Morphological filter for removing nonground measurements from LIDAR data

A. Martinez de Agirre[1] and J.A. Malpica[2]

Mathematics Department, University of Alcala
28871 Madrid, Spain
alexmtzdeagirre@hotmail.com[1]
josea.malpica@uah.es[2]

Abstract. Airborne light detection and ranging (LIDAR) is an important technology for generating high-resolution digital terrain models (DTMs) that are essential to numerous geographic information system (GIS) applications. Airborne LIDAR scans the terrain beneath the sensor path and produces a three-dimensional cloud of points corresponding to ground and nonground features (buildings and vegetation). In order to obtain the DTM, the nonground features have to be removed from the cloud of points. Currently, this is a process that requires manual editing. In this paper, following the work of Zhang et al. (2003), a progressive morphological filter has been developed to classify the cloud of points in ground and nonground points but considering the double echoes in the classification process. The algorithm has been tested with LIDAR data taken in 2006 from Alcalá de Henares (Madrid, Spain). Results show the efficacy of the method in removing nonground features semi-automatically; minimal manual editing is required for the final DTM.

Keywords: DTM, DSM, Laser, LIDAR, Filtering

1 Introduction

DTMs are numerical structures of data that represent the space distribution of a quantitative and continuous variable. In our case, such a variable is height, which is why the DTM can also be denominated Digital Elevation Model. The DTM constitutes a fundamental tool for analysis and visualizations in geographic information systems (GISs).

LIDAR technology allows determining the distance from an emitting laser to an object or surface using a pulsed laser beam. This technology is revolutionizing the way to obtain DTMs since it offers numerous advantages in the acquisition of digital elevation data over the classical systems based on photogrammetry; for example, it allows measurement of the altitude of the vegetation, it maintains a homogenous precision for the data over the area of study, and it considerably diminishes the cost and work time for large areas.

Since the 1990s many investigators have studied how to build a DTM from raw LIDAR data. The greater challenge in this process is the classification of the points as ground or nonground, and the majority of the work carried out to date has been dedicated to this issue. The pulses emitted by the laser scanner can be reflected by buildings, trees, cars, and many other objects that are higher than the ground. These above-ground elements do not belong to the DTM, and for this reason, filters are necessary to eliminate these points.

Although there are many algorithms to construct these filters, the majority belong to commercial houses and are under the protection of copyright laws, which is why they are not published in scientific journals. Currently, one of the most popular methods in published journals is the mathematical morphology of the filter opening. This filter does an erosion of the image with respect to a structuring element and later expands the eroded elements.

The algorithm developed in this paper for the extraction of DTMs from LIDAR data is novel since it uses the double echo of each pulse along with progressive mathematical morphology. This is why it can discriminate buildings and large areas of vegetation cover with respect to bare ground.

2 State of the art

Scientists began studying the possibility of using an airborne laser for measurement of land coordinates at the end of the 1960s; nevertheless, this was not possible until the arrival of geographical positioning systems (GPSs) at the end of the 1980s. Since that time, scientists and engineers have studied the different filtrate forms to classify the points provided by LIDAR.

Lidenberg (1993) described how mathematical morphology can be used for construing filters. This author advised making a first estimation for the terrain surface with an opening filter having a horizontal structuring element. Later, Kilian et al. (1996) concluded that the size of the structuring element used for the opening filter is a critical issue for which there is no simple optimal value. Instead they recommended using a series of opening filters with structuring elements of different sizes.

Vosselman (2000) proposed a method related to the erosion operator used in mathematical morphology, which is based on the altitude differences in a representative zone of the data. The idea stems from the observation that when there is a large altitude difference between two near points, this is probably not caused by a slope change of the land but for other reasons, such as a building, vegetation, or other structure that is different from bare ground.

For the classification of the objects and bare ground, Zhang et al. (2003) recommended a progressive morphological filter. The combination of erosion and expansion generates opening and closing filters that are used to filter the LIDAR data. These filters can eliminate the buildings and the vegetation of the LIDAR data, but it is difficult to detect all the elements from the nonground by using the same filtrated window. This problem is solved by gradually increasing the size of the window of the morphological filter.

