

ADAPTIVE BUILDING EDGE DETECTION BY COMBINING LIDAR DATA AND AERIAL IMAGES

LI Yong, WU Huayi

State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, Wuhan 430079, China - liyongwhu@gmail.com, wuhuayi@lmars.whu.edu.cn

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ABSTRACT:

The building edge detection plays a key role during building extraction, which is important and necessary for building description. The edges detected from aerial images have high horizontal accuracy and represent various edge shapes well. But the edge detection in images is often influenced by contrast, illumination and occlusion. LIDAR data are suitable for judging building regions, but miss some edge points due to the laser pulse discontinuousness. In order to make full use of the complementary advantages of the two data sources, a new adaptive method of building edge detection by combining LIDAR data and aerial images is proposed in this paper. Firstly, the objects and ground are separated by a filter based on morphological gradient. The non-building objects are removed by mathematical morphology and region growing. Secondly, the aerial image is smoothed by Gaussian convolution, and the gradients of the image are calculated. Finally, the edge buffer areas are created in image space by the edge points of the individual roof patch. The pixels with local maximal gradient in the buffer area are judged as the candidate edge. The ultimate edges are determined through fusing the edges in image and the roof patch by morphological operation. The experimental results show that the method is adaptive for various building shapes. The ultimate edges are closed and thin with one-pixel width, which are very suitable for subsequent building modelling.

1. INTRODUCTION

1.1 Background

Building models are the essential components of the three dimensional GIS. The building edges are the significant features of buildings. The building edge detection plays a key role during building extraction, which is important and necessary for building description. The aerial images and LIDAR data all provide powerful support to the task. The edges detected from aerial images have high horizontal accuracy and represent various edge shapes well. LIDAR point clouds are well suited for judging the points that belong to each building surface, which is beneficial to search the approximate location of each building edges. However, each data source has its own weakness beside strength for the edge detection.

In aerial images, the contrast between buildings and backgrounds is often not so high, and there are too many complex spectral and texture information in most of scenes, including occlusion, shadows and so on. Those lead to the complexity of edge detection. Some edges are not building edges we need, while some edges of buildings are missed or broken. Furthermore, edges of different objects or edges of different layers of one building are likely to stick to each other.

In LIDAR point clouds, building edges can be located by analyzing the height changing of laser footprints. However, some edge points are not gathered by LIDAR for the laser pulse discontinuousness, which cause that the horizontal accuracy of edge detection from LIDAR data is poor.

1.2 Related work

As discussed above, both data sources have their own pros and cons. In order to overcome the drawbacks using single data

source, it is considered as a promising strategy to automatically detect building edges by fusion of LIDAR data and aerial images. The correct edge detection is a challenging task due to the scene complexity. So it is a research hot spot how to combine the two different data sources in an optimal way so that their weakness can be compensated effectively by each other.

(Rottensteiner and Jansa, 2002) firstly generate initial 3D planar segments of buildings from LIDAR point clouds, and create polyhedral models and wire frames of buildings by analyzing relations of neighbouring planar segments and regularizing of building shape. Then, the initial polyhedral building models are verified in the images to improve the accuracy of their geometric parameters. The wire frames of buildings are back-projected to the images to match with image edges for improving the accuracy of the building outlines. Only straight line segments are matched with the object edges.

(Sohn and Dowman, 2007) collect rectilinear lines around building outlines by data-driven and model-driven ways for building modelling. In the data-driven way, straight lines that are significantly long and around building boundaries are extracted from optical imagery. Then the lines are geometrically regularized by analyzing the dominant line angles. The lines produced in the data-driven way do not always cover all parts of building edges because significant boundary lines may be missed due to low contrast, shadow overcast and occlusion effects. In the model-driven way, new lines are extracted from point clouds in order to compensate for the lack of data-driven line density by employing specific building models based on the assumption that building outlines are comprised of parallel lines. So only the building edges with parallel and orthogonal structure can be considered.

