the Technical University in Zvolen, Slovakia, in September 2011. The camera employed was Microsoft Vexcel UltraCamX. GrafNav and AEROoffice software were used for data processing. Image orthorectification was carried out at the Department of Forest Management and Geodesy. The Inpho software package was used for image orthorectification. Spatial resolution of the orthophotos is 30 cm. Orthophotos are used for creation of the basic dataset using vectorisation tools of the ArcGIS 10 software.

The study area is a part of the University Forest Enterprise of the Technical University in Zvolen (48°37′N, 19°04′E) (see Fig. 1). The whole territory is a part of the eruption rock region (Kremnicke vrchy) and is under the Pannon climate effect. This territory is characterized by broken relief with a different climate attitude. The study area is located in the north-west part of the Zvolen district.

Fig. 1. Study area localization

1.2. Reference dataset creation

For accuracy, an evaluation dataset was used which was created by the ArcGIS 10 Editor tool. In ArcCatalog, a feature class with types of objects – polygons and points – was created. Vectorisation was done manually by the operator. A reference dataset was created on the orthophotos with spatial resolution 30 cm. Two objects of interest were used. The first object of interest type was groups of trees with area bigger than 0.1 ha. With this object of interest borders were vectorised. 33 polygons were vectorised, representing groups of trees. The second object of interest type was individual trees. Individual trees were marked as a point on orthophotos. 120 trees were identified on the experimental area. All objects were stored in the geodatabase. The area in ha was calculated for groups of trees.

Individual trees and tree groups are mostly represented by broadleaved species like *Fagus silvatica*, *Quercus* sp., *Tilia* sp., *Acer* sp., *Prunus spinosa*, *Cerasus avium*. In three tree groups the representation of *Picea abies* was up to 10%.

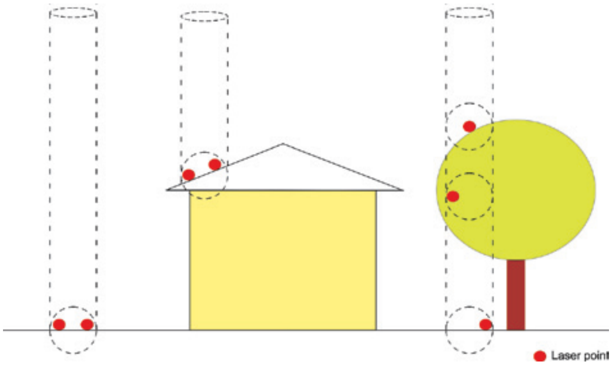

Fig. 2. Calculation of Echo Ratio in point cloud

1.3. Vegetation identification from airborne laser scanning data

The ALS data were processed using OPALS software, developed by Institute of Photogrammetry and Remote Sensing, Department of Geodesy and Geoinformation on Vienna University of Technology. The OPALS software stores ALS data using the OPALS data manager (ODM). The ODM was designed and implemented to achieve maximum performance. Data represented by points are stored in the ODM in the K-d tree; this is an extremely fast spatial indexing method; and more complex geometries in an R*-tree (Mandlburger *et al.* 2009). Details about using the multiple K-d tree can be found in Otepka *et al.* (2006).

Vegetation delineation uses the fact that laser pulses are reflected by vegetation penetration – in this case trees – at different heights. These laser pulses are vertically distributed in space. On the other hand, laser pulses are reflected by impenetrable surfaces mostly at the same height. For example, vegetation such as trees and shrubs is penetrable for laser pulse, whilst asphalt and roofs of buildings are impenetrable objects. For vegetation delineation, a measurement of local transparency and roughness was used. For this measurement the vertical distribution of laser pulses is used. Measurement was done in OPALS and made in 3D point cloud directly (see Fig. 2). This measurement is Echo Ratio (ER). The ER is derived for each laser point and defined as follows (Höfle *et al.* 2009):

$$\text{Echo Ratio [\%]} = n_{3D} / n_{2D} \times 100, \quad (1)$$

where: $n_{3D} \leq n_{2D}$; n_{3D} – number of points found in a fixed search distance measured in 3D (search in sphere); n_{2D} – number of points found in the same distance measured in 2D (vertical search cylinder with infinite height).

Search distance is important for the calculation. Setting double the average point spacing found in the data guarantees a representative number of neighbours. Too large neighbourhoods cause expanded transition zones at the borders of two objects with different surface structure (Höfle *et al.* 2009). For ER calculation a search distance of 1.2 m was used, which represents double the average point spacing in the data set. The cell values in the result raster layer refer to the penetration of laser pulses. ER value of 100% means that the laser points within the 2D search radius describe impenetrable and continuous surfaces, whereas an ER value <100% means the laser points are vertically distributed within the 2D search radius (Hollaus *et al.* 2010).

For roofs with a slope the ER value will be lower due to laser pulses' space distribution. To guarantee the high value of ER on tilted roofs, the 3D search distance has to be extended considering the roof slope. This is done by dividing the initial 3D distance by the cosine of the roof slope; this parameter is called the slope-adaptive Echo Ratio (sER) (Höfle *et al.* 2009).