The majority of the above methods have the limitation that it is difficult for the algorithms to perform a correct classification of the different constructions and the bare ground when the terrain presents certain roughness features. Using as reference the algorithm of Zhang et al. (2003), in the present paper we have improved the methodology of the progressive morphological filter by adding the echo differences.

3 Methods

The proposed algorithm for obtaining DTMs from LIDAR data is shown in the diagram of Fig. 1.

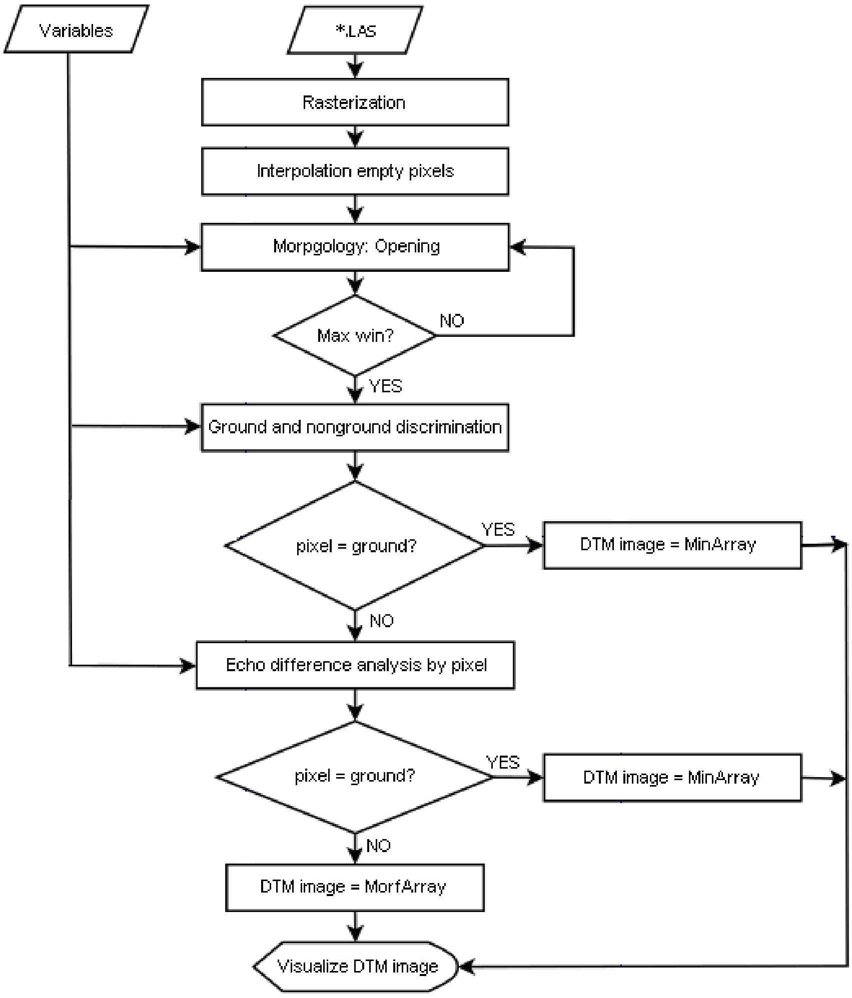


Fig. 1. DTM extraction algorithm from LIDAR data

3.1 Database entry

The raw data from which we start to extract the DTMs are the LAS files (the LASer file format exchange), which are directly provided from the aerotransported laser scanner. The archives we have been working with for the execution of this work cover a 1 km x 1 km extension and correspond to the geographical area of the city of Alcalá de Henares (Madrid, Spain).

3.2 Algorithms

Rasterization. First, we performed the rasterization of the 3D clouds of the LAS files. Our work is based on that of Streutker and Glenn (2006) who suggested dividing the data into regular cells with each containing a determinate number of individual LIDAR points depending on the local density of each cell. The final elevation for each cell is calculated as the average of the several LIDAR points that this cell has.

Interpolation. For the interpolation for the cells without LIDAR data, we used the simple method, the nearest neighbor interpolation method. We chose this method because Bater and Coops (2009) found that no method of interpolation is superior to another when used for interpolation of a DTM.

