Building Extraction from DSM Acquired by Airborne 3D Image

YOU Hongjian  LI Shukai

1 Introduction

Automatic building extraction is the research focus to obtain three-dimensional (3D) information of city. There are two main approaches to extract buildings by remote sensing; one is based on aerial photos and the other is based on stereo photos or digital surface models (DSM). Man-made buildings generally have such characteristics as limited area, evident and regular boundary, height difference between building and ground, etc. Some methods are proposed to extract buildings by using remote sensing based on these characteristics. In the 1980s, aerial photos were the main remote sensing information, so the automatic building extraction based on edge-angle analysis and shadow verification was proposed to use monocular large scale aerial color photo. With the development of photogrammetry, DSM produced by aerial stereo pairs were used to extract buildings, and this method is also combined with other methods.

The urban DSM can be produced by stereoscopic matching, and the changes of building height can be shown in DSM. Owing to the height difference between the buildings and ground, and the buildings are distributed separately, so the building can be recognized easily, and its position and shape can also be determined. The building extraction on the basis of stereo pairs is very popular and some successful algorithms have been proposed. However, owing to the weakness of matching algorithm, it is difficult and will take much time to extract all the buildings correctly. Therefore, this approach cannot meet the requirement of the fast development of cities. In
recent years, the airborne laser scanning system appeared, which can acquire DSM very fast, and some methods based on urban DSM generated by the laser scanning were proposed. High dense laser points must be collected firstly if those methods are used. In this paper, however, we will introduce a method which only adopts DSM produced by the rough laser point interpolation.

2 Airborne 3D imager and DSM production

In the 1990s, with the development of global positioning system (GPS) and scanning laser range finder, an airborne scanning laser system which integrates GPS, INS and scanning laser appeared. The airborne 3D imager integrates GPS, attitude measurement unit (AMU), scanning laser rangefinder (SLR) and spectral scanner. The spectral scanner and SLR use the same optical system, which ensures the laser point to match the image pixel seamlessly. The distinctive advantage of the airborne 3D imager is that it can produce geo-referenced imagery and DSM without any ground control points (GCPs). It is no longer necessary to set GCPs, and the software can process the data to produce DSM and geo-referenced image in nearly real-time. The prototype of the airborne 3D imager was developed in 1996 and the operational airborne 3D imager was in 1999.

During the post-processing, the laser sample points are used to generate DSM. Owing to the limited pulse rate of scanning laser rangefinder, the suitable scanning mode must be applied in order to get high dense laser points. After some experiments and comparison, it is found that the denser laser points will be obtained if the cone scanning by one point every 3-4 m² is used, therefore, the cone scanning mode is suitable for urban areas.

3 Building segmentation based on DSM

The urban DSM image generated by the 3D imager is depth image, which is shown as Fig.1. Each building can be distinguished easily, for there is height difference between the building and its surroundings. But DSM is generated by interpolation, so which is not suitable for describing the character of buildings. Therefore, we have developed a method to extract and regulate the building automatically.

Fig. 1 Raw DSM data

The first step to extract buildings is to detect the rough shape and position of buildings. The methods for detecting the target belong to image segmentation. People pay much attention to image segmentation in recent years, and it is the main question of computer vision. Hundreds of algorithms and new research advances appear every year. But there is no general method and criterion to evaluate the different algorithms.

Different regions containing different buildings can be separated by image segmentation, and these regions do not overlap even each region has the same characteristic. There are two main segmentation approaches; one is a boundary-based method which utilizes the discontinuity of gray level, the other is a region-based method which utilizes
the comparability of gray level. The former often refers to edge detection and the latter often refers to segmentation.

One or several thresholds must be selected by segmentation and the image will be divided into several regions after each pixel is compared to the threshold. The key to segmentation is how to select the threshold. There are many approaches to do this, such as pixel-based, region-based and position-based methods. Many new methods were proposed in recent years, e.g., selecting the threshold based on maximum correlation or on fuzzy C-class maximum entropy.

According to the urban DSM, we propose a self-adaptive iterative segmentation considering the mean square covariance. The algorithm can be described in detail as follows:

1) Choose a sub-image whose center is current pixel from the image as an interested region.
2) Calculate the mean gray level and root mean square (RMS) of the sub-image, because the mean gray level can be used to determine whether the pixel is ground. At the same time RMS shows the change of gray.
3) Iteratively choose the threshold from the sub-image:
   ① using the mean gray level of the sub-image as the initial threshold,
   ② dividing the image into two groups, $R_1$ and $R_2$, by the initial threshold,
   ③ calculating the mean gray level of $R_1$ and $R_2$, i.e., $t_1$, $t_2$,
   ④ calculating the new threshold $T$, $T = (t_1 + t_2)/2$,
   ⑤ repeating step ② to step ④ until $t_1$ and $t_2$ do not change.
4) comprehensively segmenting the image on the the basis of threshold $T$, mean gray and RMS of the sub-image.