The sER threshold value of 85% was used to separate vegetation from impenetrable surfaces. The threshold was based on results in the work of Smreček (2013), Smreček, Sačkov (2013). Morphological operations were performed on the resultant binary raster layer. On the binary raster layer are a set of objects (value 1) and non-object (background, value 0) elements. Two operations were used on the raster layer – dilate and erode. The dilate operation is defined as the set of all elements that are covered by the kernel, if the kernel is centred over an object element. The result of the erosion operation is a set of all elements for which the area is centred on the element, only comprising object elements (Hollaus *et al.* 2010). A circle shape with radius 2 m was used for both operations.

1.4. Vegetation delineation result evaluation

From the vegetation mask created using OPALS, polygons were selected that correspond to the polygons representing groups of trees. Groups of trees were represented by 33 polygons. Area in m^2 was calculated for these polygons. The calculated area was compared with the polygon area from the reference dataset.

Borders of polygons from ALS and reference data were also compared. For this reason ArcGIS 10 tools were used. Polygons from ALS data were converted to the vertexes (points). For each vertex the nearest distance to the border of the reference polygon was calculated. For vertexes that fall inside the reference polygons, minus value was added. These vertexes reduce the area. Vertexes with plus value are located on the non-vegetation area and expand the area of polygons that are derived from ALS data.

Individual trees were marked only by a point. Identification accuracy for individual trees was calculated. As an accuracy value the percentage of trees was selected that were found on the sER raster layer created from ALS data.

Table 1. Area and differences for polygons representing groups of trees

Polygon ID	Area [m^2]		Difference	
	Vectorised	ALS	m^2	%
1	1209.15	1297.54	−88.39	−7.31
2	5400.24	5643.50	−243.25	−4.50
3	6775.23	6875.24	−100.00	−1.48
4	14190.01	13341.60	848.41	5.98
5	772.04	934.12	−162.08	−20.99
6	1998.11	2120.76	−122.65	−6.14
7	509.96	633.33	−123.37	−24.19
8	31837.57	31744.81	92.76	0.29
9	3023.37	2932.20	91.17	3.02
10	3524.23	3376.89	147.34	4.18
11	4640.76	4665.06	−24.30	−0.52
12	4283.89	3662.01	621.88	14.52
13	3472.69	3263.03	209.66	6.04
14	16099.77	17155.53	−1055.76	−6.56
15	14276.23	14292.09	−15.86	−0.11
16	3966.41	3732.30	234.11	5.90
17	23241.84	23055.91	185.93	0.80
18	3961.90	3879.72	82.18	2.07
19	1025.43	946.64	78.79	7.68
20	941.24	907.38	33.86	3.60
21	565.46	619.47	−54.01	−9.55
22	426.05	402.93	23.12	5.43
23	3945.60	3926.35	19.25	0.49
24	6696.74	7289.79	−593.05	−8.86
25	3869.83	3572.41	297.42	7.69
26	581.37	614.43	−33.06	−5.69
27	18270.66	17799.24	471.42	2.58
28	22520.23	22530.99	−10.76	−0.05
29	1168.33	1256.04	−87.71	−7.51
30	4971.34	4660.11	311.23	6.26
31	2754.69	2623.23	131.46	4.77
32	6176.67	5949.81	226.86	3.67
33	1003.00	901.80	101.19	10.09

2. Results and discussion

First, the area difference of groups of trees was compared. The average difference between the reference dataset and data from ALS was −0.26%, with standard deviation ±8.17%. The biggest difference of 24% is by area 123 m^2. This big difference is due the high grass in south-east part of the tree group. The grass was identified as a tree by OPALS algorithm. This problem can be eliminated with defining the minimum height of the trees. In 15 cases the difference was lower than ±5%, up to ±10% were 14 polygons, two polygons had 15% difference, and two polygons had a difference bigger than −20%. Area and differences for all polygons is shown in Table 1. In their work Eysn *et al*. (2010) state that compared areas of the manually and automatically detected forests show very good agreement. In this study for the Zillertal experimental area the total forest area is 316.375 ha and 311.327 ha for the manual and automatic detected forest area respectively. Eysn *et al*. (2012) achieved accuracy of 94% for the classified forest areas.

By the visual examination of polygons derived from both data sources (Fig. 3), several differences are obvious. Boundaries derived by OPALS are more complex than polygons derived by manual vectorisation, due to the fact that vectorisation is done from the raster layer. The complexity is based on parameterization. Another reason is that operators make some generalization because of the resolution and quality of the orthophotos and the intrinsically included generalization. Differences of polygons derived by the semi-automated process and manual vectorisation were also stated in the work of Haywood and Stone (2011).

