BUILDING STRUCTURAL CORNER DETECTION USING HIGH RESOLUTION OBLIQUE AIRBORNE IMAGES

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ABSTRACT: Detecting high accuracy building structural corners promotes building three dimensional (3D) reconstruction and measurements considerably. In this paper, a method which can detect building structural corners from high resolution oblique airborne images was proposed. This corner detector can extract building corners as completely as possible so that those sparse corners can define a intact building without uncertainty caused by key points missing. The premise of this method is that straight lines are rich on the surface of building. Then, two of them intersect each other and generate a corner. In this method, straight lines were extracted firstly. Then a rule named "be mutually closest endpoints" was proposed and employed to find straight line pairs for generating corners. Corners detected by this method are not only points with gray meaning but also points which can describe the structure of building surface in certain level with topological relation. In addition, three indexes of accuracy evaluation were proposed in this paper. And results obtained from our method and another contour based method were compared according to these three indexes. Experiments conducted on different areas of images, such as image areas which contain building façade, in this paper show that this method is effective to detect building structural corners with high accuracy of subpixel. And at the same time, this method can make effective suppression on the generation of points which are not building structural corners.

1. INTRODUCTION

Building structural corners here are defined as corners which can describe the structure of building exactly and uniquely. For instance, the corners of windows, doors, balconies and that of building façade are all building structural corners. Detecting these high accuracy corners from oblique images has significant influence on improving the efficiency and accuracy of building 3D reconstruction and measurements. At present, there are mainly two kinds of corner detection strategies. Firstly, intensity based corner detection methods, for example, Moravec, Forstner, Harris, SUSAN etc (Moravec, 1977; Forstner, 1987; Harris, 1988. Smith, 1997). Secondly, edge based methods, for instance, methods proposed by Rosenfeld and Freemen, then CCS (curvature scale space) etc (Mokhtarian, 1998; Dorez, 2007).

Corner detection strategies proposed above all have their pros and cons. Intensity based methods are always sensitive to fine details and noise at the same time for the same reason (Cihan, 2013). The most important problem is that different kinds of images need different parameters and it is time consuming. Moreover, corner detectors which utilize local non-maximal suppression method, such as Harris, may generate corners clustering and it has very negative impact on building structural corner detection. Traditional edge based methods tend to depend on image segmentation and edge extraction, and there are lots of problems and large calculating quantity. An excellent method: a robust CSS corner detector which based on thresholding the turning angle curvature of image gradients was proposed to find corners and the parameters of this method is relatively easy to tune (Cihan, 2013). Unfortunately, the location accuracy of corners obtained by this method can just reach pixel level. Furthermore, this method does not consider and avoid the impact caused by mixed pixel at the junction of two edges. Several corner detector based on straight lines intersection have been proposed (A. O. OK, 2010; Hyunwoo, 2010; Demir, 2012), but they are not aiming at detecting building structural corners for high resolution oblique airborne images and have several limitations, such as error and missing detection, when applied in this condition.

In this paper, we proposed a new method to detect high accuracy building structural corners automatically from oblique airborne images. Compared with orthoimages, oblique images have the following advantages: (1) More detail information (top and side information) of building can be achieved from the oblique images due to the multiple viewpoints and perspectives of the sensors (Wei, 2011; NYARUHUMA, 2010.); (2) The oblique images are characterized by high spatial resolution and relatively large field of view angle (XIAO, 2010; NYARUHUMA, 2012).

On the foundation of advantages proposed above, opulence straight line features on building surfaces are clear in oblique images so that it makes corner detection based on straight line intersection possible. First, line segments longer than threshold, which was computed by the scale of images, were extracted. Second, a rule named "be mutually closest endpoints" was created and employed to search line segment pairs, then the coordinate of corner were computed by these line pairs. Finally, results obtained by the method proposed in this paper were compared with that obtained by a robust CSS corner detector according to three indexes of evaluation.

2. METHODS

In this paper, there are two main steps of this method. Firstly, straight line segment extraction. The algorithm of line segment extraction must be excellent because it decide the effect of the next step directly. Secondly, coplanar line segment pairs searching.

