

AN ALGORITHM OF STRAIGHT LINE FEATURES MATCHING ON AERIAL IMAGERY

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ABSTRACT:

The paper presents a method of straight line feature matching on aerial imagery. In this method, many features such as geometrical features, physical features, as well as geometrical structure information between straight lines have been simultaneously used. A hierarchical matching strategy has been adopted, which implements complete matching after main-line matching, strict matching based on feature measure of supporting region after rough matching based on comparing angle relations, and takes the upper matching result as restrictions of lower matching, thus to reduce the incorrect matching rate and improve the matching efficiency.

1. INTRODUCE

Image matching is a crucial process in digital photogrammetry and computer vision, which has a broad application in the fields of stereo compilation, imagery based map revision, imagery registration, model based object detection, motive object tracking and so on.

After years of research, image matching techniques have made much progress, and many image matching methods are presented. The existing matching techniques include gray level-based matching and feature-based matching.

The basic idea of gray level-based matching is to take an image as two-dimension signals, then search the correlation matching between signals using statistical methods. This method is simple and practical. At the same time, for that it directly matches image pixels, the matching result would not be affected by precision of feature detection and density, thus high orientation precision can be obtained. However, this method has complex computing, and is very sensitive to surface structure of object, characters (brightness or color) of pixels and imaging geometry. Therefore, whenever the imagery lacks enough texture information, or has a big imaging distortion, gray level-based matching can not be implemented.

Feature-based matching method firstly extracts the feature elements which can reflect the characteristics of object in the imagery, then determines the corresponding relation of the feature elements, and implements image matching according to the spatial relationship of corresponding feature elements. This method does not directly depend on gray level of pixels, and the feature used in matching is stable and is interference-free to noise, is adaptable to imagery. Also, this method has simple computing and high matching speed. In addition, more feature

information can be provided compared with gray-level, and the ambiguity problem in image matching can be resolved effectively. Therefore, feature-based matching has become the focus in image matching.

According to kinds of features, feature-based matching method have three kinds: point feature-based matching (Barnard S, et al, 1980; Baker H H, et al, 1981; Aronld R D, 1983; Kim Y C, e tal, 1985; Lloyd S A, et al, 1987), linear feature-based matching (Medioni G, et al, 1985; Ohta Y, et al, 1985; Nasrabadi N M, 1992; A. Luo, W. Tao, H. Burkhardt, 1996; Ho, W. P., Yip, R. K. K., 1996) and region feature-based matching (Lee H J, et al, 1990). The linear features can provide more information than point features, which are less likely to be affected by noise, and more convenient to be extracted and described compared with the region feature. Therefore, linear features are more suitable for feature-based image matching. The key problems of linear feature based matching are the extraction of linear features and the searching and matching of corresponding line pairs. A large amount of researches have been taken on linear feature extraction, however, the existing matching methods based on straight lines have the following drawbacks: (1) searching with a large number of straight line feature pairs in the overlapping imagery is usually very slow; (2) feature matching may fail due to errors in feature extraction. To solve the aforementioned problems, some matching strategies have been presented. In (Medioni G, et al, 1985; Ohta Y, et al, 1985), dynamic programming technique has been used to optimize matching process by choosing the best searching path; in (Medioni G, et al, 1985; Nasrabadi N M, 1992), right matching rate has been improved by firstly obtaining initial matching result by simple similarity rules, and then enhancing the initial matching result using relaxation iterative technique with the restriction of geometry and parallax; Fuzzy techniques and hierarchical strategy are adopted in (A. Luo, W. Tao, H. Burkhardt, 1996) to

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reduce ambiguity in matching and increase right rate. In (Xi Xueqiang, Wang Runsheng, 2000), a matching method using straight lines hierarchically and using various features by steps has been presented in the research of matching imagery and model. This method reduces the possibility of incorrect matching, improves the matching efficiency, and can implement correct matching when the imagery has been zoomed, translated and rotated.

