Individual tree and crown identification in the danube floodplain forests based on airborne laser scanning data

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Abstract. In the work, a fully automatic approach for individual tree and crown identification using laser scanning data is presented. The automatic identification was realized in parts of the Danube floodplain forests (47˚52´N, 17˚32´E). Poplar and willow plantations are dominant in the area, but there are also reservations with mixed forests of broadleaves. The general principle of workflow was identification of local maxima in the segmented point cloud and, according to specific dendrometric criteria, to decide which of the local maxima represent the tree tops. For this purpose the module “Tree and Crown Identification” from the “reFLex” software was used. Outputs of automatic detection were compared with ground data from reference plots (346 trees). The RMSE of tree and crown identification with the “reFLex” software in the area of interest was ±21 %.

Keywords. Tree detection, Crown delineation, Individual tree monitoring, LiDAR

1. Introduction

The hydropower project “Gabčíkovo” on the Danube has significantly influenced the water regime and through it the condition of the Danube floodplain forest in the region. The forest area is therefore in the long term monitored using aerial images, together with the Hungarian side, within the meaning of the agreement between the Government of the Slovak Republic and the Government of the Hungarian Republic that was concluded in 1995. Hydro-technical measures have been implemented in the area, providing a water supply to the environment of the floodplain forests and maintaining their productive potential.

Traditionally the number of trees and crown sizes are basic parameters in the practice of monitoring. Among other things, dendrometric attributes characterize stand structure, status and development of forest communities as well. This is particularly important in assessing of indigenous or planted fast growing forest communities such as soft flood forest.

Many approaches were proposed to separate tree crowns based on different derivates of the aerial images. For example, the top of a tree or tree crown can be detected by the analysis of the highest and the lowest brightness values in the RGB images [1, 2]. Another option is the application of digital surface models derived from stereo [3] or infrared images and approximation of tree crowns by ellipses [4]. Other approaches proposed use of methods for an individual tree crown delineation based on multi-scale filtering and segmentation of imagery [5], supervised classification and the Spectral Angle Mapper method [6] or semi-automatically masked non-forest segments and then applied the Isodata method for classification of tree crowns in remaining segments within the forest [7].

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Nevertheless that classification based on aerial images is an effective method of monitoring the condition of forests; the drawback of this method is a limitation in assessment of the internal structure of forest stands. Recent developments in remote sensing overcome the mentioned limitation by the application of 3-dimensional methods for obtaining and interpreting data. There are many approaches for individual tree and crown identification from airborne laser scanning data (ALS). Generally these methods are based on reflection of points in a certain height range [8] and on global or local maximum methods [9, 10].
The objective of this article is to present and evaluate the proposal of our own solution within the “Tree and Crown Identification” module within the “reFLex” software, a product of the National forest centre. The principle of the procedure is based on the algorithm that uses laser scanning data for iterative finding and testing of local maxima in the point cloud while points are segmented in a regular net. The results of workflow are selected local maxima, which should represent only “correct” tops of trees and tree crowns. The procedure was tested in the area of Danubian floodplain forests. The paper also includes an evaluation of perspectives and shortcomings of this approach.

2. Methods

2.1. Area of interest

The evaluated area of the Danube left-hand side inundation is located between the original Danube riverbed and the canal of the “Gabčíkovo” Waterworks (Fig. 1a). The area is characteristic with a developed river branch system, complexes of floodplain forests and alluvial meadows. The forest area is approximately 3,000 ha. The floodplain forest wood composition of the concerned area is, according to forest management planning from 2005, as follows (Fig. 1b): cultivated poplars (*Populus sp*.) 62 %, domestic poplars (*Populus nigra* L. a *P. alba* L.) 10 %, willows (*Salix alba, S. fragilis* L.) 17 %, ash trees (especially *Fraxinus angustifolia* VAHL.) 6 %, and other deciduous tree species 5 %, especially English oak (*Quercus robur* L.), acacia tree (*Robinia pseudoacacia* L.), sycamore maple (*Acer pseudoplatanus* L.), and alder trees (*Alnus sp.*).