3.3 Mathematical morphology

Mathematical morphology was originally developed by J. Serra (1982), it is a branch of image analysis for geometrical shape analysis and characterization. This paper focus in two fundamental morphological operators: dilation and erosion. When performed one after the other is called a opening operator. Erosion generally decreases the sizes of objects and removes small anomalies. Erosion completely removes objects smaller than the structuring element and removes perimeter pixels from larger image objects. Dilation, on the contrary, increases the sizes of objects, filling in holes, connecting areas that are separated by spaces smaller than the size of the structuring element and adds pixels to the perimeter of each image object.

The algorithm possesses a series of input variables to perform the extraction process. For the mathematical morphology we have to introduce two variables: *size of window* w_n and *constant of increase c*. The former specifies the maximum size that the structuring element will be able to have and the latter specifies the degree of increasing of the structuring element in the filter opening. The selection of the window size is important to achieve good results; one straight forward choice is to increase the window size linearly with the following equation:

$$w_n = 2cn + 1 \qquad n = 1, 2, \ldots N \tag{1}$$

The maximum window size is equal to 2cN+1.

In order to execute an echoes difference analysis, the input variables that must be introduced are: a window size, in order to determine the size of the window in which the study is made; echo difference threshold, in which the threshold value must be fixed to establish if there is a large echo difference; and the number of pixels with echo difference threshold, which determines the minimal number of neighboring pixels with an echo difference for considering whether it is a ground point.

3.4 Ground and nonground pixel discrimination

To discriminate between nonground and ground points, the difference between the image obtained by the mathematical progressive morphology filter and the original image of minimal heights is calculated. If this difference in every pixel is minor to a certain threshold (of minimal height), the above mentioned pixel will be considered as a ground pixel and the pixel for the DTM will be assigned the value of minimal height given by the last echo.

3.5 Echo difference analysis

In this step an analysis of the resulting image of the difference between the first and the last echo of each pixel is performed. The algorithm studies the echo differences of the neighboring pixels to discriminate ground and nonground points. To those pixels classified as ground pixels and that have been modified with the morphological filter in the previous step, the initial elevation value of the original image is returned.

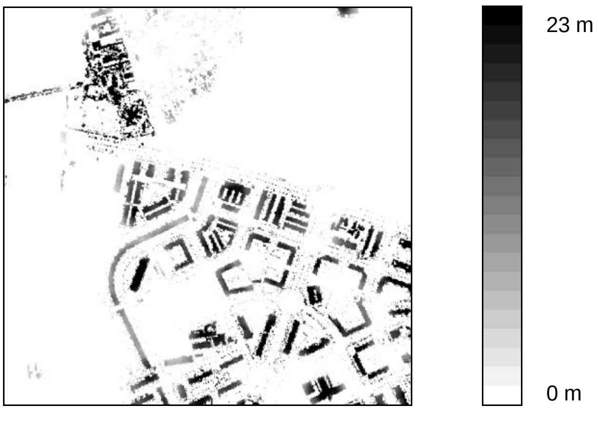


Fig. 2. Diference of echoes (neighboring pixels)

The image in Fig. 2 has been built considering:

Image with minimum heights (last echo)
Image with maximum heights (first echo)

Difference of echoes (DoE) = Image with maximum heights - Image with minimum heights

The implementation of the algorithm proposed in this paper is as follows

Imput:

DoE = Image for difference of echoes
N for maximum window size (equation (1))
C = Constant for increasing the window size (equation (1))
MaxHeight = Maximum height to be considered as ground point
ws = window size for the difference of echoes
Tdif = Threshold to consider the pixel as coming from a echoes difference
Tcte = Threshold for the whole window
MDTArray = Image with minimum heights (last echo)

