Acta Technica 62, No. 3B/2017, 429–442

Research on recognition and extraction of building contour information

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Abstract. Aiming at the low precision problem of the current building outline extraction, it is proposed an improved recognition method of geometric features and semantic description, and it is established mathematical model solving process. At the same time, the method of inner contour information recognition based on mesh density of projection points is proposed, and the realization process is also detailed. Taking the cloud data of a single building as the sample, it carries out the experiments of recognition and extraction of outer contour and inner contour information respectively. The result shows that the proposed method is not only correct in theory, but also can improve the clarity of contour information recognition and extraction, and its superiority is obvious.

Key words. Contour recognition, information extraction, geometric feature, semantic description, density grid..

1. Introduction

The building contour information includes external and internal contour information. And the external contour information refers to the building wall outer contour outline, while the internal contour refers to the windows of the building, and other details [1]. Extracting the interior and exterior contours of the building from the point cloud of the facade is a key part of the reconstruction of the building models. When building elevation profile extraction, since the building interior contour is located within the building exterior contour, therefore it should give priority to the building exterior contour extraction, namely it abstracts the building wall contour characteristic.

Since the point cloud data is composed of massive coordinate points, extracting the external contour of the building facade is actually a collection of representative contour points. The concept of geometric feature and semantic description are

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introduced in this paper.

1.1. Geometric features and semantic description

The facade point cloud and the detail feature point cloud are classified into the following categories: building wall, street surface, building top, doorway and window, the convex surface on the other walls and so on. The main geometric characteristics are as follows:

1. Size: The size of different building facings is usually different, the general building wall area is the largest, the building top surface area is less, and the window and doorway surface is generally smaller.

2. Direction: The normal vector direction of the different patches in the point cloud of the building is different.

3. Location: The location of the building point cloud in different patches and details of the location of the structure is different. The building is generally higher than the top wall of the building. The street surface is generally under the building walls.

4. Depth: The depth of different building vertical plates are different, such as the distance between the two vertical sides of the balcony and the building wall relative to the vehicle laser radar.

5. Topological relations: The topological relationship between building point cloud patches can be used to distinguish different types of facets, such as windows in the wall of the building above and not with the top surface of the building.

Based on the above-mentioned structure of point clouds and the point cloud, the paper describes semantically the different surface patches of building wall, top surface, window, doorway and street surface.

1. Street surface: After filtering, surface segmentation, the vehicle laser radar obtains the building facade point cloud, and then it may still contains a small number of street points. Street points normal vector approximation parallel to the vertical direction and building wall surface is connected to the building point cloud surface, which is the lowest position of the patch.

2. Building wall: The building wall is divided into front and side, the front is the largest area and it is connected to the top surface of the building. The normal direction of myopia is for the horizontal direction. The side area is smaller than the front area in the front of the building, the street surface, and the top of the building.

3. The top of the building: The top of the building are usually perpendicular to the horizontal angle, it is connected with the building wall and the wall is higher than the building wall.

Table 1. Semantic descriptions and geometric features

Patch name	Patch normal vector direction	Patch position	Patch area	Patch depth	Topological relation for connected patches
Facade of building	Approximately perpendicular to the vertical direction	Above the street surface below the top of the building	max	max	Street surface, building top surface
Side of building wall	Approximately perpendicular to the vertical direction	Above the street surface below the top of the building	larger	no	Street surface, the top of the building
Top of building	Horizontal angle	Higher than the wall	larger	no	Building wall
Street surface	Approximate to the horizontal direction	lowest	smaller	no	Building walls, openings
Window and doorway	Approximately perpendicular to the vertical direction	Inside the building wall	small	no	Inside the building wall

4. Windows and doorway: The windows and openings are not in the same plan with the building facade. It is generally hard to recognize the depth between window and doorway. It is usually recognized that the window is located within the building wall. The doorway is also inside the building wall, but the doorway is in contact with the street side and is larger than the window.

To sum up, the geometric features and semantic descriptions of building facades are shown in Table 1.

1.2. Facets features recognition and extraction

In order to extract the contour features of building accurately, people firstly need to identify and extract the feature point set and the inner contour feature point set of building outline. According to the above semantic description, the concept of convex hull is introduced [2].

