

DETECTION OF HIGH URBAN VEGETATION WITH AIRBORNE LASER SCANNING DATA

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ABSTRACT

Airborne laser scanning (ALS) is known as an operational tool for collecting high resolution elevation information ($> 4 \text{ pt/m}^2$). The characteristics of the emitted pulses, i.e. their spatial extent, allow the detection of multiple echoes, which occur especially in areas covered with high vegetation. In the case of forested areas this means that not only the first reflection on the canopy but also reflections on or near the ground surface are recorded.

The detection of high vegetation in urban areas (single trees, groups, and small forests next to residential areas) is needed for several applications. Classified vegetation and derived parameters, such as height, volume and density, are used in urban planning, urban ecology and 3D city modeling.

The here presented algorithm follows the principle of object-based point cloud analysis (OBPA), which consists of (i) segmentation of the original ALS point cloud, (ii) feature calculation for the delineated segments and (iii) classification to label the objects of interest. The segmentation is based on an intelligent seed point selection by surface roughness, initializing a region growing process. Point features for the segmentation and classification, respectively, are e.g. roughness, the ratio between 3D and 2D point density, or statistics on first and last echo occurrence within the segments. The advantage of the developed algorithm is that no calculation of a digital terrain model is needed and that it solely works in the original point cloud, maintaining the maximal achievable accuracy. For the evaluation of the method a flight campaign of the city of Innsbruck/Austria is used as test site.

Keywords: Object-based Point Cloud Analysis, Urban Vegetation, Segmentation, Classification

1 INTRODUCTION

Currently airborne laser scanning (ALS) data is not only used for scientific investigations but also for operational applications. Several area-wide flight campaigns generate basic geo and remote sensing data sets, which are hosted by public administrations. High resolution 3D information is available for several municipalities and cities, which now start to gain the added value of this new data source (e.g. Wack and Stelzl, 2005).

The applications of ALS cover a wide field such as urban planning, natural hazard management, or forestry using different techniques for surface characterization, process modeling, object detection and parameter derivation. The detection of high vegetation in urban areas is needed for urban tree land register, traffic noise modeling, or in digital 3D city models. In the following previous work on ALS and vegetation mapping is described (Sect. 2). In Section 3 the feature calculation and segmentation method is explained. Section 4 describes the test site

and the used data sets followed by an interpretation of the results (Sect. 5) and a short outlook (Sect. 6) on future work.

2 RELATED WORK

Vegetation detection in urban areas using ALS data faces different problems compared to the use in forestry issues due to the separation of buildings from trees and the similarity to small structures like fences or cars. A differentiation between forest and non-forest objects is not needed in forestry applications and hence the applied standard methods for vegetation detection and parametrization (e.g. Rönnholm *et al.*, 2007; Koukal and Schneider, 2006) are not fit for the diversity of objects encountered in cities. Methods for high vegetation detection and analysis developed for densely built-up areas may, however, prove useful in a “pure” forest environment.

2.1 URBAN VEGETATION MAPPING

Several studies estimate vegetation in urban areas from satellite images for different purposes, such as carbon storage modeling (Myeong *et al.*, 2006) or the comparison of vegetation occurrence in different cities (Small, 2007).

The segmentation and classification input, respectively, for most published methods determining urban land cover are rasterized ALS derivatives like digital surface models (DSM) or first/last echo difference models (FLDM) combined with high resolution infrared orthophotos. One of the first approaches doing so is described by Haala and Brenner (1999) applying an ISODATA classification on a DSM and an infrared image as inputs.

Iovan *et al.* (2007) present an automatic approach to derive urban vegetation combining NDVI (Normalized Difference Vegetation Index) and SI (Saturation Index) from a high resolution aerial image and a DSM with 20 cm resolution.

Matikainen *et al.* (2007) distinguish buildings, high vegetation and ground using an object-based image analysis (OBIA) approach (cf. Benz *et al.*, 2004). The suggested workflow requires a first and last echo DSM, the derived FLDM and an aerial image as raster input layers for segmentation. Then several segment features are derived. The most significant features and the final rules for classification are selected by a decision tree. The final classification result is stored as GIS-ready vector layer.