On the basis of the method in (Xi Xueqiang, Wang Runsheng, 2000), this paper presents a hierarchical matching strategy which implements complete matching after main-line matching, strict matching after rough matching, with simultaneously utilizing gray level, length, direction and other features, as well as the geometric structure information between straight lines. Compared with (Xi Xueqiang, Wang Runsheng, 2000), a weighed matching measure model of straight lines which simultaneously using various linear feature has been constructed, and the values of weights of different features have been discussed, thus the number of steps of matching process has been reduced and the matching efficiency has been improved; moreover, the matching strategy enhances the robustness of matching, and reduces the possibility of incorrect matching.

2. EXTRACTING STRAIGHT LINE SEGMENT

In the paper, straight lines segment are automatically extracted with Canny-operator (John Canny, 1986) and a improved Hough transformation that presented by Costa (L F Costa, B Ben-Tzvi, M sandler, 1990).

The method firstly uses Canny-operator to detect edge points in the imagery, and then obtains parameters (ρ, θ) of straight lines by Hough-transformation. After that, all feature points whose distance with the straight line satisfies $\Delta\rho < T$ are projected to x-axis and y-axis. Finally, the endpoints and length of straight lines segment are obtained by detecting the continuity of these projected points.

After the straight lines are extracted, supporting regions with certain width are selected. A supporting region is composed of pixels which are the same in gray, orientation of gradient. The supporting region has the same length with the straight line, and is five pixels in width. The region is formed by that takes points on the straight line as centers, and stretches two pixels toward up and down, or left and right. The features of each straight line are calculated based on the supporting region, which include length, direction, position, intensity, sharp degree, brightness, darkness, contrast and so on. Intensity refers to the average gray level of a supporting region. Sharp degree refers to the average gradient amplitude of a supporting region. Brightness refers to the average gray level of the brightest 10% pixels in a supporting region. Darkness refers to the average gray level of the darkest 10% pixels in a supporting region. Contrast refers to the ratio of the difference between brightness and darkness and the maximum dynamic range of difference.

3. MATCHING ALGORITHM

3.1 Determination of straight line set

An imagery pair includes left imagery and right imagery. Here right imagery is taken as reference imagery, and left imagery as matched imagery.

When straight line features of matched imagery has been extracted, the straight lines are recorded as set R, the n_1 longest unparallel straight lines in set R form a subset P, which is named main-line set. Other straight lines in set R form a subset Q, which is named non main-line set.

Straight line set M, main-line set S (the number of main-lines is n_2) and non main-line set U of the reference imagery can be determined by the same method. Set M and R are expressed in arrays, and the array elements are arranged from left to right and from top to bottom. The measures such as the coordinates of end points and midpoints, direction, length, intensity, sharp degree, brightness, darkness, contrast and so on, as well as types of straight lines are recorded. In the subset S and P, main-lines are signed with 1, and the else are signed with 0.

3.2 Main-line Matching

3.2.1 Rough matching—comparing relation of angles

Set the direction of s_i and s_j in the subset S of the reference imagery as u_i and u_j ($0 \leq u_i, u_j \leq \pi$), and the angle between them is $\alpha_{i,j}$,

$$\alpha_{i,j} = \begin{cases} |u_i - u_j|, & |u_i - u_j| \leq \frac{\pi}{2} \\ \pi - |u_i - u_j|, & \text{else} \end{cases} \quad (1 \leq i < j \leq n_2, i \neq j) \quad (1)$$

Set the direction of p_h and p_k in the subset P of the matched imagery as v_h and v_k ($0 \leq v_h, v_k \leq \pi$), and the angle between them is $\beta_{h,k}$,

$$\beta_{h,k} = \begin{cases} |v_h - v_k|, & |v_h - v_k| \leq \frac{\pi}{2} \\ \pi - |v_h - v_k|, & \text{else} \end{cases} \quad (1 \leq h, k \leq n_1, h \neq k) \quad (2)$$

For any straight line pair (s_i, s_j) in set S, searching all straight line pairs (p_h, p_k) in set P, which are subject to $|\alpha_{i,j} - \beta_{h,k}| < A$ (A is a chosen threshold value of angle). Assuming there is corresponding conditions in Figure 1.