(Chen, et. al., 2004) firstly extract 3D planes from point clouds. Then the initial building edges are detected from raster form LIDAR data by the Canny Edge Detector. Based on the rough edges, the precise building edges are extracted in image space through the Hough transform. Obviously, only the straight lines can be detected exactly. (Chen, et. al., 2006) target the buildings with straight and curvilinear boundaries. The most probable radius of a line segment is analyzed to distinguish straight lines from the curvilinear ones. There are still two line types to consider.

(Hu, et. al., 2006) extracted interactively outlines of complex building shapes from a high-resolution aerial image. Edges are detected using Canny edge detector and lines are extracted using Hough Transform from the aerial image. Because automatic method only works well for simple shapes, a primitive based method with user interaction is used to extract other outlines. A number of primitives that represent the outlines of building shapes are designed to reduce the times of user interaction. Obviously, that is a compromise between automation and demand of reconstruction building models of complex shape.

As illustrated above, most of researchers put emphases on rectifying the edges in LIDAR points using the edges from images. During the process of detecting edges from images, only the image information is considered, which still have disadvantages of detecting edges from images as mentioned above. Moreover, it is often only one or two types of lines extracted from images that are considered during compensating the weakness of edges from LIDAR data. And it is often assumed that building outlines are comprised of parallel or orthogonal lines to regularize the edges for building modelling. Actually, edges in reality are not confined to only several certain shapes. So the results of edge regularization are likely not in accord with real condition, which obviously lead to the reduction of edge accuracy and the trouble of texture mapping.

1.3 Work flow of adaptive building edge detection by fusion

In order to deal with the weakness of detecting building edges solely from point clouds or images, a new adaptive method of building edge detection by combining LIDAR data and aerial images is proposed in this paper. The purpose of the method is to make full use of the complementary advantages of the two data sources to make the edge detection adaptive for all kinds of building shapes. The work flow of this method is shown in Figure 1.

Firstly, the objects and ground are separated by a filter based on morphological gradient. The non-building objects are removed by mathematical morphology and region growing. Secondly, the aerial image is smoothed by Gaussian convolution, and the gradients of the image are calculated. Finally, the edge buffer areas are created in image space by the edge points of the individual roof patch. The pixels with local maximal gradient in the buffer area are judged as the candidate edge. The edges and roof patches are integrated by morphological closing operation. The ultimate edges are determined by the edge extraction method of mathematical morphology.

This paper is structured as 6 sections. Section 2 presents building detection. Section 3 is the pre-processing of aerial image. Section 4 describes integrating the edges in image and roof patches to generate the ultimate edges. The experiments

are described and discussed in section 5. Section 6 gives some brief conclusions.

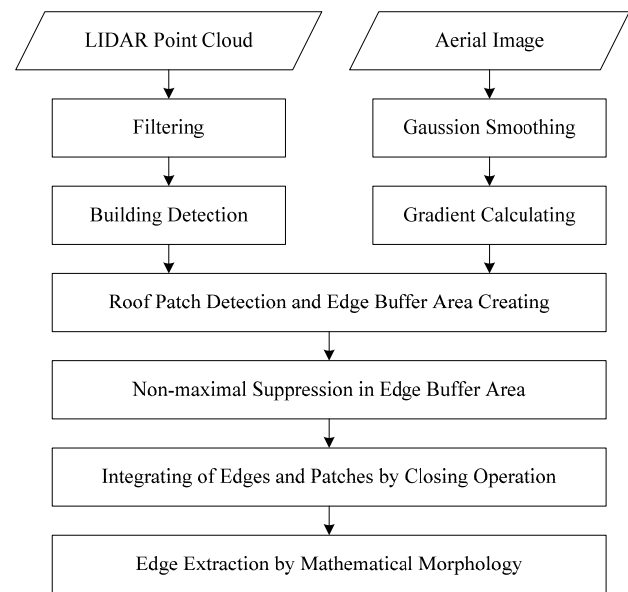


Figure 1. Work flow of adaptive building edge detection

2. BUILDING DETECTION

2.1 Mesh division of point clouds

The LIDAR data is a discrete three-dimensional point cloud that is stored according to the acquiring time. The distribution of raw points is irregular, and the data is huge. Therefore one highly effective method of data organization is in demand. In this paper, point clouds are divided by an index mesh which can support effective neighbouring search as well as maintain the high resolution potential of raw data. Because the laser pulse of LIDAR is emitted according to a certain frequency, the average point spacing can be calculated, which can be the mesh interval.

