FOREST DELINEATION AND STRUCTURE ASSESSMENT BASED ON AIRBORNE LASERSCANNING DATA

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ABSTRACT
Airborne laser scanning (ALS) data has been established as the standard method for the acquisition of high precision topographic data. In addition to the derivation of topographic models, such as digital terrain models (DTM) or digital surface models (DSM), ALS data is the main input data source for a variety of applications, e.g. building modelling, power line modelling or forestry applications. Until now a severe limitation is the availability of tools allowing computations directly on the 3D point cloud for district wide calculations. In complex 3D scenarios such as forests, the point cloud content is commonly converted to raster data (e.g. DTM and DSM) with a notable loss of information. As a result, the information on the vertical structure of vegetation is irretrievably lost. Therefore, a methodology for the delineation of forest areas and subsequent derivation of vertical vegetation strata is proposed. The presented approach combines processing steps directly in the 3D point cloud and in the raster domain using the software system OPALS (Orientation and Processing of Airborne Laser Scanning data). A number of examples located in Austria are used to illustrate the workflows.

KEY WORDS: LiDAR; nDSM; 3D point cloud; echo ratio; forest inventory; software; data management; OPALS

1. Introduction
Due to the fact that ALS is an active remote sensing technique and that a three-dimensional (3D) point can be determined from one measurement position, the acquired data has a high potential for describing the 3D structure of forests. The information about the tree height or stand height can directly be derived from a normalized digital surface model (nDSM), which is calculated by subtracting the DTM from the DSM (Hollaus et al., 2006) or from the normalized echoes directly. For the assessment of forest parameters, such as stem volume or biomass, statistical (Næsset, 1997; Næsset, 2002), (semi-) empirical (Hollaus et al., 2009) or physical (Hyyppä et al., 2001) models are commonly applied. Automated derivation of these forest parameters has already reached an operational status. Thus it is rather the questions of organizing periodic data acquisition cycles and building efficient processing chains that come into the foreground.
A severe limitation is the availability of tools allowing computations directly on the 3D point cloud. In complex 3D scenarios, such as forests, the point cloud content is often converted to raster data (e.g. DTM, DSM, nDSM) with a notable loss of information. As a result, the information on the vertical structure of vegetation is irretrievably lost.

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This article describes a methodology for the delineation of forested areas and subsequent derivation of vertical vegetation strata based on the 3D point cloud. These methods were developed within the research projects *Laser-Wood* and *TransEcoNet,* which are both ongoing projects at the Institute of Photogrammetry and Remote Sensing (I.P.F.) at the Vienna University of Technology. The presented approaches combine processing steps directly in the 3D point cloud and in the raster domain using the software system OPALS (Orientation and Processing of Airborne Laser Scanning data) (Mandlburger et al., 2009). Apart from the ALS echoes, the main input parameters are normalized heights and echo ratio maps describing the transparency and vertical distribution of the foliage. A number of examples located in Austria are used to illustrate the workflow.
The following section describes the study areas and data. In Sec. 3 the methods and workflows for forest delineation and forest structure assessment are presented followed by Sec. 4 about the basic concept of the OPALS software. Sec. 5 summarizes and discusses the results. Finally, in Sect. 5 a conclusion is given.

2. Study area and data

The study areas for the forest delineation are located in the "*Zillertal*" in the eastern part of the federal state of Tyrol, Austria. The elevations above sea level vary between 500 m up to 2000 m. The area is dominated by coniferous trees, whereas spruce (*Picea abies*) is the dominant tree species. Beside the forested areas buildings, cable cars and power lines are evident in the study areas. The used ALS data were acquired using an Optech Inc. ALTM 3100 laser scanner during multiple flight campaigns in 2008, partly under leaf-off and leaf-on canopy conditions without snow. The mean flying height above ground was 1200 m. The mean point density is about 5 echoes/m². Further information about these study areas can be found in Eysn et al. (2011). An overview of the study areas is shown in Figure 1.