Each pixel of the whole image is processed in sequence, then we can get the segmented image. The contour of building can be extracted from the segmented image by Laplacian operator. But the contour is grid structure and it only shows the coordinates and distribution, and the boundary points that belong to the same building are not linked together. We use the pixel-neighbor-based follow algorithm to follow up the boundary of buildings. Fig. 1 shows the DSM image of Beijing Yanyun Village whose resolution is 2 m, and Fig. 2 shows the extracted contour which is coupled with DSM. From the figures, we can see that most of the boundaries of the buildings have been extracted correctly.

4 Regulating the boundary of buildings

The building figure after segmentation and boundary follow only shows the rough shape of a real building, and it does not accord with the characteristic of the real building, therefore, we should regulate the boundary of the building.

Man-made building is designed and set up carefully and it is composed of regular polygons, therefore, the edges of most buildings are right-angled, i.e., the shape of building is composed of several rectangles. We divide the buildings into these types: rectangle, T
shape, L shape, U shape, I shape and \( I \) shape.

4.1 Polygon approaching the building boundary

The edge points of buildings are composed of neighbor points. Some points are in the same line, but many irregular points may appear because of noise and sampling, which can disturb the boundary. In order to regulate the boundary and get rid of the redundant boundary points, a polygon can be used to approach the building because a polygon can approach any curve. Therefore, we use split-based minimum RMS to approach the boundary of the buildings so as to eliminate the redundant points in the same line. The approached polygon can only show the rough shape of the buildings, and the polygon should be regulated again according to the characters of the buildings.

4.2 Grouping the boundary points and azimuth fitting

The boundary points must be grouped before we regulate the boundary, and the boundary points approximately in the same line should be put into the same group. Therefore, all the boundary points can be divided into several groups based on the change of the azimuth of the neighbor edges. The optimum azimuth of the edge can be calculated according to the boundary points in the same group. We use the dispersed points \((x_1, y_1), \ldots, (x_n, y_n)\) to fit the line \(y = ax + b\) or \(x = ay + b\) and then calculate its azimuth.

4.3 Calculating the main direction of building

The main direction of the buildings should be determined first in order to extract the buildings correctly, because the main direction determines the distribution of the buildings in the area. We use the azimuth of the longest edge with the minimum fitted RMS as the main direction of the building. The main direction can also be determined manually according to the distribution of the buildings in the area, because most of the buildings in an area are distributed towards the south.

4.4 Re-determining the direction of each edge

The direction of edges of the building must be re-determined on the basis of the main direction and the characters of the building. Because the cross angle of the neighbor edges of man-made building is about \(90^\circ\), the direction of each edge can be re-calculated according to the fact that the cross angle of the edge and main direction is \(90^\circ\).

4.5 Calculating the regulated edges

On the basis of the direction of the line, the normal parameter equation can be given as follows (Fig. 3)

\[
x \cos \theta + y \sin \theta = p_0
\]

where \(\theta\) is the ortho-direction of the line, which has the following relation with the azimuth \(A\) of the edge:

\(1\) when \(A > 270^\circ\) or \(A < 90^\circ\), \(\theta = 360^\circ - A\);

\(2\) when \(90^\circ < A < 180^\circ\), \(\theta = 180^\circ - A\);

\(3\) when \(180^\circ < A < 270^\circ\), \(\theta = 360^\circ - A\).

The distance \(D\) between any point \((x_0, y_0)\) and the line is:

\[
D = |x_0 \cos \theta + y_0 \sin \theta - p_0|
\]

Fig. 3 Relationship between the parameter equation of the edge and its azimuth

The point which has the longest distance to the line should be determined based on the distances between all the left points of the line and the line in order to ensure that all the boundary points are within the regulated ed-
Fig. 4 shows the regulated edges. The intercross points of the neighbor edges can be calculated in sequence, and then we can get the coordinates of the regulated buildings.

4.6 Evaluating the regulation

Some buildings may have the irregular shape, and the regulated result will be very bad; therefore, we should evaluate the result of the regulation. It is found that the ratio of the areas can show the comparability between the regulated building and initial building after some tests. The area of the building which is composed of boundary points and the area of the regulated building which is composed of regulated edges are calculated first, and then the ratio of the two areas is calculated. We may think of that the regulation is good if the ratio is within the allowed limitation, otherwise, the regulation is not ideal and the building has not been regulated well. We can use the approximate polygons to express the buildings with irregular shapes if the regulation is not suitable.

