BUILDING RECONSTRUCTION USING LINE MATCHING AND INTERSECTION FROM MULTIPLE AERIAL IMAGES

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ABSTRACT

Line matching plays an important role in building reconstruction, because majority buildings are composed of line segments along boundaries. Considering the complexity in image processing, line matching is a challenging work. The building reconstruction with line matching algorithm is performed using high overlapping aerial images in this study. The strategy is to determine the building boundaries first followed by the processing of the roof structures. The basic procedures in those two parts are similar with the differences of parameter settings. First, extracting the straight lines and using left-right matching to locate the conjugate lines in multiple images. Then, space line intersection is employed with blunder detection for 3D line positioning. The reconstruction and refinement processes are done in an iterative way. The experimental results indicate that the proposed method can reach reliable results.

Keyword: Left-right Matching, Space Line Intersection, Blunder Detection, Building Reconstruction

INTRODUCTION

Three dimensional spatial data has been widely used in the field of geospatial information. The major components in 3D GIS include buildings, roads, utilities, vegetation, etc. Among those components, building models are the most prominent in the reconstruction work. Aerial images are commonly used in building reconstruction.

Line matching plays an important role in building reconstruction, because majority buildings are composed of line segments along boundaries. Considering the complexity caused by occlusions, repetitive image patterns, and different endpoints of extracted line segments in image processing, line matching is a challenging work [Ok et al., 2010]. With the development of airborne digital cameras, an object may appear on several images providing more observations for reliable positioning. Therefore, the purpose of this study is to use multi-angle images with space line intersection for line matching and positioning.

The proposed approach used to locate 3D line segments in this study is the extraction of line segments followed by the space line intersection. It is based on collinearity condition and parametric line formation to derive the observation equations. Referring to a starting point, the direction represents a line in 3D space [Ayache and Faugeras, 1989]. The unknown parameters can be solved by least squares adjustment using multi-image observations.

A strategy of building reconstruction including two major works: boundary determination and roof structure reconstruction is employed in this study. It is observed that the building boundaries in images usually have high feature strength, and some weak edges responses exist on the roof structures. Therefore, if the building boundaries can be determined, the roof structures can thus be processed with low threshold in the stage of feature extraction. The interference of non-target objects can also be reduced.
METHODOLOGY

The proposed method includes (1) building boundary determination and (2) roof structure reconstruction. If the building boundaries can be determined, the roof structures can thus be processed and the interference of non-target objects can also be reduced. The workflow of the proposed method is shown in Figure 1.

**Building Boundary Determination**

The approach of building boundary determination comprises five parts: (1) straight line extraction, (2) line matching, (3) 3D line positioning, (4) initial model reconstruction, and (5) model refinement.

**Straight line extraction:** Since majority buildings consist of line feature, straight line extraction is needed for the line feature detecting. We thus, use Canny edge detector [Canny, 1986] combined with the Hough Transform [Hough, 1962] for the extraction. It is observed that the building boundaries in image usually have high feature strength, the features extraction for those features is performed with high threshold.

**Line matching:** The matching strategy in this study includes three parts: (1) interest line selection, (2) candidate line identification, and (3) similarity assessment.

Giving an example, Figure 2 illustrates the interest line selection. Figure 2(a) shows the line features before the selection. Considering that the line features on the target building are the majority, we employ Hough Transform for those features to find the major accumulation in Hough space. Then, the line direction histogram can be plotted counting Hough angle as horizontal axis and accumulation as vertical axis. The peaks of the histogram are the main directions of the target building. In the figure-example (Figure 2(b)), the values are 6°, 95°, and 96°. The interest lines that satisfy these orientations will be selected on master image. Figure 2(c) shows line features after the selection.

![Figure 2. The illustration of interest line selection.](image-url)
A composite matching method combining line feature and grey value is employed in this study. Three criteria, (1) epipolar constraint, (2) resemblance of line direction, and (3) grey value similarity of neighboring regions, are employed for feature matching. Since many line features could exist on each image, an epipolar region constraint is generated with a reasonable height range to reduce the search area [Zhang & Baltsavias, 2000]. Then the lines in the region with direction similar to the interest line are selected as candidates.