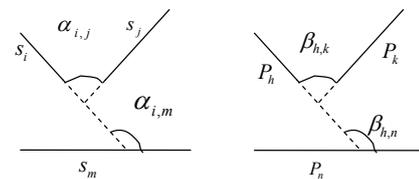


Figure 1. Sketch of angle relation

For every corresponding situation, if $s_i \rightarrow p_h, s_j \rightarrow p_k$, a corresponding straight line pair s_m and p_n with a certain direction is appointed. The angle $\alpha_{i,m}$ of s_i and s_m , and the angle $\beta_{h,n}$ of p_h and p_n should subject to condition $|\alpha_{i,m} - \beta_{h,n}| < A$, otherwise, this possible matching is to be excluded. Whether s_i and p_k, s_j and p_h are correspond to each other will be judged by the same way, if it is true, they are added into set $AMR(s_a, p_b)$, thus the matching result of angle relation comparison is obtained.

In the result of comparing angle relations, the corresponding

situation of every straight line is not unique and has many possibilities. Therefore, when the rough matching finished, feature matching should be implemented using the result of rough matching.

3.2.2 Feature matching

1. Calculation method for similarity measure of supporting region

The feature measures of supporting region are showed following: length L , direction A , intensity I , sharp degree S , brightness LE , Darkness DE , contrast C .

The similarity measure SI of two straight lines is the weighted sum of every feature measure mentioned above:

$$SI = \sum_{i=1}^8 w_i V_i / \sum_{i=1}^8 w_i \quad (3)$$

In the formula, $V_1 \sim V_6$ represent for the similarity measure of the feature L, I, S, LE, DE, C , V_7 and V_8 represent for the similarity measure of direction A and the distance between the midpoint of both straight lines. The formula is showed following:

$$V_i = \frac{\min(p_{is_i}, p_{ip_h})}{\max(p_{is_i}, p_{ip_h})} \quad i = 1, \dots, 6 \quad (4)$$

In the equation, suffix s_i and p_h represent for the straight lines feature, $p_1=L, p_2=I, p_3=S, p_4=LE, p_5=DE, p_6=C$.

$$V_7 = \frac{MAD - |A_{s_i} - A_{p_h}|}{MAD} \quad (5)$$

$$V_8 = \frac{\text{MaxDistance} - \text{Distance}(M_{s_i}, M_{p_h})}{\text{MaxDistance}} \quad (6)$$

In the formula: MAD——Maximum difference in direction

M_{s_i}, M_{p_h} ——Midpoint of straight lines s_i and p_h

$\text{Distance}(M_{s_i}, M_{p_h})$ ——the distance between the midpoints of straight lines s_i and p_h

MaxDistance ——the maximum distance of two similar straight lines.

In the formula (3), weight w_i represents for the importance of each similarity measure, and is set by specific applications. Generally, the longer the straight line, the greater the reliability of right matching, so the weights of length measure can be dynamically adjusted, but not be given a fixed value. Usually, a threshold value T is taken, if length $L > T$, then weight $w=L/T$, else $w=1$. In formula (5), even the maximum difference of direction should be determined by specific application. For instance, it can be smaller in stereo vision, while a little bigger in motion estimation.

2. The matching strategy for feature of supporting region

Based on the corresponding straight line set $AMR(s_a, p_b)$ of the main-lines in reference imagery which are obtained in the angle relation comparison, the following processes are implemented.

1) The similarity measure SI of every straight line in reference image and all the straight lines in their corresponding set $AMR(s_a, p_b)$ is calculated, two matching straight lines which similarity measure are maximal are found due to the given threshold value, then they are saved to corresponding matching set $SP(s_i, AMR(s_a, p_b))$.

2) Then the similarity measure SI of all the straight lines in reference image and all the straight lines in matched image which appear in $AMR(s_a, p_b)$ is calculated, two matching straight lines which similarity measure are maximal are found by the same way due to the given threshold value, then they are saved to corresponding matching set $PS(AMR(s_a, p_b), s_i)$.

