

# A ROBUST METHOD USED WITH ORTHOGONAL POLYNOMIALS AND ROAD NETWORK FOR AUTOMATIC TERRAIN SURFACE EXTRACTION FROM LIDAR DATA IN URBAN AREAS

Nizar Abo Akel<sup>a\*</sup>, Ofer Zilberstein<sup>b</sup>, Yerach Doytsher<sup>a</sup>

<sup>a</sup> Department of Transportation and Geo-Information Engineering  
Faculty of Civil and Environmental Engineering,  
Technion – Israel institute of technology  
Technion City, Haifa 32000, Israel  
(anizar, doytsher)@tx.technion.ac.il

<sup>b</sup> Telecom & Systems Group, Ness A.T. Ltd, Tel-Aviv 61581, Israel  
oferzilberstein@hotmail.com

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## ABSTRACT:

The data provided by LIDAR systems are presented in a dense, accurate three-dimensional form without point classification, such as buildings, trees roads, terrain, etc. The principal objective of this research is automatic terrain extraction, without prior knowledge of the DTM. The key issue is first extracting the road network, and then use it as input information to the reconstruction process of the DTM. This approach is naturally applicable to urban areas.

Various methods have been developed for terrain extraction. Most frequently used is the robust method. The essence of the robust method is computing the height of measured points by means of an interpolation function based on neighbouring points, and comparing the resulting height to the measured height. Points describing buildings will be characterized by a large positive difference versus surface points characterized either by a large negative difference or a small positive difference. To compute the new height for a certain point, a bi-dimensional interpolation function is used, whose coefficients are extracted by adjustment process in which all points within a certain computed radius around the point take part. For a function of higher order, a singularity in the coefficient matrix is possible with the resulting solution (if any) is unstable and influenced by measurement errors. Moreover, the robust method has been developed specifically for forested areas; its application to urban areas leads to erroneous classification of buildings as land and vice versa, due to the large area of buildings, particularly with complex shapes.

The objective of the present research is to improve the current method, in order to obtain better results. To achieve it, we are using orthogonal polynomials, which permit the usage of interpolation functions of a polynomial kind, without restricting the polynomial degree. An attempt was made to develop a new method base on the roads net, for computing an approximate model of the terrain. For improving the extraction process, the Roads method, and the Robust method have been merged. The algorithm for terrain extraction has been applied to four urban areas which include various kinds of problematic objects such as bridges and large buildings containing open roofs etc. Based on the qualitative aspect, the results are promising.

## 1. Introduction

LIDAR has become a reliable technique for data collection from the earth surface. The LIDAR system integrates three basic data collection tools: a laser scanner, Global Position System (GPS), and an Inertial Measuring Unit (IMU) (see figure 1.1). The laser scanner sends pulses toward the ground, which are then reflected back to the sensor after hitting an object. The time it takes for the pulse to travel from the sensor to the object and back to the sensor, together with the position and the orientation of the sensor, makes it possible to calculate the position and the elevation of the ground points.

Using the LIDAR technology we obtain dense (0.5-3 point per meter) and accurate (5-20 cm) Digital Surface Model (DSM), but with no point classification that describe various objects, such as buildings, roads, trees, terrain, etc.(see figure 1.2).

Various algorithms for automatically extraction DTM is available in the literature, Masaharu & Ohtsubo (2002) extracted DTM from complex terrain by dividing the area into small tiles and selected the lowest point to construct the initial approximation for the DTM (the method is applicable for flat areas only).

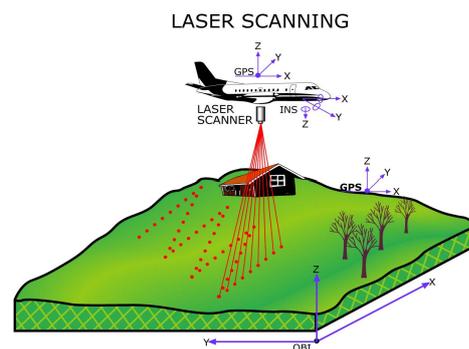


Figure 1.1 - Laser system

The most frequently used is the Robust method (Kraus and Pfeifer 2001, Briese et al. 2002).

