

AUTOMATIC REGISTRATION OF AIRBORNE IMAGE SEQUENCES BASED ON LINE MATCHING APPROACH

ZHANG Pengqiang^{a,*}, YU Xuchu^a, HAN Li^b, SONG Lihua^a

^a Zhengzhou Institute of Surveying and Mapping, Zhengzhou 450052, China -
zpq1978@163.com

^b Zhengzhou Institute of Surveying and Mapping, Zhengzhou 450004, China -

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ABSTRACT:

Traditionally, image registration approaches are classified to two categories: area-based methods and feature-based methods, where the latter use corresponding features as control objects. As the most popular feature in image processing, the line feature is well studied in recent years. In this article an automatic image sequences registration method is proposed which using corresponding straight line segments as control objects. According to the collinearity principle of corresponding straight lines, the image registration model is established. With this model, the straight line segment can be specified by arbitrary two points in it, but not its' endpoints exactly. This method break out the limitation that corresponding features must be the same. Meanwhile, to realize automatic registration process of image sequences, the algorithms of automatic straight line segment extraction and automatic straight line segments matching are designed, which satisfy the demands of image registration, under the condition that the images have preliminary registered.

1. INTRODUCTION

Image registration approaches are classified to two categories: area-based methods and feature-based methods [Barbara 2003]. To estimate the geometrical transform parameters between the source image (slave image) and reference image (master image), area-based methods scan the whole parameter space and calculate the similarity between the reference image and the transform image which created from the source image, according to every possible set of parameters. Area-based methods are effective, if there exists only simple distortion between the source image and reference image, such as translation, similarity or affine distortion. The advantage is that the automatic registration process can be realized easily. However, if there exist complicated geometrical distortions between two images, the calculation increase rapidly as the increase of parameter dimensions and expanding of parameter values, so as to it's too time-consuming to finish calculation in some conditions.

In contrast, feature-based methods have more extensive adaptability and better stability, although their processes are more complicated. In these methods the object features which extracted from two images are employed as control objects. To estimate image registration model between the source image and reference image, feature-based methods calculate the geometry relationship of corresponding object features. According to the kind of employed object features, feature-based methods are classified to three classes: area feature-based methods, line feature-based methods and point feature-based methods. In practice, because of the difficulties in describing and matching of area features and line features, they are replaced by point features usually, such as endpoints and

midpoints of straight line segments and centroids of areas. In this way employed corresponding object features must be the same strictly.

In recent years, some literatures from photogrammetry community have studied the feasibility to employ the advanced ground objects, for example, line objects, to automatic absolute orientation process. [Zhang Zuxun, 2004], [Zhang Zuxun, 2005] proposed generalized point photogrammetry, which introducing point, straight line, circle, arc, curve and limitless point, named as generalized points, into photogrammetric process. [Zhang Hongwei, 2004] demonstrated a concrete method to realize the automatic registration process between remote sensing image and vector map in detail, which using generalized points as control objects. In his method the geo-coded control generalized points are selected from vector map, while the corresponding features in image are extracted automatically. The generalized points are used as control objects to replace the ground control points (GCPs) in absolute orientation process.

In this article, we introduce straight line into automatic registration process of airborne image sequences. According to the collinearity principle of corresponding straight lines, we establish the image registration model. With this model, the straight line can be specified by arbitrary two points in it, but not its' endpoints exactly. This method break out the limitation that corresponding lines and areas must be the same. Meanwhile, to realize the automatic registration process of image sequences, we design the algorithms of automatic straight line segment extraction and automatic straight line segments matching, which satisfy the demands of image

* Corresponding author.

registration, under the condition that the images have preliminary registered.

2. IMAGE REGISTRATION MODEL

2.1 Principle: Collinearity of Corresponding straight lines

Straight lines are familiar features in airborne image sequences. They often fall into edges of man-made objects. Since edge extraction is one of well-studied techniques in image processing, we can design a robust algorithm of automatic straight line extraction from edges, with which straight line will be extracted from source image and reference image respectively. Then the extracted straight line is acted as control object for the registration process.