2.2 VEGETATION ANALYSIS ON ALS POINT CLOUD

The rasterization of the ALS point cloud enables the application of standard image analysis algorithms and a simple data fusion with raster data from other sources. While this is theoretically feasible due to the different properties recorded by different sensors, it is practically hampered by different aspects. Aerial images and ALS data are generally not acquired at the same time because of the different flight geometry requirements. Hence, the two data sources differ in their temporal object representation, which leads to errors when combining them for classification. Further problems associated with the combination of these data sets are the different geometrical object representation and shadow effects encountered e.g. in orthophotos. The main advantage in using only one dataset is the consistency in the input.

The rasterization additionally leads to an irreversible information loss if the high resolution point cloud is aggregated to a fixed raster data

model. The possibilities of analysis in the ALS point cloud is presented e.g. by Filin and Pfeifer (2006) segmenting building roofs. Höfle *et al.* (2007) apply an object-based point cloud analysis (OBPA) concept to the laser points for segmentation and classification of a glacier surface.

A study on the potential of pulsed ALS data (Wehr and Lohr, 1999) to describe vegetation is described by Moffiet *et al.* (2005) characterizing the echoes towards their return signal amplitude and height distributions in order to analyze tree species.

Reitberger *et al.* (2006), and Wagner *et al.* (in press) show the potential of full-waveform (FWF) laser scanning systems for vegetation mapping tasks, which enable the detection of low vegetation structures and a further differentiation for classification.

In forestry a standard method is the derivation of statistical measures derived from the point cloud, i.e. the spatial distribution of the points, in order to predict quantities of interest (e.g. stem volume). Parameters are obtained via sample plots (Maltamo *et al.*, 2007).

3 METHOD

The here presented method is part of an OBPA workflow, which combines point cloud segmentation, object generation, and classification using features expressing inhomogeneity as well as first and last echo information. In the following the focus lies on the segmentation algorithm describing point feature calculation (Sect. 3.1), seed point selection (Sect. 3.2), and region growing (Sect. 3.3). Finally, a visual inspection is performed to estimate the accuracy of the segmentation result (Sect. 3.4).

3.1 INHOMOGENEITY FEATURES

Investigating ALS point clouds in urban environments shows that high vegetation is characterized by (i) an elevation difference of first and last echo and (ii) by a high surface roughness. In general, building roofs, roads and meadows are planar objects and can be distinguished from vegetation structures very well. However, vegetation description by the first-/last echo difference is limited by (i) the occurrence on jump edges like building walls, (ii) the vertical resolution of pulsed ALS systems, which only allows the detection of two different echoes, if the targets have a distance larger than 1.5 m (Baltasvias, 1999), and (iii) the dependency on the canopy density and flying season, respectively (Wagner *et al.*, 2004), which means that the laser beam penetrates mainly in sparsely covered vegetation.

These characteristics of the canopy structure lead to the choice of *roughness* and *point density* calculated on all echoes in order to derive segments in a region growing segmentation, while the first-/last echo difference remains an interesting feature for object classification .

Unlike to raster analysis where the neighborhood is defined e.g. by 4 or 8 adjacent pixels, in point cloud analysis the neighborhood has to be defined by the number of neighboring points (Sect. 4.3) or by a fixed distance. The latter can be done either in the XY-plane using a circular search field or in 3D by a spherical search defined by a given radius. The radius is a function of the average shot density (Rabbani *et al.*, 2006) within the test site (Sect. 3). If the search radius is chosen too small, no neighboring points for the calculation can be found and if it is chosen too large, averaging effects occur and a smoothed result is returned.

Surface roughness can be defined in different ways like standard deviation (SD) of heights or surface irregularities defined by curvature. In the following, the SD of the orthogonal plane fitting residuals of points in the defined neighborhood is used as parameter for surface roughness. The roughness values calculated for the test site show low values

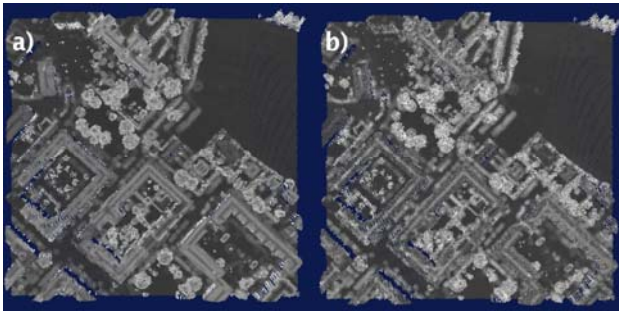


Figure 1. Roughness values calculated by a 3D neighborhood of 3 m defined by (a) SD of elevation and (b) SD of plane fitting residuals.

on streets, building roofs and meadows, while high vegetation and shrubs but also building edges reach high values. Figure 1 shows that roughness defined by the plane fitting residuals suppresses the occurrence on roof edges more than roughness defined by the 3D SD of the Z-values of the points.