Moreover, the Robust method has been developed specifically for forest area; its application to urban areas causes mistaken classification of buildings as land and vice versa, due to the large area of buildings, in particular if their shape is complex.



Figure 1.2 – 3D presentation.

In order to improve the robust method, we are using orthogonal polynomials which permit the usage of interpolation functions of the polynomial kind, with no restriction on the degree of the polynomial.

Moreover, in this paper, we also present an automatic method for DTM extraction which depicts the net roads, and using it as a first approximation of the DTM, then by iterative processing the true DTM is computed. To detect roads we use segmentation based on Normal directions, edge detections and height difference.

For improving the extraction process, the Roads method and the Robust method have been merged. The results show success, at least in the qualitative aspect.

## 2. Generating the DTM using the roads net

### 2.1 The roads method outline

We assume, prior to generating the DTM extraction, that roads patterns exist in urban areas. The basic idea is that we regard roads network as seed points in for determining the initial approximation of the DTM. To detect roads automatically we segment the data using Normal directions and height difference, these segments have been classified and the roads have been extracted. To execute this process we need to define the road accurately using its geometric properties. This explicitly defines the DTM borders. It is furthermore compared with the original DSM and if the difference falls below a predefined threshold (for example 0.3 m) the original DSM points are selected and included in the new DTM calculations. This process is repeated until the numbers of the added points in the last iteration falls below a threshold.

The LIDAR data is provided as points arranged by number of strips, these strips need to be adjusted to eliminate differences in the overlapping area, these differences caused mainly by changing the flight direction from one strip to another.

The process of segmentation uses the original data after adjustment the strips. In the first step we calculate TIN model for the surface using Delaunay algorithm, we also convert the data to a regular grid form to illustrate image processing tools and also to make the presentation of the results more easily.

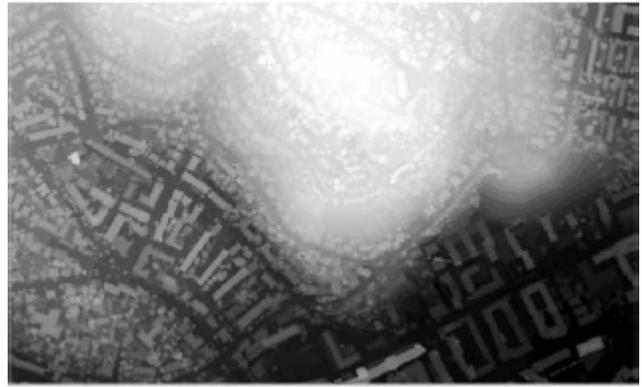


Figure 2.1 - First pulse

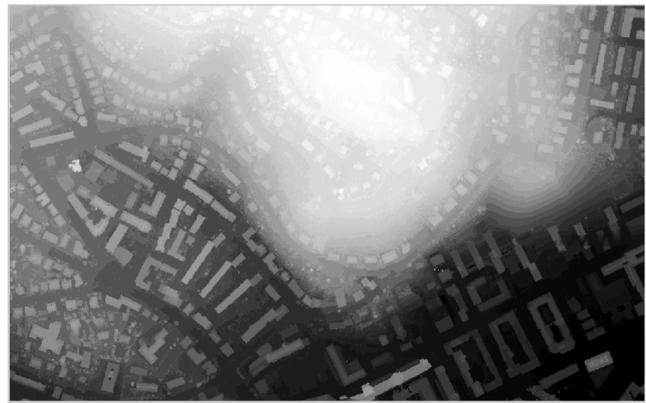


Figure 2.2 - Last pulse

Laser pulses can easily hit more than one object, especially when they hit trees. Using the first pulse (figure 2.1) can lead to problems because there are not enough points reflected from the ground and because trees may cover parts of the roads and make them thinner or discontinuous. In order to detect roads by Normal direction we use the last pulse (figure 2.2) assuming that it was reflected from the ground. Moreover to avoid discontinuous roads caused by traffic mass, high grid resolution is needed, which lead to long computation times and consumption of high memory storage. The size of the grid is set to 1 meter (figure 2.2).