Suppose that in a real vector space T, given the set W, the intersection S of all the convex sets containing V in the set W is called the convex hull of V. The convex hull of V can be constructed by the linear combination of all points $(V_1, \cdots, V_n)$ in V. In general terms, given a set of two-dimensional plane points, the collection of the outermost points of the line, get the polygon is convex, convex hull contains all the points set, as it is shown in Fig. 1.

It needs to find the convex hull of all the points of the outer contour point set and the inner contour point set of the building. Calculate all the convex hull area, the normal vector and other information. Such as: the convex hull area can represent the size of the point set size, the geometric center of the convex hull represents

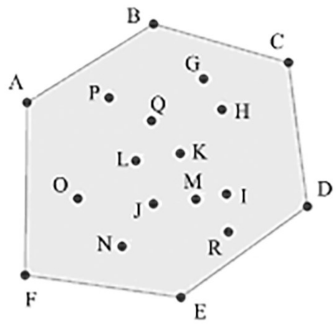

Fig. 1. Schematic diagram of convex hull

the location of the point set, the direction of the point set can be expressed as the direction vector of the convex hull, and the topological relation of convex hull can represent the topological relation of point set. Based on the identified convex hull characteristics of various point sets, the building wall contour can be extracted.

1.3. Recognition and extraction method based on geometric features and semantic description

At present, the most common method of building contour extraction is the identification extraction method based on geometric features and semantic description. The specific steps of the method are as follows [3]–[7]:

Firstly, according to the scanning line, the single point of the building outline point cloud data is arranged to extract the highest point of the vertical direction of each scanning line profile, and the points are composed of the point set that is the top point set of the building. Secondly, it is regarded the building top contour points in a leftmost point as the starting point, from left to right on the top of the building contour points for fitting a straight line, determine whether the current points to fitting the straight line distance is consistent with the distance threshold limit. If in accordance with the point into line point, it will set to be refitted straight line, if not in accordance with the distance threshold limit point, line point set as the end point, and as the initial point of the next set of linear points. Thirdly, cycle 1-2 steps are processed repeatedly until all the top outline points of the building are processed. Fourthly, the contour lines of the top of the building can be obtained by fitting the straight points of the top points of the building. Then the starting and end points of the top contour lines are projected into the ground along the vertical direction, and the four points are connected with each other to obtain a complete characteristic line of the building wall surface.

As shown in Fig. 2a, it regards the selection of a single building point cloud as the experimental data. By using the method of feature extraction of contours, it extracts the experimental data of wall contour recognition based on semantic recognition. Distance threshold $\boldsymbol{T}$ is set to 0.3 m, the experimental results shown in

Fig. 2b and Fig. 2c. In Fig. 2b, the black points are the starting point and the end point of the top point of the building wall. The black point is the top point of the building. Fig. 2c is extracted from the building wall profile characteristics.