For every straight line s_i in the reference image, corresponding straight line p_h in the matched image is found, and the unique matching straight line is finally determined by the following three judgments:

1) When the number of corresponding straight lines is 0, the line s_i has no matching straight line in matched image, and it should be deleted;

2) When the number of corresponding straight lines is 1, judging whether the matching straight line set $PS(AMR(s_a, p_b), s_i)$ includes the straight line s_i , if not, s_i is deleted, if yes, then s_i is matched with the corresponding straight line, and the straight line is save into the final matching result set $MR(s_i, p_h)$.

3) When the number of corresponding straight lines is 2, firstly judging whether the matching straight line set $PS(AMR(s_a, p_b), s_i)$ of the corresponding straight line with bigger similarity measure includes the straight line s_i , if yes, s_i is matched with this straight line, otherwise, judging whether the matching straight line set $PS(AMR(s_a, p_b), s_i)$ of the corresponding straight line with smaller similarity measure includes this straight line s_i , if yes, s_i is matched with this straight line, and the straight line is save into the final matching result set $MR(s_i, p_h)$, else, s_i is deleted.

3.3 Complete matching

The complete matching is based on the main-line matching. For all other straight lines in the reference imagery, corresponding straight lines in the matched imagery are to be found.

When the main-line matching has been implemented, for each non main-line u in the reference imagery, a nearest main-line s can be found in the corresponding main-line set S . A searching range is then determined with the straight line p corresponding with s in the main-line set P of matched imagery, and the straight lines q in the matched image corresponding with u can be found through comparing angle relation and similarity measure of supporting region, thus complete matching of all straight lines in overlapping imagery is completed.

Angle relation comparison here is difference with that in main-line matching. Here, only the angle between non main-line u and main-line s in the reference imagery should be compared with the angles between all non main-lines q and main-line p in the searching range of the matched imagery. In addition, the distance between midpoints of two straight lines is taken as the distance between two straight lines, and the searching range is determined by properly amplifying the shortest distance

between two straight lines.

4. EXPERIMENTAL RESULT

Figure 2 shows the aerial imagery pairs used in the paper, figure 3 shows the result of straight line extraction, figure 3(a) shows the straight line extraction result of matched imagery, figure 3(b) shows the straight line extraction result of reference imagery. Those darker straight lines are main-lines, less dark ones are non main-lines. In order to verify the algorithm's ability of distinguishing parallel, approximate parallel or other straight lines which interferences matching, a majority of straight lines in right imagery are selected as main-lines.

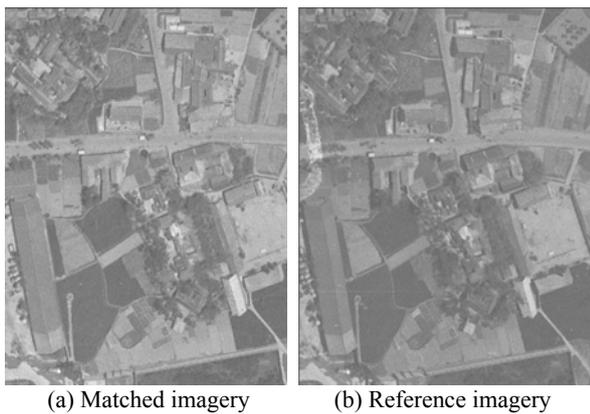


Figure 2. Experimental imagery 1

Feature measures		Weight
Intensity	wI	1
Sharp degree	wS	1
Brightness	wLE	2
darkness	wDE	2
Contrast	wC	1
Direction	wA	3
Midpoint	wM	5