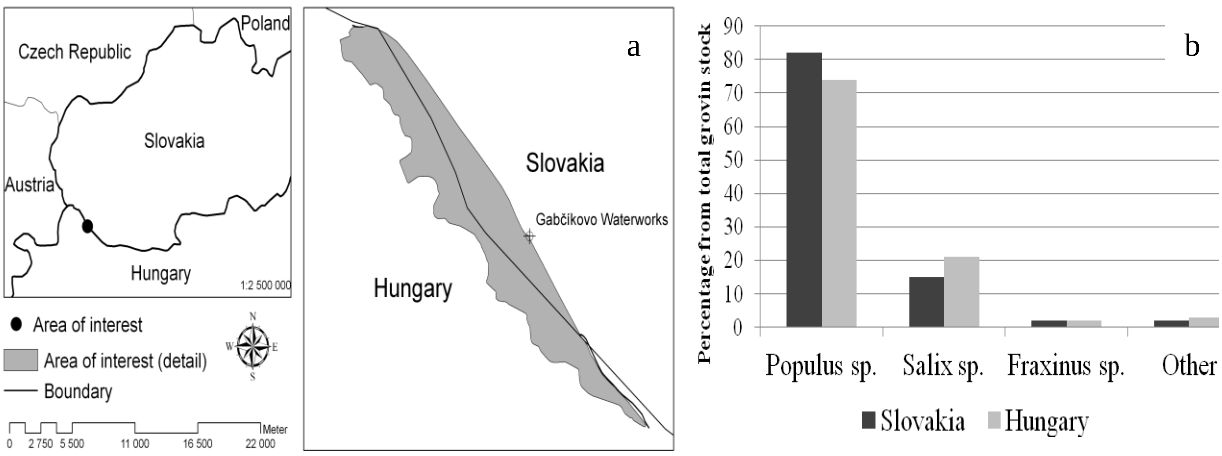

Figure 1: a) Area of interest; b) Tree species composition in the area of interest

2.2. Remote sensing data

The laser scanning was performed in September 2013 and obtained data cover all of the territory of interest. The scanning was performed by a RIEGL Q680i device, borne by Piper PA-34 Seneca at the average altitude 660 meters, scanning angle 45˚ (FOV) and scanning frequency 400 Hz (PRR) providing scanning density of ca 5 points per square meter.

2.3. Ground data

The ground true data were collected during field survey at the reference plots distributed in the territory of interest in the period September-November 2013. The plots were selected within strata defined by the combination of tree species composition and age. The overview of stand characteristics at the individual reference plots is provided in Table 1.

Table 1. Characteristics of the reference plots

Plots_ID	Area of plots (ha)	Number of trees (n)	Tree species composition (%)	Mean height (m)	Mean diameter (cm)	Crown coverage (%)
Plot_1	0.25	61	Poplar(100)	27.90	35.46	80
Plot_2	0.08	39	Poplar(97); Ash(3)	30.70	28.79	80
Plot_3	0.13	40	Willow(100)	22.90	31.73	70
Plot_4	0.41	76	Willow(89); Ash(11)	27.90	54.93	60
Plot_5	0.13	130	Ash(100)	19.10	18.84	100
Together	0.99	346	-	-	-	-
Average	0.20	69	-	25.70	33.95	78

2.4. Individual tree and crown identification

The simplified scheme of the "Trees and Crown Identification" module as part of the "reFLex" software product is provided in Figure 2.

