Automatic DTM Extraction from Dense Raw LIDAR Data in Urban Areas

Nizar ABO AKEL, Ofer ZILBERSTEIN and Yerach DOYTSHER, Israel

Key words: LIDAR, DSM, urban areas, DTM extraction.

SUMMARY

Although LIDAR is a powerful tool for collecting data of the earth surface, the collected raw data amounts to no more than clouds of x-y-z points inexplicitly describing the surface. It lacks differentiation between points measured on the terrain itself and points measured on man-made or natural objects (buildings, roads, trees etc.). In this paper, an automatic method for DTM extraction in urban areas is presented. The method is based on an initial approximation of the DTM determined by using the road network, followed by an iterative processing technique that enables computing the final (“true”) DTM. For detection of roads, segmentations based on normal direction, edge detection and height difference are used. Based on our preliminary tests, some of which are presented in this paper, the results point to a promising solution.

Automatic DTM Extraction from Dense Raw LIDAR Data in Urban Areas

Nizar ABO AKEL, Ofer ZILBERSTEIN and Yerach DOYTSHER, Israel

1. INTRODUCTION

LIDAR has become a reliable technique for collecting data of the earth surface. The LIDAR system integrates three basic data collection tools: a laser scanner, Global Positioning System (GPS), and an Inertial Measuring Unit (IMU) (see Figure 1).

The laser scanner sends pulses toward the ground, which are reflected to the sensor when they hit an object., The time that 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, make it possible to calculate the position and the elevation of the ground points.

Using LIDAR technology, we can obtain a dense (0.5-3 points per meter) and accurate (5-20cm) Digital Surface Model (DSM). It is important to note that the accuracy and resolution depend on the flight characteristics (speed and altitude), and sensor characteristics (scan angle and emission rate) ([Ferris, 2002]; [Airborne, 1999]). Different aspects of the LIDAR technology, such as accuracy and resolution, have been studied in recent years by many researchers ([Wack and Wimmer, 2002], [Haala et al., 1998], [Hill et al., 2000] and many others).

Various algorithms for automatic DTM extraction are described in the literature. Masaharu and 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). Briese et al. (2002) present robust methods for automatic determination of a DTM from point cloud data. These robust methods operate on the original data points and allow the elimination of off-terrain points and modeling the terrain surface by a single process. Kraus and Pfeifer (2001) developed a filtering method suitable for wooded and hilly areas. Brovelli et al. (2002) present an automatic method for determining the DTM by calculating the differences between observed and interpolated DSMs and detecting edges using gradients to eliminate off-terrain points.

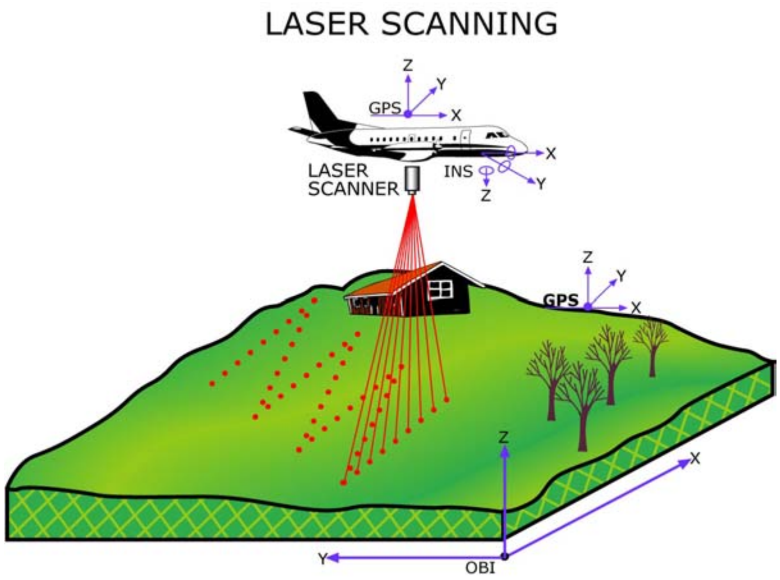

Figure 1. Schematic description of the LIDAR system

2. METHOD OF GENERATING THE DTM

2.1 Method Outline

We assumed, prior to generating the DTM extraction, that road patterns exist in urban areas. The basic idea is that we regard the road network as seed points for determining the initial approximation of the DTM. To detect roads automatically, we segment the data using normal directions and height differences, until 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 number of the added points falls below the threshold.

