LIDAR Image Processing with Progressive Morphological Filtering

Yilong Lu and Xinyuan Lin

***Abstract*—High-resolution digital terrain models (DTMs) are essential for many topographic applications and LIDAR (Light Detection and Ranging) is one of the latest optical remote sensing technologies that used to generate DTM. Airborne LIDAR systems usually return a three-dimensional cloud of point measurements with irregular spacing. In order to generate a DTM, measurements from unwanted features such as trees, vehicles have to be classified and removed. In this study, a progressive morphological filtering and its parametric performance in removing unwanted LIDAR measurements are studied. Numerical experiments show that the progressive morphological filter is more effective than the traditional morphological filter.**

***Index Terms*—Digital surface model, digital terrain model, LIDAR, morphological filter.**

I. Introduction

LIDAR (Light Detection and Ranging) [1] is one of the latest optical remote sensing technologies used to generate high-resolution digital terrain models (DTMs) that are widely utilized for many geographic information systems (GSI) related analysis and visualization. LIDAR has gained increasing acceptance for topographic mapping and the commercial market for LIDAR has developed significantly in the last few years. LIDAR technology has higher accuracy than RADAR and has wide applications in archaeology, geography, geology, geomorphology, remote sensing, atmospheric physics, and transportation. Airborne LIDAR systems usually return a three-dimensional cloud of point measurements with irregular spacing. In order to generate a DTM, measurements from unwanted features such as trees, vehicles have to be classified and removed.

Morphological filter is able to extract urban features from LIDAR data for many GIS applications [2]. To generate an accurate DTM, the algorithm should be able to identify and differentiate ground and non-ground features and then remove non-ground features. Removing non-ground points from LIDAR data sets has proven to be a challenging task. Most of the techniques work on the assumption that man-made objects and natural features standing above the surrounding surface can be subtracted from a digital surface model (DSM).

Yet, LIDAR data can only be visualized and processed by expensive commercial software nowadays and there is still a lack of simple, user-friendly and low cost software for LIDAR data's DTM generation.

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In this study, a progressive morphological filtering code based on Matlab [3] has been developed to remove unwanted LIDAR measurements and a parametric study is conducted to understand the effects of filter parameters. By selecting appropriate parameters, the measurements of unwanted objects were removed, while wanted measurements could be preserved.

II. Morphological Filter

Morphology is a broad set of image processing operations that process images based on shapes. Morphological operations apply a filtering window to an input image, creating an output image of the same size. In a morphological operation, the value of each point in the output image is based on a comparison of the corresponding point in the input image with its neighbors.

There are two fundamental morphological operations, dilation and erosion, that are commonly employed to extend (dilate) or reduce (erode) the size of features. While dilation adds points to the boundaries of objects in an image, while erosion removes points from object boundaries in an image. The number of points added or removed from the objects in an image depends on the structuring element used to process the image. The structuring element is a set of coordinate points that determined the precise effect of the operation.

The dilation and erosion of the object *A* by *B* are defined by (1) and (2), respectively,

$$A \oplus B = \left\{ z \mid B_z \cap A \neq \varnothing \right\} \quad (1)$$

$$A \odot B = \left\{ z \mid B_z \subseteq A \right\} \quad (2)$$

where B_z is the translation of B by the vector z, namely.

$$B_z = \left\{ b + z \mid b \in B \right\}, \ \forall \in E \quad (3)$$

When the structuring element *B* has a center, and this center is located on the origin of *E*, then the erosion of *A* by *B* can be understood as the locus of points reached by the center of *B* when *B* moves inside *A*. Dilation is the opposite of the erosion [4].

In the morphological dilation and erosion operations, the state of any given point in the output image was determined by applying a specific rule to the corresponding point and its neighbors in the input image.