We use the points \((X_k, Y_k)\) to calculate the area \(S\):

\[
S = \frac{1}{2} \left( \sum_{k=0}^{n} X_k Y_{k+1} - \sum_{k=0}^{n} X_{k+1} Y_k \right) \quad (3)
\]

Use the pixel within the building as the center to search the pixels which meet the requirement, and the height of the pixel is the height of the building. Therefore, with the coordinates and height of the building known, the entity of each building can be output in specific format. Fig. 5 shows the edges of regulated building matched with DSM.

5 Height filling

If we fill the building with height, then we can get the building DSM. There are several region filling algorithms such as polygon filling method, side filling method and seed filling method. The polygon filling algorithm is complex but independent of the device. The seed filling algorithm require a seed pixel in the region, so it is not very suitable for our case. We apply the side filling method and make some improvements. First, we determine the line which has the minimum value in \(Y\) axis while it is parallel with \(X\) axis based on the turning points of the building, then the pixel is scanned and filled with the height in sequence in \(Y\) axis. If the pixel gray value is the height, then its value will be reset to 0; If the pixel value is 0, then its value will be set to height. The sides of the building are processed in turn, and the building is filled with the correct height. No matter how complex the building is, the filling result is always very good. Fig. 6 shows the side filling process.

Fig. 7 shows the filled result. The building
DSM formed by regulation is suitable for the characters of the 3D building, and its 3D display is realistic. Fig. 8 shows the 3D display of the buildings which is processed by extraction and regulation.

6 Conclusions

In this paper we proposed a self-adaptive iterative segmentation considering the mean square covariance and this algorithm can detect the boundary of the building effectively, using the DSM data acquired by airborne 3D imager. We also studied the regulation method which is composed of polygon approaching, azimuth grouping, main direction determining and edges regulation to regulate the buildings in accordance with the characteristic of the man-made building. Because of the limited density of the laser points, some buildings may be merged together. With the resolution of the image of the improved 3D imager, the image acquired simultaneously with DSM should be helpful to extract the buildings. Therefore, in the near future, how to combine image and DSM to extract building automatically is the next objective to be further studied. In addition, how to extract building and reflect the different character is-
tics of city is another research subject.

References

1. Haala N, Brenner C (1999) Virtual city models from laser altimeter and 2D map data. *Photogrammetric Engineering & Remote Sensing*, 65(7):787-796
2. Ackerman F (1999) Airborne laser scanning—present status and future expectations. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(2-3):64-67
3. Weidner U, Forstner W (1995) Towards automation building extraction from high-resolution digital elevation models. *ISPRS Journal of Photogrammetry & Remote Sensing*, 50(4):38-49
4. Baillard C, Maitre H (1999) 3D reconstruction of urban scenes from aerial stereo imagery: a focus strategy. *Computer Vision and Image Understanding*, 76(3):244-258
5. Baillard C, Dissard O, Jamet O, et al. (1998) Extraction and textural characterization of above ground areas from aerial stereo pairs: a quality assessment. *ISPRS Journal of Photogrammetry & Remote Sensing*, 53(3):130-141
6. Mass H G (1999) The potential of height texture measurement for the segmentation of airborne laser scanner data. The 4th International Airborne Remote Sensing Conference and Exhibition, Ottawa.
7. Hiroshi M, Hiroyuki H, Izumi K (1999) Extraction of building shapes from laser scanner data using region segmentation method. International Workshop on Vision-based Techniques in Visualization and Animation, Onuma, Japan.
8. Haala N, Brenner C (1999) Extraction of buildings and trees in urban environment. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(2-3):130-137
9. Baltsavias E P (1999) Airborne laser scanning: existing systems and firms and other resources. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(2-3):164-198
10. Petzold B, Reiss P, Stossel W (1999) Laser scanning—surveying and mapping agencies are using a new technology for the derivation of digital terrain models. *ISPRS Journal of Photogrammetry & Remote Sensing*, 54(2-3):95-104

(Continue from Page 15)
4. Gruen A (1985) Adaptive least square correlation: a powerful image matching technique. *Journal of Photogrammetry and Remote Sensing*, 14(3):175-187
5. Zhang Y J (2002) Three dimensional reconstruction and visual inspection of industrial sheetmetal parts with image sequences. [Ph. D dissertation]. Wuhan: Wuhan University. (in Chinese)
6. Wang Z Z (1984) Principles of photogrammetry. Beijing: Publishing House of Surveying and Mapping. (in Chinese)
7. Jin W X, Yang X H (1994) Photogrammetry. Beijing: Publishing House of Surveying and Mapping. (in Chinese)
8. YU Z T, Lu L C (1982) Principles of survey measurement. Beijing: Publishing House of Surveying and Mapping. (in Chinese)