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2 authors:

Hossein Arefi
Mainz University of Applied Sciences

Michael Hahn
Hochschule für Technik Stuttgart

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Hossein Arefi
Dept. of Geomatics, Computer Science and Mathematics
Stuttgart University of Applied Sciences
Stuttgart, Germany
Hossein.arefi@hft-stuttgart.de

Michael Hahn
Dept. of Geomatics, Computer Science and Mathematics
Stuttgart University of Applied Sciences
Stuttgart, Germany
Michael.Hahn@hft-stuttgart.de

Abstract— Airborne laser scanning has become an accepted technique for acquiring Digital Surface Models of the Earth surface. One of the major and still unsolved problems is the automatic separation of the topographic surface and 3D objects which cover the topographic surface.

For this purpose a hierarchical segmentation procedure using morphological operations is developed and compared with more classical methods that are using morphological operations with a single structuring element to separate terrain from non-terrain surface models. The classical methods have a limited functionality in areas where a range of very small to very big 3D objects exists as well as in areas with a big variety of height differences.

Starting point for the hierarchical process are morphological operations with different structuring element sizes applied to the Laser range data. For LIDAR systems which record first and last pulse both data sets are employed. The key of the segmentation process is to analyze the generated sequence of morphologically filtered data to extract ground points with high probability and separate them from non-ground points. Aggregation to regions and the extraction of regions properties provide the basis for 3D object extraction. Further analysis focuses the feature description for the 3D regions which provides the input for classifying and separating 3D objects, in particular buildings and vegetation regions, from the ground surface regions. The local range variation, surface normal and NDVI features are utilized for evaluating the segmented regions.

This procedure has been applied to a data set which was recorded by the TopScan laser scanning system with the density of about 1 point per square meter.

Keywords- laser scanning; Mathematical morphology; segmentation; building extraction; trees extraction

I. INTRODUCTION

The steadily increasing quality and availability of airborne laser scanner (LIDAR) systems pushes research towards the analysis of those data. 3D Mapping and GIS data collection using LIDAR data is a great challenge and research aims at the development of automatic processes, e.g. on the extraction and modeling of buildings and trees. Algorithms have been proposed for segmentation and classification of off-terrain points or, more general, objects from LIDAR data as well as from Digital Surface Models (DSM). Work related to our approach was presented by Weidner [1] who proposed a procedure for Digital Terrain Model (DTM) generation based on a DSM and morphological processing. An opening operator with a fixed structuring element and global thresholding is applied for the segmentation of 3D regions. For discriminating buildings from vegetation objects two features one based on step edges and a second one using the variance of surface normals have been employed.

Other strategies and techniques have been developed to extract 3D objects, in particular buildings from DSM data. Those processes often take of other sources, for example, 2D GIS data (Brenner [2]) or digital aerial images (Ameri [3]).

The focus in this paper is given to the conceptual issues for separating the 3D off-terrain regions from the terrain surface. The procedure starts with morphological opening applied to the last pulse range data. Conceptually morphological filtering with a fixed size of the structuring element (Kilian et al. [4]) is running in a trap as there is generally no single optimal value for the size of the filter. Therefore it is quite evident to extend the concept towards the use of a sequence of morphological filters with different structuring element sizes.

This conceptual extension can be achieved by creating a sequence of TopHat filtered images with different structuring element sizes, thresholding the filtered images, region segmentation, classification of the regions based on region properties and fusion of the regions to one final result. Classification comprises the evaluation of the regions using regions properties including feature descriptors.

The paper is organized as follows. A brief review of mathematical morphology used in this research is given in section II. The concept for hierarchical segmentation and classification is explained in section III and the experiments and results are presented in section IV. Section V summarizes the achievements and draws some conclusions.

II. MATHEMATICAL MORPHOLOGY

Mathematical morphology is a well known theory for the analysis of spatial structures. Morphological operators are best suited to the selective extraction or suppression of image structures (Jähne et al. [5]). The selection is based on their shape, size, and orientation. This can be achieved by probing the image with the structuring element (SE), which is an operator data set of given shape. A morphological operation transforms an image by means of a structuring element into the new image. Morphological opening is one of the basic morphological operations; it is a dilation of the eroded image. The opening γ by a structuring element β is denoted by γ_β and is defined as the erosion with *SE* β followed by the dilation with the transposed *SE* $\dot{\beta}$

$$\gamma_\beta = \delta_{\dot{\beta}} \varepsilon_\beta \qquad (1)$$

where δ and ε denote the dilation and erosion successively. The opening removes all object pixels that cannot be covered by the structuring element when it fits the object pixels. In contrast to the opening the closing fills all background structures that cannot contain the structuring element. Related to the application of Equation (1) the selection of a proper structuring element is essential. The structuring element should be selected by using the knowledge about the shape, size, and orientation of the structures which have to be filtered.

