

# BARE EARTH EXTRACTION FROM AIRBORNE LIDAR DATA USING DIFFERENT FILTERING METHODS

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Commission III, WG III/3

**KEY WORDS:** LIDAR, Point Cloud, Classification, DTM, Landscape, Segmentation

## ABSTRACT:

Over the past years, several filters have been developed to extract bare-Earth points from airborne laser scanner data. we conducted a test to determine the performance of three different filters and applying wavelets for the degradation of blunders in LIDAR data, and to identify directions for future research. Five selected samples have been processed by three participants. In this paper, the test results are presented. The paper describes the characteristics of the used filter approaches. The filter performance is analysed qualitatively. The performance of all filters depends on the complexity of landscapes in which they used. In general, wavelet denoising is found to perform well and it is hardly recommended to use wavelets for de-noising the LIDAR data. Future research should be directed towards the usage of wavelets in the filtering algorithms.

## 1. INTRODUCTION

The use of airborne Light Detection And Ranging (LIDAR) technology offers rapid high resolution capture of surface elevation data suitable for a large range of applications. The commercial use of LIDAR in the last few years has gained more importance as more reliable and accurate systems are produced. While LIDAR has come a long way, the election of appropriate data processing techniques for the generation of models is still being researched. In order to produce digital elevation models, filtering and quality control pose the greatest challenges, consuming an estimated 60–80% of processing time (Flood, 2001), and so underlining the necessity for research in this field. Some comparison of known filtering algorithms and problems have been mentioned in Huising and Gomes Pereira (1998), Haugerud and Harding (2001), Tao and Hu (2001) and Sithole and Vosselman (2003). However, an experimental comparison is available, although it would be useful to improve the performance of the different approaches by adding some hints on how to apply the algorithms. In order to assess the weaknesses of the different approaches we used the available reference data.

Therefore, we established a study to compare the performance of three automatic filters developed to date, with the aim of:

- determining the comparative performance of these filters,
- applying wavelet denoising method for the detection of blunders in LIDAR data, and
- identifying directions for future research on filtering point clouds.

To achieve these aims, we used the ISPRS web site at which datasets were provided for testing. processing all datasets was not possible, but we used some. Results were received from three participants. The algorithms are: Hierarchical terrain recovery algorithm by utilizing Image pyramid (Hu, 2003), Filtering of Airborne laser scanner data based on segmented point clouds (Sithole, 2005), Slope based filtering (Vosselman,

2000). We used these algorithms because of their novel methods for extracting the bare-Earth from airborne laser scanner point clouds.

This paper is structured as follows: The laser scanning data used in this paper is described in Section 2. Section 3 describes three selected filter algorithms. Section 4 deals with filter concepts. Section 5 describes the application of wavelet in LIDAR denoising and The results of the implementations are described and discussed in Section 6. In Section 7, the conclusions are drawn with respect to the objectives set out.

## 2. TEST DATA

Within the ISPRS web site (<http://www.itc.nl/isprswgIII-3/filtertest/StartPage.htm>) we found some free datasets which belongs to the OEEPE project on laser scanning (OEEPE, 2000), FOTONOR acquired data with an Optech ALTM scanner over the Vaihingen/Enz test field and the Stuttgart city centre. By the kind permission of Commission III, Working Group 3, subsets of this dataset are available for the comparison of filtering algorithms. Also reference data which was produced by interactively filtering the datasets is accessible.

### 2.1. Data provided to the participants

A total of five samples (of urban area) were chosen because they contained a variety of features that were expected to be difficult for the filtering. The datasets included terrain with steep slopes, dense vegetation, densely packed buildings with vegetation in between, large buildings, multi-level buildings with courtyards,

ramps, underpasses and etc. The samples of urban areas were recorded with a point spacing of 1–1.5 m (0.67 points per square metre). For each of the samples the reference data is available. This reference data has been compiled by semi-automatic filtering and manual editing. Each record in the

reference data files contains the X, Y, and Z coordinates followed by either a 0 (ground point) or 1 (non-ground point). Figure.1 shows a part of an urban test site.



Figure 1. a part of an urban test site

### 3. OVERVIEW OF FILTERING ALGORITHMS

An overview of the algorithms and a characterisation of filters are given in Table 1. The filtering algorithms are described in more detail below.

#### 3.1. George Vosselman

The basic idea is based on the observation that a large height difference between two nearby points is unlikely to be caused by a steep slope in the terrain. More likely, the higher point is not a ground point. Clearly, for some height difference, the probability that the higher point could be a ground point decreases if the distance between the two points decreases.