2.2 Generating Method

The generating process is as follows:

(1) Due to the randomly distributed raw data points, and the fact that data collected from the same object but from two different sensor positions (two different passes) cause an object like a road to appear discontinuous, the data is interpolated by means of a linear function. It is aiming to enable processing with regularly distributed grid data, where smoothing the data can be achieved by using a median filter and other image processing tools.

(2) Data is filtered using a median filter to remove noise and smooth the data, especially where two strips overlap.

(3) Using the Delaunay algorithm we calculate the TIN model for the surface. For each triangle in the TIN model we calculate the direction of the normal and mean heights of the three points that compose it.

(4) Using the region growing approach each triangle (To) is compared with all its neighbors (Ti: i = 1, 2,…, n), for each two triangles (To and Ti). If the difference in the normal direction is below a threshold (Δn) while the difference in mean height does not exceed a threshold (Δh), the two triangles are considered to present the same segment. Each triangle added to the segment is also checked against its neighbors. In doing this we segment the data by normal directions, segmenting not only roads but roofs as well.

(5) Each segment is classified either as a road or not a road. To this end, the following set of decision rules is checked:

1. **If** the area of the segment exceeds the area of the largest house (a predefined value) **then** the segment may be a road.
2. Then if the segment's solidity, the proportion of the pixels in the convex hull that are also in the region, is close to zero, the segment is a road.

(6) Roads may include bridges, elevated roads or tunnel openings that have to be classified as objects and therefore removed. To this end, we construct and use a library of templates for detecting these types of objects in various directions and on various scales.

(7) Because the data has been smoothed, the road segments may include some undesired points such as edges which need to be removed. Such unwanted points were detected and removed by edge detection of the surface objects. The solution provided by image processing cannot be adopted directly, because the position of the edge is not reliable, and we therefore determine the edge as a combination of a solution provided by the image processing tools, with the gradient calculated by:

$$G_m = \sqrt{G_x^2 + G_y^2} = \sqrt{\left(\frac{dz}{dx}\right)^2 + \left(\frac{dz}{dy}\right)^2}$$

1. If a point was classified as road and the gradient magnitude exceeded a threshold (Δg) then it has been removed.
2. To detect objects we also fill in the closed edges and classify them as objects, and by comparison with the road segments these objects are removed.

(8) The first approximation of the DTM is calculated by interpolating elevations of every regular grid using the roads as seed points.

(9) By using iterative processing, the original DSM points are compared with the DTM and if the difference falls below a predefined threshold ($\Delta h = 0.3m$, for example) the original DSM points are selected. These points then compose the new DTM data points and the DTM is recalculated. This process is completed when the number of the points added during the present iteration is less than 100 points.

3. TEST RESULTS

3.1 Data used

The data were provided by ISPRS Commission III, WG III/3 "3D Reconstruction from Airborne Laser Scanner and InSAR data". Different areas were selected because of their diverse feature content (buildings, railroads, roads, bridges …). The point density is roughly 0.67 points per square meter; and data also include the first and last pulse returns. Data summary is presented in Table 1.

Table 1. Data summary

Location	Site(s)	Data bounds				Planimetric resolution
		Xmin	Xmax	Ymin	Ymax	points/sq.meter
	Site 1	512050	513150	5403440	5404100	0.67
City	Site 2	513450	513870	5402650	5403280	0.67
	Site 3	512023	512549	5403120	5403500	0.67

3.2 DTM generation

3.2.1 Interpolating and smoothing

In the first step we calculate the TIN model for the surface using the Delaunay algorithm. Here we can realize that areas scanned twice from two different position of the sensor have at least differences in elevation. In other words, objects such as roads, which are supposed to be continuous objects, are not so described. Figures 2 and Figure 3 show a difference in the height of points collected from the road, and such differences could be as much as 40 cm.