The TopHat filtered image is calculated by an arithmetic difference between the image and its opening.

$$TH = I - \gamma \qquad (2)$$

I indicates the original image and γ the opening of the original image. Through the opening image structures smaller than the structuring element are removed thus the TopHat filtered image (Equation 2) 'highlights' those structures and prepares them for further processing.

III. HIERARCHICAL SEGMENTATION AND CLASSIFICATION

The basic concept of the hierarchical process for extraction and classification of 3D off-terrain regions from LIDAR data is the following: TopHat filtered images with different structuring element sizes are generated and thesholded to separate potential off terrain 3D regions from background. Region segmentation, classification of the regions based on region properties and fusion of the regions to one final result are further major steps. Classification of the regions is carried out rule based and uses geometric region properties together with other feature descriptors. The properties are the size of the region, the "NDVI" based on first and last pulse range data, the local range variation defined by the difference between the maximum height and the minimum height in a local window and the variance of the surface normal.

The proposed algorithm is illustrated in Figure 1. In the following we discuss feature extraction including filtering in a pre-processing step followed by segmentation and classification (Figure 1).

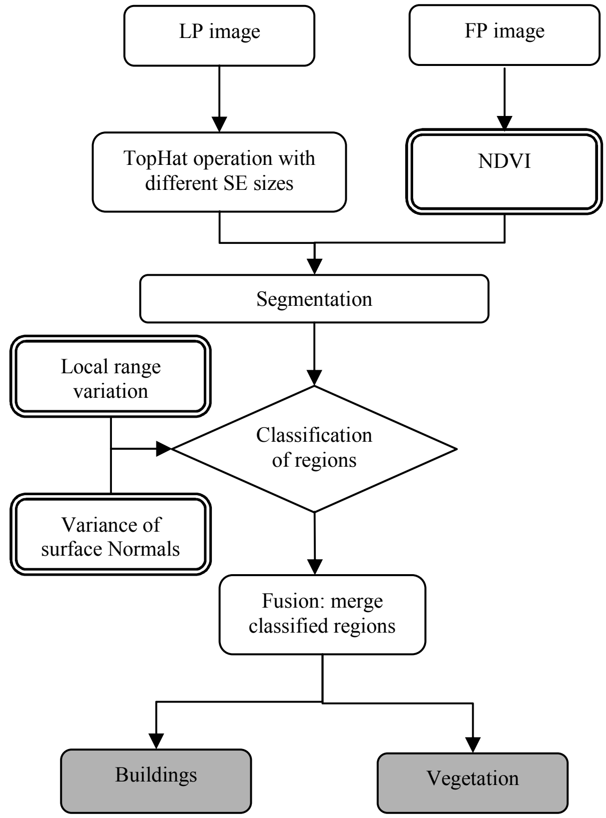

Figure 1. Proposed algorithm for segmentation and classification of LIDAR image

Pre-processing:

1. Calculate an NDVI image which is basically the difference between first and last pulse range data. This texture image mainly serves for the separation of vegetation points from non-vegetation points.

2. Calculate the local range variation image as a second textural image. This texture serves for separating off-terrain points from terrain points. The local range variation feature is defined by the difference between maximum and minimum values in a local 3 by 3 window in last-pulse image. Local range variation will be basically applied to evaluate the boundaries of segmented regions.

3. A third texture is created by calculating the variance of surface normals. This texture intends to support further evaluation of the segmented regions. It serves basically for the refinement with the goal to detect remaining vegetation areas (those not indicated properly with the NDVI) and separate them from buildings areas. The geometric region properties like size or shape are not sufficient for separating these two types of regions because e.g. large areas with rectangular shape may indicate vegetation as well as buildings. The feature image with the variance of the surface normals is shown in Figure 2.

4. TopHat filtering according to Equation (2) using the last pulse laser image as input is another preprocessing step. TopHat filtering is carried out with a series of structuring

element sizes. Each of the TopHat filtered images emphasizes regions of a certain size.

