AN INTEGRATED FEATURE BASED METHOD FOR SUB-PIXEL IMAGE MATCHING

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ABSTRACT:

Feature matching is to find the pair-wise corresponding features in the reference and sensed images. The features can be an edge, a corner, an end point, a line or a curve, etc. Image matching as the fore-step of image fusion and registration, image mosaic, automatic change detection, etc., the matching accuracy highly impacts these applications. Normally these applications require the matching accuracy to be sub-pixel. However, the matching unit of the feature-based methods is "one pixel". In this paper, after analyzing the image matching algorithm, an integrated method is proposed to detect the point features by the means of the combined advantages of Harris operator and Förstner operator. With this method, the matching accuracy can reach sub-pixel. The thought of matching principle based on bridge mode method on initiate matching points is introduced, when matching feature points by the method of template matching and conformal transform, to eliminate the low precision effect on the following matching points. The effect is caused by the cumulated error due to the low precision of initiate matching points. The proposed method has been tested by three pairs of overlap SPOT images. These images were captured in the flat area, mountainous area, and in different time. The results show that the matching accuracy can reach sub-pixel, and the position is accurate with the method described in this paper. The method is also robust, effective, and suitable for realization of automatic image matching.

1. INTRODUCTION

Image matching is finding correspondences between tow elements of images. It is widely used in remote sensing, medical imaging, computer vision etc. The applications in remote sensing include image fusion and registration, image mosaic, automatic change detection, environment monitoring, weather forecast, super resolution image creation, etc.

The common image matching methods can be divided into intensity-based methods and feature-based methods (Ni, and Liu, 2004). The widely used methods are feature-based methods. Feature-based matching methods are typically applied when the local structural information is more significant than the information carried by the image intensities. They allow registering images of completely different nature and can handle complex between image distortions (Zitová and Flusser, 2003).

The feature-based methods are to detect two sets of features in the reference and sensed images. The features can be an edge, a corner, an end point, a line or a curve, etc. Feature matching is to find the pair-wise corresponding features. Image matching as the fore-step of image fusion and registration, image mosaic, automatic change detection, etc., the matching accuracy will impact these applications. Normally these applications require the matching accuracy to sub-pixel. The matching unit of the feature-based methods is "one pixel". The pair-wise corresponding features can be used as an input for sub-pixel matching with other methods.

In this research, after analyzing several kinds of feature interest operators, an integrated feature based method is proposed for sub-pixel image matching. Firstly, Harris operator is used for detecting feature points. Each point is corresponding to one pixel. So the matching accuracy can only reach one pixel. Then the detected points by Harris operator is regarded as the window center of Förstner operator. The surface fitting algorithm is used to calculate the more accurate position of the feature. With this method, the matching accuracy can reach sub-pixel. During feature matching by the method of template matching and conformal transform, the thought of matching principle based on bridge mode method on initiate matching points was introduced, to eliminate the low precision effect on the following matching points. The effect is caused by the cumulated error due to the low precision of initiate matching points.

2. FEATURE-BASED MATCHING METHODS

2.1 Feature Extraction

The feature extraction methods are to detect two sets of features in the reference and sensed images. The features can be points, lines or regions. In this research the feature detection methods are mainly deal with the point features. The point feature's group consists of methods working with line intersections, road crossing, centers of regions, end points, corners, etc. Much effort has been spent in developing precise, robust, and fast method for corner detection. Point feature detection operator is also called interest operator. The reputable operators are Harris, Förstner, Moravec, etc. The integration of Harris and Förstner operators are used for the detection of point features in this paper.

2.1.1 Harris operator (Harris and Stephens., 1988)

It computes a matrix related to the autocorrelation function of the image. The squared first derivatives of the image signal are averaged over a window and the eigenvalues of the resulting matrix are the principal curvatures of the auto-correlation function. An interest point is detected if the found two curvatures are high. The main advantages of Harris operator are (Remondino, 2006, Xie, etc., 2003, Zhang, etc., 2006, Shu, etc., 2004): 1) the operator is simple and suitable for automatically feature detection. 2) The detected points are well proportioned and valid. 3) The quantity of detected points could be determinate by the users according to their requirements. 4) The detected points are invariant to scale and rotation, and the operator is stable. The disadvantage is the detection accuracy can only reach one pixel.

2.1.2 Förstner operator (Förstner and Gulch, 1986)

It uses the auto-correlation function to classify the pixels into categories (interest points, edges or region). The detection and localization stages are separated, into the selection of windows, in which features are known to reside, and feature location within selected windows. Further statistics performed locally allow estimating automatically the thresholds for classification. Förstner operator is well used for photogrammetric applications (Zhang and Zhang, 2002, Zhang, etc., 2001, Remondino, 2006). This algorithm can be operated with weight in the optimal window center. The accuracy is much higher. The disadvantages of this algorithm are that it requires a complicate implementation, and is sensitive to the lightness and contrast of images.