2.1. Line Segment Extraction

By comparing different kinds of line segment extraction algorithms, we find EDLines, a linear time line segment detector which can produce accurate results and requires no parameter tuning, is good for our requirements (C. Topal, 2010; C. Akinlar, 2011). The precision of this algorithm can reach sub pixel level. The process of EDLines is shown in figure 1.

Parameters in EDLines are all built-in, and here it is unnecessary to tune them except for a line fit parameter: minimum line length *n*. EDLines fits a line segment according to adjacent pixels which lie on a straight line from detected edge when the number of these adjacent pixels is enough. To put it simply, if the line segment is shorter than minimum line length it will be omitted by EDLines. Equation (1) is the computing method of minimum line length *n*. In this equation, *p* is a fixed value and we need not to discuss it. N represents that the size of image is $N \times N$, namely that the minimum line length decided by the size of image. For example, when the image size is 512×512, $n = 12$ and when it is 3000×3000, $n = 15$. However, in this paper, the equation of determining minimum line length is not appropriate. Here, the object of corner detection is features lie on building. Therefore, the minimum line length should be determined by the size of features and the resolution of images. The resolution(R) of oblique airborne image is 8 cm - 15 cm and the minimum size(S) of building surface features, such as windows, doors, balconies, are close to 100 cm. So *n* should be set as $\frac{S}{R}$ (6 - 13 pixel) and here we chose an empirically optimize value 8.

$$n = \frac{-4\log(N)}{\log(p)}, where \quad p = 0.125 \tag{1}$$

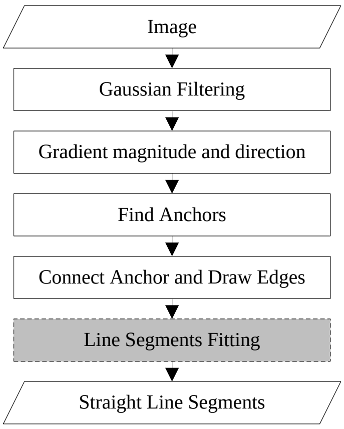


Figure 1 EDLines extraction

2.2. Line Pairs Searching and Corners Generation

On the basis of the straight line segment extraction, we need to search line pairs which can intersect each other, thus generate feature point. Because of the limitation of line extraction algorithm, the line segments which should intersect each other do not explicitly meet in 2D images. Thus, to find corners, line segments extracted above must be extended and intersect each other then generate an “L” structure, the corner lie on the “L” is what we want. Each of the end points of the line segment was processed respectively by the same principle called “be mutually closest endpoints”.

Actually, there is another kind of junction, “T” structure, in image space. We do not regard it as corner in this paper, because we find it is always generated by two line segments which actually lie on foreground and background of the image respectively and the junction does not exist in real world.

For an endpoint ***s1*** of a given line segment ***l1***, the principle of L-corner comprised of four steps as is illustrated in figure 2:

(1) Searching line segment which intersect ***l1*** with an angle. When the angle is greater than threshold (30°), put these line segments in set ***Sc***.

(2) Searching line segment ***li*** with an endpoint ***si*** which is the closest one to endpoint ***s1*** belonging to line segment ***l1***. If the distance between ***s1*** and ***si*** is smaller than threshold, then conduct the following step (3).

(3) Regard ***li*** and ***si*** as given line segment and current processing endpoint respectively. Repeat step (1) and (2), if the line segment ***l1*** and endpoint ***s1*** can be searched, endpoint ***s1*** and ***si*** are mutually closest and line ***l1*** and ***li*** can intersect each other.
(4) Compute the intersection point (***corner***) of ***l1*** and ***li***, save the corresponding relationship between intersection point and line segments.

Corners extracted here are not independent with each other, but relate to neighbor corners through line segments between them. If necessary, higher level geometries can be constructed based on these corners and line segments.