They explicitly define the acceptable height difference between two points as a function of the distance between the points:  $Dh_{max}(d)$ . In general, this will be a non-decreasing function. Further details can be found in Vosselman (2000).

#### 3.2. Yong Hu

The algorithm will identify terrain points by finding local minima and other topographic points, and recover the terrain surface in a coarse-to-fine manner. First, after screening the blunders, the scattered 3-D points are transformed into a grid-based range image by selecting the point of lowest elevation in each grid. Then, the raw range image is processed to fill void areas and correct distortions. Then, an image pyramid is generated.

The top-level image is hypothesized to be a coarse DTM if its grid size is larger than the largest non-terrain object. Finally, the coarse DTM is refined hierarchically from the top level to the bottom level. At each level, denser terrain points are identified, and the nonterrain points are replaced by interpolated elevations using surrounding terrain points. The bottom-level image represents the expected bare Earth surface.

Post-filtering is performed on the resultant DTM to improve its quality for mapping purposes. This smoothing attempts to correct the influence of speckles and undesired non-terrain

undulations of the DTM. At last, the void areas in the raw range image may be duplicated to preserve water regions.

The quality of the derived DTM is subject to thresholding parameters used in the algorithms. The optimal values of these parameters may vary with the scene complexity. One can use a priori knowledge, if available, including the terrain relief range, the maximum and minimum building sizes, heights and areas, the maximal tree height, etc to determine the parameters empirically first, and then adjust them adaptively if multi-return or intensity data is available. Further details can be found in Hu (2003).

#### 3.3. George Sithole

The algorithm emphasis is placed on establishing the topological and geometric relations between bare-Earth and object surfaces. Filtering is defined as the identification of surface segments whose perimeter is raised above their neighbourhood. Meaningful surfaces can be reconstructed for large objects but not for small objects (too few points). Therefore, in the algorithm large and small objects are detected separately. Large objects are treated by segmentation of the point cloud, while small objects by smoothing of the point cloud in a later stage.

The segmentation of a point cloud into smooth surfaces is the first important step of the algorithm. Two points are considered to be part of the same surface if there is a smooth path of adjacent points between them. This definition allows for discontinuities within a surface as long as there is a path around a discontinuity that connects points on both sides.

In this filter scan line segmentation algorithm is used in a different manner by definition and segmentation of scan lines with multiple orientations. A point cloud is sliced into contiguous profiles, and this slicing is done in several directions. Once profiles have been obtained, they are segmented to get line segments that represent continuous planar curves on surfaces in the landscape. Segmentation of the point cloud is achieved by overlaying all segmented profiles which lead to the generation of a graph, and a surface segment is therefore a connected subgraph. The usage of the profiles in several directions hence provides an elegant way to combine the profile segmentation results to a surface segmentation. Two adjacent parallel profile segments are connected only if there exists a profile segment with another orientation that contains points of both these parallel segments.

The algorithm can be described as a procedural stripping away of objects from the bare-Earth in the following sequence, large objects, bridges, and small objects. In each step of the sequence smaller and smaller objects are removed. The explicit detection of bridges is necessary to ensure the reliability of the detected bare-Earth. Further details can be found in Sithole (2005).

Participants	Filter description
George Vosselman— Delft University of Technology	Slope-based filter
Yong Hu— University of Calgary	Hierarchical terrain recovery
George Sithole— Delft University of Technology	Segmented point clouds

Table 1. Test participants

#### 4. FILTER CONCEPT

Every filter has an assumption about the structure of bare-Earth points in a landscape. Here, In the Slope-based algorithm (Vosselman), the slope or height difference between two points is important. If the slope exceeds a certain predefined threshold, then the highest point is assumed to belong to an object. In hierarchical terrain recovery algorithm (Hu), the top-level of an image pyramid is assumed to be a coarse bare-Earth. In such algorithms a smooth condition is established to validate that the elevation at the current level and the estimated elevation from the reference level are reasonably close at every point of a local patch. If any point in the current window violates the smooth condition, then that point is classified as a non-terrain point. In Segmentation-based algorithm (Sithole), the assumption is that every points in a segment must belong to an object if their segment is above its neighbourhood. It is important to note that for such a concept to work the segments must delineate objects and not facets of objects.

#### 5. WAVELET DE-NOISING

Blunder detection of LIDAR data by using wavelets in this paper is based on the decomposition of the raw LIDAR image in order to detect salient changes in height. In the context of Airborne laser scanning data, a filter response represents a discontinuity caused by a blunder whereas the underlying landscape do not response. By employing blunder detection using wavelets, low frequencies such as ground or large objects are separated from the high frequency components which represent blunders.

