Estimation of the Off-Terrain from Airborne Laser Scanning Data using Multiple Polynomials

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Abstract. A possibility to filter airborne laser scanning data is the approximation of the terrain with polynomials. A major issue here is the determination of an appropriate degree of the polynomial. The quality of the approximation depends directly on this polynomial degree.
In this article we present a method where the terrain is approximated using polynomials of different degree at the same time. To show the capability of the methods some exemplary results are compared to the results of a traditional, polynomial based terrain approximation.

Keywords: LIDAR, Classification, Surface, Method

1 Introduction

For several years digital terrain models (DTM) and digital surface models (DSM) for a larger area are acquired using Airborne Laser Scanning (ALS) or Light detection and ranging (LIDAR) as an alternative to photogrammetric methods. The first result after a surveying flight is usually the DSM represented by unequally distributed points. These points have to be classified (filtered) in order to establish a DTM. The quality of the DTM is highly influenced by the filter technique used during the classification process.

The multitude of filter techniques for LIDAR data can be grouped as follows: local interpolation, edge/slope based filtering and clustering, morphological filters, area driven classification by segmentation, and global interpolation. An overview on the numerous research on classification and filter of LIDAR data is given by Liu [4]. But, the development of filter methods is an ongoing process. There are recent publications on local interpolation [2, 5] and on gradient based interpolation [7].

This article focuses on a global interpolation method, which will be explained. We forbear from an explanation of other methods due to the lack of space.

A global approximation approach for the terrain was presented by Akel et al. [1], some parts base on a strategy with robust estimation of Kraus and Pfeifer [3]. The classification of the points is based on an approximation of the terrain

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using orthogonal polynomials. These orthogonal polynomials are estimated along a thin buffer (sometimes mentioned as scan lines).

A challenge of this method is the definition of a useful degree of the polynomials. In [1] an initial polynomial was used which approximates 60% of all points. The coefficients of the polynomial were determined using a robust estimation method. In this estimation the points above the polynomial get less weight than the points below the polynomial (Fig. 1). Each point was classified to be on or below the terrain, or above the terrain. In the next step the degree of the polynomial was reduced and the coefficients were determined again. The points were classified again and the classification was compared to the precedent classification. If there was no change in classification the polynomial was kept, otherwise the degree of the polynomial was decreased again.

Fig. 1. An initial polynomial function (dark grey) is estimated using all laser points (black dots). An optimized polynomial function (light grey) is estimated using a robust least square adjustment.

For the classification into terrain and off-terrain points the estimations of the two orthogonal polynomials have to be taken into account. A point was defined as point on the terrain, if the distance of the point to one of the orthogonal polynomials was below a certain threshold.

An improvement of the result is achieved by a segmentation of the points according to their classification. During this process, some local structures can be eliminated.

A slightly different approach of this algorithm was used in [6]. Here, the degree of the polynomials is increased systematically, starting at a degree of 10. The data are computed piecewise, tiling them into pieces of $1km^2$. Apparently a degree of 20 is useful for tolerably flat areas.

2 Specific Problems

If the degree of the polynomial is not adequate the altitude of the terrain is under- or overestimated. Some difficulties arise if the quotient between off-terrain points and terrain points is high. (This means a lot of points represent roof, vegetation, etc. and only few points represent the terrain.) Furthermore, the estimation is weak if vegetation is located close to the roof of a building. In these cases the polynomial is bending towards the off-terrain points and these points are detected as terrain (Fig. 2, left part). At the same time the curvature of the polynomial should not be too rigid. Otherwise some terrain structures like dikes are not fully recognized (Fig. 2, right part).

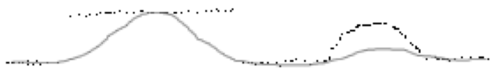

Fig. 2. Two problems occurring during the estimation of the polynomial degree: If the curvature is too weak a part of a building may be detected as terrain (left part) and if the curvature is too strong a ditch may not be detected as terrain (right part). Black dots: LIDAR points; grey line: estimated polynomial.

The influence of a polynomial degree that is too high is also shown in Figure 3: An area of 200m x 200m is filtered using polynomials of degree 15 (left) and 20 (right). Since the areas extend is rather small, the polynomials of degree 20 lead to a massive misinterpretation. (An impression how the correct interpretation should look like is shown in Figure 4.)

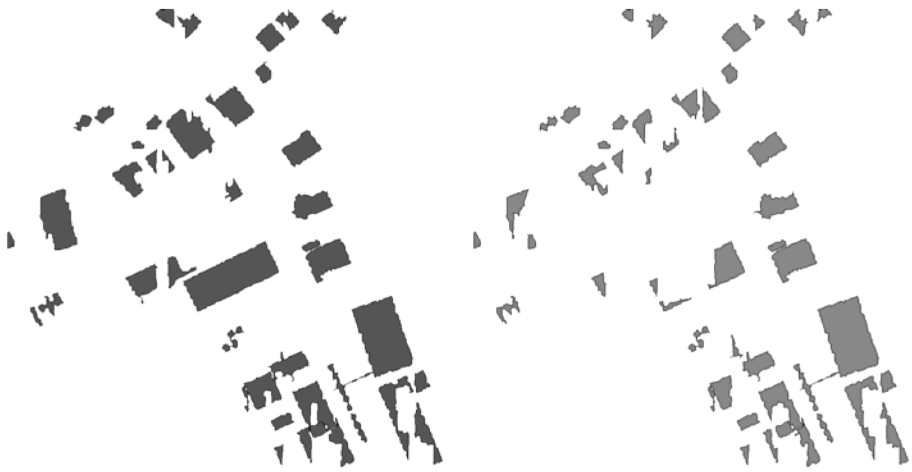

Fig. 3. Estimation of the off-terrain points in an area of 200m x 200m using polynomials of degree 15 (left) and degree 20 (right), with a following segmentation.