The progressive morphological filter is applied to the image for minimum heights

```
1 for each window size w_n
2    Z ← Assign elevation points from MDTArray
3    Z_f = erosion(Z)
4    Z_f = dilation (Z_f)
5    MDTArray ← Z_f
6 end for

7    difheightsArray = initial MDTArray – final MDTArray {from steps 1-6}
8    for with i and j over the whole image
9       if difheightsArray[i,j] < MaxHeight then {it is classified as ground point)
10         MDTArray[i,j] = initial MDTArray[i,j]
11      else      {Difference of echoes analysis (pixel by pixel) }
12      for m=i-ws to m=i+ws
13         for n=j-ws to n=j+ws
14            if DoE[m,n] > Tdif then ignore
15      end double for
16      if cont < Tcte then
17         MDTArray[i,j] = minArray[i,j]   {End of analysis for difference of echoes }
18   end for sentence 8
```

4 Results and discussion

After several runs of the algorithm for refinement, the following images show the results using some of the input values we considered optimum.

In the second image (Figure 3(b)) we can notice that the topography of the study area, where the proposed method has been applied, shows low slopes and a new urbanized area with quite small buildings. We can see how the DTM (Figure 3c) obtained automatically with our proposed method needs little manual editing (Figure 3d) to show high precision.