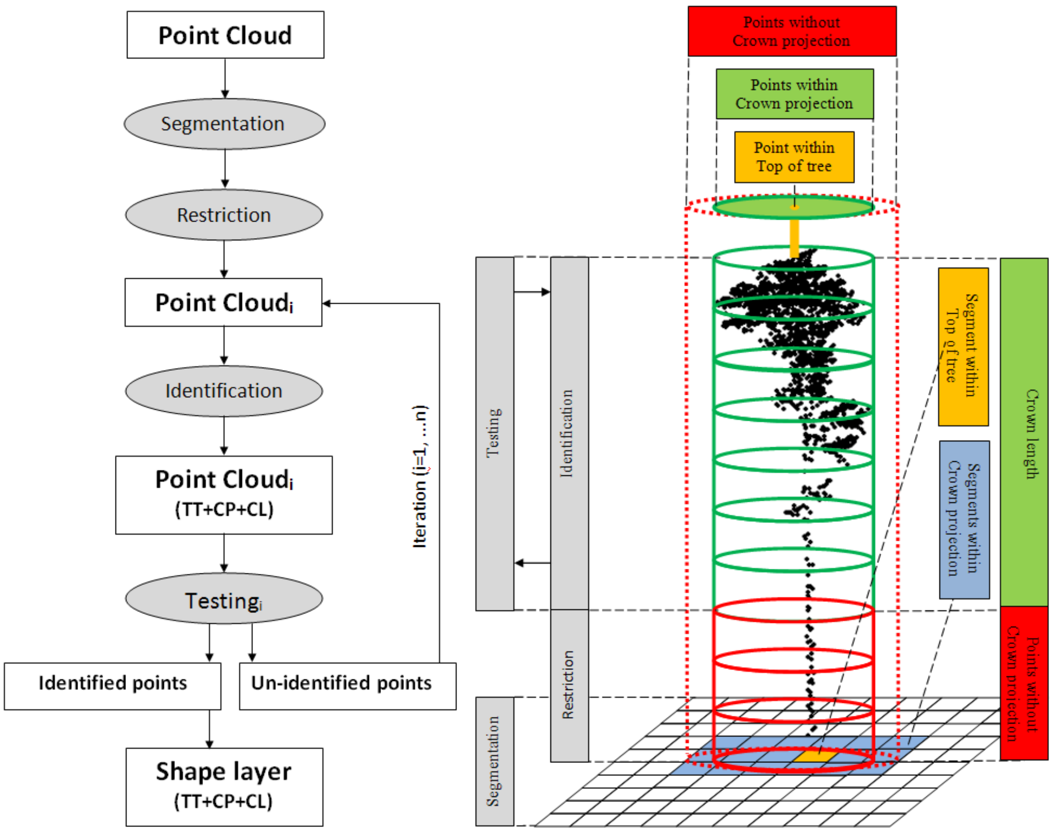

Figure 2: Simplified scheme of individual tree and crown identification
Note: TT – Top of tree; CP – Crown projection; CL – Crown length; i – Iteration (i=1, ...n)

The main source of information is a processed point cloud which contains only geo-referenced points of the class “vegetation”. For effective processing, the regular segmentation is applied as a first step and points characterized by the height below a user-defined threshold are eliminated (restriction). The identification of local maxima is applied in such a reduced point cloud in each segment and crown projections and crown lengths are assessed. As a result some points are attributed to the local height maxima defining individual tree crowns. Such points are then tested against the criteria of whether these points can be part of a single tree crown. The testing criteria include user defined limits of crown diameter, distance between trees and height difference between tree tops. The points in the segments which passed testing criteria are assigned with attributes of “first tree tops” and “first crowns” and are exported in vector format – point layer of tree tops and polygon layer of tree crowns. The remaining points are again iteratively tested until they are assigned with either the tree top or crown attribute.

2.5. Results evaluation

The number of trees identified from remote sensing data was compared to the data from the field survey at the reference plots. The data from the field survey can be considered as ground true and from the comparison provides the accuracy of results obtained by the application of “reFLex” algorithm. The significance of difference was tested and confidence interval of results was calculated.

3. Results

The outputs of the module “Trees and Crown Identification”, which is part of the in-house software “reFLex”, are vector layers in ESRI shapefile format (*.shp). An example of such an output file is in Figure 3. The point objects represent single trees (tree tops) and polygon objects represent tree crowns (crown projections). The outputs of field survey (red points) and from the processing of laser scanning data (blue points and lines) are displayed simultaneously in Figure 3a. The outputs of laser scanning data processing overlaid over a normalized digital surface model (nDSM) are displayed in Figure 3b.