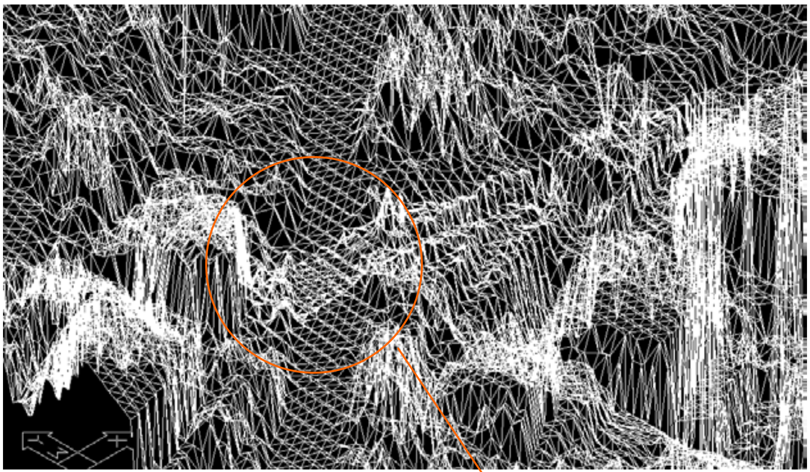

Figure 2. Areas measured twice

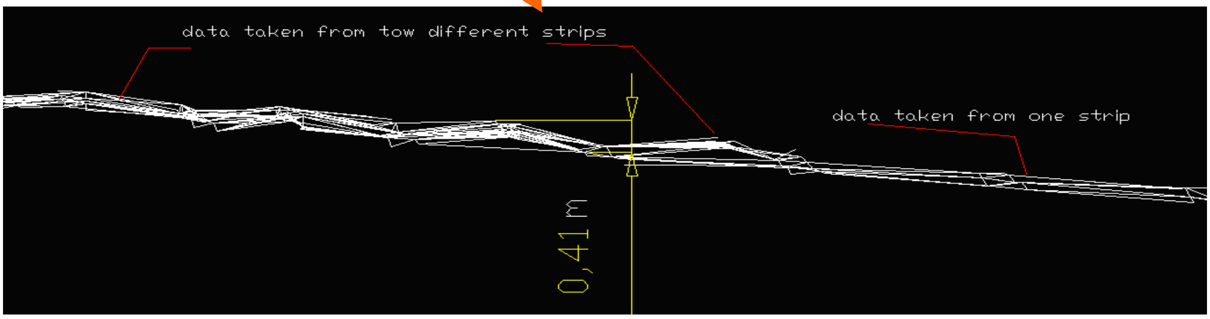

Figure 3. The discontinuity in the road

To solve this problem we construct a regular grid using linear interpolation. The median operator (3x3) is then applied to smooth out particular areas.

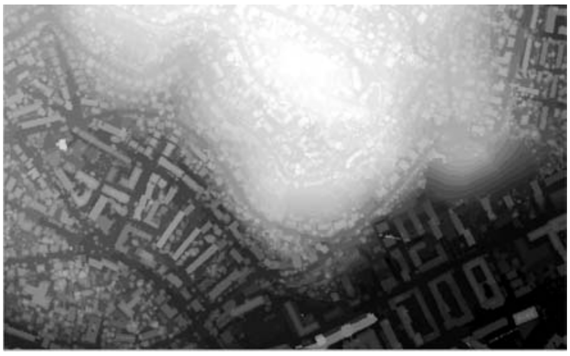

Figure 4.a.
First pulse

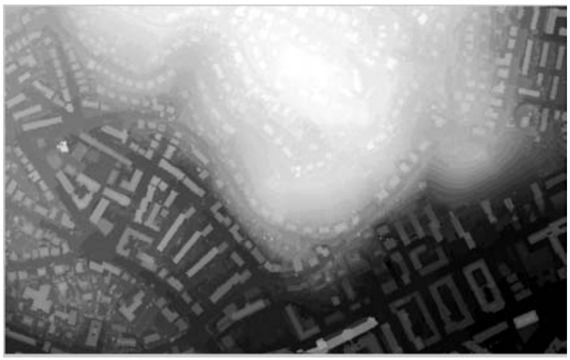

Figure 4.b.
Last pulse

Laser pulses can easily hit more than one object, especially when they hit trees. Using the first pulse 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, assuming that it was reflected from the ground. Moreover, to avoid discontinuous roads caused by traffic mass, high grid resolution is needed, leading to long computation times and requiring high memory capacity. The size of the grid is set to 1meter (Figure 4.a, Figure 4.b).

3.2.2 Segmentation and classification

The results of the segmentation by normal directions and height difference are shown in Figure-5. In this segmentation we use Δh=0.5 m (difference in heights) and Δn=6 degrees (difference 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 6).