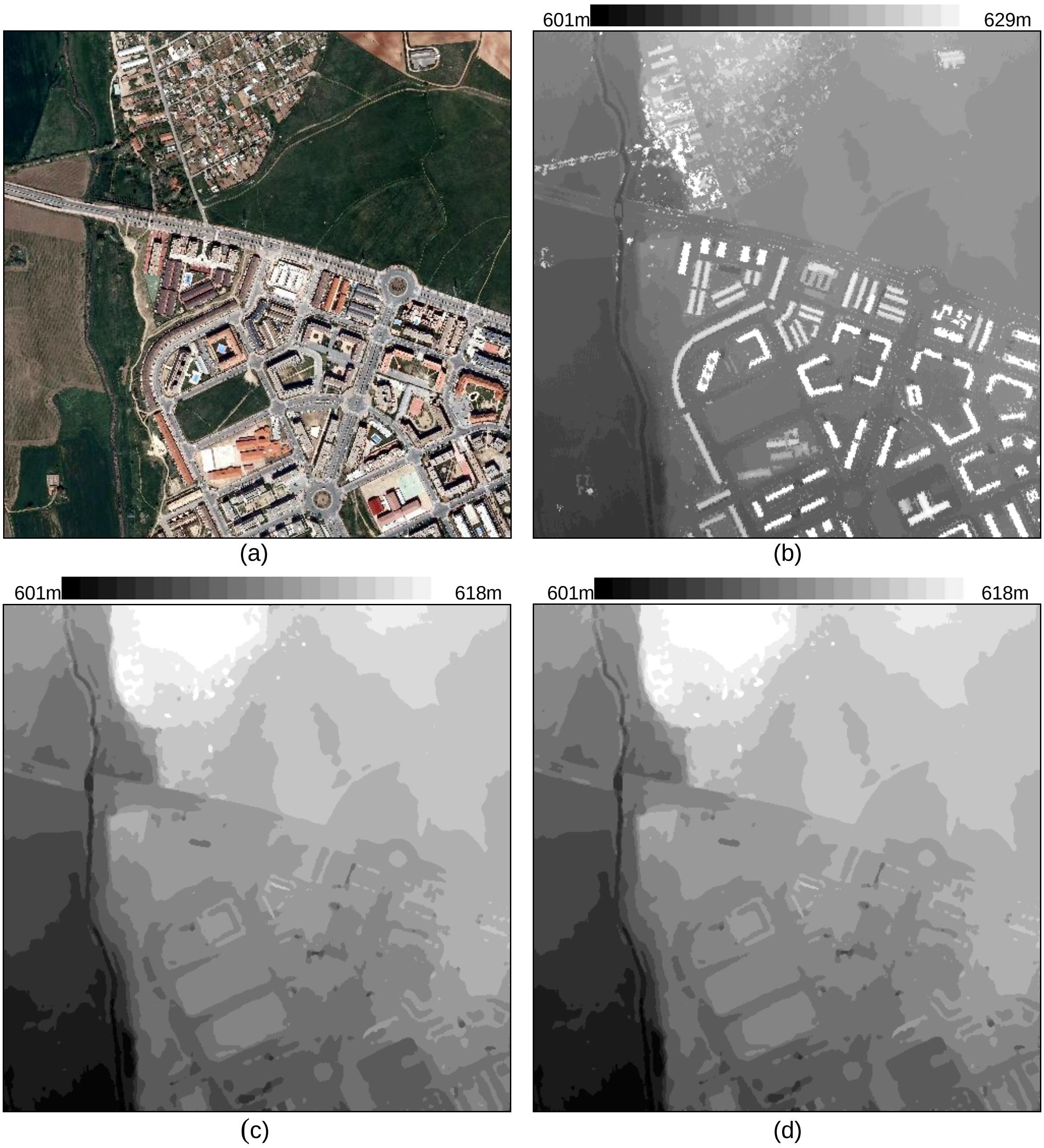


Fig. 3. (a) Aerial image, (b) DSM, (c) DTM extracted with the algorithm, (d) DTM extracted with the algorithm and manually cleaned

Resolution is of 1 meter, therefore a image of 1000x1000 pixels represents a 1km^2 of terrain.

In the following images (Figure 4) we can see residential buildings, large buildings—perhaps sport centers or industrial bays—and open areas under construction under construction. We can notice in the DTM image obtained by the algorithm how some of these large buildings have not been correctly removed, so manual editing has been used for their removal (Figure 4d).

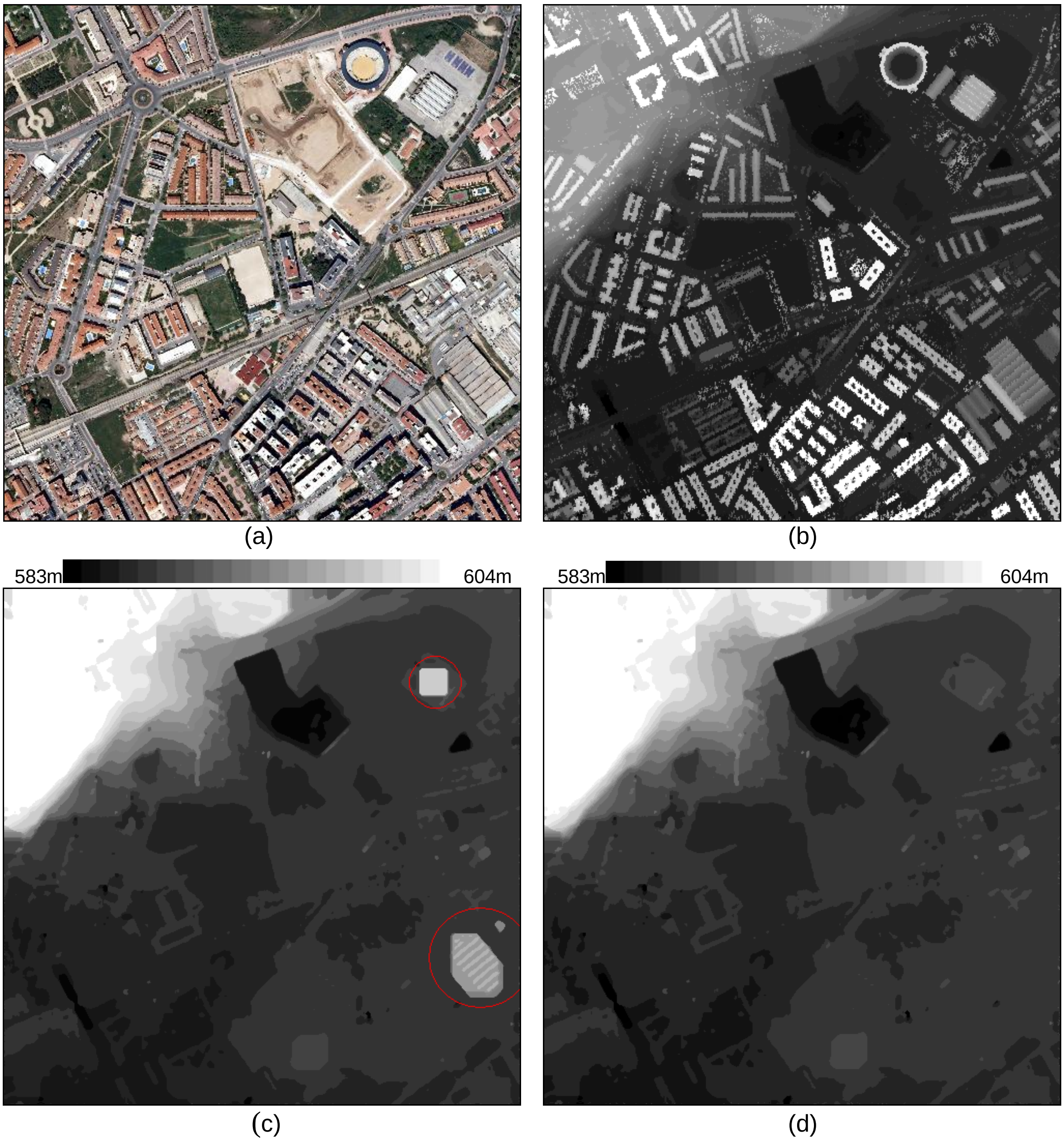
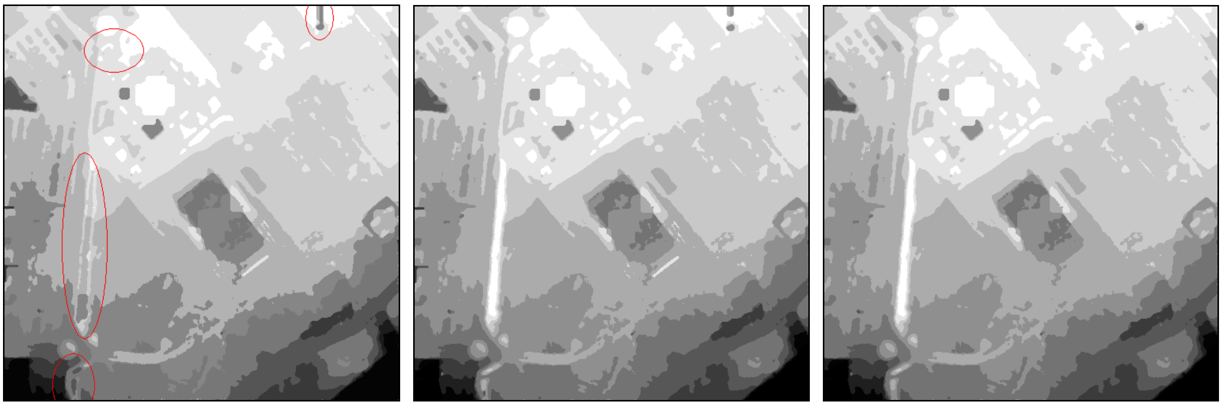