As shown in figure 1, we suppose that the source image has rotational and translational distortion compare to the reference image. Let L_i^r and L_i^s ($i=1,2,3$) represent three corresponding straight lines in the reference image and source image

respectively. After rotating and translating, the source image is located at the right position, which is the position of the registered destination image. Here the straight line L_i^d (transformed from L_i^s) in destination image and the corresponding straight line L_i^r in reference image are located in the same one straight line. Considering the difference of pixel values between the reference image and source image, each endpoint of corresponding straight lines L_i^d and L_i^r does not need to be the same coordinate. This is the principle of registration: collinearity of corresponding straight lines. Compared with point feature-based method, the advantage is that the straight line can be specified by arbitrary two points in it, but not its' endpoints exactly. Meanwhile, because the straight line can be extracted automatically and precisely, this method has the potential promotion of both efficiency and precision.

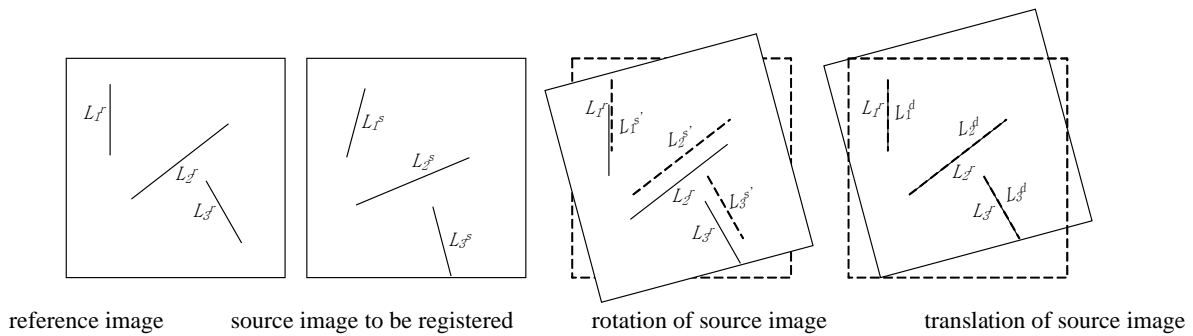


Figure 1. Principle of image registration with straight line-based approach

2.2 Registration Model for Image Sequences

To establish the registration model, we adopt direct image registration method. That is, for every pixel in the source image, the corresponding pixel coordinate is found in the registered destination image. The coordinate transform formula

$$x^d = f(x^s, y^s) \quad y^d = g(x^s, y^s) \quad (1)$$

is used to resample image gray levels (i.e. colors) to construct the registered destination image. Where (x^d, y^d) represents an image coordinate in the registered destination image, (x^s, y^s) represents a pixel grid in the source image. The core task of image registration is to determine the form and parameters of formula (1).

As shown in figure 2, the straight line L^r in the reference image corresponds to the straight line L^s in the source image. In this model, the endpoints of two straight lines need not to correspond one-to-one. The straight line L^d in the registered destination image is created from L^s after be registered. Its' two endpoints are transformed from two endpoints of L^s by formula (1). According to the collinearity principle, straight lines L^d and L^r are in one straight line. In another words, every points in L^d are located in L^r .

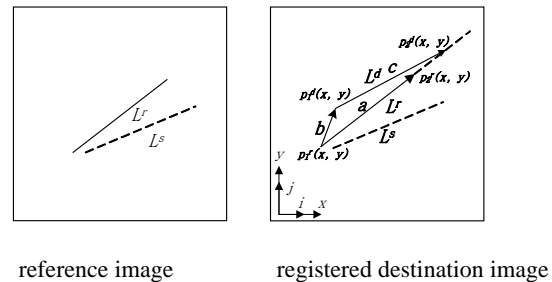


Figure 2. Model of image registration with straight line-based approach

Let symbols p_1^r, p_2^r represents arbitrary two points in L^r , p_1^d, p_2^d represents arbitrary two points in L^d , respectively. In practice these points can be endpoints of L^r and L^d . Let symbol **a** represents the vector from p_1^r to p_2^r , **b** represents the vector from p_1^r to p_1^d , **c** represents the vector from p_1^d to p_2^d , respectively. The expressions are:

