TECHNIQUE OF EXTRACTING BUILDING BOUNDARIES FROM SEGMENTED ALS POINTS

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ABSTRACT: Many studies have been conducted on extracting buildings from ALS(Airborne Laser Scanning) data. After segmentation or classification of building points, additional steps such as generalization is required to get straight boundary lines that better approximate the real ones. In much research, orthogonal constraints are used to improve accuracies and qualities. All the lines of the building boundaries are assumed to be either parallel or perpendicular mutually. However, this assumption is not valid in many cases and more complex shapes of buildings have been increased. A new algorithm is presented that is applicable to various complex buildings. It consists of three steps of boundary tracing, grouping, and regularization. The performance of our approach was evaluated by applying the algorithm to some buildings and the results showed that our proposed method has good potential for extracting building boundaries of various shapes.

KEY WORDS: Building, Airborne Laser, Building Boundary, boundary extraction, boundary generalization

1. INTRODUCTION

ALS data has been used in many fields; DEM generation, building extraction, urban modeling, environment and so on. It has gotten more attention, especially in building detection and modeling, and 2D building polygons are of great importance for managing and updating GIS data such as digital maps.

Building foot prints or roof prints can be extracted from raw ALS point data through some processes such as filtering, segmentation, or classification. Once segmentation is complete, some additional steps are usually required. Firstly building boundaries are extracted from segmented building point clouds. These boundaries are seldom clean, but are zigzag-shaped and their corners are by and large inaccurate. Therefore generalization or regularization is needed to get more accurate information for useful GIS data.

Oh(2001) detected initial critical points by revising Jenk's algorithm based on buffer and angle threshold. Next, building boundaries were linearized by reducing the number of critical points iteratively based on conditions of distance and angle. Jwa(2003) applied a split and merge method based on Douglas Peuker algorithm to detect critical points. Then final building boundaries are extracted by least square fitting. The two methods mentioned above did not utilize the characteristic that right angles exist in buildings.

In much research, orthogonal constraint was used to extract more accurate and realistic building boundaries using the particularity of buildings. Alharthy and Bethel(2002) presented a polygon extraction algorithm which calculated the angle histogram and estimated the dominant directions of line segments. This algorithm was applied under the constraint that building boundaries have only two dominant directions. Ma(2005) classified line segments into two groups which were supposed to be perpendicular. Then the average azimuth of each group was calculated by the weighted method and each segment was adjusted having calculated azimuth. Sampath and Shan(2002) used the least squares method under the condition that the slopes of the parallel lines are equal and the product of the slopes of the perpendicular lines is -1.

In the research mentioned above, they tried to generalize or regularize building boundaries by assuming that most buildings have only right angles, i.e., that all the line segments of building boundaries are either parallel or perpendicular to each other. However, in reality, many buildings have non-right angles as well as right angles and moreover buildings of more complex shapes have been increased. For such buildings, the above mentioned algorithms may be impossible to extract boundaries.

In this research, a new approach was proposed which is applicable to complex-shaped buildings. The proposed method consists of three steps: boundary tracing, boundary generalization, and boundary regularization. In boundary tracing and generalization, traditional algorithms were revised considering the particularity of buildings. In boundary regularization, a modified least squares method was proposed that utilizes orthogonal constraint also for buildings having right angles and non-right angles. Chapter 2 to 4 will give a full detail of the three steps. We selected four buildings of different complex shapes and applied our proposed method to test accuracies, qualitatively and quantitatively. Additionally, to test the performance depending on errors, we made random different-sized errors to a building.

2. BOUNDARY TRACING

To trace boundaries, the raw data points have to be segmented or classified into building points in advance. In this paper, we start from segmented building points skipping the segmentation of original points cloud. The first step in proposed algorithm, boundary tracing is to detect boundary points from segmented building points. The convex hull algorithm is modified to apply to complex-shaped buildings.

The convex hull algorithm determines the smallest convex set containing discrete points. However, many buildings with a complicated shape are not convex but concave. A modified version of the convex hull algorithm was proposed by Lee(2003) and Sampath and Shan(2007). They restricted search space to the points within defined distance so that boundary points can be detected for concave buildings. Their method may miss the critical points at a corner, which play an important rule in the processes of boundary generalization and regularization. To overcome that problem, we propose newly modified convex hull method of restricting search space by grid. We construct grids for the points in a building and store them clockwise. The search space is restricted to the points in the current cell (i.e., that containing the previous detected boundary point) and the next cell.