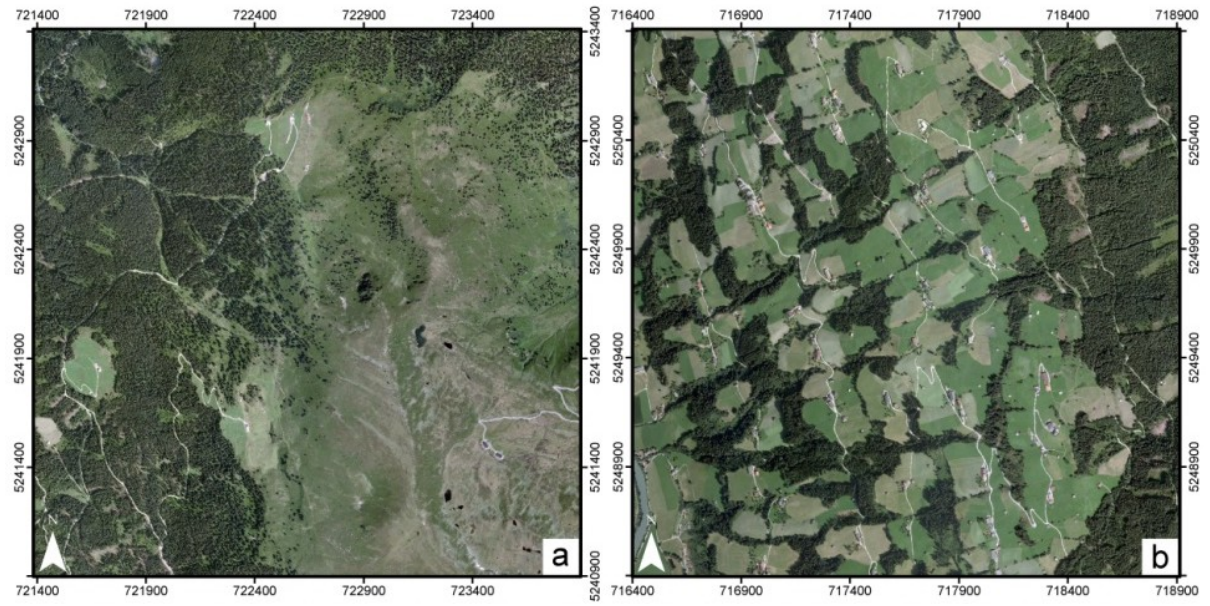

Figure 1: Orthophotos of the study areas located in the "Zillertal". (a) Study area 1 shows a looselystocked forest at high elevations. (b) Study area 2 shows a patched, fragmented forest. (adapted from Eysn et al., 2011).

For the forest structure assessment a study area in the southern part of the *Leithagebirge* was used. The *Leithagebirge* is a low mountain range on the borders of the federal states

Lower Austria and Burgenland in Austria. The study area features a complex of semi natural and agricultural landscape composed of forest, vineyards and fields. The analysed ALS data were acquired in March 2007 under leaf-off conditions using a RIEGL LMS-Q560 full-waveform laser scanner. For this area about 18 returns per m² are available. Further information about this study area can be found in Mücke et al. (2010).

