THE RESEARCH OF LINE MATCHING ALGORITHM UNDER THE IMPROVED HOMOGRAPH MATRIX CONSTRAINT CONDITION

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ABSTRACT:

Focusing on the mismatching problems in line matching, this paper integrates the radiation information and the geometry information of the imagery as the multi-constraint conditions, and presents an improved line matching algorithm based on the improved homograph matrix constraint condition. This algorithm firstly obtains the homologous points by feature matching, and for each line to be matched, it calculates the homograph matrix with the homologous points in the neighbourhood of this line. And then it projects the line to be matched line in target image to the search image by the homograph matrix, and determines the candidate lines according to the distance between the central points of lines and the distance between two lines; In these candidate lines, this algorithm further determines the possible homologous lines according to the similarity constraints of the line angles, the distance from the origin of image to the lines, and the overlap of lines; Finally, the epipolar constraint is adopted to find out the overlap segments between homologous lines，and the real homologous line will be determined by the gray similarity constraint. This paper adopts the unmanned aerial vehicle images and UCX digital aerial images to carry on the experiments, and verifies the validity of the algorithm in this paper.

1. INTRODUCTION

Linear features are the important features of imagery, and also the important outlines of objects for their 3D reconstruction. Different with the point features, the linear features have richer image information, and are less affected by noise. Line Matching is simply finding the corresponding images of the same 3D line across two or multiple images of a scene. It is often the first step in the reconstruction of scenes such as an urban scene (Mosaddegh, 2008).

Comparing with the point matching, the line matching has the following main advantages: ⑴more geometry constraints of linear features are used, and the matching results will be more reliable and in high accuracy; ⑵linear features are not sensitive to noise in the extraction, and less affected by the geometric distortion and gray deformation of image. Linear features will effectively improve the accuracy of matching; ⑶the number of line feature is far lower than the number of feature points, and the stereo matching based on linear features will greatly improve the efficiency of matching; ⑷the linear features are easier for extraction and description.

However, line matching is much more difficult to obtain a reliable matching result by single constraint. Mainly due to the following reasons: linear features commonly found in the edges of objects. In different view points, the linear features may appear occlusion, fracture, etc., and cause the image textures on both sides of lines would be different; for the same ground object, the direction of its lines projected into different images will also be different, so the candidate lines to be matched may appear the results of “one-to-null”, “one-to-one”, “one-to-multiple” and even “multiple-to-multiple”; simultaneously, because of the incompleteness of linear feature extraction and the inconsistency of homologous line endpoints, the direction, length and texture features of lines cannot directly be used as the primitives in line matching.

For now, the existing line matching algorithms can be divided into two categories: one is based on the structure information of linear features: mainly considering the geometry attributes of the line (length, degree of overlap, gradient, direction, location) in the matching process; The other is based on the dominant points of line: according to the dominant points, a line is divided into a number of discrete points, and the matching of feature line is achieved by matching these dominant points in it. Each algorithm has its own advantages and disadvantages at the same time. Due to the influence of various factors in the imaging process, as well as the complexity of line matching, it deserves to research a matching algorithm having high accuracy, excellent applicability, and good robustness.

Fu Dan (2008) proposes a linear matching method based on the polar constraint and the RANSAC algorithm, and effectively solves the matching problem of partly occluded lines in the image. Li Tao (2008) proposes a robust and fast line matching algorithm based on the supporting region of line, which enhances the ability of this algorithm to adapt to the noise. However, these algorithms lack effective geometric constraints, and bear not only the complexity of their own, but also the low success rate of line matching. In this case, this paper integrates the radiation information and the geometry information of the

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imagery as the multi-constraint conditions, and presents an improved line matching algorithm based on the improved homograph matrix constraint condition. This algorithm firstly obtains the homologous points by feature matching, and for each line to be matched, it calculates the homograph matrix with the homologous points in the neighbourhood of this line. And then it projects the line to be matched line in target image to the search image by the homograph matrix, and determines the candidate lines according to the distance between the central points of lines and the distance between two lines; In these candidate lines, this algorithm further determines the possible homologous lines according to the similarity constraints of the line angles, the distance from the origin of image to the lines, and the overlap of lines; Finally, the epipolar constraint is adopted to find out the overlap segments between homologous lines，and the real homologous line will be determined by the gray similarity constraint.