$$\mathbf{a} = (x_2^r - x_1^r)\mathbf{i} + (y_2^r - y_1^r)\mathbf{j}$$

$$\mathbf{b} = (x_1^d - x_1^r)\mathbf{i} + (y_1^d - y_1^r)\mathbf{j}$$

$$\mathbf{c} = (x_2^d - x_1^d)\mathbf{i} + (y_2^d - y_1^d)\mathbf{j}$$

According to the collinearity principle, points p_1^d and p_2^d of straight line segment L^d are in the straight line L^r . Mathematically, every cross products of each two vectors of \mathbf{a} , \mathbf{b} and \mathbf{c} equal to $\mathbf{0}$, i.e.

$$\mathbf{a} \times \mathbf{b} = \mathbf{0}$$

$$\mathbf{a} \times \mathbf{c} = \mathbf{0}$$

In details,

$$(x_2^r - x_1^r)(y_1^d - y_1^r) - (y_2^r - y_1^r)(x_1^d - x_1^r) = 0$$

$$(x_2^r - x_1^r)(y_2^d - y_1^d) - (y_2^r - y_1^r)(x_2^d - x_1^d) = 0$$

Translate it to the error equations,

$$V_{ab} = (x_2^r - x_1^r)(y_1^d - y_1^r) - (y_2^r - y_1^r)(x_1^d - x_1^r)$$

$$V_{ac} = (x_2^r - x_1^r)(y_2^d - y_1^d) - (y_2^r - y_1^r)(x_2^d - x_1^d) \quad (2)$$

Taking formula (1) to equation (2), using enough number of corresponding straight line segments, a group of error equations are built. Then the Unknown parameters of formula (1) are found by a least squares adjustment process. For example, take affine transform

$$x^d = a_0 + a_1 x^s + a_2 y^s$$

$$y^d = b_0 + b_1 x^s + b_2 y^s$$

as coordinate transform form, we need to find 6 transform parameters. Every pairs of corresponding straight lines can give 2 error equations, so we need 3 pairs of corresponding straight lines at least. They should be distributed uniformly in the whole image. In addition, there is a connotative basic request: each two pairs should not be parallel if there are only 3 pairs of corresponding straight lines.

3. AUTOMATIC EXTRACTION OF STRAIGHT LINE SEGMENT

Traditional straight line extraction methods include Hough transform [Hough 1962], which transforms binary image function to straight line parameter description. The maximum values in parameter space are the straight lines in image space. However, because of poor positioning capability, Hough transform is not a good method to extract control straight lines from image. [Zhang Hongwei, 2004] adopts a “feature extraction and straight line tracking” process to extract straight line segments from image. Firstly the prominent edges are extracted using Canny operator (Canny 1986). Then the edges are thinned and tracked to get edge chains with one single pixel width. At last edge chains are separated and merged until they can be fitted as straight line segments.

To act as control objects of image registration, straight line segments must be the prominent features in both reference and source image. In this article, two characters of the prominent straight line segment are proposed. They are

- (1) The length of the straight line segment must be above a threshold value N , and
- (2) The vertical distance from every point in the chain to the fitted straight line must be below a threshold value Δ .

Using these two characters, we can detect the straight line segments from the chains extracted by Canny operator.

However, we cannot directly detect them using these two characters above, in fact. Because, if we want to validate whether these two characters come into existence, we must fit a straight line with the chain firstly. In this way we blindly suppose that all points in the chain are from one straight line. In practice straight line segments are often embodied in parts of the whole chain. In this condition, we cannot rightly divide straight line parts from the whole chain, using these two characters. As shown in figure 3, the solid line represents a edge chain code, which assembled by a straight line segment AC and a curve CB . The dashed line represents the fitted straight line. This fitted straight line satisfies the two characters, but it is not a right division of straight line segment AC .