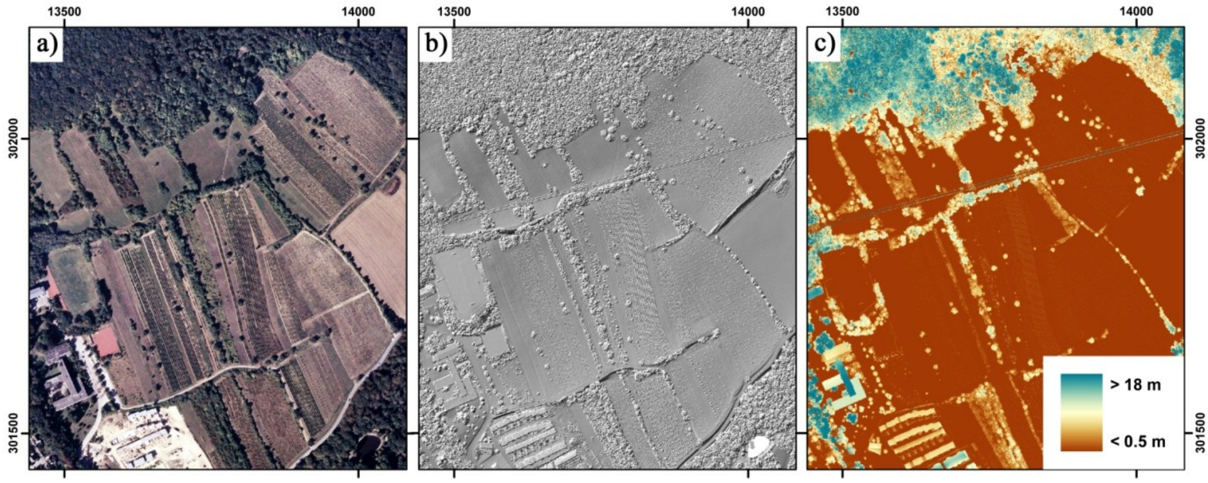

Figure 2: (a) True colour orthophoto of the study area used for forest structure assessment. (b) Landscape dependent digital surface model (DSM), (c) normalised DSM (nDSM), the colour coding represents the normalised heights. (adapted from Mücke et al., 2010)

3. Methods

In the following section the pre-processing of the ALS data and the implementation of the forest delineation and forest structure assessment is described. For all processing steps the software OPALS (section 4) was the fundamental platform for the realization of the workflows.

Pre-processing of the ALS data

For this study the ALS data were available as georeferenced point clouds. Also the DTMs were already available with a spatial resolution of 1x1 m² for the *Zillertal* study areas and 0.5x0.5 m² for the *Leithagebirge* study area. Within previous studies the DTMs were calculated using the hierarchic robust filtering approach described in Kraus and Pfeifer (1998), implemented into the software Scop++ (Scop++, 2011).

For the processing of the DSM a land cover dependent derivation approach (Hollaus et al., 2010) was chosen. This approach uses the surface roughness to combine two DSMs that are calculated based (i) on the highest return per raster cell (DSM_{max}) and (ii) on moving least squares interpolation (DSM_{mls}). For the final DSM the DSM_{max} is selected for rough surfaces (i.e. forests, building borders, etc.) and the DSM_{mls} for smooth surfaces such as non-forested areas, building roofs, etc.

By subtracting the DTM from the DSM a normalized digital surface model (nDSM) was created. Furthermore, all returns were normalized by subtracting the DTM height from their elevation values.

In addition to these topographic models a slope adaptive echo ratio (*sER*) map (Höfle et al., 2009), as a measure for local transparency and roughness of the top-most surface, was calculated. The spatial resolution of the derived raster products is 1x1 m² for the *Zillertal* study areas and 0.5x0.5 m² for the *Leithagebirge* study area.