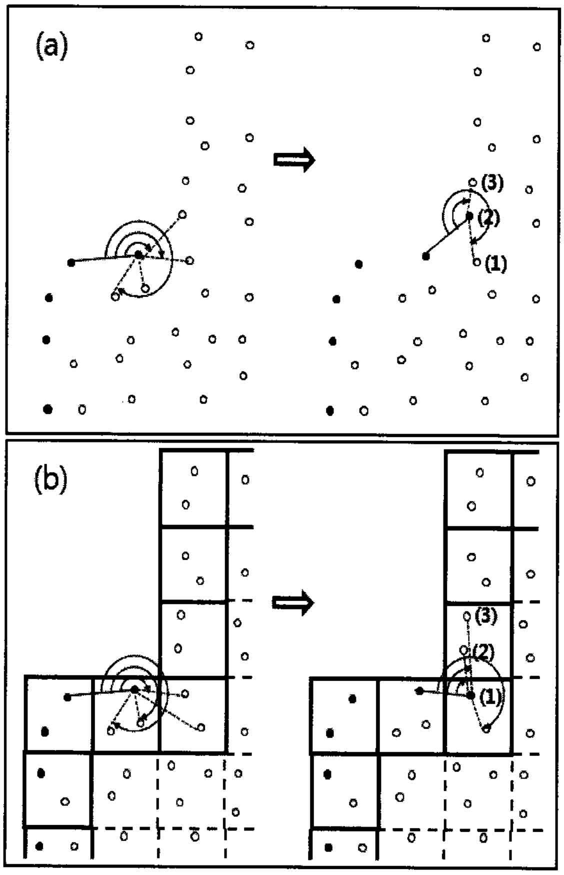

Figure 1. Boundary tracing (a) previous method (b) proposed method

3. BOUNDARY GROUPING

After tracing the boundary, grouping is conducted to form groups of points belonging to the same line segment. Because boundary points are stored in a clockwise sequence, they can be grouped through detecting the corner points which are the first and last points of each line segment. There are limitations in applying the conventional generalization algorithms (Douglas and Peucker, 1973: Jenks, 1989) directly to building boundaries to detect the corner points. Therefore, we detect corner points by using a two-stage procedure based on distance and angle. In the first stage, the Douglas-Peucker algorithm based on orthogonal distance is used. In the second stage, by considering the peculiarity of buildings, we use the constraints of orthogonal distance, angle, and minimum length of the edge. After extracting the corner points, boundary points between adjacent points are put together into the same group.

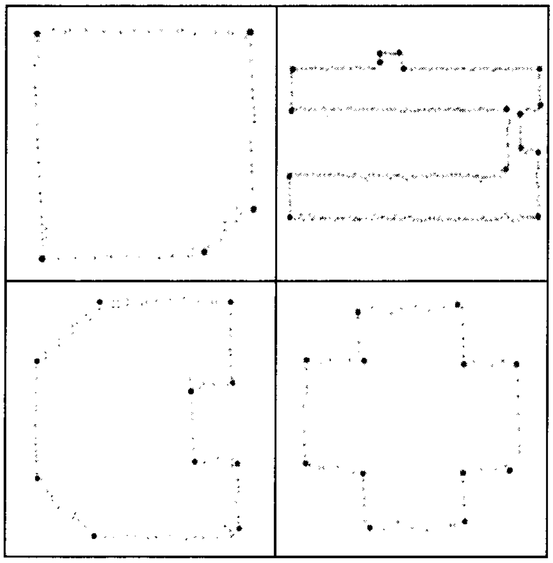

Figure 2. Extraction of corner points for grouping

4. BOUNDARY REGULARIZATION

4.1 Classification of line segments by azimuth

After grouping boundary points, each group is classified into three classes according to the average azimuth of points. This is to apply different least square equations to orthogonal classes and the other class. Groups with the most frequent azimuth are assigned to class Az_1 of dominant direction. Groups perpendicular to Az_1 are classified into class Az_2 and other groups are assigned to Az_3.