2. PRINCIPLES

2.1 The Flowchart of Line Matching Based on Multi-Constraint Conditions

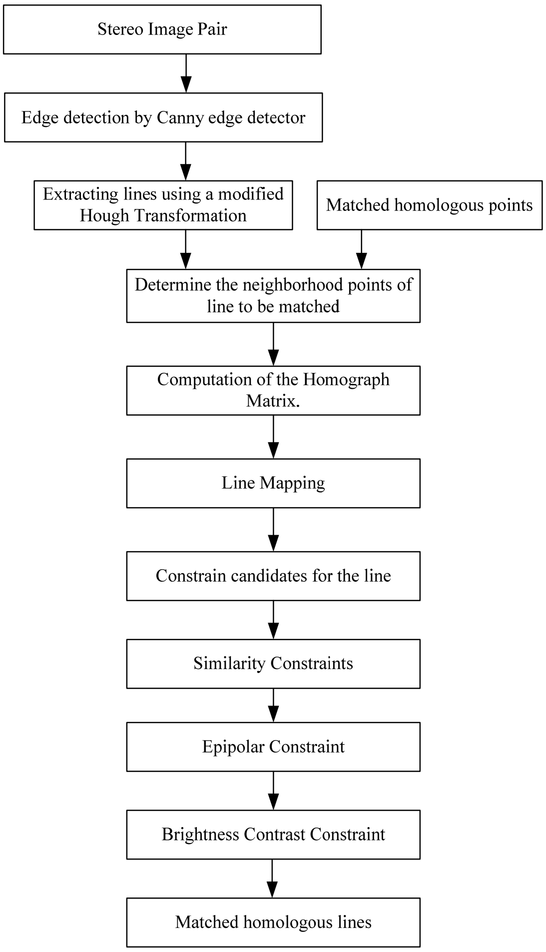


Figure 1. The flowchart of line matching based on multi-constraint conditions

2.2 Homograph Matrix

2.2.1 The Principle of Homograph Matrix

Homograph matrix is a mathematical concept, it defines the relationship between two images that any point in one image can be find the corresponding point in another image, and the corresponding point is unique, and vice versa (Wu Fuchao,2002). The homograph matrix can determine the correspondence relationship between images, and transfer the features from one image to the other. Through the location constraint of two line segments sets, the homograph matrix can realize the collection of matching lines.

Let $a=(x,y,1)^T$ as the homogeneous coordinates of the point on the left image, and $b=(x',y',1)^T$ as the homogeneous coordinates of the point on the right image. Then the transform from point a to point b by homograph matrix H will be described as $b=Ha$, where H is a matrix of 3×3 size, and defines the one by one relationship between the points of two image points. H is defined as following (Lou Anying,2010) :

$$\mathrm{H}=\begin{bmatrix} \mathrm{h}_{11},\mathrm{h}_{12},\mathrm{h}_{13} \\ \mathrm{h}_{21},\mathrm{h}_{22},\mathrm{h}_{23} \\ \mathrm{h}_{31},\mathrm{h}_{32},\mathrm{h}_{33} \end{bmatrix}=\begin{bmatrix} \mathrm{h}_1{}^{\mathrm{T}} \\ \mathrm{h}_2{}^{\mathrm{T}} \\ \mathrm{h}_3{}^{\mathrm{T}} \end{bmatrix} \tag{1}$$

Where $\mathrm{h}_i{}^{\mathrm{T}}(\mathrm{i}=1,2,3)$ is the vector $(\mathrm{h}_{i1},\mathrm{h}_{i2},\mathrm{h}_{i3})$. By the matrix H, the corresponding point of point a in the right image can be expressed as:

$$\begin{cases} x'=\dfrac{h_1{}^T a}{h_3{}^T a} \\ y'=\dfrac{h_2{}^T a}{h_3{}^T a} \end{cases} \tag{2}$$