2.1.3 Methodology

Firstly, feature points are detected by the Harris operator. Each point is corresponding to one pixel in the image. Then the detected points by Harris operator is regard as the window center of Förstner operator. The surface fitting algorithm is used to calculate the more accurate position of the feature. With this method, the matching accuracy can reach sub-pixel. The detailed implementation steps are as follows.

If the intensity of the image is $\mathrm{I(x,y)}$ at the point (x, y), the matrix of auto-correlation is，

$$\mathrm{M} = G(\sigma) \otimes \begin{bmatrix} I_x & I_x I_y \\ I_x I_y & I_y \end{bmatrix} \tag{1}$$

Where $G(\sigma)$ is the Gaussian filter for image smoothing, I_x and I_y are gradients in x and y direction.

Then the corner response function in position (x, y) can be written as:

$$f(x, y) = \frac{Det(\mathrm{M})}{Tr(\mathrm{M})} = \frac{\lambda_1 \lambda_2}{\lambda_1 + \lambda_2} \tag{2}$$

Where λ_1 , λ_2 are the eigenvalues of M, $Tr(\mathrm{M}) = \mathrm{M}_{xx} + \mathrm{M}_{yy} = \lambda_1 + \lambda_2$ is the trace of M, $Det(\mathrm{M}) = \mathrm{M}_{xx}\mathrm{M}_{yy} - (\mathrm{M}_{xy})^2 = \lambda_1 \lambda_2$ is the determinate of M. The interest feature point is detected where the response function has the maximum value.

For high accuracy matching, the interest points need to be oriented in sub-pixel. The 2ed order polynomial surface fitting method can be used for sub-pixel orientation (Zhang, etc., 2001, Xie, etc., 2003, Wu, etc., 2004). The idea of surface fitting is to be centered by the optimal point of pixel precision and do surface fitting according to similitude measure, then to find out the accurate matching site by solving minimum (maximum) point. The function is as:

$$z(x, y) = ax^2 + by^2 + cxy + dx + ey + f \ ,$$

where $z(x, y)$ is the corner response value at position (x, y), a, b, c, d, e, f are the unknown coefficients. Figure 1 and figure 2 illustrate the corner response window and their respect position. Here point (x, y) is the feature point, f_4 is its corner response value. The overdetermined equations (equation 3) can be formed with the 9 points in a 3x3 window. The coefficients can be derived from the equation. Then the surface fitting function is known. The maximum value is the precise position of the corner feature point.

f_0	f_1	f_2
f_3	f_4	f_5
f_6	f_7	f_8

Figure 1: 3 x 3 window

$(y_0, x_0) = (-1, -1)$	$(y_1, x_1) = (-1, 0)$	$(y_2, x_2) = (-1, 1)$
$(y_3, x_3) = (0, -1)$	$(y_4, x_4) = (0, 0)$	$(y_5, x_5) = (0, 1)$
$(y_6, x_6) = (1, -1)$	$(y_7, x_7) = (1, 0)$	$(y_8, x_8) = (1, 1)$

Fig.2: respect position of points in 3 x 3 window

The overdetermined equation is written as: $Ax = B$, where

$$A = \begin{bmatrix} x_0^{\ 2} & y_0^{\ 2} & x_0 y_0 & x_0 & y_0 & 1 \\ x_1^2 & y_1^2 & x_1 y_1 & x_1 & y_1 & 1 \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_8^2 & y_8^2 & x_8 y_8 & x_8 & y_8 & 1 \end{bmatrix}, \quad x = \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \end{bmatrix},$$

$$B = \begin{bmatrix} f_0 \\ f_1 \\ \vdots \\ f_8 \end{bmatrix} \tag{3}$$

Solving the equation with pseudo-inverse matrix method, then

$$x = \left(A^T A\right)^{-1} A^T B \tag{4}$$

Calculating the gradients in x and y directions of the quadric surface and form the equations,

$$\begin{aligned} \frac{\delta z}{\delta x} &= 2ax + cy + d = 0 \\ \frac{\delta z}{\delta y} &= 2by + cx + e = 0 \end{aligned} \tag{5}$$

There is an extreme point at (x_σ, y_σ), where $x_\sigma = \dfrac{2db - ce}{c^2 - 4ab}$, $y_\sigma = \dfrac{2ae - dc}{c^2 - 4ab}$. If the value at this point is maximal in the window, then the precise position of the feature point is at $(x + x_\sigma, y + y_\sigma)$.