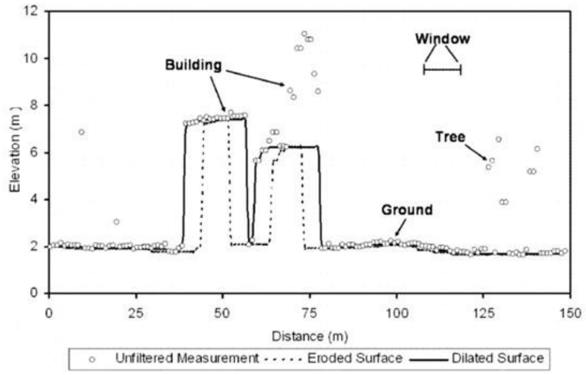
For a set of LIDAR measurement $p(x, y, z)$, the operation of dilation is to obtain the maximum elevation valued in the neighborhood of p, as defined in (4). Whereas, erosion was used to find the minimum elevation valued, as defined in (5).

$$d_p = \max_{(x_p, y_p) \in w} (z_p) \tag{4}$$

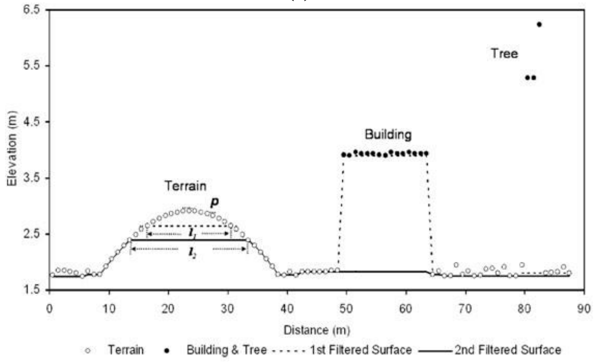
$$e_p = \min_{(x_p, y_p) \in w} (z_p) \tag{5}$$

where point ($x_{p,}$ $y_{p,}$ $z_{p,}$) is a set of point representing point *p*'s neighbors within a window *w*.

In general, dilation and erosion are often used in combination to implement image processing operations. For example, the definition of a morphological opening of an image is achieved by implementing erosion of the datasets first and then dilation, using the same filtering window size for both operations. The related operation, morphological closing of an image, is the reverse: it consists of dilation followed by erosion with the same structuring element. An illustration of performing an opening operation using one-dimensional filtering window is shown in Fig. 1(a).



(a)



(b)

Fig. 1. Illustration of (a) opening operation and (b) progressive morphological filtering [5].

In the example shown in Fig. 1(a), the pre-process was carried out before going through the filter. During the pre-processing, the unfiltered points were sampled every 1×1 m^2 cell along the profile. After that, the filtered data were obtained by applying an opening operation with a window size of 11m. As a result, the objects (e.g. trees) with size smaller than then window size were removed by erosion, and other large object could be restored the shapes by dilation.

Then, the selection of the appropriate filtering window size and distribution of buildings or tress in a specific area became the essential point for the success of this method. The filtering window size and shape would be designed according to the features of surface.

A very significant drawback of this method is that, when performing opening operation on LIDAR, in order to decide window size, the distribution of features such buildings and trees in a specific area should be precisely considered and studied before performing opening operation for a fixed window size is not able to detect all non-ground features with various size cannot detect features of various sizes.

III. Progressive Morphological Filter

A progressive morphological filter was the iteration of the basic morphological filter by increase the window size gradually.

In order to achieve this filter, the gridded surface was prepared in pre-process for filtering. Then, an opening operation that similar to basic morphological filter should be applied to the grid surface iteratively. In the first filtering process, the initial window with length l_1 was used to obtain the first filtered surface. Then in the next iteration, a larger window size l_2 was applied to the 1st filtered surface to get a further filtered surface. For every filtering process, only the objects' size larger than each window size would be preserved. An illustration of progressive morphological filtering using one-dimensional filtering window is shown in Fig. 1(b).

In Fig. 1(b), the first filtered surface was obtained by applying initial filtering window size l_1 of 15m to the gridded data. Some individual trees with size smaller than l_1 were removed. The second filtered surface was derived by applying a filtering window size l_2 of 21m to the first filtered surface. Then, a further smoothed surface would be exposed.

By performing the progressive morphological filter, it could effective remove all unwanted objects at various sizes from a LIDAR dataset as increase the window size gradually.

There are two ways available to increase the window size. One is to increase window size linearly:

$$w_k = 2kb + 1 \tag{6}$$

The other way is to increase window size exponentially:

$$w_k = 2b^k + 1 \tag{7}$$

In (6) and (7), *b* is the base value and *k* donates the number of iterations with *k*=1, 2, ….

