Estimation of vertical forest layer structure based on small-footprint airborne LiDAR

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1. Introduction

Knowledge about the 3D structure of the vegetation is of critical importance for Natura 2000 (N 2000)-related habitat assessment. Besides the characteristics of the canopy the presence or absence of understory (sub-dominant tree and shrub layers), its cover and species composition are important indicators of habitat quality in many forest types.
Airborne LiDAR is known to accurately depict the canopy surface, an ability that is usually exploited to derive vegetation heights and to compute an nDSM, which may also depict multiple vegetation layers. However, this layer information can only be based on the upper crown heights of the dominant plants. Yet, ALS is capable of entering the canopy through small gaps and thus depicting the arrangement of foliage masses below, a fact that cannot be accounted for in the nDSM.

In this contribution, this penetration capability of ALS is used to derive information on the abundance of sub-dominant vegetation layers.

2. Study area and data

The selected study area is located in Hungary in the Great Forest of Debrecen (Nagyerdö), which is included in the Debrecen-Hajdúböszörményi tölgyesek N 2000 site. The forest consists of several extended old stands (80 – 120 yrs.) with high nature conservation value. The stands are multi-layered, featuring two distinct tree layers (dominant and sub-dominant), as well as a shrub and species rich herb layer. The typical tree species are pedunculate oak (*Quercus robur*), field maple (*Acer campestre*), wild cherry (*Prunus avium*) and linden species (*Tilia* spec.).

For this study airborne LiDAR data acquired under leaf-on and leaf-off conditions with a RIEGL LMS-Q680i full-waveform laser scanner mounted on a fixed-wing aircraft were at hand. The mean echo density was determined with 27.5 echoes / m^2 (leaf-off) and 29.4 echoes / m^2 (leaf-on) under consideration of all available echoes (first, intermediate, last of many).

3. Method

The underlying hypothesis is that the distribution of ALS echoes in the vegetation allows drawing conclusions on its structural complexity. Given adequate penetration of the canopy by the laser beams, a lack of echoes in a certain height interval is therefore founded in the absence of vegetation to act as a reflector, rather than in the occlusion from higher parts of the canopy. The clustering of ALS echoes on the other hand is an indication for the presence of a significant amount of foliage mass, and is consequently considered to represent a vegetation layer.

The presented approach for the estimation of vegetation layer structure is based on this hypothesis. The method derives vertical layering information on pixel and on plot level. In this way, the high spatial resolution provided by LiDAR can be exploited to detect the layer structure of small vegetation objects, while the fine resolution results are used to derive the stratification for an area wide assessment.

On the pixel level, first height densities (i.e. percentage of echoes per height level) are calculated for each grid cell from the LiDAR point cloud. If a pixel holds more than a pre-defined percentage in a certain height interval, this interval is set to 1, if not, it is set to zero (i.e. binarization). Subsequently, the actual layer structure estimation is carried out on a raster basis. The algorithm probes all pixel positions for vertical sequences of intervals set to 0 or 1. A sequence begins or ends if a 0-interval is encountered. One sequence corresponds to one vegetation layer (see *Figure 1*a).

On the plot level, all pixels of one height interval are considered together as one binary map (called a slice). The algorithm proceeds in a similar way as for the pixel, as it searches for slices containing only 0-intervals. Such a slice is consequently considered as a gap, separating two distinct vegetation layers (see *Figure 1*b).

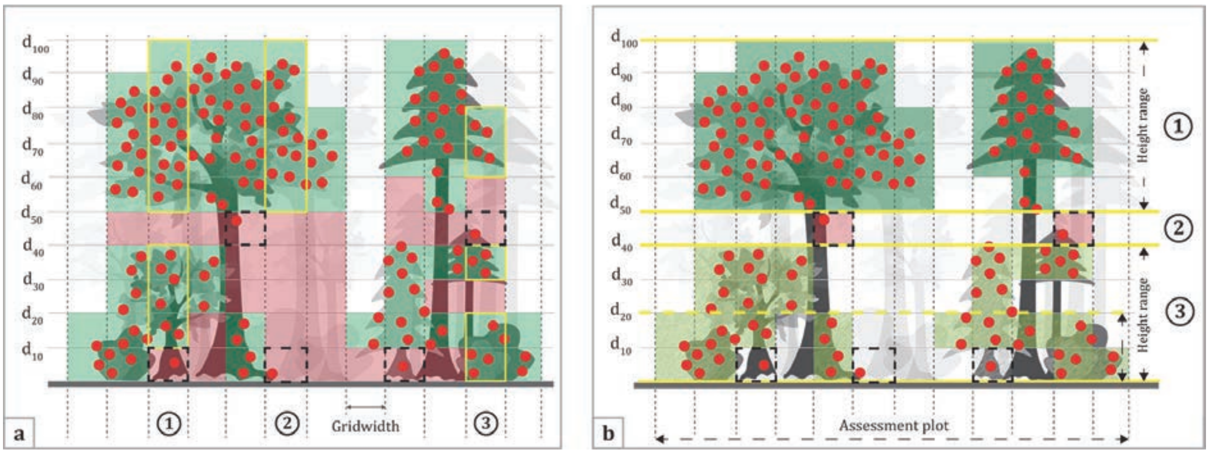

Figure 1: (a) Structure is estimated on the pixel level. Connected vertical sequences of green intervals correspond to one vegetation layer (yellow outlines). Red intervals correspond to vertical gaps (no echoes were found). If an interval does not hold enough echoes, it is neglected (dashed black outlines). In example 1 there are two layers, in example 2 only one layer, and in example 3 there are three layers. (b) Structure is estimated on plot level. All pixels of one height interval are considered together. Example 2 contains only 0-intervals, thus separating the two layers represented by examples 1 and 3.