Every mesh cell may contain no point, one point or more than one point. During any neighbouring computation or morphologic operation of 3D point clouds, the corresponding mesh cell is firstly found out. Then all points in the cell are taken out to carry out computation or judging respectively.

2.2 Separating of object and ground points

The process of separating object points and ground points is called filtering. A new method of filtering based on morphological gradient is proposed (LI and WU, 2007). The morphological gradient of each point is calculated using the method suitable for filtering. Then, some points are chosen based on gradients to carry on an improved opening operation iteratively. The iterative times are controlled through analyzing the gradient histogram. During each time of iteration, a point is classified as an object point if its difference between the height after opening operation and the original height is more than a threshold. The filter based on morphological gradient can reduce the nonessential computation as well as the possibility that errors happen. DSM generated from LIDAR data of the test area is shown in Figure 2. The DEM generated after filtering is shown in Figure 3.

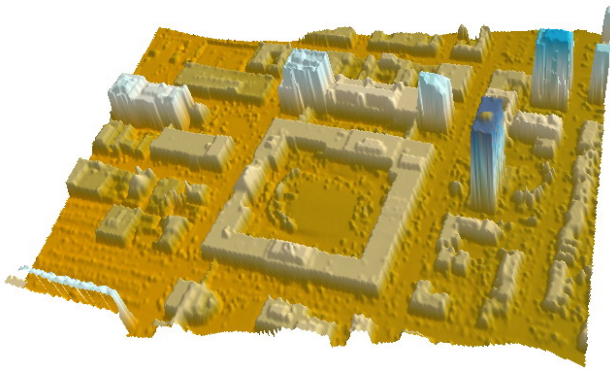


Figure 2. DSM generated from LIDAR data

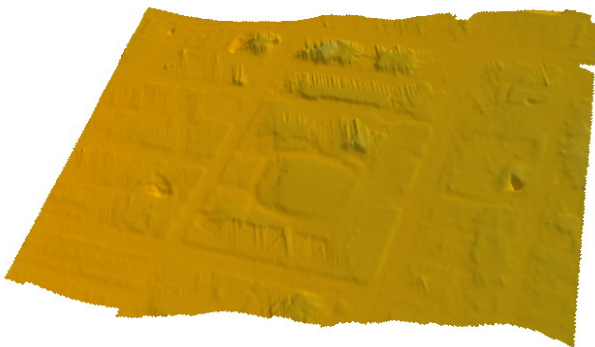


Figure 3. DEM generated after filtering

2.3 Detection of Building points

The object points derived by filtering include buildings, vehicles, vegetation and so on. The building points are usually detected by region growing. But there are often other objects that are attached to buildings, for example, vegetation and low objects. The building detection method proposed in this paper consists of three steps. Firstly, those low object points are removed if its difference between its height and the adjacent ground height is less than 2 meters. Secondly, a morphological opening operation is carried out, which can break the non-building portions that are attached to buildings. Thirdly, the connected regions are detected by the region growing technique, and those that are larger than a certain threshold are regarded as buildings. The mesh cells that contain object points are marked with true, and the mesh cells that do not contain object points are marked with false. That is equivalent to form a binary image. The morphological opening operation and region growing are carried out based on the binary image, which can enhance computation efficiency and get the same result with computing directly to point clouds. The result is shown in Figure 4.

There are some laser points on wall, which may influence the subsequent extraction of roof patches and determination of building edge points. So the wall points need to be detected. A building point is judged as wall point if there are a much higher point, a much lower point and few points that have approximate height in its neighbourhood.