The second feature to derive vegetation segments is the point density, which can be calculated in 2D (Eq. (1)) or 3D (Eq.(2)).

$$p_{2D} = N_{2D} / \pi * r^2 \quad (1)$$

$$p_{3D} = N_{3D} / (4/3 * \pi * r^3) \quad (2)$$

$$DR_{3D/2D} = p_{3D} / p_{2D} = N_{3D} / N_{2D} * 1/r * 3/4 \quad (3)$$

where:

r ... search radius [m]

N_{2D} ... number of points within r in 2D

N_{3D} ... number of points within r in 3D

p_{2D} ... point density in 2D [m^{-2}]

p_{3D} ... point density in 3D [m^{-3}]

$DR_{3D/2D}$... point density ratio [m^{-1}]

The p_{3D} shows a promising separability of vegetation and solid objects (where the laser beam cannot penetrate), but suffers from disturbing artifacts caused by overlapping flight strips and flight geometry deviations e.g. caused by heading or pitch. These effects can be adjusted by the calculation of the $DR_{3D/2D}$ (Fig. 2c). While building walls have a similar $DR_{3D/2D}$ as vegetation, they can be distinguished by the roughness feature as building walls are planar elements.

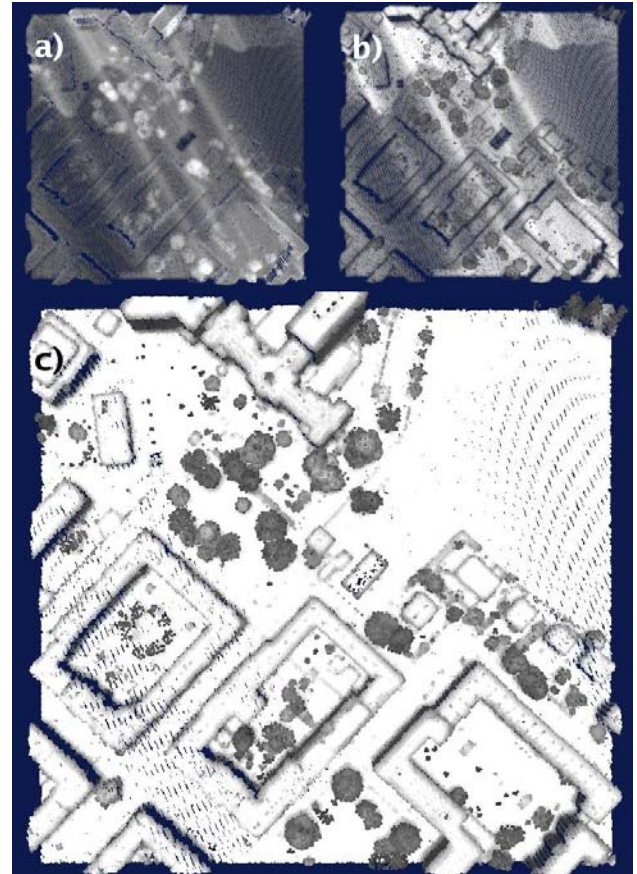


Figure 2. (a) point density in 2D (p_{2D}), (b) point density in 3D (p_{3D}), (c) point density ratio ($DR_{3D/2D}$).

3.2 SEED POINT SELECTION

In a first step all points with higher roughness than a certain threshold are selected for region growing. All these points are potential seed points. After sorting the points by roughness, a region growing process starts at the point with the highest roughness value.

3.3 REGION GROWING

For each seed point k nearest neighbors (e.g. $k=5$) are selected as candidate points, which are checked by their roughness and $DR_{3D/2D}$. If the candidate point lies within the defined maximum range it becomes part of the segment and is used as a next seed point. The growing of the segment is limited by a 3D maximum growing distance and the segment size (minimum and maximum number of points per segment).