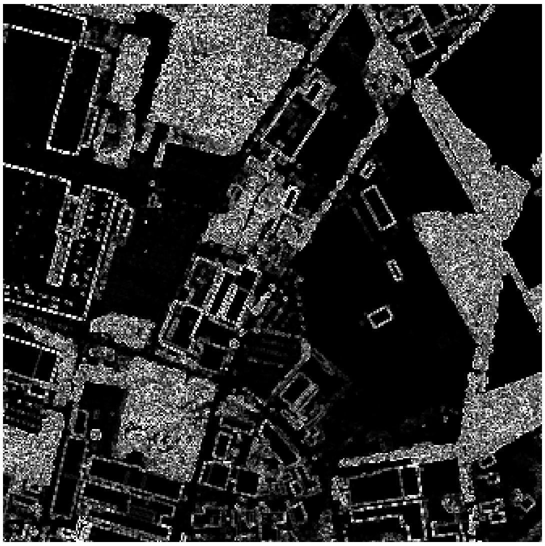

Figure 2. Variance of surface normals

Segmentation:

In this step the TopHat filtered laser data as well as the NDVI image are binarised by thresholding. For the TopHat filtered images a threshold of, for example, 2m might be used to separate objects like buildings from the ground. In the NDVI a 30 cm threshold might be used with the idea to separate vegetation from the ground. The thresholds directly reflects the assumption on what should be considered as an off-terrain point.

Connected components and labeling are carried out to obtain regions. For each individual region properties like the size of the region and the boundary coordinates of the region are calculated.

Classification:

Within the classification step a number of decisions are made according to the following rules:

Rule 1: Regions are considered to be vegetation regions if the NDVI values indicate a height difference between first pulse and last pulse range of more than the 30 cm as already mentioned in the segmentation step. The threshold is selected in such a way that measurement noise and meaningless low height differences are considered properly.

Rule 2: Regions found to be vegetation regions by applying rule 1 are eliminated from the regions obtained by segmentation of the TopHat filtered image.

Rule 3: The regions remaining after the application of rule 2 are further investigated by means of the local range variation image. Here only the boundary pixels of each region are taken into account. Regions that have an elevation along the boundary higher than e.g. the 2m threshold will remain as off-terrain regions. Otherwise those regions are considered to represent the ground surface.

Rule 4: Regions remaining after the evaluation with rule 3 mostly represent buildings but still some vegetation areas are present. Discrimination between vegetation and building regions is based on the variance of the surface normals which is calculated for all pixels within the boundary of each region. Regions with a low value for the average of the surface normal are classified as building regions, the remaining ones as vegetation regions.

Hierarchical processing and Fusion:

Segmentation and rule-based classification are applied in a hierarchical manner. The procedure starts with small structuring elements, e.g. of 40 m by 40 m and produces corresponding small-sized vegetation and building regions.

By increasing the size of the structuring element with increments of e.g. 30 m a sequence of growing structuring elements is obtained. The processing with each of those structuring elements produces corresponding classified regions which reflect the size of the structuring element. In this way a set of vegetation and building regions is generated.

Fusion deals with the integration of these individual regions. Mathematically it is a logical set operation based on Boolean logic. Building regions as well as vegetation regions of different size are obtained in the final result. In this logical fusion process parts of buildings which have been found with the smaller structuring elements are completed with the results obtained by the larger structuring element. In flat terrain a certain object may be extracted with small and larger structuring elements. Contrary is the situation for undulating terrain. Within segmentation large structuring elements may extract crests which are rejected within the classification step.

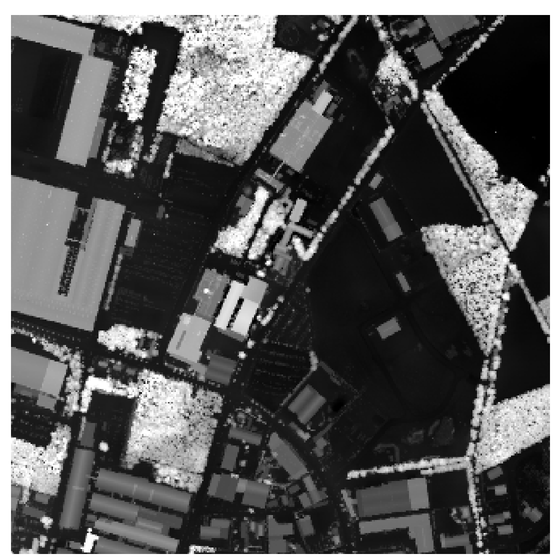

Figure 3. First-pulse LIDAR range image

IV. EXPERIMENTAL INVESTIGATION

The LIDAR data used in this experiment have been recorded with TopScan's Airborne Laser Terrain Mapper (TopScan, 2005). The average density of the measured 3D points is about 1.7 per m^2. The urban area contains buildings of different size as well as dense vegetation regions. In Figure 3 the first-pulse LIDAR range image from the city of Rheine in Germany is shown.