$$\begin{cases} l_i \in Az_1 & if \quad |\theta_i - \theta_{r1}| < \Delta\theta \\ l_i \in Az_2 & if \quad |\theta_i - \theta_{r1}| - 90 < \Delta\theta \\ l_i \in Az_3 & else \end{cases} \tag{1}$$

θ_i = the azimuth of line segment l_i, θ_{r1} = the average azimuth of Az_1, θ_{r2} = the average azimuth of Az_2, and $\Delta\theta$ = threshold of azimuth

4.2 Extraction of boundaries

For line segments classified as Az_1 or Az_2, the least squares method is conducted under the constraint of orthogonal conditions. The equations are given below, and all the unknown parameters in Eq. (2) are solved simultaneously:

$$\begin{cases} ax_{im} + by_{im} = c_i & for\ l\ of\ Az_1 \\ ax_{jm} - by_{jm} = d_j & for\ l\ of\ Az_2 \end{cases} \tag{2}$$

For line segments classified as Az_3, the simple least squares method is applied individually to each line segments:

$$a_k x_{kl} + b_k y_{kl} = 1 \qquad (k = 1, 2, \cdots) \tag{3}$$

5. EXPERIMENTAL RESULSTS

5.1 Result on real buildings

To apply our algorithm, we selected four buildings of different types which are common in urban areas. An accuracy assessment was carried out by comparing the resulting building boundaries with the aerial photos. From visual inspection, the extracted boundaries show a reasonably good match to the photos. However, in all the examples, some systematic shift in the extracted boundaries from the roof of the buildings in the aerial photo is found. This is because the buildings in the aerial photo are relief-displaced.

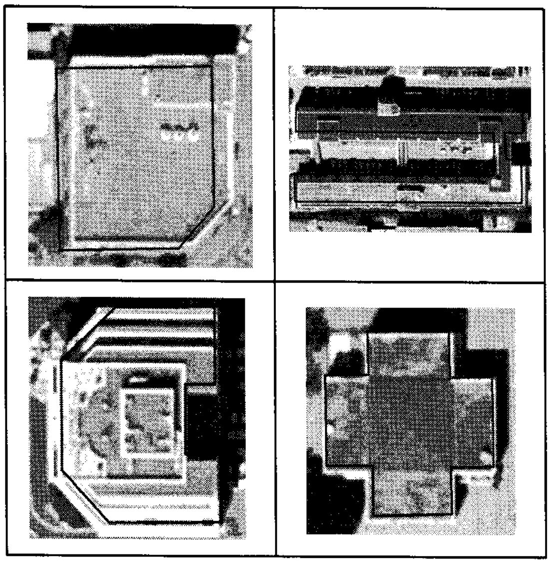

Figure 3. Extracted 2D polygons atop aerial photo

For quantitative assessment we used a 1:1,000 digital map and aerial photo as reference data. Firstly AOR(Area Overlap Ratio) was calculated.

$$AOR = \frac{S_O}{S_R} \times 100 \tag{4}$$

S_O : *overlapped area*

S_R : *area from reference*

From the values given in Table 1, we can see reasonably acceptable AOR values ranging from 94.27% to 97.97%. Though AOR value can help us decide roughly how well to extract boundaries, it doesn't reflect commission errors well. To make up for this, we calculated MDE(mean distance error) which is the average distance between extracted boundaries and real boundaries.

$$MDE = \lim \frac{\sum_{k=1}^{n} h(k)}{\sum_{k=1}^{n}} = \frac{\int_0^{l_B} h(l)dl}{\int_0^{l_B} dl} = \frac{S_{NO}}{l_B} \tag{5}$$

l_B : *lenghs of boundary*

S_{NO} : *area not overlapped*

It can be seen that MDE values range from 0.17m to 0.43m in table 1. Building 4 has larger AOR and MDE than building 2 and 3, which means that building 4 contains fewer omission errors, but building 2 and 3 are more similar to referenced data.