Table 1. The weight of feature measures

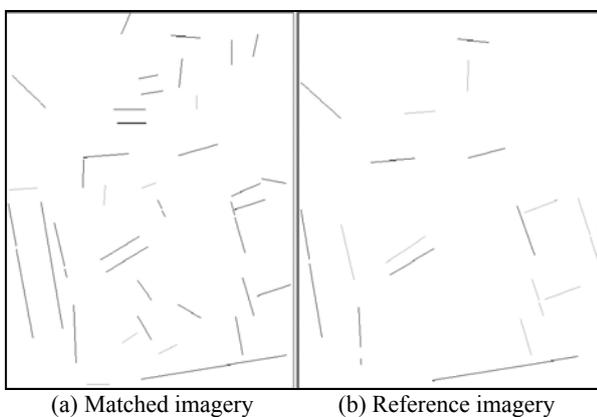


Figure 3. The result of straight line extraction

Figure 4 shows the matching result, figure 4(a) shows the straight lines of matched imagery, figure 4(b) shows the straight

lines of reference imagery. Straight lines with same tab in (a) and (b) are correspond.

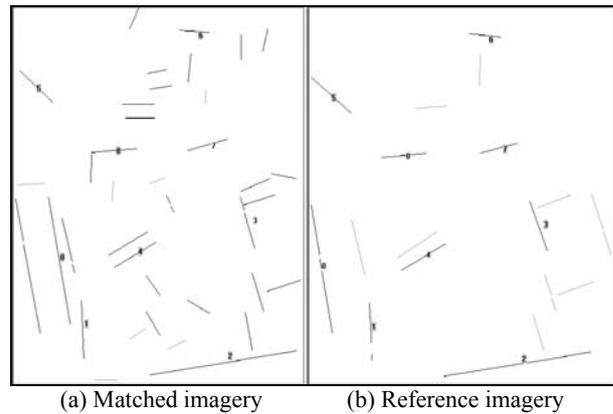


Figure 4. The result of straight line matching

The measures of supporting region include length L , direction A , intensity I , sharp degree S , brightness LE , darkness DE , contrast C .

Table 1 shows the weights of the feature measures used in matching aforementioned. For weight of length, firstly set the threshold value $T=50$, when $L>T$, $w=L/T$, else $w=1$. The maximum difference of direction $MAD=6^\circ$, the maximum midpoints distance $MaxDistance=20$.

The imagery pairs showed in figure 2 is aerial imagery with scale 1:10000. It can be seen from the figure that the overlapping imagery is relatively dark, especially the reference image, and the edges of objects is not obvious enough. Moreover, the scale is rather small, and the features of objects are not clear, which bring difficulties to extracting straight lines. For these two situations, the following two experiments are taken. The first experiment is for the imagery pair showed in figure 5 which has the same scale, but the edges is rather obvious, the experimental imagery and matching results are showed in figure 5 and figure 6. the second experiment is for the imagery pair which have relatively large scale (1:8000), illumination is strong, while the boundaries of buildings are obscure. The experimental imagery and matching results are showed in figure 7 and figure 8.