In fact, the point a is corresponding with the point b in the right image, and $b=(x',y',1)^T$. Then the following equation can be drawn:

$$\begin{cases} h_1{}^T a-x'(h_3{}^T a)=0 \\ h_2{}^T a-y'(h_3{}^T a)=0 \end{cases} \tag{3}$$

All of the homologous points in the stereopair will obtain the above equations, and merges all the equations into a matrix expressing:

$$LH=0 \tag{4}$$

Where:

$$L=\begin{bmatrix} a_1{}^T,0,-x_1'a_1{}^T \\ 0,a_1{}^T,-y_1'a_1{}^T \\ \dots \\ a_n{}^T,0,-x_n'a_n{}^T \\ 0,a_n{}^T,-y_n'a_n{}^T \end{bmatrix} \qquad H=\begin{bmatrix} h_1 \\ h_2 \\ h_3 \end{bmatrix}$$

n is the group number of corresponding points. To ensure that the equations have a solution, there must be at least 5 groups corresponding points, and then using the least square algorithm to calculate the image transformation matrix having minimum error, i.e., the homograph matrix H.

2.2.2 Constraint of Candidate Lines Based on the Modified Homograph Matrix

In the field of computer vision, the homograph matrix only be applied to transfer the features between two images. This paper introduces the principle of homograph matrix in the line matching algorithm, and realizes the effective location constraint for the line segments sets of the left and right images. For aerial images, according to the complex surface relief especially in the urban areas, if only adopt one homograph matrix in the matching process, the offset of homologous lines will be very large after the projection of homograph matrix. In order to avoid this situation, this paper modifies the homograph matrix algorithm. For each line to be matched, it utilizes the homologous points in the neighbourhood of line to calculate the homograph matrix.

Firstly, it determines the existing homologous points in the neighbourhood of line to be matched, and calculates the homograph matrix with them. Then, it projects the line to be matched to the right image based on the homograph matrix, and determines the possible candidate lines in the right image according to the distance between the central points of lines and the distance from central point to other lines. The principle is shown as Figure 2:

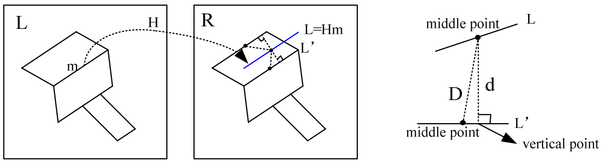


Figure 2. Constraint of candidate lines based on the modified homograph matrix

2.3 Gray Similarity Constraint

Taking the fitted two line sets A and B as the references, and comprehensively considering the following three kinds of similarity constraints:

(1) Similarity constraint of line angle

The slope k of the extracted line can be calculated by the coordinates of the two end points, and then the inclination θ of this line also can be solved.

$$\theta = \arctan k \tag{5}$$

$$An\_sim(m_a, m_b) = \cos(\theta_a - \theta_b) \tag{6}$$

Where θ_a is the inclination of target line m_a, and θ_b is the inclination of searching line m_b.

(2) Similarity constraint of distance from the origin of image to the line the polar equation of line is:

$$\rho = x \cdot \cos\theta + y \cdot \sin\theta, 0 \le \theta \le \pi \tag{7}$$

Where ρ is the distance from the origin of image to the line in the polar space, i.e., the vertical distance from the origin to the line.

$$Rho\_sim(m_a, m_b) = abs(\rho_a - \rho_b) \tag{8}$$

Where ρ_a is the distance from the origin of target image to the target line m_a, and ρ_b is the distance from the origin of target image to the searching line m_b.

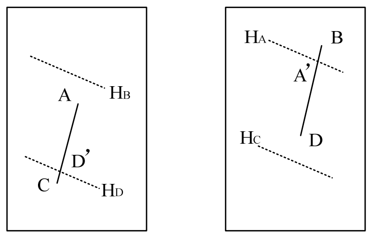
(3) Similarity constraint of overlap between lines

$$Lap\_sim(m_a, m_b) = \frac{overlap(m_a, m_b)}{\min(length(m_a), length(m_b))} \tag{9}$$

Where $overlap(m_a, m_b)$ expresses the overlap length of line m_a and line m_b, $length(m_a)$ is the length of line L_A, and $length(m_b)$ is the length of line m_b.