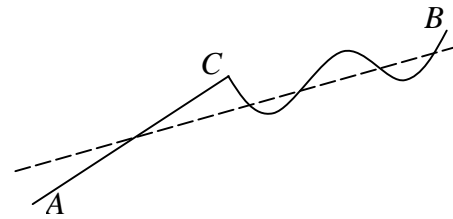


Figure 3. Edge chain code and fitted straight line

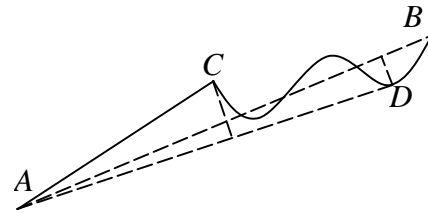


Figure 4. Straight line segment detection with a link line between head and tail of edge chain

As shown in figure 4, deriving from the two straight line segment characters, if a straight line segment is embodied in the edge chain, a line AC can represent this straight line segment. Here AC is a link line between head and tail of the straight line part in the edge chain. Using this rule, we design a straight line segment detection process. In this process, the fitted straight line is replaced by line AB , a link between head and tail of the whole edge chain. Then all points in edge chain are checked to validate whether these two characters are met. If both two characters are met, the output straight line will be fitted with all points in edge chain. Otherwise, the edge chain is divided into two parts AD and DB . Here D is the farthest endpoint from straight line AB . Then the “detecting and dividing” process is performed with these two edge chains. This process is repeated until all the edge chains divided into short chains. That is, except the edge chains which have fitted to straight line, all others have pixels less than N , thus the two characters will be not met anymore.

The algorithm is described as follows: for each chain code of edge,

- (1) This chain is abandoned and the process turns to the next chain, unless the number of pixels in it is above the threshold value N ;
- (2) This chain is abandoned and the process turns to the next chain, unless the length of AB , a link line from the head

point to the tail point of the chain, as shown in figure 4, is above the threshold value N ;

- (3) The vertical distances are calculated from every points in the chain to AB . The maximum value M of the vertical distances and corresponding point D are recorded.
- (4) This chain represents a straight line segment if $M < \Delta$. The straight line is fitted using all pixel points in the chain. Two endpoints of the straight line segment are determined by point A and B . The endpoints should not exceed the scope area of A and B . Then the process turns to the next chain.
- (5) This chain does not represent a straight line if $M \geq \Delta$. The chain is divided into two chains AD and DB . The process turns to (1).

With the algorithm above, all straight line segments in edge chains are extracted. In practice only prominent features are used in registration process. So it is necessary to pick prominent straight lines. A convenient rule is to hold those straight line segments, which have the maximum length. Figure 5 shows the result of straight line segment extraction from airborne image, where $N = 20$ pixels, $\Delta = 2.0$ pixels. Top left corner of image is shown in figure 5.



Figure 5. Result of straight line segment extraction

4. AUTOMATIC MATCHING OF STRAIGHT LINE SEGMENTS

This is the critical step for the whole process of automatic registration. In this article we suppose that the images have preliminary registered. There are some approaches to get preliminary registered airborne image sequences. If video scene changes slowly, just shortening sampling interval can obtain preliminary registered image sequences. If video scene changes quickly or sampling interval is long, we can do rough geometric rectification for all image sequences, using the parameters of platform position and sensor attitude. Thus all images are taken to one reference coordinate frame. But because of the error of parameters, in this way we can not get precise rectified images. So image registration process is necessary yet.

In this article, three constraints of corresponding straight line segments in the preliminary registered images are proposed as follows.

- (1) The distance of the mid-points of corresponding straight line segments should be below a threshold value M , which is determined by the residual shift error of the preliminary registered image.
- (2) The included angles between every pairs of corresponding straight line segments should equal approximately. This angle value is determined by the residual rotation error of the preliminary registered image.
- (3) All pairs of corresponding straight line segments should be one-to-one correspondence. Every pairs of corresponding straight line segments should hold the same set model parameters of image registration.