Forest delineation
For the forest delineation the geometrical criteria of the forest definition of the Austrian national forest inventory (NFI), i.e. area, height, crown coverage and width are used. In this approach, the hierarchy of the criteria is defined as follows: (i) min. height, (ii) min CC, (iii) min area and (iv) min width, whereas (iii) and (iv) are checked in an iterative process. The minimum height is set to 3.0 m and is considered by applying a height threshold on the nDSM heights. The resulting potential forest mask contains, in addition to forested areas, artificial objects, i.e. buildings, power lines, cable cars, etc. which have similar objects heights as forests. Eysn et al. (2010) have developed a workflow to remove these artificial objects based on the sER map and on morphological operations. The sER can be used to differentiate between buildings and forested areas and is defined as the ratio between the number of neighbouring echoes in a fixed search distance of 1.0 m measured in 3D and all echoes located within the same search distance in 2D (Höfle et al., 2009; Rutzinger et al., 2008). An sER value of 100% means that the echoes within the 2D search radius describe a planar surface (e.g. roofs), whereas a sER value <100% means that the echoes are vertically distributed within the 2D search area and thus indicating transparent objects i.e. forests, building borders and power lines. An empirically determined sER threshold of less than 85% is used to create the vegetation mask. Finally, morphological operations (open, close) are applied to remove the remaining building borders and power lines from the vegetation mask (Eysn et al., 2010).
Based on the Austrian NFI, the crown coverage (CC) has to be larger than 30% for forested areas. In general, the quantity CC defines the projected crown area of trees within a reference area. Since there is no exact definition of the size and the shape of the reference area available in the NFI, different results are derived if different methods (i.e. moving window approaches) using different kernel sizes and shapes are applied. Eysn et al. (2011) have developed a new unambiguous approach for determining CC based on defining CC as a relation of the sum of the crown areas of three neighbouring trees at a time and the area of their convex hull. To detect individual tree positions a local maximum filter is applied. Furthermore, a Delaunay triangulation is applied to define the neighbouring trees. The crown diameters are assessed using empirical relationships between tree height and crown radius. These relationships are calibrated based on Austrian NFI in-situ data. For the study areas in the *Zillertal* the calibrated function is applied, whereas the tree heights are extracted from the nDSMs. Detailed information about this approach for assessing CC can be found in Eysn et al. (2011). The minimum forest area is defined with 500 m² and is applied by using GIS queries. Areas not fulfilling the minimum area criterion are eliminated, forest gaps smaller than the minimum area are filled. For delineating the final forest area fulfilling the mentioned definitions of the Austrian NFI, further morphologic operations and GIS analyses are applied to check the minimum area and width iteratively.

Forest structure assessment
One of the most important forest structure quantities is the number of vertical vegetation layers. Based on the laser echoes the vertical distribution of the vegetation can be described. As the analyzed ALS data were acquired under leaf-off conditions the penetration of the vegetation by the laser pulses is assumed to be very high and even lower vegetation layers will be represented in a proper form. Due to performance reasons a forest mask, as described above, is used to reduce the point cloud. Furthermore, the point cloud is divided into a terrain and a vegetation point cloud using a normalized height threshold of 10 cm. For assessing the number of vertical forest layers the height levels of the layers have to be defined. This can be done in two different ways:

- The height levels are defined as the percentage of the maximum occurring point height. The defined levels are e.g. 0 to 33% (*L1*), 34 to 66% (*L2*) and 67 to 100% (*L3*).
- The height levels are defined as fixed height thresholds e.g. 1 to 7 m (*L1*), 7 to 15 m (*L2*) and >15 m (*L3*).

For each grid cell or segment representing a single tree crown the number of vegetation points per height layer and the total number of vegetation points are determined. Finally, the ratio of these two quantities is computed (Mücke et al., 2010). For the generation of the forest structure map a decision tree based classification approach is used to determine the number of vertical forest layers.