2.4 Epipolar Constraint

If a pair of matching lines satisfies all the above similarity constraints, then the epipolar constraint will be used to find out the corresponding overlap segments between the two lines (Wu Bo, 2012). For example, for a pair of matching lines AC and BD in Fig. 3(a) and (b), the epipolar lines of the end points of AC and BD can be derived as illustrated using dashed lines in Fig. 3. By intersecting these epipolar lines with the lines AC and BD, the overlap segments between these two lines can be obtained, which is AD' and A'D.

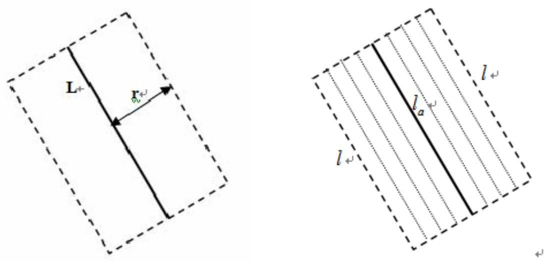


(a) Left image (b) Right image

Figure 3. Using epipolar constraint to find corresponding overlap segments for line matching

2.5 Brightness Contrast Constraint

After the epipolar constraint, it obtains the overlap segments of homologous lines. The brightness contrast in a local buffering region along both sides of the matching lines can be used to further disambiguate the line matching.



(left) the supporting region of linear feature

(right) the decomposition of supporting region

Figure 4. Linear feature supporting region and decomposition

Firstly, it needs to introduce the concept of linear feature supporting region. As shown in Figure 4 (a), L is a straight line segment which length is n in the discrete image surface. Then limits a rectangular area with the central axis is L and the width is $2r$, and this rectangular area will be defined as the linear feature supporting region of line L. As shown in Figure 4 (b), the supporting region can be decomposed into $2r+1$ parallel line segments with equal length. L and the left r line segments are defines as the left linear feature supporting region, also L and the right r line segments are defines as the right linear feature supporting region. The gray value of the point j in the line i will be marked as g_i^j. Arranges the gray values of $(r+1)\times n$ points in the left supporting region can be arranged as a matrix form, and then the gray value matrix of the left linear feature supporting region can be obtained. Simultaneously, the gray value matrix of the right linear feature supporting region also can be obtained. On both sides of the to-be-matched lines, the Normalized Cross Correlation (*NCC*) values will be calculated separately between the image gray values within the supporting region. The larger one is taken as the final *NCC* value for this line.Then the correlation coefficients of the linear feature supporting regions can be calculated.

$$Area\_sim = \max(NCC_L, NCC_R) \qquad (10)$$

Where NCC_L 、 NCC_R are the correlation coefficients of the left and right supporting regions for corresponding lines.

3. EXPERIMENTAL ANALYSIS

This paper adopts the unmanned aerial vehicle images and UCX digital aerial images to carry on the experiments of line matching.

3.1 Experiment 1

The experiment data are two images cut from the stereopair imaged by unmanned aerial vehicle, and the image sizes both are 512×512 pixels. Fig. 5(a) is the target image, and Fig. 5(b) is the searching image.

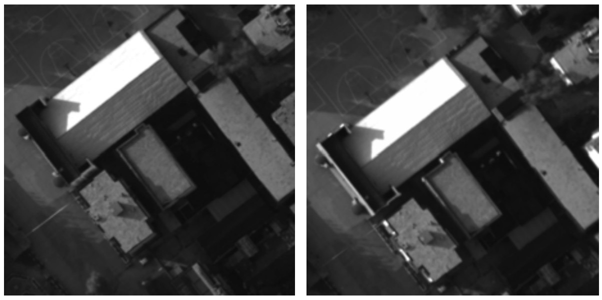
⑴ Computation of the homograph matrix.