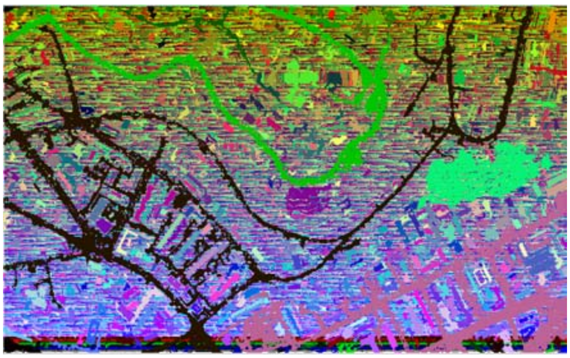

Figure 5. Segmentation

Figure 6. Classification (Roads)

3.2.3 Removing unnecessary points

As mentioned, due to the smoothing processing, the segments we classified as roads may also contain edges or noise such as cars. To remove these points, we detect edges in two different ways: gradient with threshold Δg=1(Figure 7.a), and image processing edge detection using the "Laplacian of Gaussian method" (Figure 7.b). After applying the region growing technique, we can remove from the roads any edge point or any object misclassified as a road.

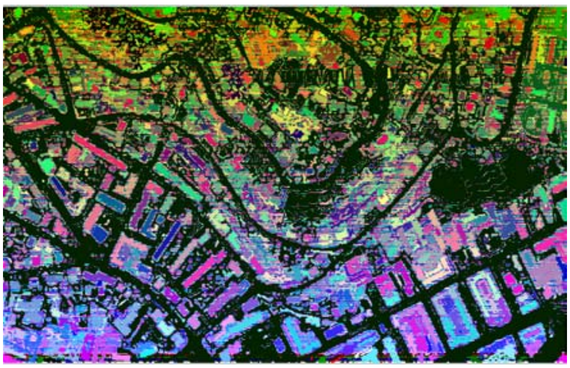

Figure 7.a. Edges by gradient and segmentation by region growing

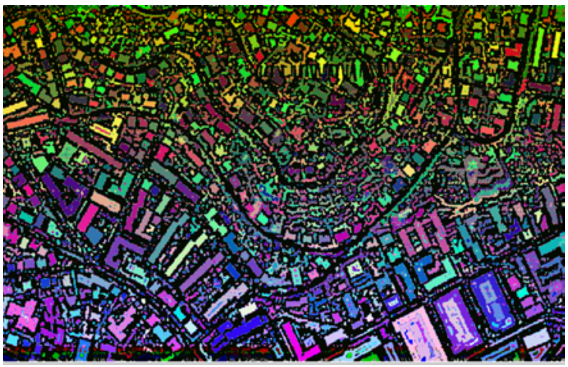

Figure 7.b. Edges by image processing and segmentation by region growing

We can also add areas that seem to be part of the DTM, but only if the area exceeds the largest house area (Figure 8). Figure 9 shows the DTM points after removing the edge points.

Figure 8. Adding large segments to roads

Figure 9. Removing edges, bridges, elevated roads, tunnels etc.

3.2.4 Final DTM

Using the points derived from the last step, we can determine the first approximation of the DTM by iteratively comparing the DTM with the original DSM. If the height difference is less than 0.3 m, 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) have no data, by the end of the processing all DTM points have been added. In some cases, where there are no roads, we can manually add seed points to overcome the problem. The number of added points gradually decreases smaller with each iteration.

If a small height difference value is selected, Δh, for use in the last step, the algorithm requires very long computation time (2-3 hours) to approach the true DTM. On the other hand, a high value may add unwanted points, such as small trees or cars.
Total number of points in the DSM: 466,652.
Number of points comprising the initial approximate DTM: 104,772.
Number of points added:
First iteration: 50,807 points.
Second iteration: 25,759 points.
Third iteration: 8,981 points.

Total number of points added after 10 iterations: 163,456.