The LIDAR point cloud is first regularly gridded. The resulting matrix is then decomposed using the Discrete Wavelet Transform (Goswami and Chan, 1999) into low frequencies and high frequencies. The energy is evenly distributed among sub-images and therefore, the amplitudes of sub-images becomes lower (Bartels, Wei, and Mason, 2005). In this study, level 4 decomposition is applied to the LIDAR data. Discontinuities give responses in the details depending on their relative position to the wavelet kernel.

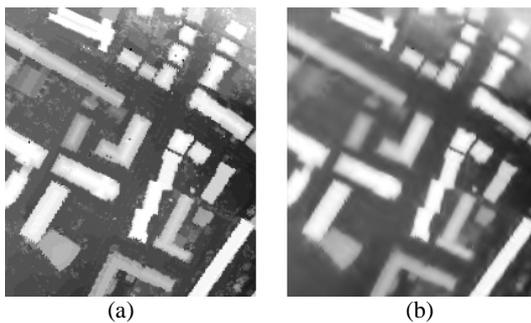


Figure 2. (a) LIDAR range image, (b) degradation of blunders by wavelets.

Figure.2(a,b) depicts wavelet de-noising on LIDAR range image using Symlets(6) wavelet filter (Daubechies, 1992). The scene in Figure.2(a) represents building blocks of different height on the terrain with blunders. Applying wavelet de-noising, blunders in the scene are degraded as shown in Figure.2(b). As shown in Figure.2(b), two observations can be made. First, blunders could be successfully degraded. Second, It can clearly be seen that the filter response depends on the degree of the salient height, i.e. the larger difference between adjacent height values the higher is the magnitude of the

responses. However, as expected, it can also clearly be seen that flat roofs are not degraded as there is no distinctive change in height.

#### 6. RESULTS

The filter results of these algorithms have been analysed in various ways. The data of five reference samples has been used to assess the performance of the algorithms in several difficult terrain types.

The quantitative assessment was done by evaluating Type I (rejection of bare-Earth points) and Type II (acceptance of object points as bare Earth) errors. It must be stressed that the results which are presented here do not cover the difficulties in filtering as observed in the data, yet in general all the filters worked quite well.

The output of Hu's filter is gridded, and it is altered in position from the original. Therefore, DEMs were generated for the filtered data and the height of the points in the reference data were compared against these DEMs. The Type I and Type II errors have to be understood in the context of height comparison of the reference against the filtered DEMs.

Vosselman			
Test Samples	Type I errors %	Type II errors %	Number of points
Samp11	43.2	5.7	38010
Samp12	23.8	3.5	52119
Samp21	10.4	1.6	12960
Samp31	5.6	1.9	28862
Samp41	51.8	2.6	11231
Hu			
Test Samples	Type I errors %	Type II errors %	Number of points
Samp11	13.6	7.8	38010
Samp12	4.8	2.6	52119
Samp21	1.5	12.7	12960
Samp31	6.1	1.9	28862
Samp41	21.6	1.7	11231
Sithole			
Test Samples	Type I errors %	Type II errors %	Number of points
Samp11	28.3	13.7	38010
Samp12	3.7	2.6	52119
Samp21	3.3	1.7	12960
Samp31	2.3	3.2	28862
Samp41	6.8	4.9	11231

Table 2. percentages of Type I and Type II errors

All the filtering algorithms fails sometimes. This failure is caused by the fact that filters are blind to the context of structures in relation to their neighbourhoods. Because of this, a trade-off is involved between making Type I and Type II errors. The computed errors (over all the datasets) ranged from 1.5 to 51.8%, 1.6 to 13.7% for Type I, Type II, respectively. Vosselman's filter focus on minimizing Type II errors. This tendency to minimizing Type II errors, partly suggests that they consider the cost of Type II errors to be much higher than that of Type I errors. Table 2. shows the percentages of Type I errors and Type II errors for three tested algorithms.

## 7. CONCLUSIONS

In this paper a comparison of three different filtering methods was presented. The objectives of the study were to: (1) determine the performance of filter algorithms, (2) applying wavelet denoising method for the detection of blunders in LIDAR data and (3) establish directions for future research. In general, all the filters worked quite well in landscape of low complexity. As seen in Table 2, the performance of a filter can differ depending on the feature content of a landscape. The problems that pose the greatest challenges appear to be complex cityscapes and discontinuities in the bare-Earth. So, the combination of different strategies may be a solution. Wavelet de-noising methods showed their talent in the detection and degradation of blunders among LIDAR data. Therefore, it is hardly recommended to use wavelets in other researches and even in the filtering methods for the sake of object detection.

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