Besides the window size, other parameters should also be set in order to implement the algorithm i.e. initial elevation difference threshold, maximum elevation difference and terrain slope, which are set based on elevation variations of the terrain to eliminate opening operation's defect that the original filter progress tends to produce a surface below the terrain measurements, leading to incorrect removal of the measurements at the top of high-relief terrain.

IV. Results and Analysis

The set of data used in this section was collected in Singapore, with 41, 452 measurement points. The area is indicated in Fig. 2 from Google Map [6].

From Fig. 4(a) to Fig. 4(d), a distinct effect of the progressive morphological filter was demonstrated. It could be seen that all the unwanted objects was removed while the wanted objects such as the ground and buildings were well preserved. However, a few wanted parts were filtered (such as the small parts on the top of building) in Fig. 4(c) and Fig. 4(d). It was because of those parts' width may similar to the unwanted objects.

Fig. 2. Google map aerial photo of the area where the LIDAR data was taken (not in the same time period, some ground true are different).

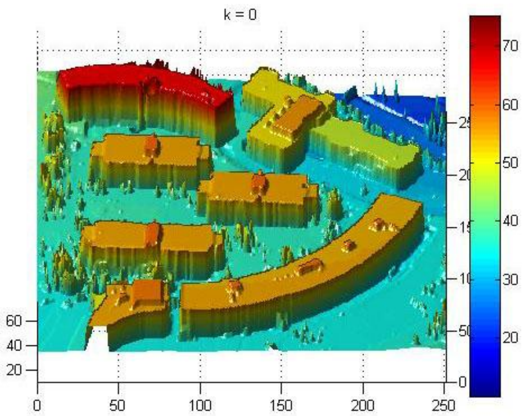
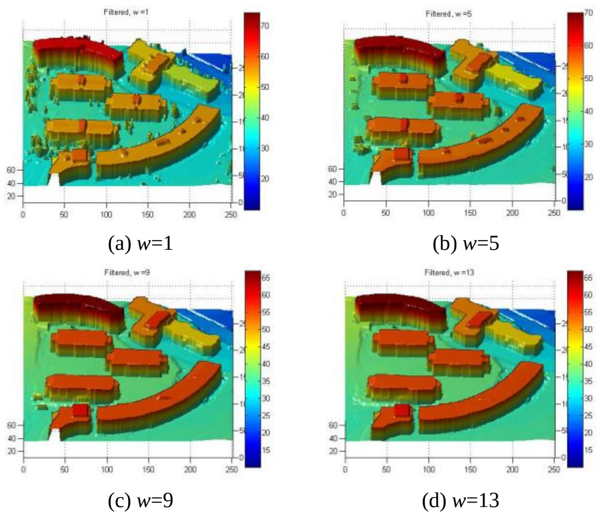


Fig. 3. Gridded data before filtering.



(a) w=1

(b) w=5

(c) w=9

(d) w=13

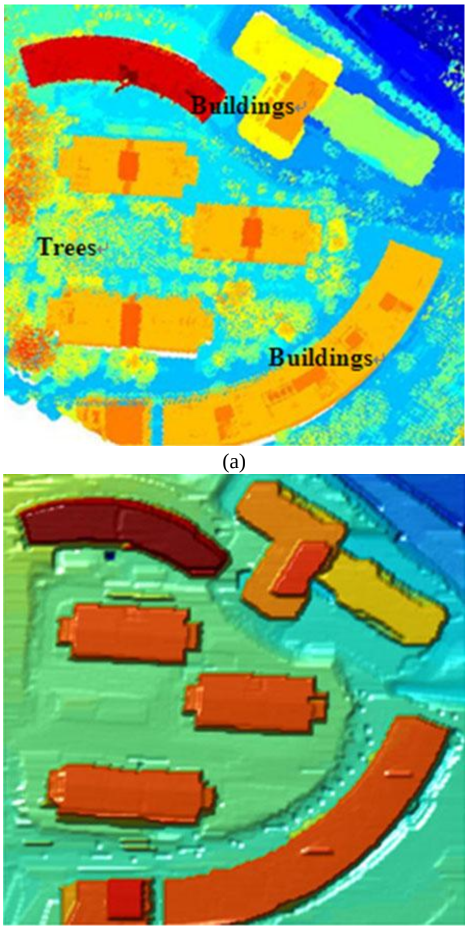
Fig. 4. Progressive morphological filtering results.