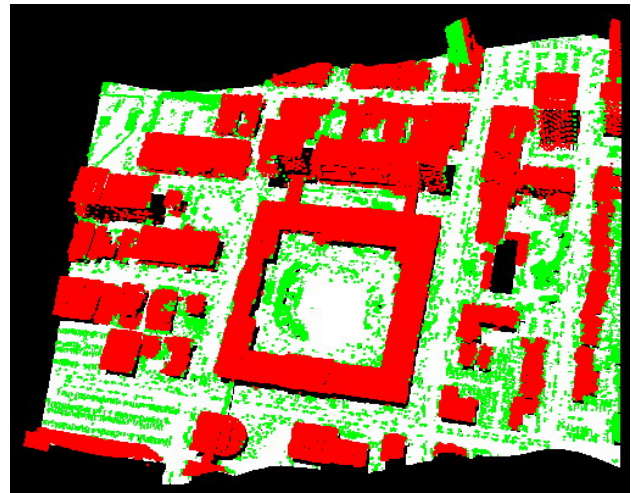


Figure 4. Building detection result. Red points are buildings, green points are other objects, and white points are ground.

3. IMAGE PREPROCESSING

The Canny edge detector (Canny, 1986) is a very popular edge operator, which is widely used in digital image processing including remote sensing image processing. The Canny operator works in four stages: Firstly, the image is smoothed by Gaussian convolution. Secondly, a 2-D first derivative operator is applied to the smoothed image to calculate the gradient magnitude and direction. Thirdly, the process of non-maximal suppression (NMS) is imposed on the gradient image. Finally, the edge tracking process exhibits hysteresis controlled by two thresholds.

The non-maximal suppression and edge tracking are mainly responsible for the success of the Canny edge detector. But if the two steps are carried out solely using images, the determinations of edges are random. The building edge detection is easily influenced by other edges. Some building edges may be missed as shown in Figure 8. So the first two steps, namely Gaussian smoothing and gradient calculation, are implemented to the aerial image. The non-maximal suppression and edge tracking processes are to implement by combining LIDAR points and images in the following steps.

4. EDGE DETECTION BY FUSION

4.1 Creating of edge buffer area

In order to conduct the building edge detection in images, the buffer areas are derived by building edge points. Firstly, the building roof patches are detected from LIDAR point cloud. The point sets with continuous heights are detected. And the point set whose amount is larger than a certain threshold forms a building roof patch.

Secondly, edge points of the patch are detected. The edge points include not only the ones in the patch, but also the neighbouring ones that do not belong to the patch. That is, if there is a point out of the patch in the neighbourhood of a point in the patch, the point in the patch is marked as inside edge point, and the point out of patch is marked as outside edge point as shown in Figure 6.

Thirdly, the inside edge points and outside edge points are back-projected to the image since the image have been orthorectified. The edge buffer areas are created around the edge points, which can be used to locate the real edge points.

4.2 Detection of initial edges in image

The initial roof patch edges can be detected from images by the edge buffer area. Because it is sure that there is at least one edges along the buffer area, the non-maximal suppression and edge tracking processes are carried out along the buffer area.

Firstly, the non-maximal suppression is performed in the buffer area. A pixel is judged as the candidate edge if it has local maximal gradient value by comparing along the gradient direction. That process is to make sure of only one response to the great extent along the buffer area, and suppress the responses of false edge.

Secondly, the edge tracking is implemented based on the candidate edges determined by the non-maximal suppression. Traditional Canny operator carries on the edge tracking controlled by two thresholds, namely a high threshold and a low threshold. The tracking of one edge begin at a pixel whose gradient is larger than the high threshold, and tracking continues in both directions out from that pixel until no more pixel whose gradient is larger than the low threshold. The process is called hysteresis. It is usually difficult to set the two thresholds properly, especially for remote sensing image. The illumination and contrast of different portions of remote sensing image are often non-uniform. Even the gradient changes for the different parts of an individual building are very different.

In this paper, the edge tracking is carried out by inside edge points. The long edges in the neighbourhood of the inside edge points are accepted as building edges. The process is implemented without thresholds because there are not many candidate edges by NMS in buffer area.