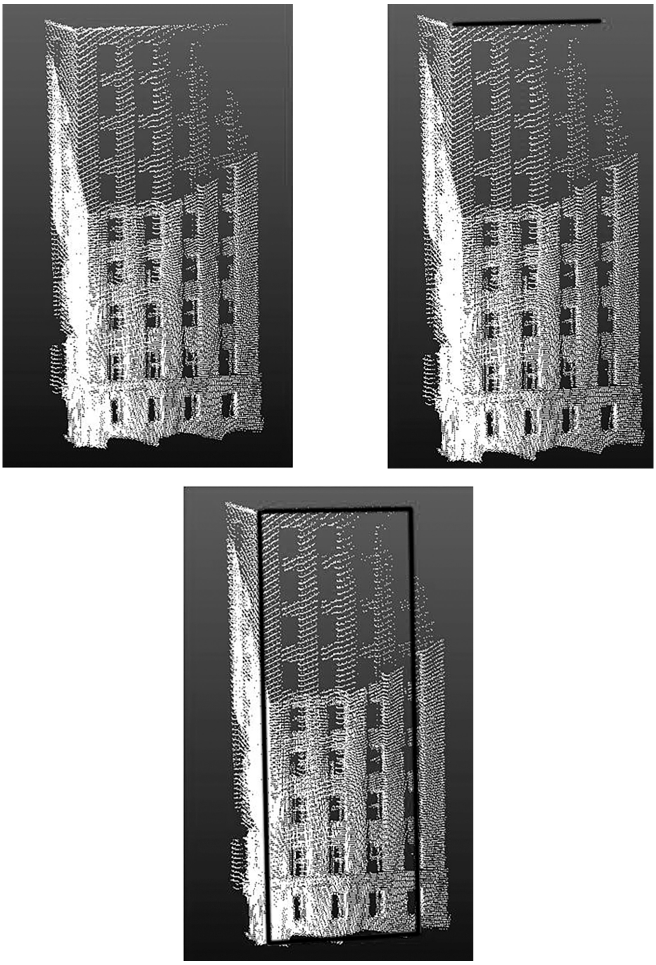

Fig. 2. a) Single building point cloud (top left), b) Extraction results of top point set (top right), c) Results of wall contour extraction (bottom)

From the results of the feature extraction of building wall contour, the extracted building wall contour is different from the actual building wall contour. Reason for this error is: when the vehicle laser radar scanning to obtain point cloud, due to other surface occlusion and scanning system error will result in data deletion, the selected top point of the wall surface does not necessarily contain all the top points of the wall surface. Based on this situation, the paper puts forward a reasonable improvement method based on the original building contour extraction method, and it established a corresponding mathematical model which is testified by experimental results.

2. Contour recognition extraction improved method

When the vehicle borne laser radar scanning blocks, it not only can obtain the main wall building point cloud, but also can get the building side wall point cloud, the main wall and side wall will be vertical intersected. So, a contour extraction method is proposed through the calculation of the intersection and angular point of the main wall and side wall of buildings. The realization of the method is as follows:

First of all, to solve the wall convex hull, assumed the plane convex hull for a complete space. Generally, the space plane equation is

$$Ax + By + Cz + D = 0\,. \tag{1}$$

The plane parameters $(A,\ B,\ C,\ D)$, the formula (1) to rewrite

$$\alpha\hat{x} + \beta\hat{y} + \gamma\hat{z} = 1\,. \tag{2}$$

Assumed $\alpha = \alpha_0 + \delta_\alpha$, $\beta = \beta_0 + \delta_\beta$, $\gamma = \gamma_0 + \delta_\gamma$, $\hat{x} = x + v_x$, $\hat{y} = y + v_y$, $\hat{z} = z + v_z$, into the formula (1) can be obtained

$$\alpha_0 v_{xi} + \beta_0 v_{yi} + \gamma_0 v_{zi} + x_i \cdot \delta_\alpha + y_i \cdot \delta_\beta + z_i \cdot \delta_\gamma + \alpha_0 x_i + \beta_0 y_i + \gamma_0 z_i - 1 = 0\,. \tag{3}$$

Among $i = 1,\ 2,\ 3,\ \cdots,\ n$, the formula (2) can be carried out

$$\begin{bmatrix} \alpha_0\beta_0\gamma_0 & & & \\ & \alpha_0\beta_0\gamma_0 & & \\ & & \ddots & \\ & & & \alpha_0\beta_0\gamma_0 \end{bmatrix}_{n\times 3n} \begin{bmatrix} v_{x1} \\ v_{y1} \\ v_{z1} \\ \\ v_{xn} \\ v_{yn} \\ v_{zn} \end{bmatrix}_{3n\times 1} + \begin{bmatrix} x_1 & y_1 & z_1 \\ x_2 & y_2 & z_2 \\ \vdots & \vdots & \vdots \\ x_n & y_n & z_n \end{bmatrix} +$$

$$+ \begin{bmatrix} \delta_\alpha \\ \delta_\beta \\ \delta_\gamma \end{bmatrix} + \begin{bmatrix} \alpha_{x1} + \beta_{y1} + \gamma_{z1} - 1 \\ \alpha_{x2} + \beta_{y2} + \gamma_{z2} - 1 \\ \vdots \\ \alpha_{xn} + \beta_{yn} + \gamma_{zn} - 1 \end{bmatrix} = 0\,. \tag{4}$$

The formula (4) simplified class

$$\underset{n\times 3}{W} + \underset{n\times 3n}{A}\,\underset{3n\times 1}{V} + \underset{n\times 3}{B}\,\underset{3}{\delta\hat{x}} = 0\,. \tag{5}$$