2.2 Image Matching

The matching method is based on normalized cross-correlation and conformal transformation techniques. The normalized cross-correlation is used to compare the similitude of the matching points in the template searching window. The conformal transformation technique is used as an assistant when the correlation coefficient is not very high (Deng, and Wang, 2005). Figure 3 shows the flowchart of matching algorithm. During feature matching by the method of template matching and conformal transform, the thought of matching principle based on bridge mode method (Zhang, etc., 1998) on initiate matching points was introduced, to eliminate the low precision effect on the following matching points. The effect is caused by the cumulated error due to the low precision of initiate matching points.

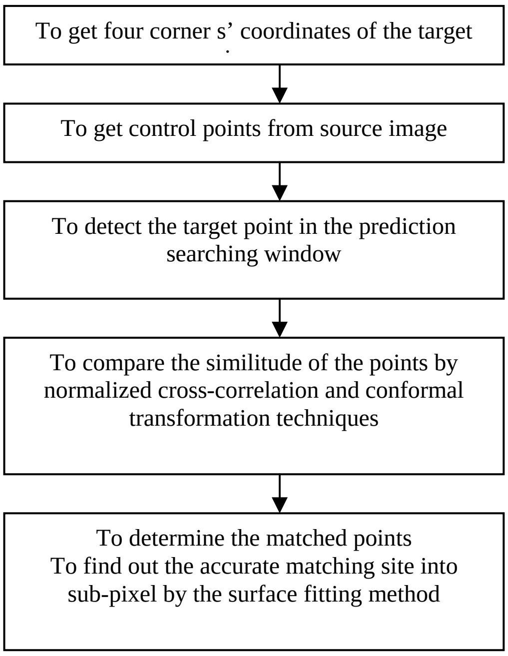

Fig.3: Flowchart of Matching Algorithm

3. EXPERIMENTS

The proposed method has been tested by three pairs of overlap SPOT images. Two pairs were captured in the same time, located in flat area and mountainous area respectively. One pair was captured in different time. The images were geometric rectified respectively. Table 1 shows the tie points accuracies which were calculated according to the transform formula.

Different image pairs	Root mean square errors
Flat area	0.0641
Mountainous area	0.6235
Different acquisition time	0.5775

Table 1: The position matching accuracy of the experimental data (unit: pixel)

In the flat area, the geometric distortion is low. The matching points on the overlap area have high correlation and with high matching accuracy. In the mountainous area and in different acquisition time, the image distortion is high. The matching points not only have differences in radiant value, but also have distortions in geometry (such as, shift, scale, rotation, etc.). Thus the conformal transformation techniques were used to improve the matching accuracy. Figure 4 shows the matching results of the 3 pair images.

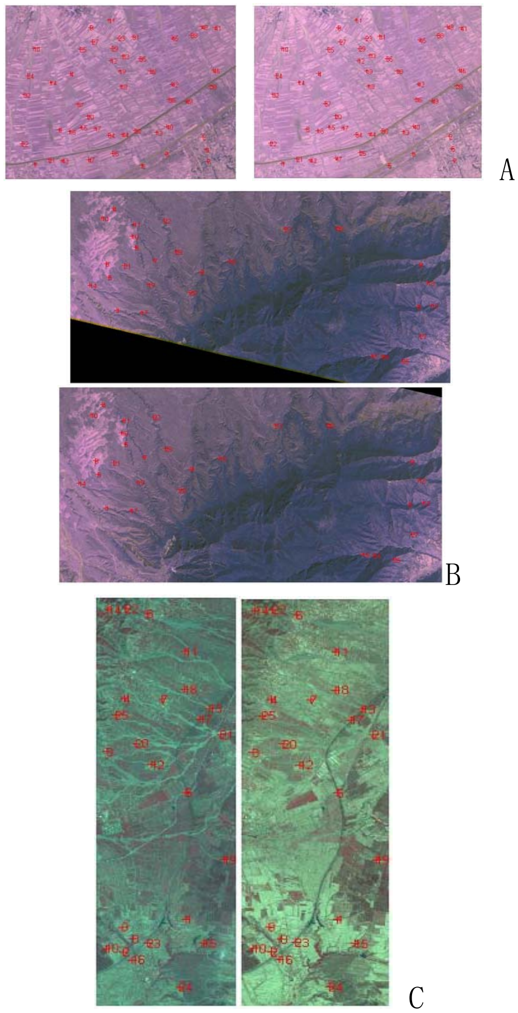

Figure4. Matching results: A: images of flat area; B: images of mountainous area; C: images acquired in different time

4. CONCLUSION

In this paper an integrated feature based method for sub-pixel image matching has been proposed. During feature extraction Harris operator was used to detect the point features, then the Förstner operator and the surface fitting method were used for sub-pixel orientation. The template matching and conformal transform techniques were used for feature matching, and the thought of matching principle based on bridge mode method on initiate matching points was introduced, to eliminate the low precision effect on the following matching points. It shows that the method is robust, effective, and suitable for realization of automatic image matching from the experiment.

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