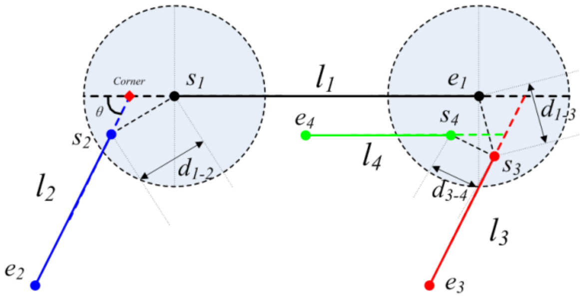


Figure 2 Principle of searching intersecting line segment pairs: in this figure, l_1 is current line segment and l_2 meet all of the rules of intersecting with it in the direction of s_1. In the other direction, l_3 is found by e_1 but it is not the right line segment because the procedure is irreversible due to the interference of l_4.

3. EXPERIMENTS AND RESULTS

In this section the performance of the proposed method was measured by comparing its results with a contour-based algorithm, a robust CSS corner detector (Cihan Topal, 2013).

Traditionally, accuracy (ACU) and localization error (LE) are usually employed in the evaluation of the performance of corner detectors (Farahnaz, 2001). The prerequisite of assessing ACU and LE is to find where the real corners are. However, it is subjective because different people have different judgements, and LE is particularly sensitive to this problem. In addition, different uses of corners decided the assessment methods and rules of corner detectors. In the process of oblique images, corners are usually employed in 3D (three dimensional) reconstruction. In this experiments, we evaluated the performance of our corner detection algorithm by detection rate(DR), redundancy rate(RR) to replace ACU and a index of stereos matching accuracy(SMAI) instead of LE, as is shown in equation (2), (3), (4).

Efficient detector should be insensitive to noise and transformation. The SMAI is an index which can be used to assess the stability of our detector for noise and transformation. For perspective projection, a plan can be transformed to another one with a matrix, namely that if the detector is stable enough, plan corners in stereo image pair can be transformed by a matrix A and the error($\left\| X'' - X''_t \right\|$) should be little enough.

$$DR = 100 \times N_{true} / N_{real}, \quad RR = 100 \times (N_{detected} - N_{true}) / N_{real} \tag{2}$$

$$\begin{cases} x = ax' + by' + c \\ y = dx' + ey' + f \end{cases} \tag{3}$$

$$X''_t = X'A$$

$$\textbf{and } X''_t = \begin{bmatrix} x_1 & y_1 & 1 \\ x_2 & y_2 & 1 \\ \cdots & \cdots & \cdots \\ x_n & y_n & 1 \end{bmatrix}, X' = \begin{bmatrix} x'_1 & y'_1 & 1 \\ x'_2 & y'_2 & 1 \\ \cdots & \cdots & \cdots \\ x'_n & y'_n & 1 \end{bmatrix}, A = \begin{bmatrix} a & d \\ b & e \\ c & f \end{bmatrix}$$

$$SMAI = \sum_{i=0}^{n} \left\| X''_i - X''_{ti} \right\| \Big/ n \tag{4}$$

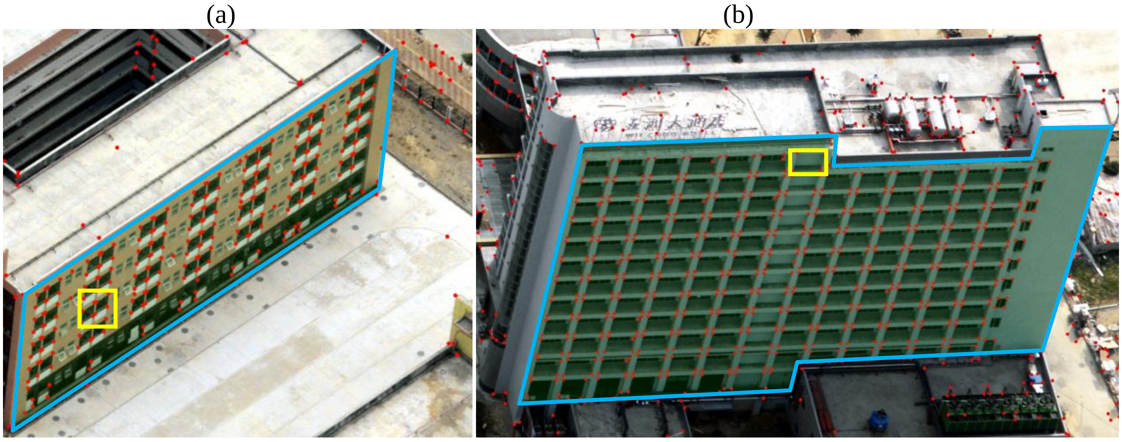
In this experiment, we conducted our detector and a robust CSS detector on two stereo image pairs of building façades respectively. The resolution of these images is about 0.1 m. We set the least line length, angle threshold, distance threshold as 8 pixels, 30° and 10 pixels respectively in our method. And the parameters of a robust CSS detector in the online demo are set as follows: curvature threshold is 4, maximum line fit error is 0.25 and angle validation threshold is 160.