4. OPALS

OPALS (**O**rientation and **P**rocessing of **A**irborne **L**aser **S**canning data) is a scientific software project developed at the I.P.F., TU Vienna (Mandlburger et al., 2009). The aim of OPALS is to provide a complete workflow for processing large ALS projects with focus on the following topics: processing of raw sensor data, quality control, georeferencing, modelling of structure lines, filtering of ALS point clouds, DTM interpolation, and subsequent applications like city modelling, forestry, hydraulics etc. OPALS is a modular system consisting of small units (modules), each covering a well defined task. Each module is available in three different implementations: (i) as command-line executable, (ii) as Python module (Phyton, 2010), and (iii) as C++-class library via DLL linkage. Arbitrary workflows can be constructed by embedding the respective OPALS modules in a scripting environment. To handle ALS data in the order of >10^9 points, a central data management component (OPALS Data Manager, ODM) was developed, providing efficient spatial data access and an administration concept for storing arbitrary point attributes (e.g. echo width, amplitude, classification, normal vector, sER, etc.). The flexible software concept of OPALS allows the combination of different modules as e.g. command-line executables or Python modules. Especially for the forest delineation (section 3) the Python modules of OPALS have been used intensely to build a workflow in Python which also opened the possibility to use additional Python side-packages e.g. OGR / GDAL (GDAL, 2011). One of the main advantages of using the OPALS Python bindings is the possibility to directly grab the intermediate results of the OPALS modules for further calculations within the scripting environment. Related to the forest structure assessment in section 3 this possibility was used to directly grab the number of vegetation points within a segment by using the Python module of OpalsHisto for analyzing the point cloud in combination with OGR for defining the segments.

5. Results and discussion

Forest area delineation

The delineated forestmask serves as an additional input for the forest structure assessment to define the forested areas fulfilling the restrictions of the Austrian NFI.

The delineation result for the loose stocked forest (Figure 3a) shows a very jagged forest mask at the upper timberline. Since there is no clear defined forest border like at denser forests at lower elevations this result is feasible. A visual inspection of the results based on an orthophoto proves that only forested areas are detected by the algorithm. Single trees on the open terrain as well as too loose stocked areas are reliably removed from the forest mask. Reference data like manually delineated forest maps based on orthophotos are very hard to obtain for such loose stocked forests at the upper timberline and the quality of interpreted forest maps is very limited and correlated to the interpreters experience and knowledge. Compared to a manual interpretation the presented approach is fully automated and shows user independent results.

The resulting forest map for the fragmented forest (Figure 3b) shows a good agreement with a manual inspection of the forested areas based on an orthophoto and the nDSM.

Only forested areas are detected since buildings, power lines, etc. are reliably removed based on the presented method for eliminating artificial objects (Figure 3c,d,e). Forested areas not fulfilling the minimum width criterion of the NFI are reliably removed.