### 2.2 Segmentation and classification

The results of the segmentation by Normal directions and height difference are shown in figure 2.3. In this segmentation we use  $\Delta h=0.5$  m (difference in heights) and  $\Delta n=6$  degrees (different in Normal direction). Road segments are considerably larger than any other segment, and also their area to boundary ratio approaches zero. The segments have been classified and the roads have been detected (figure 2.4).

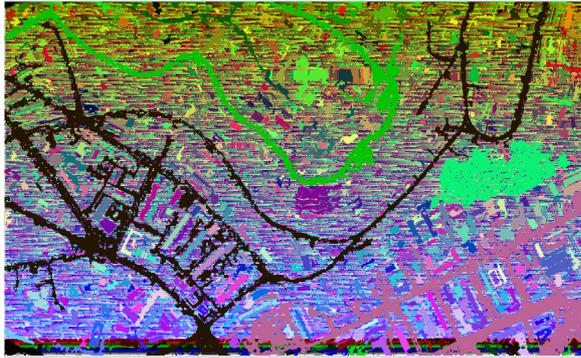


Figure 2.3- Segmentation



Figure 2.5- All points data used to calculate the final DTM



Figure 2.4- Classification (roads)

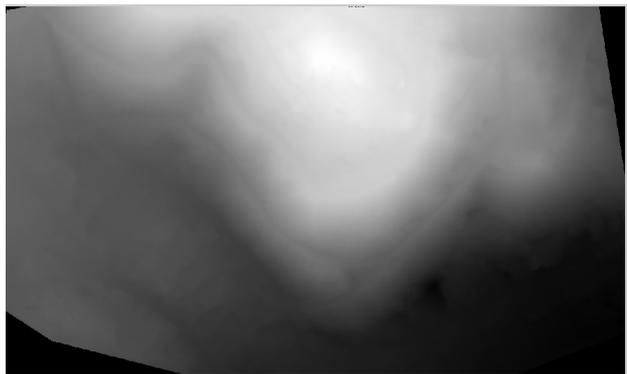


Figure 2.6- The final DTM

### 2.3 Final DTM

Using the points derived from the last step, we can determine the first approximation of the DTM, iteratively comparing the DTM with the original DSM. If the height difference is less than 0.3 meter the original DSM points are selected and added to the DTM, whereupon the DTM is recalculated. This iterative processing ends when the number of points added during the present iteration is less than 100 points. Although some areas (see area A figure 2.4) have no data, by the end of the processing all DTM points have been added (figure 2.5). In some cases, where there are no roads, we can manually add seeds points to overcome the problem. The number of added points gradually decreases in each iteration.

Total number of points in the DSM is : 466,652.  
 Number of points built the first approximate DTM is: 104,772.  
 Number of points was added is as follow:  
 First iteration: 50,807 points.  
 Second iteration: 25,759 points.  
 Third iteration: 8,981 points.  
 Total number of points added after 10 iterations : 163456.

The final result of the DTM is presented y figure 2.6.

## 3. Generating the DTM using the Robust method with Orthogonal Polynomials.

### 3.1 The robust method outline

The essence of the robust method is computing the height of the measured points by means of an interpolation function on the basis of neighbouring points and comparing the resulting height to the measured height. Points describing buildings will be characterized by a large positive difference vs. surface points characterized either by a large negative or a small positive difference. For computing a new height of a certain point, use is made of a bi-dimensional interpolation function, the coefficients of which will be extracted by a correlation process in which all the points within a certain radius around the point under consideration will take part. For a function of higher order, a singularity in the coefficient matrix is possible; the resulting solution (if resulting at all) is unstable and influenced by the measurement errors.