In this step, it firstly realizes the image matching based on feature points, and the succeed matched corners in the stereopair images are shown as Fig. 5(c). Then substitutes the matched points to the equation group $LH=0$, obtains the coefficient matrix L, and computes the matrix $L^T L$. Finally it solves the homograph matrix H through the Singular Value Decomposition about matrix $L^T L$ (Wang Jinquan, 2008).

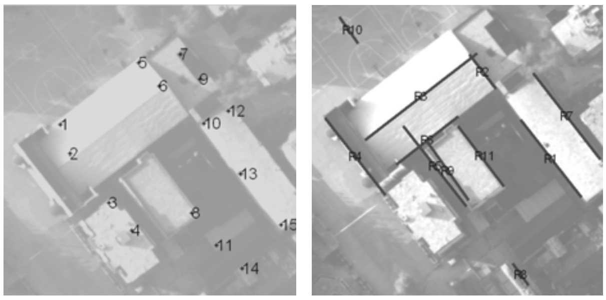
$$H = \begin{bmatrix} 1.0181 & 0.04434 & -3.6743 \\ 0.006193 & 1.064 & 42.29 \\ 7.3797e-006 & 0.000117 & 1 \end{bmatrix} \qquad (11)$$

⑵ Line extraction and matching

This paper adopts the Canny edge detection operator to carry on the edge detection of image, and gets the binarization edge image. Then it extracts the lines from the binarization edge image using the improved Hough Transform. By setting the threshold, it avoid the over connection problem for long-distance points, and filters out some short straight lines. The line extraction results are shown as Fig. 5(d) and Fig. 5(e). Using the computed homograph matrix H, it projects the line set in Fig. 5(d) to the image coordinate system defined by the searching image, and the overlap results of two line sets are shown as Fig. 5(f). This paper determines the candidate lines according to the distances between the lines to be matched, and fixes the homologous lines using other constraint conditions, then obtains the matching results are shown as Fig. 5(p) and Fig. 5(q). Through the visual interpretation, the "one-to-multiple" phenomenon can be found in the matching results, which is due to the broken lines in the extraction, and belongs to the correct matching results. From this experiment it can be found that the homograph matrix carries on the effective constraint to the line matching, reduces the complexity of matching algorithm, and improves the accuracy rate of matching.

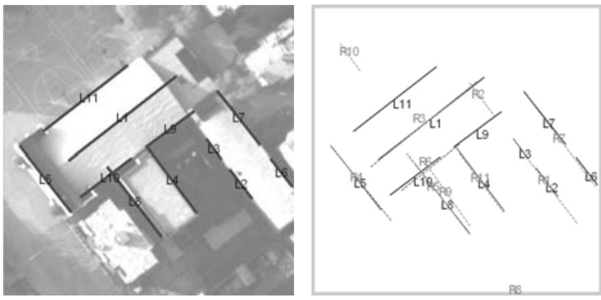


(a) The target image (b) The searching image



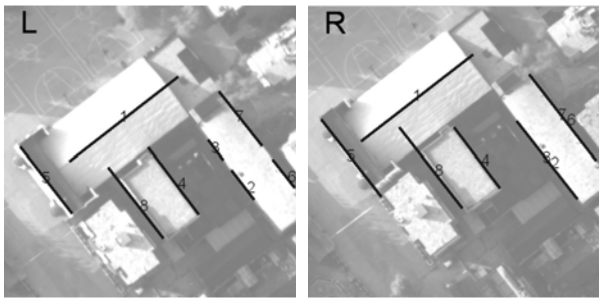
(c) (left) The positions of points matched in the two images

(d) (right) The results of extracting lines in the target image



(e) (left) The results of extracting lines in the searching image

(f) (right) The fitting of the two sets of straight line segments



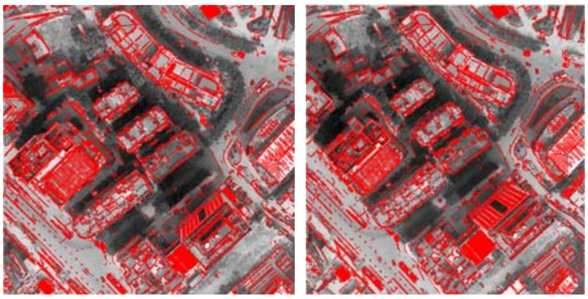
(p) (left) The straight lines matched in the target image

(q) (right) The straight lines matched in the searching image

Figure 5. The original images and the results of post-processing

3.2 Experiment 2

In order to further verify the validity of the algorithm proposed in this paper, this paper makes another experiment with the UltraCamX (UCX) digital aerial images. Firstly, its carries on the line extraction using the same method in the Experiment 1, and the results is shown as Fig.6.