In this test, the window size is set to increase linearly based on (6). This is because the window size difference between two iterations is smaller than the exponential increase, which will be easier for manipulation and comparison. And the base value b is set to be 2 and no. of iterations is set to be 4.

As shown in Fig. 4, the local morphology with relative elevation difference donated by the color bar is clearly shown. Thus, it can be concluded that the DTM is successfully obtained.

Both basic morphological filter and progressive morphological filter could remove the unwanted measurements from LIDAR dataset at the point level. By plotting the results, it is shown that using the appropriate filtering window size would give a remarkable improvement for the dataset when generated the DTM. Ideally, the window size of the morphological operation not only should be small enough to preserve all wanted information, but also large enough to remove unwanted objects. Unfortunately, an ideal window size does not exist in the real world as different size was used for different objects. Thus, it may hard to set a predefined filtering window size for all objects.

As comparing to basic morphological filter, the progressive morphological filter produces better results by increasing the window size gradually. This technique solves the main problem for basic morphological filter. But due to the complexity of progressive morphological filter, it would take longer execution time.



(a)

(b)

Fig. 5. (a) Unfiltered LIDAR data with direct mapping [7] and (b) filtered data with progressive morphological filtering.

The progressive morphological filter was also encountered the trouble of omission and commission error. In order to measure the effectiveness of the filter, these two errors need to be examined. Both qualitative and quantitative methods were employed. The qualitative method checked the quality of filtering performance. By visually comparing the unfiltered and filtered data, this method was used to verify that unwanted features such as trees were eliminated entirely and wanted features were remained completely. Then, the quantitative method examined the correctness of the filtered measurements at the point level from a random sample. The raw LIDAR data and filtered measurements would be used to help identify filtering errors. The unfiltered raw data and filtered data are shown in Fig. 5 for illustration. The unfiltered results are produced from LIDAR data direct mapping without any distortion [7].

V. Conclusion

For generating high resolution DTM, LIDAR measurements from unwanted objects was separated and removed. In this report, the pre-processing was introduced first to sample those irregular spacing raw data. Three interpolation methods were included. Then, morphological filter and progressive morphological filter was built to remove unwanted LIDAR measurements. Both of these two filters were able to remove the unwanted objects by demonstration. As comparing the experimental results of two filters, it was shown that the progressive morphological filter was more effective. The progressive morphological filter could classify and remove the unwanted objects more accurately by gradually increasing the window size of the opening operation.

In order to perform the success of filtering method, selections of the filtering parameters did a great impact on the removal of unwanted objects. Appropriate parameters could be found based on analyzing wanted and unwanted measurements in the study area. The filtering process was highly automatic and requires little human interference, which was desirable when processing voluminous LIDAR measurements.

References

[1] Lidar 101: An Introduction to Lidar Technology, Data, and Applications. [Online] Available: http://www.csc.noaa.gov/ digitalcoast/_/pdf/ What_is_Lidar.pdf.

[2] G. Prisetnall. J. Jaafar, and A. Duncan, "Extracting urban features from LIDAR digital surface models," *Computers, Environment and Urban Systems*, vol. 24, no. 2, pp. 65-78, March 2000.

[3] MathWorks - MATLAB and Simulink for Technical Computing. [Online] Available: http://www.mathworks.com.

[4] Mathematical Morphology. [Online] Available: http://en.wikipedia.org/wiki/Mathematical_morphology.

[5] K. Zhang, S. C. Chen, D. Whitman, M. L. Shyu, J. Yan, and C. Zhang, "A progressive morphological filter for removing nonground measurements from airborne LIDAR data," *IEEE Trans. on Geoscience and Remote Sensing,* vol. 41, no. 4, pp. 872-882, April 2003.

[6] Google Map. [Online] Available: http://maps.google.com.

[7] X. Wang, K. J. Zhou, J. Yang, and Y. L. Lu, "MATLAB tools for LIDAR data conversion, visualization, and processing," *Proc. SPIE,* vol. 8286, pp. 82860M1-8, October 2011.

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