The dependencies of the method on involved parameters (i.e. grid size, extent of height intervals, threshold used for minimum percentage of echoes) are investigated and the respective results are compared. The ground estimations are used to evaluate the method's success for both data sets (leaf-on and leaf-off) on plot-level. The pixel-based results are evaluated visually using the 3D LiDAR point cloud.

4. Results

The pixel-based result is a map holding the number of vegetation layers found for each pixel. *Figure 2* shows results for two selected assessment plots and different parameter settings. It can be seen that the layer map represents the visual impression from the point cloud very well. Where a distinct shrub and top layer are present, the method detected two layers correctly.

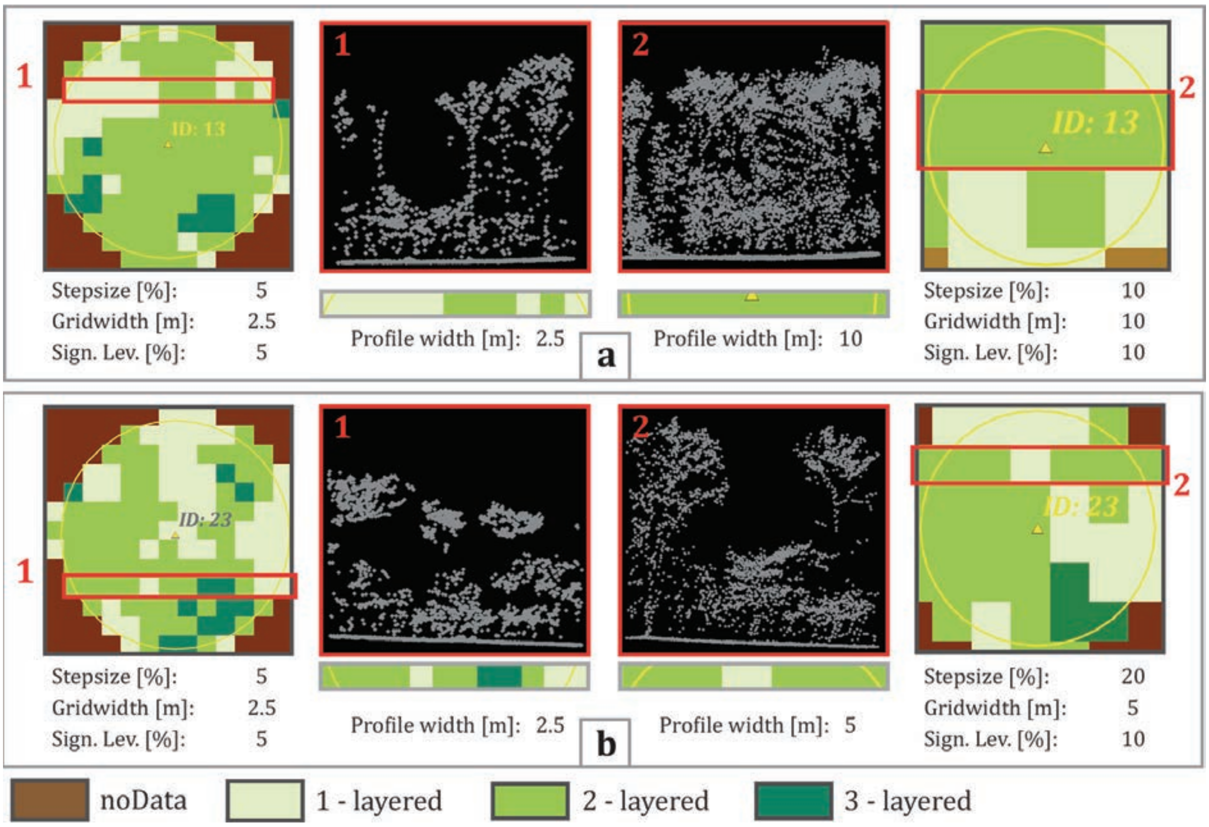

Figure 2: Examples for pixel-based results. The colour-coded maps show the detected total number of layers per pixel. Profiles from the LiDAR point cloud are depicted for comparison. Extracts of the respective locations of the profiles in the layer map are given below the profile views. The profile widths for all examples equal the grid widths used to generate the corresponding layer maps.

For the plot-level, the evaluation was carried out automatically through a comparison of layer presence or absence in the field data and the LiDAR-based results. Computing pairs of completeness and correctness for every used parameter setting determined the quality of the result. The method was successful in the detection of distinct layers, either shrubs or trees, with completeness and correctness > 80%, regardless of data input (e.g. acquisition time, parameter setting). The quality was significantly weaker for sub-dominant tree layers (i.e. in between shrub and top canopy layer).

5. Conclusion

The presented LiDAR-based method for detection of understory vegetation enables the derivation of vegetation layer structure estimates in resolutions and area extent on a highly objective basis, which is not simply doable with manual assessments. The results can be employed to derive the area percentage of a certain site that is one-, two, or multi-layered, and how much is covered by shrub layer. ALS-based layer structure maps are able to deliver a valuable input for the planning of N 2000 ground surveys, in order to optimize involved processes (e.g. identify areas of significant change, or where to go first, etc.), and they can be an essential input in remote-sensing-based habitat quality assessment.

Acknowledgements

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