After the line features selection and identification, Left-right matching is employed to compare the grey value similarity of those possible features with Normalized Cross Correlation (NCC). Two windows (Left and Right) are opened on both sides of lines features. Figure 3 illustrates the matching windows with respect to the feature line. M and N are window size which depends on the interest line. M represents the number of pixels along the line. N is the half number of pixels across the line.

**3D line positioning:** In this stage, we use successfully matched lines for 3D line positioning. The proposed approach comprises two parts: space line intersection and blunder detection.

A 3D line can be represented by space parametric line equations with a starting point and a direction vector. Figure 4 shows the scheme of a 3D line, where \((X_0, Y_0, Z_0)\) represents the starting point, \((S_X, S_Y, S_Z)\) represents the direction vector. To cope with the parameter dependency, the equations need to be modified. Depending on the direction of line, we may use a coordinate plane which is located at \(X = 0\) or \(Y = 0\). Then, the starting point is the intersection point of the space line and the plane. The direction vector is also normalized depending on the line direction. Figure 5 delineates the schematic plot of the modified 3D line equations. In Figure 5(a), \((0, Y_0', Z_0')\) represents the intersection point of space line and plane of \(X = 0\), where \((1, S_Y', S_Z')\) means the normalized direction vector. In Figure 5(b), \((X_0', 0, Z_0')\) represents the intersection point of space line and plane of \(Y = 0\), \((S_X', 1, S_Z')\) means the normalized direction vector. Based on these line equations and collinearity condition equations, the distance from the image line to the back-projected line is used to derive the observation equations. The line parameters can be solved by least squares adjustment.

To cope with the possible matching errors, a strategy for the exclusion of the incorrect matched lines is needed. The strategy referring to Robust Estimation [Chen and Lee, 1992, Ghilani, C.D., 2010] is conceptually employed. The proposed approach evaluates the quality of space line intersection. The largest residual in the observation equations is skeptical as an unreliable one. We, then, relax the
observation weight for the next adjustment computation. If the precision of the adjustment improves, we relax the weight further more. The iteration stops when the solution tends to be stable. Finally, the incorrect matched lines become dummy in the 3D positioning.

**Initial model reconstruction:** Since the objective is to reconstruct building models, filtering out those non-target line segments is required. First, space parametric line equations are used to calculate the elevation along each 3D line. Figure 6 shows the scheme of the elevation calculation. By counting the number of different elevation, the most likely building segment is the one with majority elevation. Then, we can employ SMS algorithm [Rau & Chen, 2003] using 3D lines which satisfy the elevation to reconstruct an initial model.

![Figure 6. Scheme of the elevation calculation](image)

**Model refinement:** Once the initial model is reconstructed, buildings units need to be refined to regularize the shape and detect unreasonable ones. An iterative procedure is performed in the refinement. First, we calculate the ratio of each side of model length and it’s correspond 3D line length. If the ratio smaller than the threshold, the 3D line is eliminated. Then, the model is updated using the remaining lines. The procedure proceeds until all the unreasonable 3D lines are eliminated.

**Roof Structure Reconstruction**

In this stage, we use the building boundary model to generate the roof top area. Figure 7 shows the generation procedure. The roof structure can thus be reconstructed in the area with the similar procedure of the building boundary determination. The proposed approach repeats the previous five parts: (1) straight line extraction, (2) line matching, (3) 3D line positioning, (4) initial model reconstruction, and (5) model refinement.

![Figure 7. Generation of roof top region.](image)

Since there could be some weak edges responses existing on the roof structures, the straight line extraction is performed with a lower threshold. After the extraction, the other steps are performed similarly. Since the roof top areas are produced by the back projection of the building boundaries, all of the extracted lines are selected in this stage to avoid line missing. Then the procedure of generating building boundary model is repeated to reconstruct the roof structure.

**EXPERIMENTAL RESULTS**

Test data sets were obtained from DMC II images, the camera information is shown in Table 1. Figure 8 shows the target buildings. Three data sets include 7 images with double strips in Case 1, 8 images with double strips in Case 2, and 5 images with single strip in Case 3.
Table 1. Camera information

<table>
<thead>
<tr>
<th>Camera</th>
<th>DMC II</th>
</tr>
</thead>
<tbody>
<tr>
<td>Focal Length</td>
<td>91.9817 mm</td>
</tr>
<tr>
<td>Row/Column</td>
<td>12096 x 11200 pixels</td>
</tr>
<tr>
<td>Resolution</td>
<td>0.1 m</td>
</tr>
<tr>
<td>Image Size</td>
<td>87.091 mm x 80.640 mm</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>7.200 μm x 7.200 μm</td>
</tr>
</tbody>
</table>

Figure 8. Target building on master image.