4 TEST SITE

The test site is located in the city of Innsbruck (Tyrol/Austria). The acquisition campaign was carried out with an Optech ALTM 3100 scanner in November 2005. An area of 269.6 km² was scanned with ca. 4 shots per m². The test site (300 m², 15,952 first and 189,121 last echos) contains block buildings, one-family houses, small structures (cars and fences), and vegetation of different geometry, height, and species.

5 RESULTS

Tests of different segmentation settings show the applicability of the segmentation concept. The results in Figure 3 are compared with an orthophoto (taken in 2003) and a shaded DSM. Differences between the orthophoto and the ALS data are due to the different years of acquisition (Sect. 4). The resulting segments (Fig. 3b) cover the main tree groups, single trees and shrubs, which are derived with the following settings. A high roughness threshold of 0.7 m eliminates most planar areas such as ground, roof and building walls. The region growing is limited by a maximum growing distance of 5 m and a minimum segment size of 20 and a maximum segment size of 1000 points. The features are calculated for all points within a search radius of 3 m. For each seed point 5 candidate points are checked by their homogeneity (maximum deviation to seed point: $\pm 1 \text{ m}^{-1} DR_{3D/2D}$ and $\pm 1 \text{ m}$ roughness).

Reasoned by the tight segmentation settings most building roof edge points are not included in the final segmentation result. The segmentation works very well for high deciduous trees (Fig. 3c/1), but also for low vegetation like bushes and hedges (Fig. 3c/2). Nevertheless, some trees did not pass the segmentation criteria (Fig. 3c/5). Points not representing vegetation are building wall fragments (Fig. 3c/3) and parked cars (Fig. 3c/4), which are partly segmented as vegetation points.

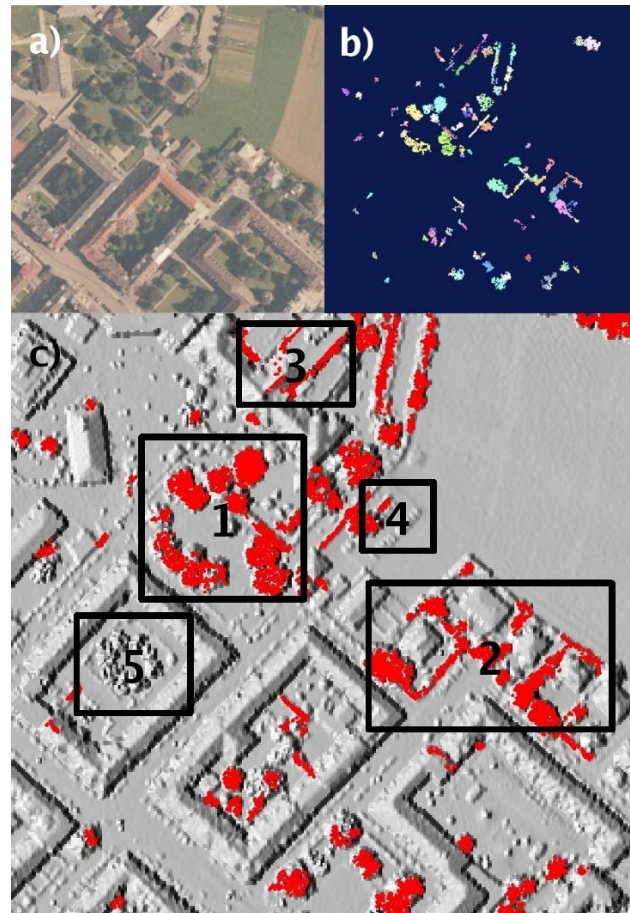


Figure 3. (a) aerial image, (b) segmented point cloud, (c) comparison of segmentation and shaded digital surface model.

6 OUTLOOK

The presented segmentation approach using inhomogeneity criteria shows promising results for the further integration in an OBPA workflow in order to detect and classify urban vegetation. Future work will focus on classification using additional segment features (Moffiet *et al.*, 2005; Höfle *et al.*, 2007) and the implementation of vector object generation. An additional part will be the adaption of the method to use FWF information for vegetation classification (Reitberger *et al.*, 2006; Wagner *et al.*, in press). Focus will also lie on reference data collection and error assessment to prove the quality and reliability of the presented work.

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