Building corner detection is the purpose of this paper, in order to avoid the uncertainty in determining corners, so that only corners which can describe building structure, such as corners of windows and balconies, would be considered in computation of DR and RR, as the blue polygon image areas shown in figure 3. Some parameters of detection assessment are shown in table 1. In this table, the parameters suggest that DR of the robust CSS vary more drastically than L corner detector for different images when the parameters were fixed. To some images, the DR of robust CSS detector is higher, but the RR is also greater.

In addition, the precision of the robust CSS reaches just pixel level because the detector extract corners by computing the curvature of contour pixel by pixel. Corner was defined in where the curvature is large enough in this method. But the contours are not accurate for the existence of mixed pixel. As is shown in figure 4, contours are all arc, where should have been sharp, at corners. However, get corners by L detector can avoid this limitation and improve the accuracy of corners to reach sub-pixel level. The accuracy would be assessed by SMAI subsequently.

Traditionally, location error assessment are conducted by comparing detected corners with manually marked corners. However, manually marked corners are not necessarilly accurate. Therefore, we employ SMAI to replace LE here. As is shown in fiure 5, the match error of the robust CSS corners is bigger than L corners in general. And the SMAI of this four groups are 0.7262 pixels, 0.9148 pixels, 0.6737 pixels and 0.8769 pixels respectively. All of these suggest that the L corner detector is stable and the accuracy of corners detected by it is relatively high.

(a) (b)



(c) (d)

Figre 3 Results of corner detection: (a), (b) CSS; (c), (d) L corners

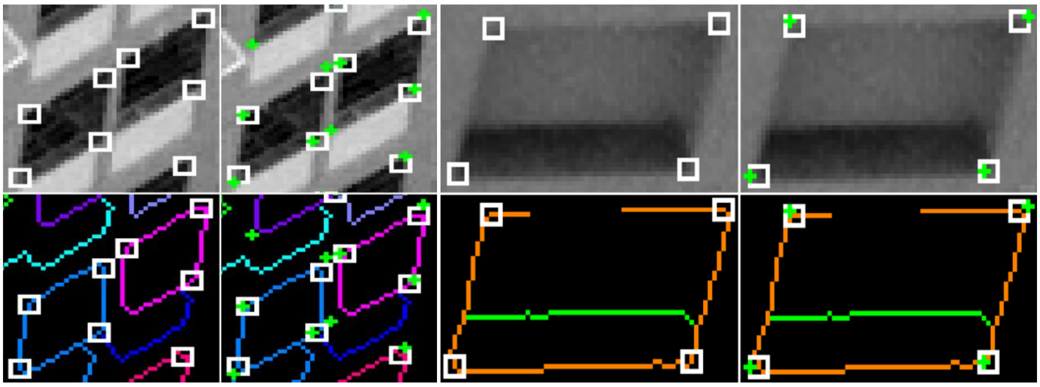


Figure 4 Corners Detected by Different Detectors of Yellow Areas in Figure 3: white squares are corners detected by robust CSS and green crosses are that detected by L corner.