When $\min = V^T PV$, that:

$$\begin{cases} B^T K = 0 \\ A^T AK + B\delta_{\hat{x}} + W = 0 \end{cases}, \tag{6}$$

$$\delta_{\hat{x}} = -(B^T(A^TA)^{-1}B)^{-1}B^T(A^TA)^{-1}W\,, \tag{7}$$

$$\begin{bmatrix} \alpha \\ \beta \\ \gamma \end{bmatrix} = \begin{bmatrix} \alpha_0 \\ \beta_0 \\ \gamma_0 \end{bmatrix} + \delta_{\hat{x}}\ . \tag{8}$$

That is, the estimated parameter values are

$$\begin{cases} \alpha = \alpha_0 + \delta_{\hat{x1}} \\ \beta = \beta_0 + \delta_{\hat{x2}} \\ \gamma = \gamma_0 + \delta_{\hat{x3}} \end{cases} . \tag{9}$$

2.1. Plane intersection line

If there are two non-parallel planes, they must intersect at a line L, as shown in Fig. 3

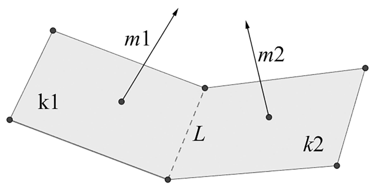

Fig. 3. The two non-parallel planes in the straight line L

Suppose these two planes are k_1, k_2, normal vector

$$\begin{cases} S_1 = \boldsymbol{m}_1 \cdot K \\ S_2 = \boldsymbol{m}_2 \cdot K \end{cases} . \tag{10}$$

Therefore, the two plane intersection point set must meet the following linear equation

$$K = a\boldsymbol{m}_1 + b\boldsymbol{m}_2\,. \tag{11}$$

The simultaneous equations (10) and (11) can be obtained

$$\begin{cases} S_1 = a\left\|\boldsymbol{m}_1\right\| + b\left\|\boldsymbol{m}_1 \cdot \boldsymbol{m}_2\right\| \\ S_2 = a\boldsymbol{m}_1 \cdot \boldsymbol{m}_2 + b\left\|\boldsymbol{m}_2\right\|^2 \end{cases} \tag{12}$$

Respectively, the solution of a, b:

$$\begin{cases} \frac{S_2\boldsymbol{m}_1 \cdot \boldsymbol{m}_2 - S_1\|\boldsymbol{m}_2\|^2}{(\boldsymbol{m}_1\boldsymbol{m}_2^2 - \|\boldsymbol{m}_1\|^2\|\boldsymbol{m}_2\|^2} = a \\ \frac{S_1\boldsymbol{m}_1 \cdot \boldsymbol{m}_2 - S_2\|m_1\|^2}{(\boldsymbol{m}_1\boldsymbol{m}_2^2 - \|\boldsymbol{m}_1\|^2\|\boldsymbol{m}_2\|^2} = b \end{cases} . \tag{13}$$

Bring a and b into formula (11), it can get the intersection line equation

$$L = K + t(\boldsymbol{m}_1 \cdot \boldsymbol{m}_2) = (a\boldsymbol{m}_1 + b\boldsymbol{m}_2) + t(\boldsymbol{m}_1 \cdot \boldsymbol{m}_2)\,. \tag{14}$$

The intersection point set can be obtained on the basis of intersection equation.

2.2. Angular point extraction

Usually, the same building wall, the wall and the street are building side perpendicular to each other. Respectively set the plane k_1, k_2, k_3, three lines were L_1, L_2, L_3, Normal vector $\boldsymbol{m}_1$,$\boldsymbol{m}_2$,$\boldsymbol{m}_3$, its form is shown in Fig. 4.