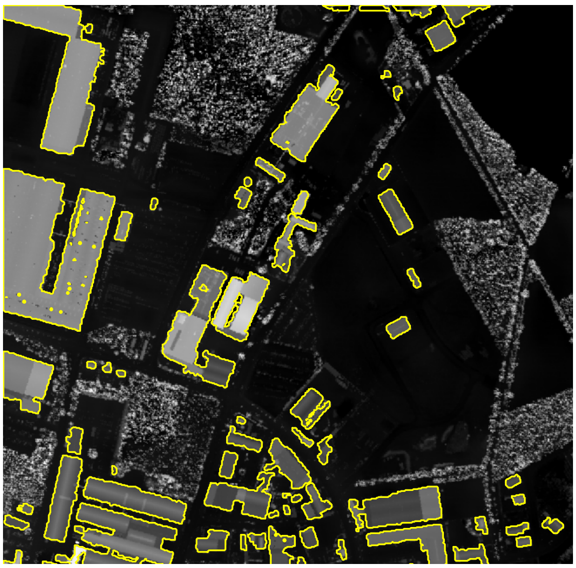

Figure 4. Extracted buildings; the boundary is superimposed on last-pulse image

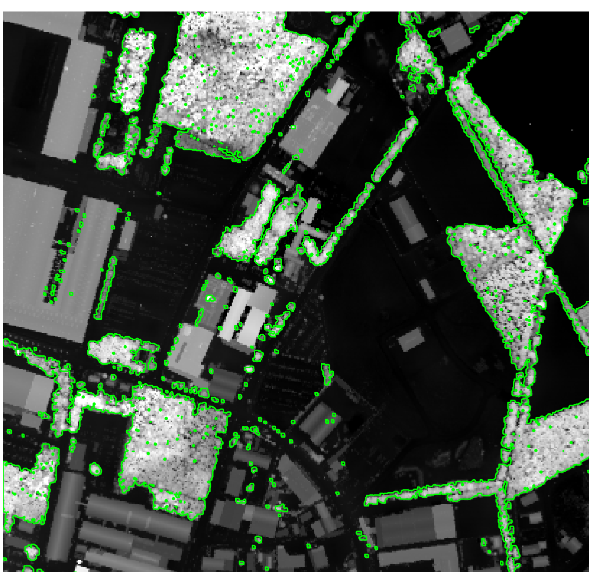

Figure 5. Extracted vegetation, the boundary is superimposed on first-pulse image

In this study area the size of buildings varies from about 70m2 to 60.000m2. Five squared structuring element matrices with 40m, 80m, 120m, 180m, 250m width size have been chosen. The extracted buildings are visualized in Figure 4 by superimposing the boundary of all regions to the last-pulse LIDAR image. Ground truth for evaluation the quality is not available but visual comparison of the extracted building regions with original image shows that the procedure provides a promising result.

Figure 5 shows the results for the extracted vegetation regions. The boundaries of all vegetation regions is overlaid in green color to the first-pulse LIDAR image. Visual inspection confirms that the process is working quite well.

V. SUMMARY AND CONCLUSION

The paper presents a hierarchical approach for segmentation and classification of the airborne LIDAR data. Morphological TopHat filtering with different structuring element sizes, segmentation and classification of building and vegetation regions are the main components of the procedure. The rule-based classification process employs three types of texture images based on the NDVI, the local range variation and the variance of surface normals.

An experiment is carried out with airborne LIDAR data recorded in Northern Germany in the City of Rheine. Visual inspection has shown that the results are quite promising. A very few small objects, in particular very thin rectangular shaped ones have not been extracted. They are already lost within the thresholding process.

In total, most of the vegetation and building areas have been classified correctly. The boundaries for the vegetation and building regions fit properly to the extension of the objects. The algorithm copes well with objects which are quite different in size. As expected, the large and medium sized vegetation and building regions are more accurately represented in the result than the very small ones.

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