Table 1. Building Extraction Results

Building	01	02	03	04
Area from LiDAR (m^2)	580.09	2414.09	715.12	378.44
Area from AP/DM (m^2)	588.04	2523.44	748.4	396.97
Area Overlapped (m^2)	576.12	2378.78	713.14	377.61
Area Not Overlapped (m^2)	15.89	179.96	37.25	20.18
AOR (%)	97.97	94.27	95.02	95.12
MDE (m)	0.17	0.37	0.32	0.43

5.2 Result on buildings with errors

To evaluate the performance of the proposed method for buildings with errors, we made random different-sized errors to a building. In Figure 4, value *e* means maximum absolute value of errors in x and y directions. Up to an error of 0.6m the building boundary was extracted so well and the MDE values range from 0.018m to 0.058m. From figure 5, it can be seen that the larger error original data have, the better proposed method compensate it.

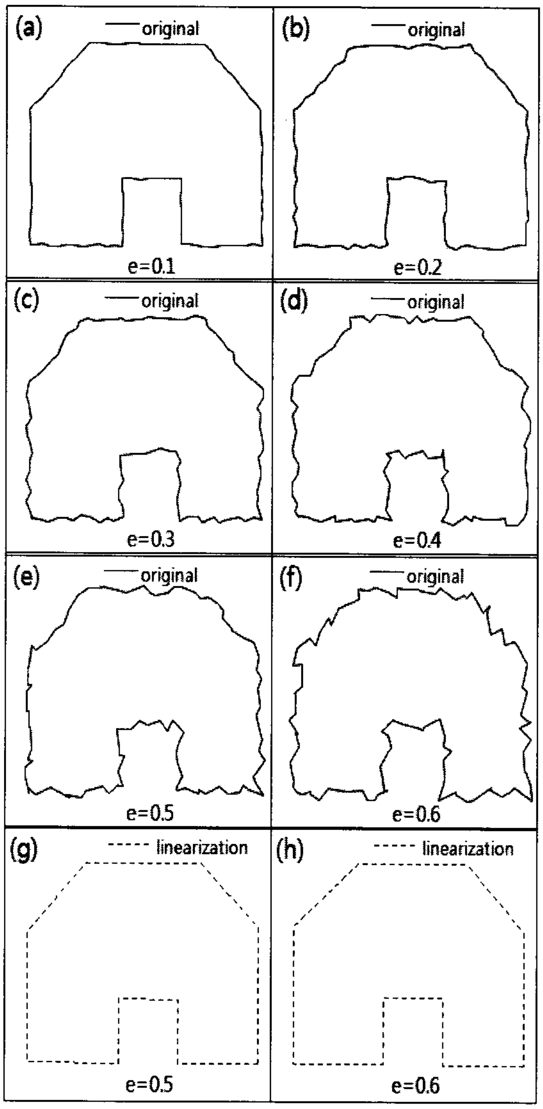

Figure 4. Original boundaries with random error and extracted polygons

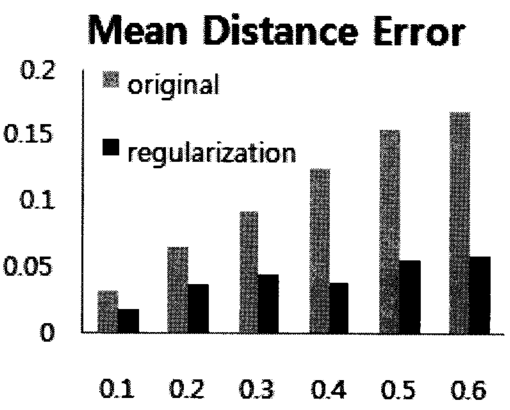

Figure 5. MDE of extracted polygons and original data

6. CONCLUSIONS

In this paper a new approach was proposed that can extract boundaries from complex shapes of buildings. The method consists of three steps such as boundary tracing, boundary generalization, and boundary regularization. Each step contains algorithm that range from slight modification of conventional one to entirely new concept. From the results of visual and numerical tests, our proposed approach has good potential for extracting various types of building boundaries. Furthermore the method is more effective in case the original data have larger errors. However, it requires further experiments to ensure that our approach is robust for many types of buildings. Also, it will be a good challenge if we compare the accuracies of building boundary extraction according to point spacing.

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