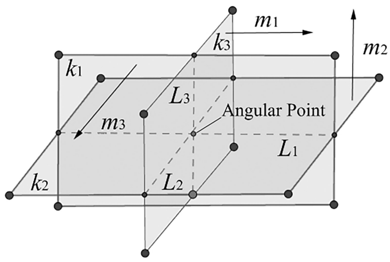

Fig. 4. The schematic diagram of building's main surface, side, ground surface

From the above chart, there is an intersection when two arbitrary planes are intersected; there is a common point when two arbitrary lines intersecting. That is to say, $\boldsymbol{m}_1 \cdot (\boldsymbol{m}_2 \times \boldsymbol{m}_3) \neq 0$. It shows that any two planes intersect an intersection of arbitrary intersecting lines. There is a common point, that is to say. Suppose three planes intersect one by one, then they must be at one point. Therefore, the condition for three planes intersecting is: $\boldsymbol{m}_1 \cdot (\boldsymbol{m}_2 \times \boldsymbol{m}_3) \neq 0$.

It can be identified that k_3's normal vector $\boldsymbol{m}_3$ and the intersecting lines will not be orthogonal, such three plane conditions for reference. This paper calculates the angular point formula about three planes intersect each other

$$K = \left[(\boldsymbol{m}_1 \cdot k_1)(\boldsymbol{m}_2 \times \boldsymbol{m}_3) + (\boldsymbol{m}_2 \cdot k_2)(\boldsymbol{m}_3 \times \boldsymbol{m}_1) + \frac{(\boldsymbol{m}_3 \cdot k_3)(\boldsymbol{m}_1 \times \boldsymbol{m}_2)}{\boldsymbol{m}_1 \cdot (\boldsymbol{m}_2 \times \boldsymbol{m}_3)}\right]. \tag{15}$$

Will be carried out on the type was

$$\begin{cases} k_1 : a_1x + b_1y + c_1z + d = 0 \\ k_2 : a_2x + b_2y + c_2z + d_1 = 0 \\ k_3 : a_3x + b_3y + c_3z + d_2 = 0 \end{cases} \tag{16}$$

Convert the above x, y, z coefficients to a matrix form

$$F = \begin{bmatrix} a_1 & b_1 & c_1 & d \\ a_2 & b_2 & c_2 & d_1 \\ a_3 & b_3 & c_3 & d_2 \end{bmatrix} \tag{17}$$

Use of Gaussian elimination, you can solve for x, y, z.

Through the above analysis, it can get the intersection point set and the corner point coordinates accurately, and can fit and extract the building intersection line. At the same time, according to the center symmetry principle of building facade, it can realize the accurate restoration of building elevation profile.

3. Algorithm test

The specific flow of the improvement method is shown in Fig. 5.

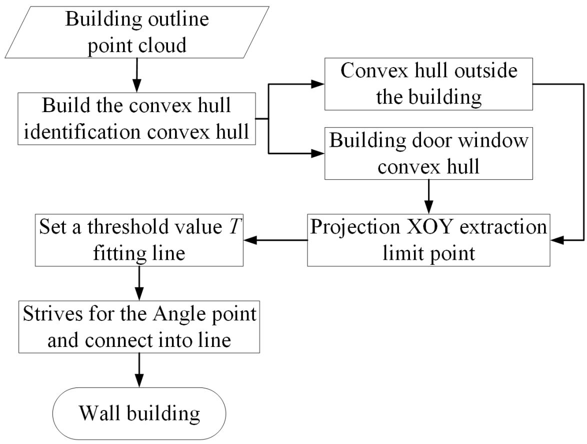

Fig. 5. Flow chart of improved algorithm

In order to illustrate the superiority of the improved method, it analyzes the single building facade point cloud that mentioned above. Using the improved method of building contour extraction, the distance threshold T is set to 0.3 m. The experimental results are shown in Fig. 6a and Fig. 6b. In Fig. 6a, the black point is the calculation of the angular points, the other black point is the intersection point set.

It can be seen from the experimental results that the extracted building wall features are basically the same as the actual building contours, which shows that the improved method of building wall contour feature extraction can make up for the deficiency of the original method, and then realize the accurate reduction of building outline.

4. Building elevation internal contour extraction

Because of the point cloud data with a large amount of data, including noise and out of plane and elevation feature information with depth and so on. Good considering various methods of extraction, this paper proposes a method of extracting minutiae point projection window density grid based on the window of a building outline feature extraction.