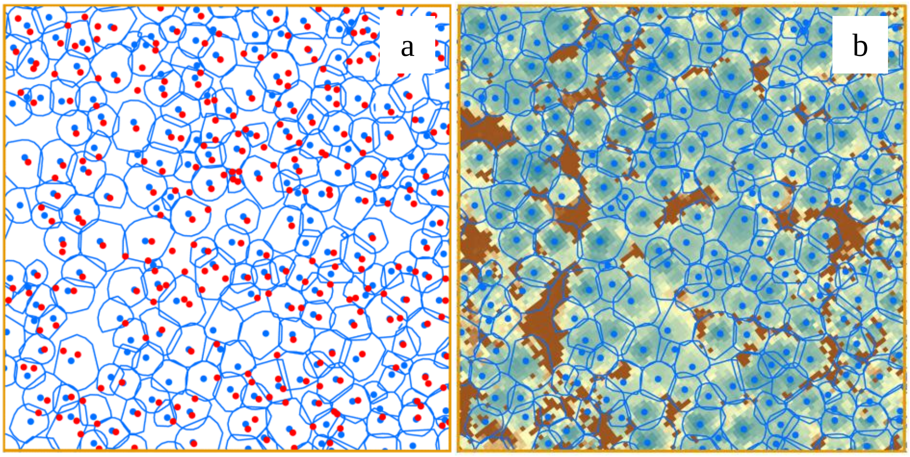

Figure 3: The positions of tree tops and crown projections: a) The positions of trees measured in the field (red points) and detected from laser scanning data (blue points), blue polygons represent crown projections detected from laser scanning data; b) The positions of tree tops and crown projections overlaid over a digital surface model (nDSM)

The numbers of trees observed at the plots in the field and detected from laser scanning data including their relative proportion are provided in Table 2. According to the analysis of results the dif-

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ferences in the accuracy between single plots were not significant and therefore cannot be attributed either to the diverse species or the canopy. The assessment of tree tops can be characterized as conservative since the number of detected tree tops at four of five plots was lower than the number of trees observed in the field. The trees omitted in detection are often growing in clusters (Fig. 3) below the main canopy layer (Fig. 4).

Table 2. The number of trees observed in the field and detected from laser scanning data

Characteristic	RP1	RP2	RP3	RP4	RP5	$\bar{x}$	s_x
N_{TER}	61	39	40	76	130	69	±37
N_{ALS}	55	24	27	89	113	62	±39
$PN_{ALS}/N_{TER}\%$	62	90	68	117	87	85	±22

Note: RP1-5 – reference plot No. 1-5; $\bar{x}$ – mean; s_x – standard deviation; N – number of trees; TER – observed in the field; ALS – detected from laser scanning; $PN_{ALS}/N_{TER}\%$ – the percentage ratio of the number of detected trees to the number observed in the field.