Using orthogonal polynomials will permit the usage of interpolation functions of the polynomial kind, with no restriction on the degree of the polynomial, this make it easier to remove building or other objects from the DTM.

The process is iterative, where in each iteration a smaller  $\Delta H$  (difference between original points and the polynomial) is set. The same processing is made in two directions and the final DTM is a combination between the two.

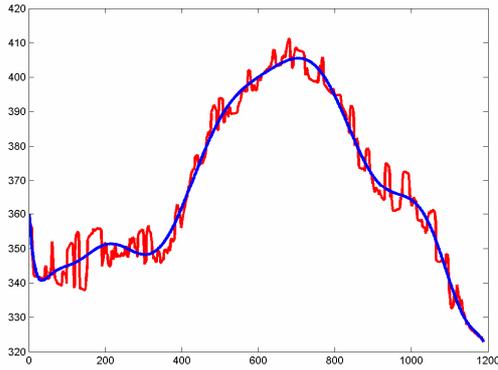


Figure 3.1- a , Iteration number 1 ,  $\Delta h=7.05$  m

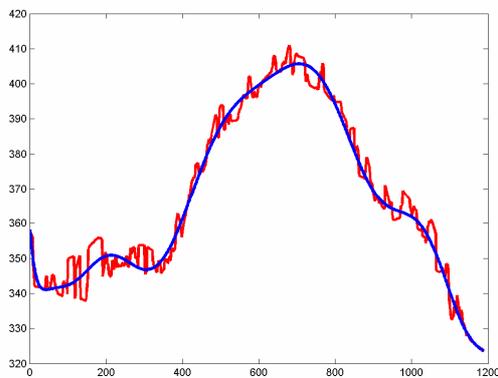


Figure 3.1- b, Iteration number 5 ,  $\Delta h=3.05$  m

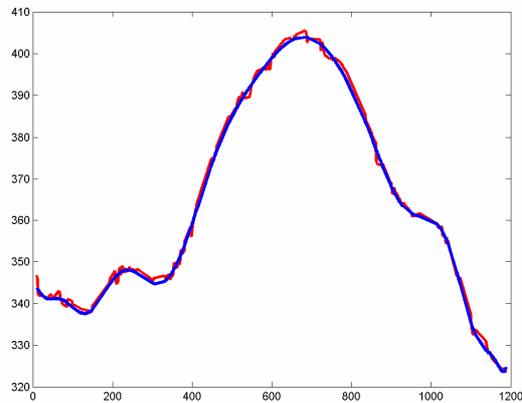


Figure 3.1- c, Iteration number 8 ,  $\Delta h=0.05$  m

#### 4. Results:

For all for comparing the results of all methods we classified the data to three groups: 1. ■ red- objects, 2. ■ green – double pulse, 3. □ yellow – Terrain.

#### 4.1 DTM generated by roads- figure 4.1



Figure 4.1- Results of the final classification using the road method, site No. 1.

In areas A there where no roads extracted so also the DTM cannot be extracted too. All building have been detected and removed, comparing to the results obtained by GRASS, we can notice that in area G there is a building which is classified as DTM, but using the roads net this building is easily classified truly as a building.

#### 4.2 DTM generated by robust method - figure 4.2



Figure 4.2 - Results of the final classification using the road method, site No. 1.



Figure 4.3 – 3D presentation of site No. 1.



Figure 4.4- Results of the Final classification obtained by the GRASS program site No. 1.

### 4.3 The Final DTM

#### Combination between the robust and the roads methods

##### Disadvantages of the robust method:

By using orthogonal polynomials we can overcome labelling buildings as a DTM, but we still have misclassification in points near tunnels which have been classified as objects although they belong to the DTM.