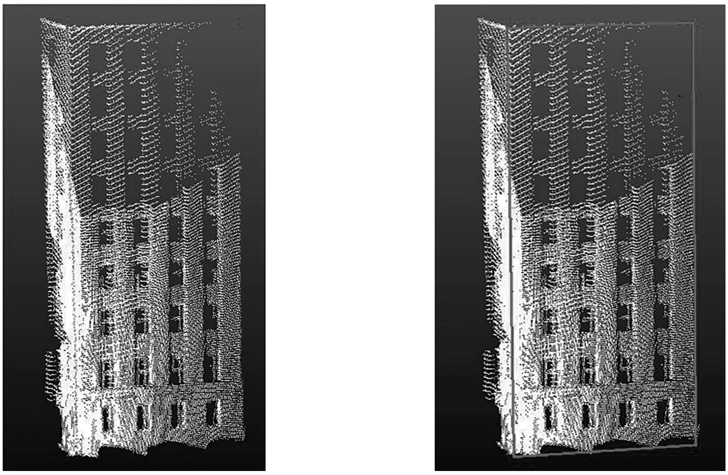

Fig. 6. a) Extracted results of intersection points (left), b) Extracted results of the contour of building wall (right)

4.1. Extracting the edge point of the frame point cloud

After the window point cloud is projected to the elevation plane, the frame point cloud of the window is extracted by the structural features of the window on the actual building. From the above analysis, people know that the glass can't emit laser point, the window frame point cloud has become an important data extracted window contours. The method of extracting window frame point cloud is divided into the following steps: firstly, the building is meshed to construct triangulated irregular network, and it is constructed the triangulation, which is shown in Fig. 7a and Fig. 7b.

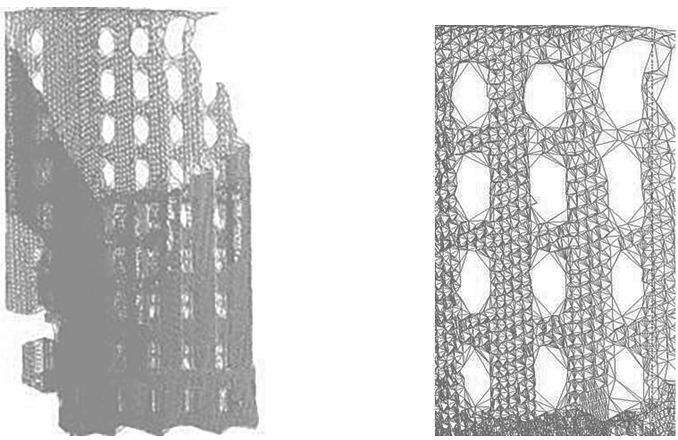

Fig. 7. a) Building facade overall triangulation (left), b) Local amplification (right)

First, the edge length is set to determine the edge length of each triangle in the triangulated irregular triangle. And the edge point of the window is extracted according to the edge length threshold. Then the edge points are clustered and the edge points belonging to the same boundary are classified into one class. Finally, the point cloud is extracted. In the triangle network, each triangle is connected with the other three triangles, and the small triangle of the window frame point cloud is connected with only one or two other triangles. According to the above characteristics, the number of triangles of small triangles is used to extract the point cloud at the void. If the number of external triangles is 3, it is judged as the point cloud at the void. On the contrary, it is determined as the contour point outside the elevation.

4.2. Meshing

The maximum X, Y coordinates and the minimum X, Y coordinates of each point in the subset of the point cloud edge points of any window frame are obtained, which are $X_{\min}$, $Y_{\min}$ and $X_{\max}$, $Y_{\max}$ respectively. It is known that this window frame has four feet $(X_{\min}, Y_{\min})$, $(X_{\min}, Y_{\max})$ and $(X_{\max}, Y_{\max})$ respectively, the horizontal and vertical straight lines are used for the four points, and the above-mentioned processing is performed for all the window point cloud point sets. The rectangles that divided into horizontal and vertical lines are numbered and arranged according to the coordinates of the foot points. Each rectangular grid is composed of three kinds of attributes, which are the coordinates of the center point of the rectangular grid, the area of the rectangular grid and the number of points in the rectangular grid.