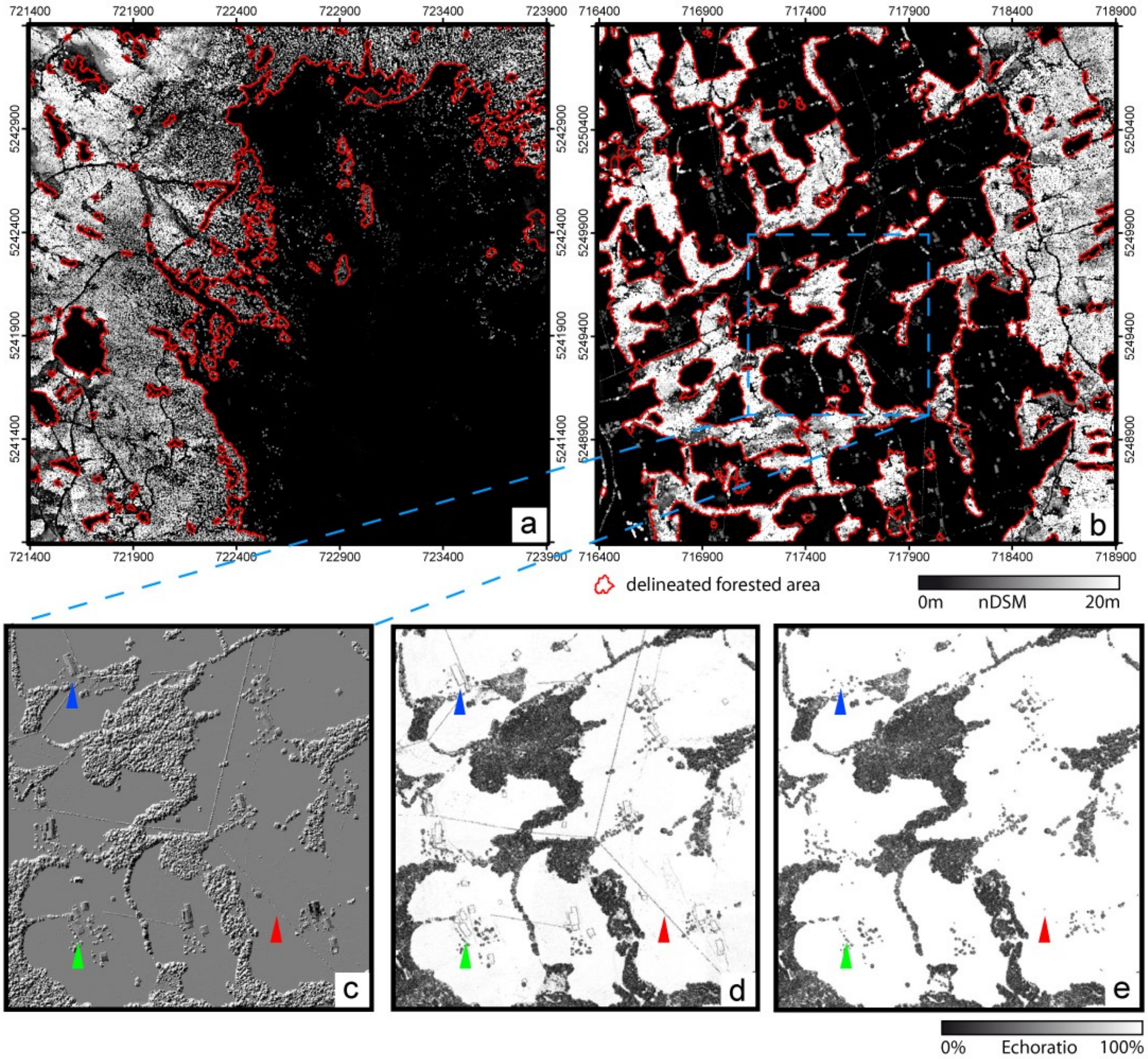

Figure 3: Results of the forest delineation based on ALS data and the additional elimination of artificial objects. (a) delineation result for the loose stocked study area as an overlay of a z-coding of the nDSM (b) delineation result for the fragmented forest as an overlay of a z-coding of the nDSM (c) detail of the fragmented study area: coloured markers point to buildings and power lines visible in a shading of the nDSM (d) sER map of the detail showed in image c showing the same coloured markers pointing to buildings and power lines, (e) enhanced sER map of the detail showed in image c with removed buildings and power lines.

Forest structure assessment

As described in section 3, the reference unit for the derivation of forest layers is either a grid cell or a segment representing a single tree crown. In general, the authors consider segments to be the more accurate representation of vegetation objects. Therefore, a segmentation approach as described in Höfle et al. (2008) is applied. Subsequently, each segment is assigned the according values from the resulting forest layer raster maps. Mean values for each segment are derived and a decision tree based strategy is used to classify the segments, the results of which represents the forest layer map (figure 4). Figure 4 also shows three profiles, which are used for evaluation of the proposed methodology of layer structure derivation. In the chosen study area four types of vegetation structure were identified: (L1 + L3) > 80 % (shown in red), (L2 + L3) > 80 % (shown in light green), L3 > 80 % (shown in dark green) and equally distributed (shown in yellow). Below the profile views the corresponding lines of the forest layer map are given, demonstrating that the classification result corresponds very good with the actual vegetation structure in the study area. Deviations are mainly due to high local variations, which cannot be considered when they occur within a segment.