For comparison of borders, vertexes were divided into two groups. The first group contains vertexes with a negative value; these vertexes fall inside the reference polygons. The second group contains vertexes with a positive value; these vertexes fall outside the

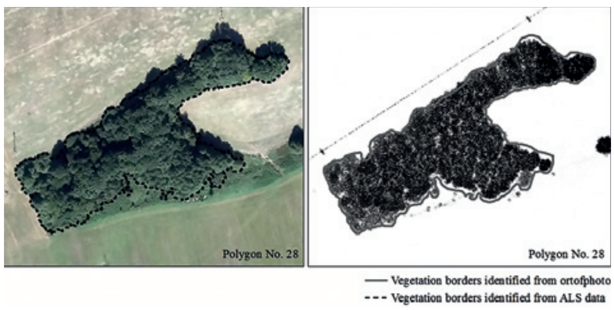

Fig. 3. Identified vegetation borders from ALS data on an orthophoto (left) and vectorised vegetation borders upon the sER raster layer (right)

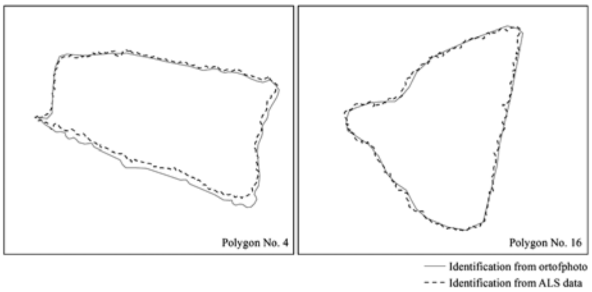

Fig. 4. Borders comparison of groups of trees created on orthophotos and from ALS data

reference polygons. An example of polygon borders is shown on Figure 4. Because of crossing two borders derived from orthophoto and ALS data, the minimum distance in the first group was 0 m, and maximum distance was 28.6 m. The average distance was 2.24 m with standard deviation ±2.8 m. The variance in the first group was 7.86 m. In the second group the minimum distance was 0.001 m, maximum distance was 15.9 m. The average distance was 1.84 m with standard deviation ±2.04 m, and the variance was 4.15 m. These results are bigger than the results from the study of Straub *et al.* (2008). He used 66 points measured using GNSS technology. The mean deviation was 1.08 m for automatically delineated vegetation boundary and 0.82 m for visually delineated vegetation boundary. The maximum deviation was 9.12 m for automatically delineated vegetation boundary and 2.88 m for visually delineated vegetation boundary. In comparison to our results, the results derived by these authors are lower. The reason for such big differences is that these authors made the measurements in terrain using GNSS technology in comparison to our vectorised data from orthophotos. Ørka *et al.* (2012) state that predicted forest lines representing forest boundaries showed a good correspondence with the field measurement. In their work, the visual inspection of 26 field locations for field measurements did not have a satisfactory match of fields measured and ALS derived boundaries.

From 120 trees on the experimental area, 118 trees were identified from ALS data. This result represents 98% accuracy. No false positives were identified on the experimental area. In two cases trees were not exactly identified. The positions of these two trees identified from ALS data were markedly moved from the position identified from orthophotos. Also the crown polygons representing the trees identified from ALS data had a markedly different shape from the shape on the orthophotos. Due to these facts these trees were marked as unidentified. The reason may be some error due to data preprocessing, or changes in the landscape during the time between the images being taken and laser scanning. Because trees were identified in nature, this high accuracy was expected. The problem with tree identification from ALS data is that some tree species are clipped for garden purposes. The result is a very dense crown, which is impenetrable for laser pulses (Smreček 2013). In the work of Smreček (2013) the accuracy for tree identification from ALS data was 97% for trees with crown diameter higher than 5 m. Trees that are permanently clipped were not identified. The accuracy of identification for trees with crown diameter lower than 5 m was 62%. The reason is a low crown diameter, crown form and also high crown density. In the work of Straub *et al.* (2008) the accuracy of individual tree identification was from 52 to 69%. In the work of Ørka *et al.* (2012) two tree lines from 26 field locations did not have a satisfactory match of field measured and ALS derived boundaries.

Conclusions

It was shown that the automated method of ALS data processing presented in the paper can be used for vegetation mapping. The delineation of vegetation was based on the measurement of local transparency and roughness. For this measurement the vertical distribution of laser pulses was used. The fact that vegetation (trees, shrubs) is penetrable for laser pulses was used. For the extraction of vegetation regions, the number representing local transparency and roughness was used.

Two types of object of interest were identified from ALS data; automated data processing was used. The first objects of interest were groups of trees with minimum area of 0.1 ha. The second objects of interest were individual trees. As reference data manually vectorised borders of groups of trees were used and the position of individual trees. Manual vectorisation was done on orthophotos with spatial resolution 30 cm. On the experimental area, 33 polygons were vectorised representing groups of trees and 120 individual trees. All groups of trees were identified from ALS data. The area between polygons from reference data and derived from ALS data was compared. The average difference was –0.26%, with standard deviation ± 8.17%. For individual trees, 118 trees of 120 were identified. The high accuracy was expected due to good laser pulse penetration through crowns.

Based on the results and also on the work of other authors (Straub *et al.* 2008, Eysn *et al.* 2012, Ørka *et al.*

2012), we confirmed that the ALS is fully applicable for automated forest/vegetation delineation. Laser pulse penetration through vegetation is the big benefit of ALS data in comparison to photogrammetry. The 3D position of the points and reflected laser pulses can be used for improving results; using height as parameters bushes can be excluded from the vegetation search. Fully automatic methods for ALS data processing may exclude the operator's errors.

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