4.3 Edge extraction by fusion based on morphology

Practically, it is difficult to detect continuous and stable edges solely from the images. There are still some broken lines and noise existing in the edges processed by previous steps. The point clouds actually provide the initial closed edges around the roof patches. So the two kinds of edges from the two sources can be fused to form the complete edges.

Firstly, the morphological closing operation is employed, which is produced by the combination of dilation and erosion operations. During the process, the edges detected from images in buffer areas are integrated into the individual roof patch. That is, a new patch is formed, which contain not only the original patch but also the edges detected from images.

Secondly, the edge extraction from the new patch is carried out by mathematical morphology as following formula (Gonzalez et al., 2003):

$$\beta(A) = A - (A \ominus B) \quad (1)$$

where A = the new patch
 B = structuring element with 3×3 size
 $\beta(A)$ = the edge of the new patch

$$A \ominus B = A \text{ is eroded with structuring element } B$$

The ultimate edges are determined using the morphological method of edge extraction.

5. EXPERIMENTAL RESULT AND DISCUSSION

The LIDAR data used in this research covers an area in Toronto, Canada. The data is obtained by Optech ALTM 3100 system. The average density of the point clouds is 0.8 point/m^2 . The ground sampling distance of the aerial image is 1m.



Figure 5. Aerial image

The edge points inside and outside each patch are detected from LIDAR data as shown in Figure 6. The horizontal range of building edges can be determined by the buffer area formed from edge points as shown in Figure 7.



Figure 6. Edge points detected from LIDAR data. The orange denotes the edge points inside roof patches, and the blue denotes the edge points outside roof patches.

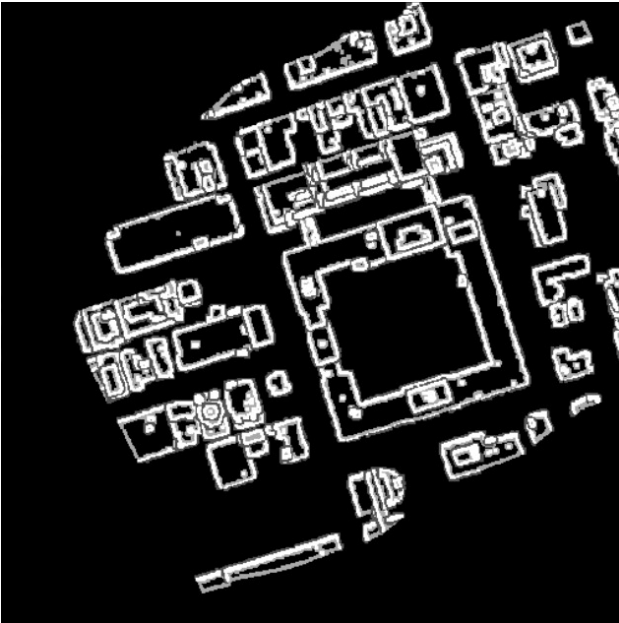


Figure 7. Edge buffer area formed in the aerial image

The non-maximal suppression is the critical step of the Canny edge detector. If the step is carried out solely using images, the edges are easily influenced by the pixels not in the neighbourhood of roof patches. Many building edges with weak contrast are missed by NMS of the whole image as shown in Figure 8. It can be sure that there are building edges in the buffer area. So building edges can be more efficiently derived by NMS in buffer area, which provide more edges to compensate the LIDAR data as shown in Figure 8.

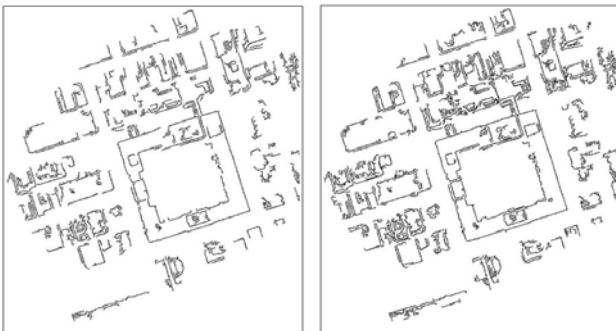


Figure 8. Comparison of NMS. The left are edges around roof patches by NMS of the whole image, and the right are edges derived by NMS in buffer area.