Figure 10. All data points used to calculate the final DTM

Figure 11.a. The final DTM

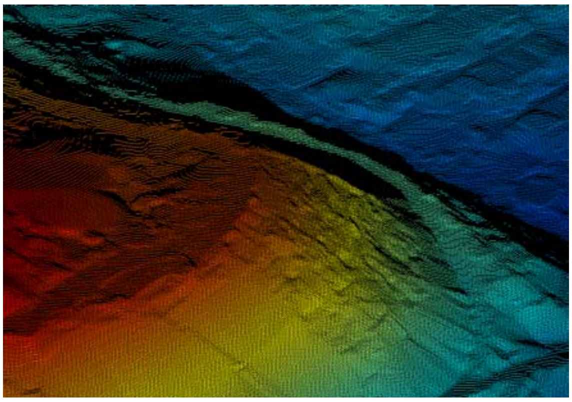

Figure 11.b. A 3D visual of the final DTM

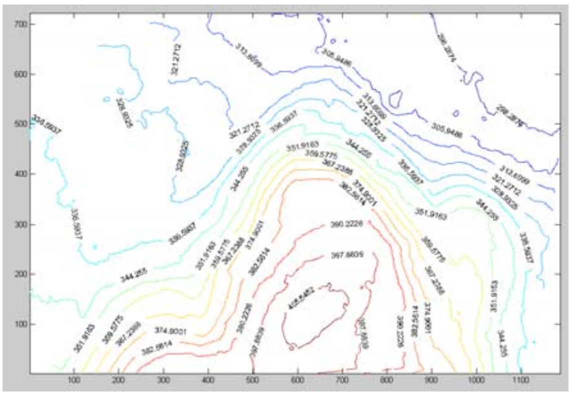

Figure 11.c. Contours describing the final DTM

4. CONCLUDING REMARKS

Many algorithms have been developed in order to automatically extract DTMs from urban areas, most based on point classification. In this paper, an independent object classification algorithm is presented. This method was tested on several different urban areas and the achieved results appear reliable. As the proposed method is dependent on pattern structure, it is mainly applicable to urban regions.

REFERENCES

[1] An Introduction to Lidar (LESSON 5), www.ferris.edu/htmls/academics/course.offerings/burtchr/sure382/Lessons/LESSON5.htm accessed 19/2/2002.

[2] H. Masaharu, and K. Ohtsubo (2002). A Filtering Method of Airborne Laser Scanner Data for Complex Terrain. Commission III, Working Group III/3.

[3] M.A. Brovelli, M. Cannata and U.M. Longoni (2002). Managing and Processing LIDAR Data within GRASS. Proceeding of the Open source GIS – GRASS users' conference - Italy.

[4] K. Kraus and N. Pfeifer, (2001). Advanced DTM Generation from LIDAR data, IASPRS, Vol. XXIV – 3/W4, Annapolis, MD.

[5] R.Wack, A.Wimmer Joanneum Research, DIGITAL TERRAIN MODELS FROM AIRBORNE LASER SCANNER DATA – A GRID BASED APPROCH, Institute of Digital Image Processing, Wastiangasse 6, 8010 Graz, Austria.

[6] Ch. Briese , N.Pfeifer, P. Dorninger, (2002). Applications of the Robust Interpolation for DTM Determination. Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Gusshausstrabe 27-29. Commission III WG III/3.

[7] Airborne 1 Corporation (1999). Technology Summary: LIDAR. At: http://www.airborne1.com/techmain.html.

[8] Haala, N., C. Brenner, and K.H. Anders, (1998). 3D urban GIS from laser altimeter and 2D map data, In: ISPRS, Vol. 32, Part 3/1, pp. 339-346.

[9] John M. Hill, Lee A. Graham, and Robert J. Henry, (2000). Wide-Area Topographic Mapping and Applications Using Airborne Light Detection and Ranging (LIDAR) Technology PE&RS August 2000, VOLUME 66, NUMBER 8.

CONTACTS

Nizar Abo Akel
M.Sc. Graduate Student
Department of Transportation and Geo-Information Engineering
Faculty of Civil and Environmental Engineering
Technion – Israel Institute of Technology
Haifa 32000
ISRAEL
Tel. + 972 4 8292358
Fax + 972 4 8234757
Email: anizar@tx.technion.ac.il

Dr. Ofer Zilberstein
Manager, Imaging & Mapping Department
Telecom & Systems Group, Ness A.T. Ltd
Tel-Aviv 61581
ISRAEL
Tel. + 972 3 5483540
Fax + 972 3 6486386

Prof. Yerach Doytsher
Head, Department of Transportation and Geo-Information Engineering
Faculty of Civil and Environmental Engineering
Technion – Israel Institute of Technology
Haifa 32000
ISRAEL
Tel. + 972 4 8293183
Fax + 972 4 8234757
Email: doytsher@geodesy.technion.ac.il