##### Disadvantages of the roads method:

1. We can't always generate the DTM in areas that do not contain road network.
2. Elevated bridges will be classified as DTM

For better results we combine the tow methods as follow:

1. The DTM generated by roads method is taken as a basic DTM.
2. In areas where DTM could not be generated because lack of road network, we use DTM generated by the robust method.
3. To remove bridges we applied the robust method another iteration on the DTM.

The results shown in figure 4.5 are more reliable comparing to the results obtained by GRASS figure 4.4.



Figure 4.5- Results of the final classification of combining the road method with the robust method - site No. 2.

#### Site 2

Another site but more complex than the first one which contain: 1. bridges, 2. Tunnel, 3. complex building. See figure 4.6

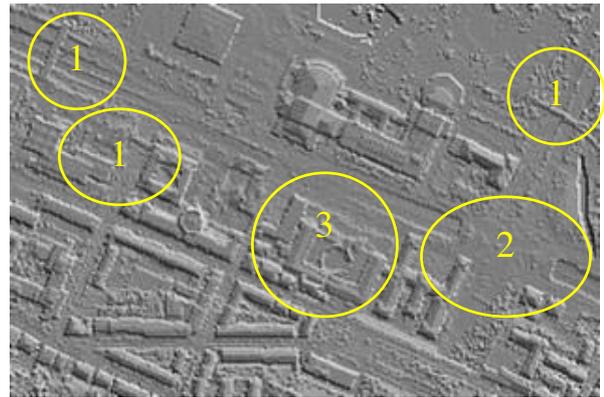


Figure 4.6 – 3D presentation of site No. 2.

The results obtain by GRASS shown in figure 4.7 include many misclassification points specially near the tunnel (A,B), also areas E and F are roads but they have the same misclassification.

The results obtain by the roads method are shown in figure 4.8, areas 1 are bridges that have been classified as DTM, where all roads have been extracted.



Figure 4.7-Results of the final classification obtained by the GRASS program, site No. 2.

Good results are also obtained by the roust method using the orthogonal polynominal, but still there are misclassification specially near the tunnel (see A & B figure 4.9) that classified as objects although these areas belong to the DTM, but the results are better than those obtained by GRASS.



Figure 4.8 -Results of the final classification using the road method, site No. 2.



Figure 4.9- Results of the final classification using the robust method, site No. 2.

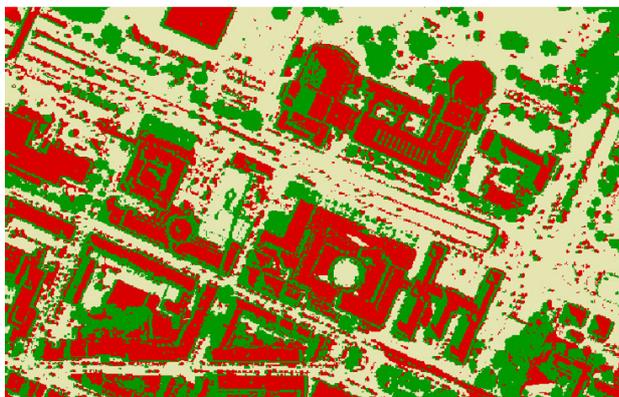


Figure 4.10 -Results of the final classification of combining the Road Method with the robust method, site No. 2.

The final DTM obtained by combining the roads and the robust orthogonal methods are shown by figure 4.10. these results shown a perfect DTM extraction at least in the qualitative aspect.

#### 4. CONCLUSION

In this paper we present automatic object classification algorithm from LIDAR data, in urban area, with no prior information. An improving of the robust method has been made using orthogonal polynomial. Using the roads net as input information, can give a reliable DTM, The optimal result is obtained by merging the robust and the roads methods. The methods have been tested on different types of terrain and the results found to be reliable and stable.

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