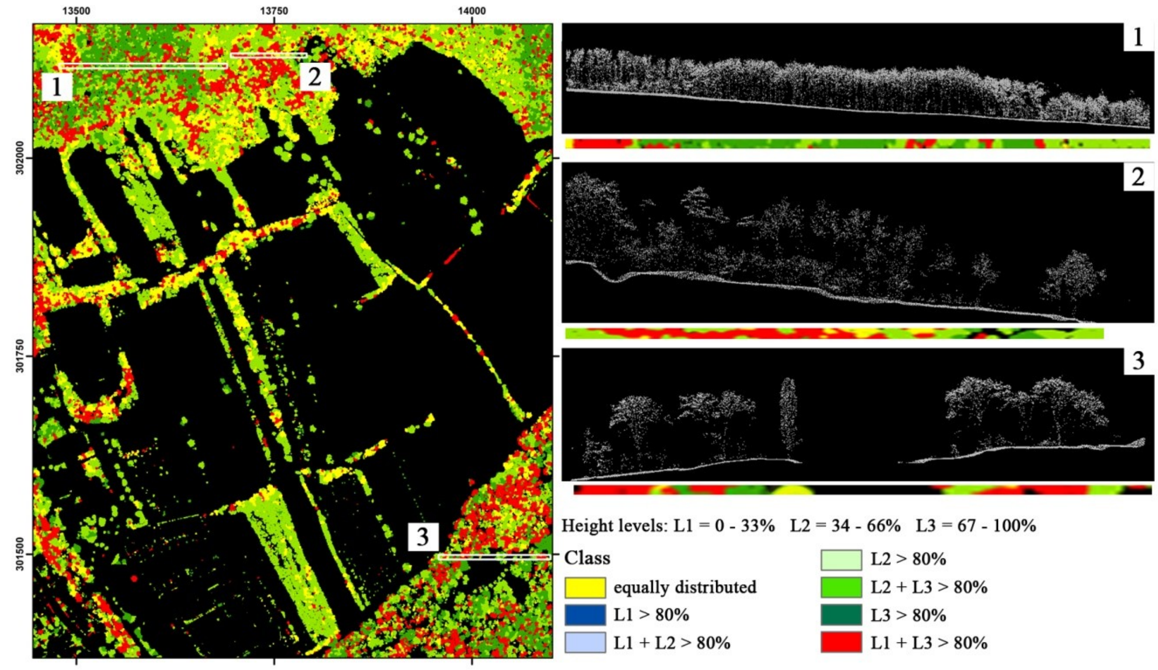

Figure 4: left: Forest structure map derived from the 3D point cloud. Right: Profile views of the ALS point cloud. The location of the profiles can be found in the left image. Below the profiles the corresponding lines from the forest structure map are given.(adapted from Mücke et al., 2010).

6. Conclusion

The increasing availability of dense ALS data and the needs of analyzing forested areas as a large scale application is a challenging task for both, the software handling the data and the implementation of algorithms. The presented study for analyzing forested areas using the software package OPALS provides a powerful tool to handle large 3D point clouds. In this study the additional benefits of using the 3D point cloud directly are demonstrated for the delineation of forested areas as well as the assessment of the vertical forest structure. For example the calculated slope adaptive echo ratio map, which describes the local penetrability and the roughness of surfaces, allows the differentiation between the elevated objects buildings and forests. The delineation of forested areas shows feasible results for the investigated study areas. It could be demonstrated that artificial objects are reliably removed and only forested areas are detected using the presented automatic workflow. The implementation of geometrical criteria of a forest definition leads to user independent results for the forest delineation. For assessing the vertical forest structure the normalized heights of the returns enable the extraction of the layer structure even for small reference units such as grid cells or tree crown segments. The derived structure information is basically a fundamental input parameter for many applications e.g. biodiversity studies. Concluding it can be stated that this additional 3D information (i.e. penetrability of the surface, vertical distribution of vegetation) is not available if only the 2.5D topographic models are used.

7. Acknowledgement

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8. References

Eysn, L., Hollaus, M., Schadauer, K. and Roncat, A., 2011. Crown coverage calculation based on ALS data, SilviLaser 2011, Hobart, Australia, 10.