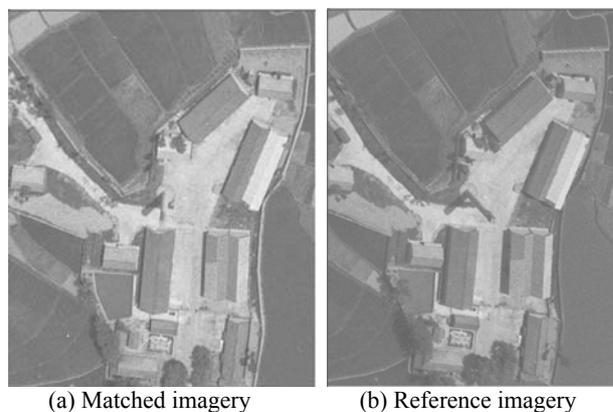


Figure 5. Experimental imagery 2

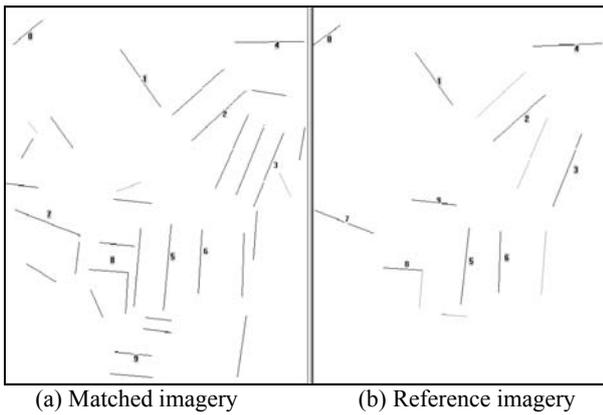


Figure 6. The result of straight lines matching

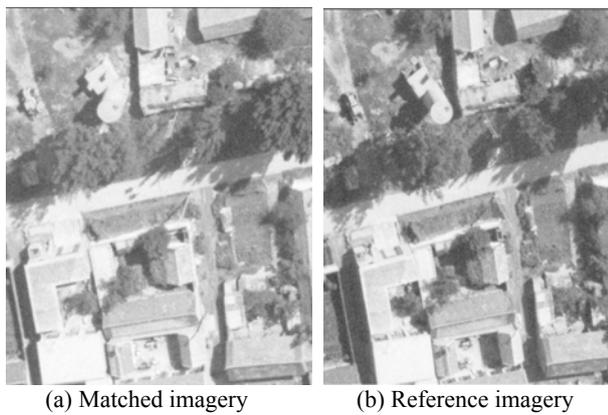


Figure 7. Experimental imagery 3

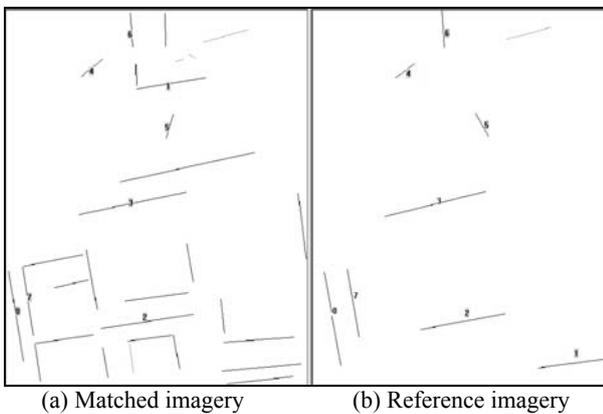


Figure 8. The result of straight lines matching

The experiments above can prove that, in the condition of straight line extracted correctly, the matching results are relatively good under all three conditions, and have not been affected a lot.

In first imagery pair, the number of straight lines used in matching is 9 for reference imagery and 31 for matched imagery. The number of matched straight lines is 9, thereinto, it is 8 for correct matching and 1 for incorrect matching. The correct rate is 88.9%.

In second imagery pair, the number of straight lines used in

matching is 10 for reference imagery and 31 for matched imagery. The number of matched straight lines is 10, thereinto, it is 9 for correct matching and 1 for incorrect matching. The correct rate is 90%.

In third imagery pair, the number of straight lines used in matching is 9 for reference imagery and 31 matched imagery. The number of matched straight lines is 9, thereinto, it is 8 for correct matching and 1 for incorrect matching. The correct rate is 88.9%.

It can be seen from the matching result that, the main cause of incorrect matching is that, the incorrect matching straight lines is approximately parallel to the reference straight lines, and the gray supporting regions of straight lines are similar. If the weight and threshold are not selected properly, incorrect matching occurs.

5. CONCLUSION

This paper researches on a matching method based on the straight line feature of aerial imagery. The method adopts a hierarchical straight line matching strategy, which uses the matching result of first step as restriction to reduce the searching range, thus to finish complete matching of the whole imagery. In every step of matching, a two-step matching strategy is adopted, which takes full advantage of the relation between straight lines and the physical features of straight lines, making the matching more accurate.

It can be seen from the matching result that, this method is accurate and efficient, and has a high speed. However, it has not overcome the incorrect matching caused by parallel straight lines. Therefore, much more restrictions should be put in to matching in the future research. Matching method based on any style line is also a focus in the future research.

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