Table 1 Detection and Redundancy Rate

Image ID	ADCN	FRCN	FTCN	FDCN	DR	RR
1_a_LCR	312	224	220	251	0.982	0.138
1_a_CSS	383	224	159	265	0.710	0.473
1_b_LCR	298	224	211	258	0.942	0.210
1_b_CSS	437	224	194	355	0.866	0.719
2_a_LCR	875	596	574	597	0.963	0.039
2_a_CSS	1160	596	581	623	0.975	0.070
2_b_LCR	786	596	570	589	0.956	0.032
2_b_CSS	1114	596	593	636	0.995	0.072

Note: 1_a and 1_b is stereo image pair and so is 2_a and 2_b. ADCN, FRCN, FTCN, FDCN, DR and RR stand for all detected corners number, fa çade real corners number, fa çade true corners number, fa çade detected corners number, detection rate and redundancy rate respectively.

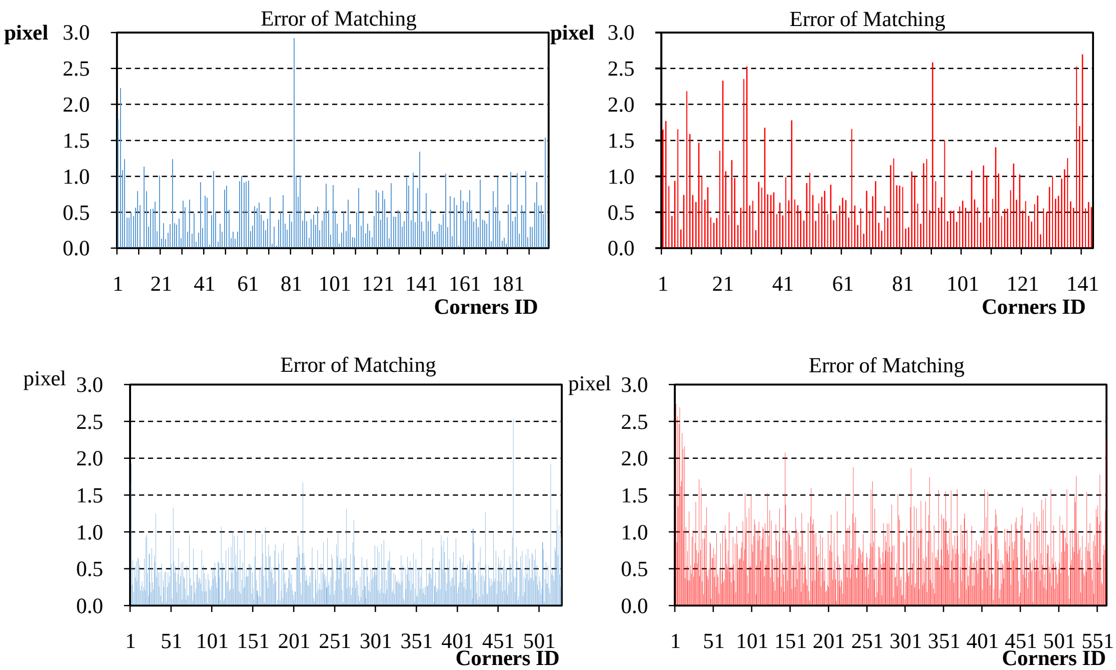


Figure 5 SMAI of Image Pairs: (a) corners matching error of 1_a and 1_b L, (b) the robust CSS corners matching error of 1_a and 1_b L, (c) L corners matching error of 2_a and 2_b, (d) the robust CSS corners matching error of 2_a and 2_b

4. CONCLUSION

In this study, we proposed a building structural corner detection method for high resolution oblique airborne images. The experiment shows that the corner detection method can extract building structural corners efficiently with high accuracy of sub-pixel level. At the same time, corners which are not building structural key points were suppressed to a certain extent. In addition, Corners detected by L detector are not independent with other corners and straight lines. The relationship among corners and lines make constructing higher level geometric structure possible. This can be used to 3D reconstruction, structure analysis, damage assessment and so on. Finally, detector evaluation index, such as DR, RR and SMAI, were proposed in this paper and they are reasonal for evaluate efficiency and accuracy of this building structural corner detector.

Further study should be conducted on following issues. First, building structural corner detector need to be improved for low resolution images. Because straight lines on the surface of building are difficult to extract from low resolution images. Second, comprehensive application of different corner detectors in detecting corners from complicated images is another valuable field for study.

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