After the extraction of the straight lines, line direction histogram is derived for selecting the interest lines. There are 32, 29, and 31 lines which satisfied the orientation conditions are selected on master image in three cases, respectively. Figure 9 shows line features after the selection.

Table 2 shows matching success rate and correctness rate in three test cases. The correctness rate is calculated from those successful matching. The success rate of case 3 is only 70.77%, it is caused by the material of the roof structure which is with the material of glass. Other reasons such as its repetitive texture and the line features parallel the epipolar line also cause the matching ambiguity. One of the possible ways to solve the problem is using crossing strip images. Unfortunately, crossing strip images are not available in this study. Table 3 shows the standard error before and after the blunder detection. From the table we can find that blunder detection can improve the quality of 3D line positioning.

Table 2. Matching success rate and correct rate

<table>
<thead>
<tr>
<th>Unit: %</th>
<th>Success Rate</th>
<th>Correctness Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>94.29</td>
<td>90.38</td>
</tr>
<tr>
<td>Case 2</td>
<td>88.46</td>
<td>83.97</td>
</tr>
<tr>
<td>Case 3</td>
<td>70.77</td>
<td>80.00</td>
</tr>
</tbody>
</table>

Table 3. Standard error before and after using the blunder detection.

<table>
<thead>
<tr>
<th>Unit: pixel</th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>5.127</td>
<td>0.802</td>
</tr>
<tr>
<td>Case 2</td>
<td>3.637</td>
<td>0.830</td>
</tr>
<tr>
<td>Case 3</td>
<td>14.069</td>
<td>0.580</td>
</tr>
</tbody>
</table>
The next discussions focus on the accuracy of the reconstructed buildings. Figure 10 shows the building model of three cases. Table 4 shows the RMSEs of building models. The ground truth of three cases is measured manually. According to Table 4, the RMSEs can reach 0.15m in both X and Y directions, and 0.5m in Z direction. Since we only compare the model with the ground truth that we can identify, there could be some incomplete or unreasonable building units.

Table 5 shows the RMSEs of building boundary model in Case 3. Figure 11 shows the boundary model of Case 3. Due to the matching ambiguity, the roof structure in Case 3 is reconstructed incompletely. Notice that the building boundary, instead of the roof super structure, in Case 3 is accurately reconstructed.

![Figure 10. Building model of three cases.](image)

![Figure 11. The boundary model of Case 3.](image)

**Table 4. The RMSEs of model.**

<table>
<thead>
<tr>
<th>Unit: m</th>
<th>RMSE(_x)</th>
<th>RMSE(_y)</th>
<th>RMSE(_z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 1</td>
<td>0.092</td>
<td>0.068</td>
<td>0.164</td>
</tr>
<tr>
<td>Case 2</td>
<td>0.139</td>
<td>0.162</td>
<td>0.277</td>
</tr>
<tr>
<td>Case 3</td>
<td>0.164</td>
<td>0.122</td>
<td>0.645</td>
</tr>
<tr>
<td>All</td>
<td>0.153</td>
<td>0.137</td>
<td>0.524</td>
</tr>
</tbody>
</table>

**Table 5. The RMSEs of building boundary model in Case 3.**

<table>
<thead>
<tr>
<th>Unit: m</th>
<th>RMSE(_x)</th>
<th>RMSE(_y)</th>
<th>RMSE(_z)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case 3</td>
<td>0.103</td>
<td>0.093</td>
<td>0.103</td>
</tr>
</tbody>
</table>

**CONCLUSIONS**

This paper has proposed a scheme for building reconstruction using line matching and 3D lines positioning. The experimental results show that the strategy of building reconstruction can reach reliable results. The RMSEs of building model are 0.15m in both X and Y directions, and 0.5m in Z direction. Since a portion of the feature lines are parallel to epipolar line, matching ambiguity is difficult to reduce. This situation may be solved if cross strip images are available. It is observed that some building units were not completely reconstructed. An inference engine including topological analysis is suggested.

**ACKNOWLEDGEMENTS**

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REFERENCES