Eysn, L., Hollaus, M., Vetter, M., Mücke, W., Pfeifer, N. and Regner, B., 2010. Adapting α-shapes for forest delineation using ALS Data, 10th International Conference on LiDAR Applications for Assessing Forest Ecosystems (Silvilaser 2010), Freiburg, Germany, 10.

GDAL, 2011. GDAL - Geospatial Data Abstraction Library. http://www.ggal.org/, last access: 17.11.2011.

Höfle, B., Hollaus, M., Lehner, H., Pfeifer, N. and Wagner, W., 2008. Area-based parameterization of forest structure using full-waveform airborne laser scanning data. In: *SilviLaser 2008, Sept. 17-19, 2008*, Edinburgh, UK, Vol.: 8.

Höfle, B., Mücke, W., Dutter, M., Rutzinger, M. and Dorninger, P., 2009. Detection of building regions using airborne LiDAR – A new combination of raster and point cloud based GIS methods. *GI_Forum 2009 - International Conference on Applied Geoinformatics, Salzburg*, 66-75.

Hollaus, M., Mandlburger, G., Pfeifer, N. and Mücke, W., 2010. Land cover dependent derivation of digital surface models from airborne laser scanning data. In: *ISPRS Commission III Symposium PCV2010*, Saint-Mandré, France, Vol. Proceedings of the International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences Volume XXXVIII: 6-6.

Hollaus, M., Wagner, W., Eberhöfer, C. and Karel, W., 2006. Accuracy of large-scale canopy heights derived from LiDAR data under operational constraints in a complex alpine environment. *ISPRS Journal of Photogrammetry & Remote Sensing*, 60(5), 323-338.

Hollaus, M., Wagner, W., Schadauer, K., Maier, B. and Gabler, K., 2009. Growing stock estimation for alpine forests in Austria: a robust lidar-based approach. *Canadian Journal of Forest Research*, 39(7), 1387-1400.

Hyyppä, J., Kelle, O., Lehikoinen, M. and Inkinen, M., 2001. A Segmentation-Based Method to Retrieve Stem Volume Estimates from 3-D Tree Height Models Produced by Laser Scanners. *IEEE Transactionon on Geoscience and Remote Sensing*, 39(5), 969-975.

Kraus, K. and Pfeifer, N., 1998. Determination of terrain models in wooded areas with airborne laser scanner data. *ISPRS Journal of Photogrammetry and Remote Sensing*, 53(4), 193-203.

Mandlburger, G., Otepka, J., Karel, W., Wagner, W. and Pfeifer, N., 2009. Orientation And Processing Of Airborne Laser Scanning Data (opals) - Concept And First Results Of A Comprehensive Als Software. In: *ISPRS Workshop Laserscanning `09*, Paris, Vol. IAPRS, Vol. XXXVIII, Part 3/W8: 55-60.

Mücke, W., Hollaus, M. and Prinz, M., 2010. Derivation of 3D landscape metrics from airborne laser scanning data, SilviLaser 2010, Freiburg, Germany, 11.

Næsset, E., 1997. Estimating Timber Volume of Forest Stands Using Airborne Laser Scanner Data. *Remote Sensing of Environment*, 61(2), 246-253.

Næsset, E., 2002. Predicting forest stand characteristics with airborne scanning laser using a practical two-stage procedure and field data. *Remote Sensing of Environment*, 80(1), 88-99.

Rutzinger, M., Höfle, B., Hollaus, M. and Pfeifer, N., 2008. Object-Based Point Cloud Analysis of Full-Waveform Airborne Laser Scanning Data for Urban Vegetation Classification. *Sensors*, 8, 4505-4528.

Scop++, 2011. SCOP++ - Programpackage for Digital Terrain Models, http://www.ipf.tuwien.ac.at/products; http://www.inpho.de. Last accessed November 2011.