The overlay of roof patches and edges derived by NMS in buffer area is shown in Figure 9. There are some hollows in patches because the density of point cloud does not match the image resolution. The patches and edges are integrated into new patches by morphological closing operation as shown in Figure 10. Moreover, the hollows in patches are fitted by the closing operation, which is beneficial to edge extraction from the new patches.

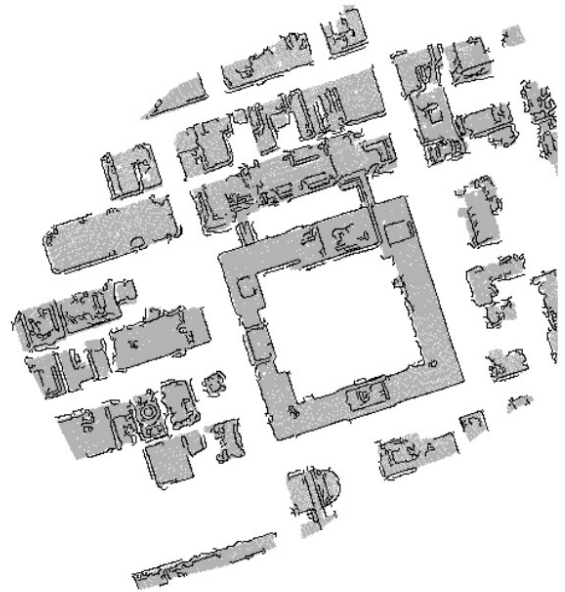


Figure 9. Overlay of patches and edges derived by NMS in buffer area. The gray is roof patches, and the black is edges derived by NMS in buffer area.



Figure 10. Integrating of patches and edges by morphological closing operation

The ultimate edges are determined by the edge extraction method of mathematical morphology. The edges are closed and thin with one-pixel width. Not only the boundaries but also the edges of different building layers are extracted completely.

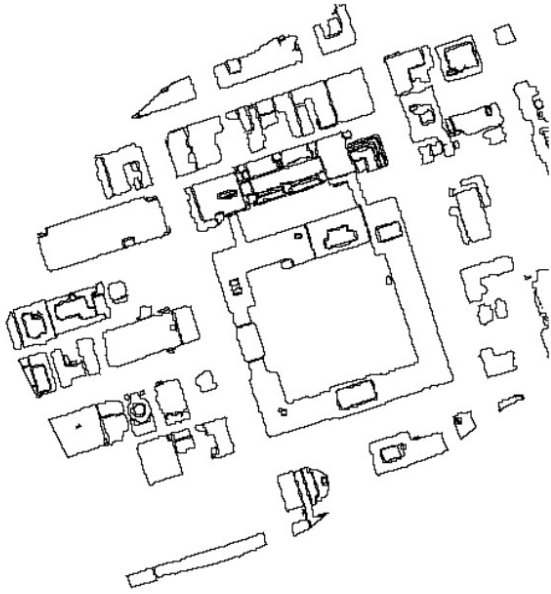


Figure 11. The ultimate edges

6. CONCLUSION

In order to make full use of the complementary advantages of the LIDAR data and aerial images, a new adaptive method of building edge detection by fusion of the two data sources is proposed in this paper. Firstly, the objects and ground are separated by a filter based on morphological gradient. The non-building objects are removed by mathematical morphology and region growing. Secondly, the aerial image is smoothed by Gaussian convolution, and the gradients of the image are calculated. Finally, the edge buffer areas are created in image space by the edge points of the individual roof patch. The pixels with local maximal gradient in the buffer area are judged as the candidate edge. The ultimate edges are determined through fusing the edges in image and the roof patch by morphological operation. The experimental results show that the method is adaptive for various building shapes. The merits of the two data sources are employed efficiently during the building edge detection. The ultimate edges are closed and thin with one-pixel width, which are very suitable for subsequent building modelling.

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