According to these three constraints, the algorithm of automatic straight line segments matching is designed as follows:

- (1) For every straight line segments i in source image, calculate distances iS_j from it's midpoint to the midpoints of all straight line segments j in reference image. Every straight line segments j is treated as a candidate matching iCM_j of i if ${}^iS_j < M$.
- (2) For every pairs of candidate matching of straight line segments, calculate included angles $\theta_j \in [0, \pi/2]$ between them. The included angle θ_p with the maximum probability is found. From point of calculation, this value is a space $[\theta_p - \delta, \theta_p + \delta]$. Any candidate matching iCM_j is abandoned if $\theta_j \notin [\theta_p - \delta, \theta_p + \delta]$.
- (3) Now, each straight line segments in source image may have just one corresponding straight line segment in reference image, may several features, or may no feature. To eliminate all wrong correspondences, we establish a simple registration model with those one-to-one correspondences, and give up all correspondences which don't fit this model.

The correspondences of straight line segments established by the algorithm above are incomplete. That is to say, the algorithm doesn't establish all correspondences of extracted straight line segments. But the established correspondences are reliable, which satisfies the requirement of image registration.

5. EXPERIMENTAL RESULT

Figure 6 shows results of straight line segments extraction, matching and image registration of aerial image sequences. The reference image and source image are sampled from airborne aerial video, with a sampling interval of 0.1 second. In both reference and source image 50 prominent straight line segments are extracted, respectively. The top left corners of images are shown in figure 6. Although the source image is preliminarily aligned to the reference image, there is offset in y direction. The source image is registered with a second-order polynomial model. In registered destination image, the offset is corrected.

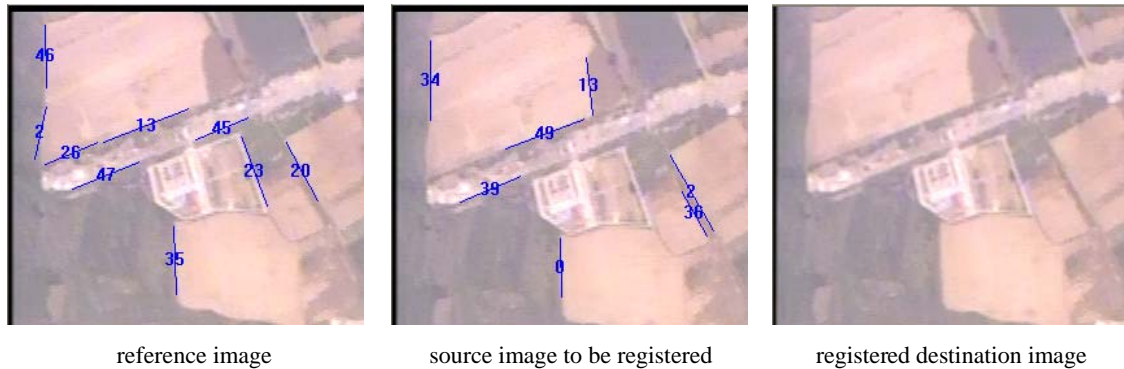


Figure 6. Results of straight line segments extraction, matching and image registration of aerial image sequences

The result of straight line segments matching, 5 visible pairs of correspondences of figure 6, is list in table 1. There are 31 pairs of correspondences of straight line segments between the source and reference image in fact. They are all right correspondences.

	number of straight line segment				
reference image	46	13	47	20	35
source image	34	49	39	2	0

Table 1. Result of straight line segments matching

6. CONCLUSION

Automatic registration process of image sequences is a fundamental step in many applications of airborne video processing and analysis. In this article an automatic image sequences registration process based on Line matching approach is proposed, which has the superiorities both in computer efficiency and algorithm robustness. The experimental result demonstrates that the process can be applied to automatic registration of airborne image sequences. In addition, it can be extended to the automatic registration of remote images which include prominent straight line segment features, such as aerial images, large-scale satellite images and medium or small-scale satellite images of urban area.

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