(left) Target image (right) Searching image

Figure 6. The line extraction results by improved Hough Transform

Then, the homologous points are obtained by plane-sweeping matching algorithm in this paper (Collins, 1995), and the homologous points result are shown as Fig. 7. Different with the Experiment 1, because of the great elevation differences in the image coverage area, for each line, the homograph matrix is computed respectively by the homologous points with in the neighborhood of each line in the matching process. The final matched lines are shown as Fig.8. From the matching results it can be drawn that the accuracy rate of line matching is higher, but the matching results are relatively sparse. This is because there are only few homologous points in the neighborhood of lines to be matched, and the computing accuracy of the homograph matrix is low. These factors cause to a large distortion while projecting to the right image, and hardly find out the homologous lines.

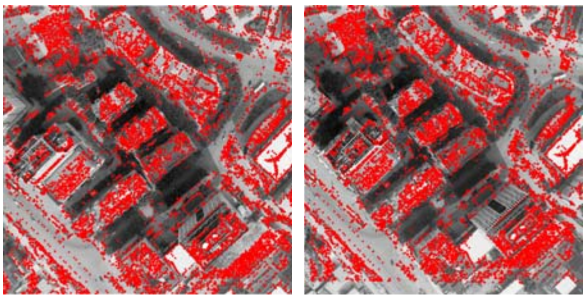
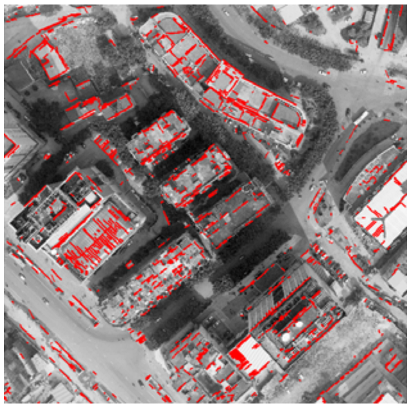
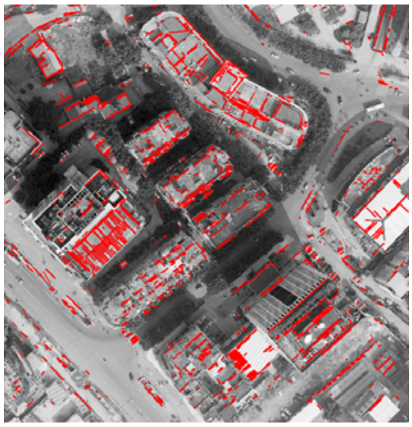


Figure 7. Corresponding points are obtained by plane-sweeping matching method



(a) Target image



(b) Searching image

Figure 8. The line matching results under the multi-constraint conditions

4. CONCLUSIONS

The line matching is the hot issue and difficult problem in the 3D reconstruction. This paper analyzes the technical difficulties of this research, and presents the line matching algorithm under the improved homograph matrix constraint condition focusing on the limitations of existing methods. Especially for buildings covered areas in the cities, this paper adopts the improved homograph matrix to constraint the line matching. For each line to be matched, it computes the homograph matrix respectively by the homologous points in the line supporting region, and effectively avoids the large distortion caused by using the single homograph matrix for the image having great elevation differences in the image coverage area. This paper simultaneously integrates the multiple similarity functions to constrain the line matching, and improves the efficiency and accuracy of line matching. The deficiency of this paper is the line matching result depending on the uniform distribution and intensity of the homologous points, and the matching results are relatively sparse. It needs to carry on the intensive matching by adopting comprehensive homograph matrix or other constraint conditions.

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