4.3. Grid classification

The classification grid is classified according to the principle of projection density. Projection point density is the point cloud data projection to a plane, the number of points per rectangular grid. The grid density is calculated as

$$P = M/S\,, \tag{18}$$

where P and M are density and number of points in the rectangular grid respectively, S is the area of the rectangle can be calculated by

$$S = (X_{\max} - X_{\min})(Y_{\max} - Y_{\min})\,. \tag{19}$$

Formula (18) and (19) are used to calculate the density of points in the rectangular grid.

Since the windows on the glass can't reflect the laser point, the glass accounts for most of the entire window area, it can be considered that the window can't emit laser point. In the rectangular grid which represents the window, the density of the projected points should be zero. The density of the projected points in the rectangular grid representing the wall of the building should be equal to the density of the initial elevation point cloud data. However, due to the variety of urban features in the inevitable acquisition in the scanning point cloud of the building have a small part of the occlusion by other objects. There may also be errors in the extraction of window frames, and there may be a small number of building wall points within the rectangular grid representing the window. The meshes are classified by formula (20):

$$\begin{cases} P < T_1 d & \text{Building metope grid} \\ P > T_2 d & \text{Building window grid} \\ else & \text{other} \end{cases} . \tag{20}$$

In the above formula: P is the density of points in the rectangular grid; T_1, T_2 is the setting density threshold; d is the initial elevation point cloud data density. The rectangular mesh can be classified by formula (20).

4.4. Grid clustering

Some rectangular grids which have been classified represent the building window point cloud. In order to get accurate window point data, it is needed to classify the grid which represents different windows. The rectangular grid which represents the same window is normalized into the same rectangular mesh set. In order to obtain the rectangular grid set of the same window, it needs to use clustering analysis method. The specific processes are as follows: each rectangular mesh is treated as a separate class. Respectively as: $p_1, p_2, p_3, \cdots, p_n$, a total of n class G were $G_1, G_2, \cdots, G_n$. There is n class of G, respectively as $G_1, G_2, \cdots, G_n$. The distance matrix is calculated as follows

$$D = \begin{bmatrix} d_{12} & d_{13} & d_{14} & \cdots & d_{1n} \\ & d_{23} & d_{24} & \cdots & d_{2n} \\ & & d_{34} & \cdots & d_{3n} \\ & & & \ddots & \vdots \\ & & & & d_{n-1,n} \end{bmatrix} . \tag{21}$$

The calculation formula of d_{ij} in matrix D is as follows

$$d_{ij} = \sqrt{(p_{i\mathrm{x}} - p_{j\mathrm{x}})(p_{i\mathrm{x}} - p_{j\mathrm{x}}) + (p_{i\mathrm{y}} - p_{j\mathrm{y}})(p_{i\mathrm{y}} - p_{j\mathrm{y}})} . \tag{22}$$

The minimum element D_{XY} in D is then selected for comparison with the set threshold. If it is less than the set threshold, G_{X}, G_{Y} will be classified as a new category, otherwise the cluster ends. Repeating the above steps until all rectangular meshes is finished.

Still selected Fig. 8 shows a single building for point cloud experiments. First of all, the facade point cloud of the building is triangular meshed. Since the distance between points is 5 cm, the triangle side length threshold is set to 10 cm. The density threshold values T_1 and T_2 are set to 0.05 and 0.95, respectively. The results are shown in Fig. 8.

From the figure, in this paper, the method is used to extract the contour of the

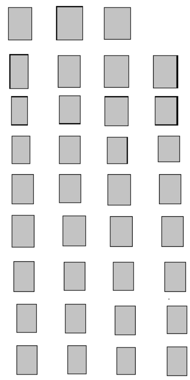

Fig. 8. Window profile extraction results

window, and the result is good. Due to the lack of data in the original point cloud, the window extraction result is partially missing and the windows are of different sizes.

5. Conclusion

1. The concrete realization process of traditional building contour extraction method and the problems in the calculation are analyzed.

2. It puts forward the improvement method of recognition and extraction based geometry feature recognition and semantic description. At the same time, the corresponding computing model is built.

3. This paper presents a method to identify the inner contour information based on the mesh density of projection points. At the same time, it analyzes its concrete realization flow.

4. Taking the single-building point cloud data as the sample to carry on the experimental analysis, the superiority of the method for extracting the outer contour and the inner contour information is verified.

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Received April 30, 2017