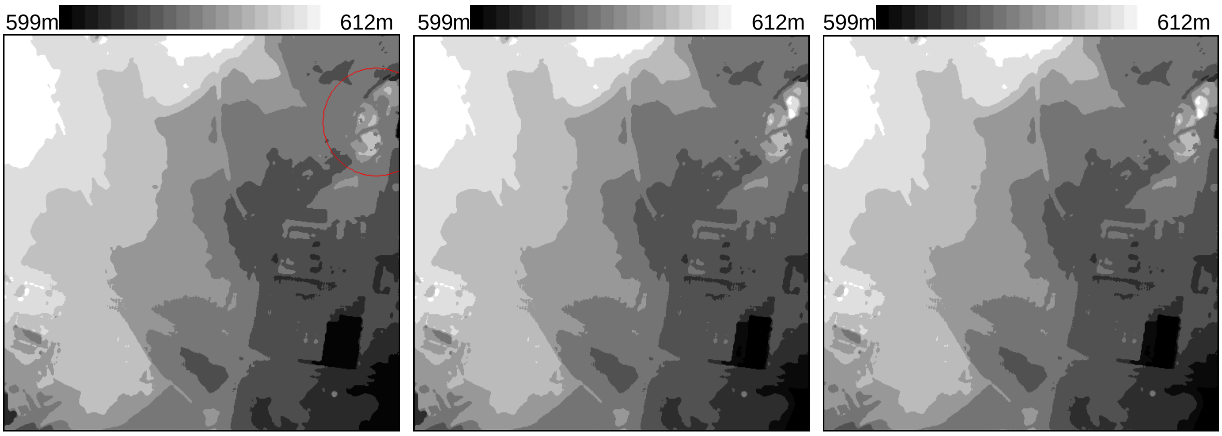
Fig. 4. (a) Aerial image, (b) DSM, (c) DTM extracted with the algorithm, (d) MDT extracted with the algorithm and manually cleaned