We investigated also the standard deviation of the robust estimation in dependence to the polynomial degree. Unfortunately, this function has several (more than 2) local minima. There is no general rule at which point the global minima exists. So it remains unclear with which degree the terrain should be approximated.

3 Classification using multiple polynomials

To overcome these drawbacks, we changed the estimation from a discrete one to a continuous one, where the distance (height) between the orthogonal polynomials is summed up. If the sum is above a certain threshold a point is classified as off-terrain point, otherwise as a point on or below the terrain. Additionally, and more importantly, the distance between estimated terrain and measured points is evaluated for several polynomials with different degrees. The notion for this was the observation that the polynomials approximate the points on the terrain rather reliable while problems mentioned arise mainly for the approximation for off-terrain points.

4 Results

To show the capability of the method we classified the points of in two areas. The first is an area of 200m x 200m. A surface model of this area is shown in Figure 4 (left-hand side). For this area the points are classified using some edge detection algorithm and some manual editing (Fig. 4 right-hand side).

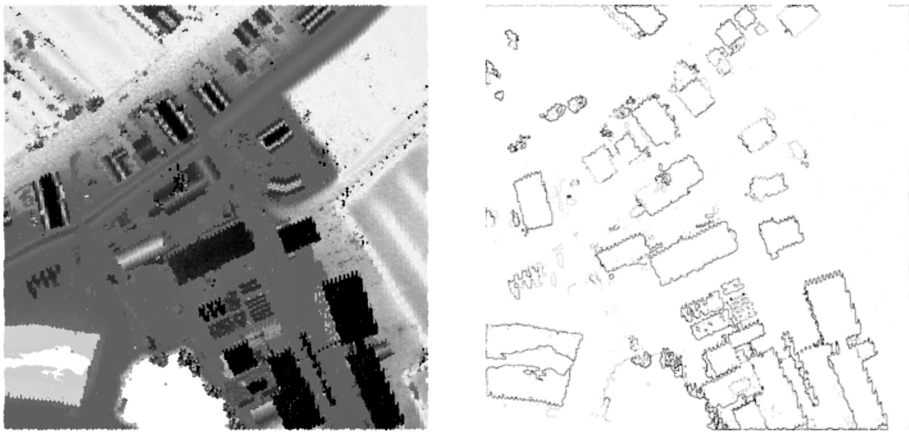

Fig. 4. Area under investigation: Altitude of the surface (the darker the higher, left-hand side) and edges of the surface objects in the area (right-hand side).

Figure 5 (left-hand side) shows the same area using the classification and segmentation according to [6] (method A) and our method (method B) with summed distances of several terrain approximations (right-hand side). With method $A = 3665.67m^2$ were detected as off-terrain, with method B $5708.84m^2$. Method A detected $0.29m^2$ as off-terrain that were not detected with method B, and $2009.88m^2$ vice versa. With the mixed classification method the points were classified much better.

The second region is an area of 1km x 1km. It is a rather flat area with buildings located in Northern Germany. Here, method A detected $35850.58m^2$ as off-terrain, where method B detected $49134.10m^2$ (with $4320.90m^2$ and $11234.17m^2$ resp. that are obviously classified wrong). Method A detected $337.88m^2$ as off-terrain where method B detected terrain, and $13569.86m^2$ vice versa.

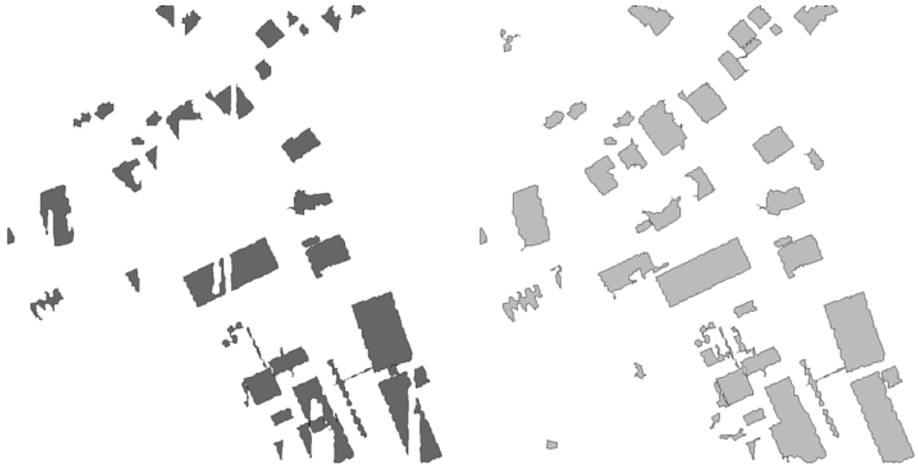

Fig. 5. Result of the classification and segmentation of off-terrain points. Left: polynomial estimation with degree 20 (starting at degree 5). Right: Mixed classification using polynomials between degree 5 and 20.

5 Further work

In this article we presented an alternative method for global terrain approximation with orthogonal polynomials. For the area under investigation the method showed some promising results. But, the method has to be tested for more areas and especially such with a moved topography.

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