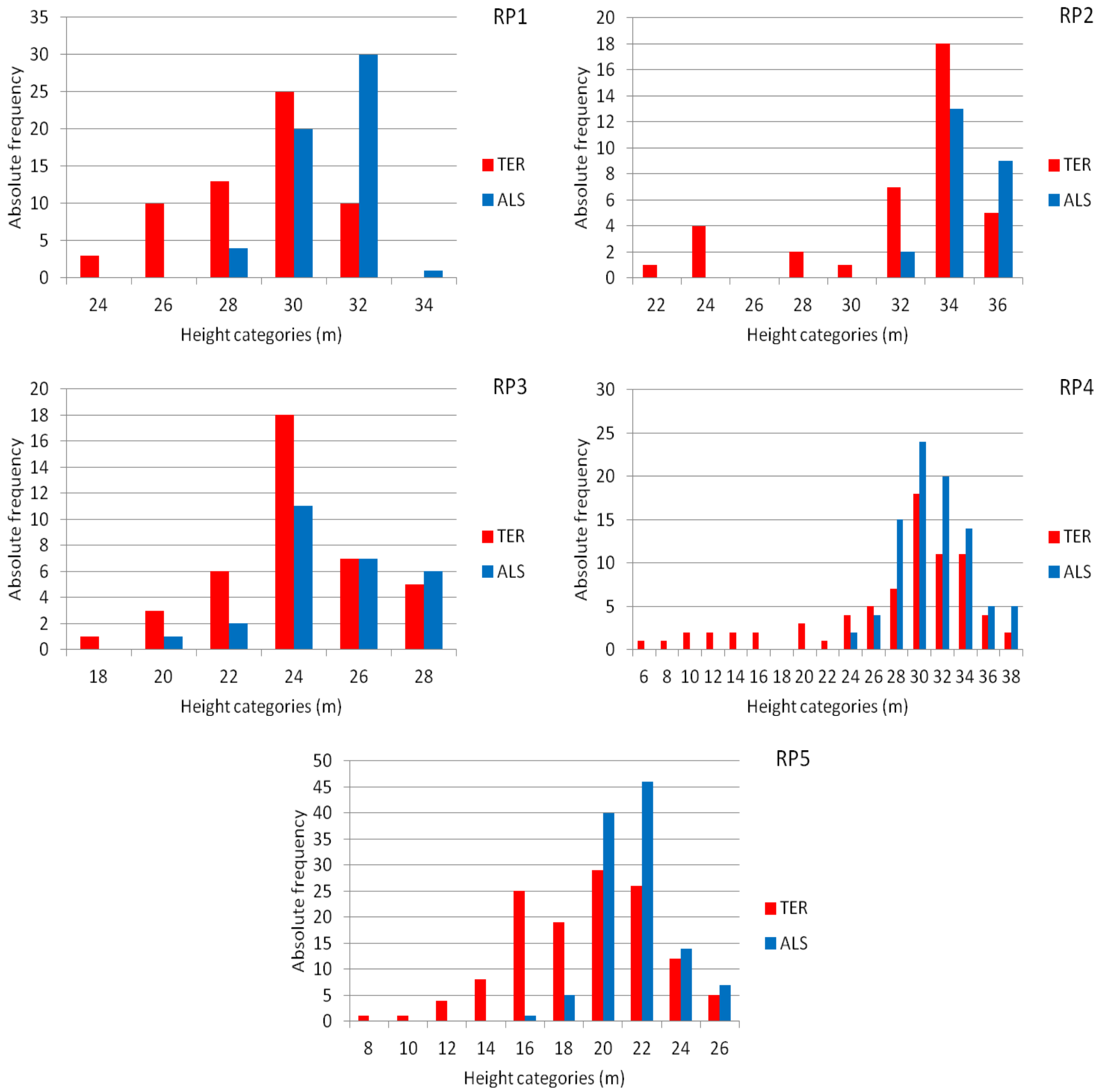

Figure 4: The absolute frequencies of detected (blue columns) and observed trees (red columns) in tree height categories

The absolute differences between the detected number of trees and the number of trees observed in the field at individual plots are in the range from -17 to +13; the relative differences are from -38 % to +17 % (Table 3). On average, the number of detected trees was underestimated by 11%. However, due to the variability of results between individual plots this underestimation was not significant at the significance level 95 %. According to the results we can expect that the number of trees detected by our method will for individual assessments differ from the real number of trees by ±21 %.

Table 3. Differences in the number of trees detected from laser scanning data and observed in the field

Difference	RP1	RP2	RP3	RP4	RP5	$\bar{e}$; $\bar{e}$ %	s_e; s_e%	RMSE; RMSE%
e_i	-6	-15	-13	13	-17	-8	±12	±14
e_i%	-10	-38	-33	17	-13	-11	±18	±21

Note: RP1-5 – reference plot No. 1-5; e_i, e_i% – absolute and relative difference; $\bar{e}$, $\bar{e}$ % – mean absolute and relative difference; s_e, s_e% – absolute and relative standard error; RMSE, RMSE% – absolute and relative root mean square error of individual assessments.

4. Conclusions

The monitoring of forests in the area of the hydropower scheme "Gabčíkovo" is performed regularly as the impact of the changed water regime on the forests is of interest. The methods of remote sensing provide a long-term and effective wall-to-wall alternative to the laborious field measurements usually located at a limited number of plots. The airborne laser scanning is an innovative approach providing additional info to the aerial imagery.

The module "Trees and Crown Identification" described in this study was developed for the in-house "reFLex" software. The proposed method provides remote assessment of the number of trees, which is an important parameter for characterization of the structure of forest stands and also for assessment of other dendrometric parameters necessary for individual-tree detection approaches (ITD). The proposed approach provides assessment of the number of trees with RMSE ±21 % when compared to the number observed in the field. The omission of trees prevailed at tested plots and omitted trees were usually smaller in height and diameter than stand averages of these parameters. We can assume that omission of these trees should not have significant impact on the assessment of timber volume.