The following images (Figs. 5 and 6) show the improvement of the algorithm once the analysis of the difference of echo is applied. In the first images the errors that the opening filter makes when eliminating ground points are shown with red ellipses (Figs. 5a and 6a). In the next images (Figs. 5b and 6b) the improvement made to the algorithm by introducing echo differences is noticeable. And finally, in the third series (Figs. 5c and 6c) we can see the digital model after manual editing.



(a) (b) (d)

Fig. 5. (a) DTM automatically extracted without echo difference analysis, (b) DTM extracted by the algorithm with echo difference analysis, (c) DTM manually corrected



(a) (b) (d)

Fig. 6. (a) DTM automatically extracted without echo difference analysis, (b) DTM extracted by the algorithm with echo difference analysis, (c) DTM manually corrected

In Table 1 a quantitative analysis for the precision of the algorithm for the DTM extracted in Fig. 3 and Fig. 4 is given

Table 1. Precision for the DTM extraction algorithm Fig. 3 and Fig.4.

	change (DSM - DTM)	**correct**
Fig. 3	10,9064%	99,8680%
Fig. 4	26,0212%	94,9057%

In Fig. 3 the percentage of pixels which change of value from the image of DSM to the image DTM (manually corrected) is of a 10,91%, and the percentage of pixels that the automatic algorithm have correctly changed is of a 99,87%. In Fig, 4 there are more buildings than in Fig. 3; consequently, a change of a 26,02% have happen between the DSM and the manually corrected DTM.

In the following table is shown the comparative analysis considering the return of echoes and without considering then.

Table 2. Precision for the DTM extraction algorithm Fig. 3 and Fig.4, considering with echoes and without them.

	change (DSM - DTM)	correct (without echoes)	correct (with echoes)
Fig. 5	13,0834%	90,9320%	97,5480%
Fig. 6	5,3400%	94,2772%	97,3109%

In Fig. 5, the percentage of pixels that have changed between the DSM and the DTM is of a 13,08%. The algorithm without considering the return of echoes has performed correctly a 90,93% of changes; however, the percentage of correctly detected pixels increase to a 97,55% when considering the return of echoes. The image in Fig. 6 has suffer only the change of a 5,34%. In this image the correctly change pixels without considering the return of echoes have been of a 94,28%, while this value increase to a 97,31% when considering them.

5 Conclusions

The main contribution of this paper is the improvement to the algorithm by Zhang et al. (2003) by adding the echo difference information from the laser. Our results show how the algorithm generates, in most cases, DTMs that need little manual editing to show a high precision. Attempts to improve the present algorithm by adding slope analysis and height standard deviation provided no noticeable improvements.

The algorithm explained here has some limitations. One of these is in the analysis of the return difference of the pixels that are at the edges of the image. This restriction is due to the inability of the algorithm to correctly analyze the echo difference in the edge pixels since the window in which that analysis is done is small and does not provide the necessary information compared to the other pixels in the image. Another limitation is the ability to fix the size of the structuring element. The dimensions of the structuring window increase progressively until a size set by the user. If the fixed size of the structuring window is small then the largest buildings are not eroded, but if the structuring element is too large then the algorithm is too slow.

This work has opened new investigation lines that we will pursue in the future, such as the possibility of extracting information from multiple echoes for each pulse. In this paper we have only worked with first and last echoes for each pulse, but information from multiple echoes might improve the algorithm. Another line of research that might improve the algorithm is the fusion of LIDAR data with spectral data, such as RGB and infrared bands of the digital images that are obtained during the same flights of the LIDAR. The infrared band could contribute valuable information to discriminate ground points with respect to vegetation coverage and buildings.

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