The results of our method are satisfactory as in previous studies the RMSE was in the range ±32-89 % [11, 12, 13]. Our results may be better due to the relatively simple structure of planted floodplain forests at the reference plots; however, such even-aged stands of broadleaved trees are characterized by dense canopy with limited height diversification of canopy limiting detection of individual tree tops.

Further research will be oriented to the testing of the proposed approach in different geomorphologic and ecological conditions and further tuning of methods for automated processing of ALS data providing detection of individual trees and their crown parameters important for timber volume and forest stand structure assessment.

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References

[1] Pouliot D A, D J King, F W Bell & D G Pitt, 2002. *Automated tree crown detection and delineation in high-resolution digital camera imagery of coniferous forest regeneration*. Remote Sensing of Environment, 82: 322-334.

[2] Wang Y, S Y Soh & H Schultz, 2006. *Individual tree crown segmentation in aerial forestry images by mean shift clustering and graph-based cluster merging*. International Journal of Computer Science and Network Security, 6 (11): 40-45.

[3] Hirschmugl M, M Ofner, J Raggam & M Schardt, 2007. *Single tree detection in very high resolution remote sensing data*. Remote Sensing of Environment, 110 (4): 533-544.

[4] Wolf B M & Ch Heipke, 2007. *Automatic extraction and delineation of single trees from remote sensing data*. Machine Vision and Applications, 18 (5): 314-330.

[5] Jing L, B Hu, T Noland & J Li, 2012. *An individual tree crown delineation method based on multi-scale segmentation of imagery*. ISPRS Journal of Photogrammetry and Remote Sensing, 70: 88-98.

[6] Pontius J, M Martin, L Plourde & R Hallett, 2008. *Ash decline assessment in emerald ash borer-infested regions: A test of tree-level, hyperspectral technologies*. Remote Sensing of Environment, 112: 2665-2676.

[7] Bucha T & M Slávik, 2013. *Improved methods of classification of multispectral aerial photographs: Evaluation of floodplain forests in the inundation area of the Danube*. Folia Forestalia Polonica, Series A, 55 (2): 58-71.

[8] Meng H, N Currit & K Zhao, 2010. *Ground Filtering Algorithms for Airborne LiDAR Data: A Review of Critical Issues*. Remote Sensing, Vol. 2, 22 March 2010: 833-860.

[9] Rossmann J, M Schluse, A Bücken & P Krahwinkler, 2007. *Using Airborne Laser-Scanner-Data in Forestry Management: a Novel Approach to Single Tree Delineation*. In: ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007: conference proceedings. Vol. 36, Part 3/W52. Espoo (Finland), 2007: 350-354.

[10] Heinzel J N, H Weinacker & B Koch, 2008. *Full automatic detection of tree species based on delineated single tree crowns - a data fusion approach for airborne laser scanning data and aerial photographs.* In: SilviLaser 2008 Proceedings: conference proceedings. Edinburgh (UK), 2008: 76-85.

[11] Heurich M, S Schadeck & H Weinacker, 2004. *Forest Parameter Derivation from DTM/DSM Generated from LiDAR and the Digital Modular Camera (DMC)*. In: International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. ISSN 1682-1750, vol. 35, part. B: 84-89.

[12] Lindberg E & M Hollaus, 2012. *Comparison of Methods for Estimation of Stem Volume, Stem Number and Basal Area from Airborne Laser Scanning Data in a Hemi-Boreal Forest.* Remote Sensing, 4(4): 1004-1023.

[13] Kaartinen H, J Hyyppä, X Yu, M Vastaranta, H Hyyppä, A Kukko, M Holopainen, C Heipke, M Hirschmugl, F Morsdorf, E Næsset, J Pitkänen, S Popescu, S Solberg, B M Wolf & J C Wu, 2012. *An international comparison of individual tree detection and extraction using airborne laser scanning*. Remote Sensing, 4: 950-974.

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