THE STUDY ON AUTOMATIC AND HIGH-PRECISION RECTIFICATION AND REGISTRATION OF MULTI-SOURCE REMOTE SENSING IMAGERY

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ABSTRACT:

The high precise method of automatically rectifying and registering the multi-source remote sensing imagery, which are from different sensors, with different resolutions and taken from different time, is presented in this paper. First of all, the image to be registered is roughly rectified by using the polynomial model. Then, the feature points, which are distributing evenly over the roughly rectified image are extracted automatically. Guided by the extracted feature points, the homologous control points to be used in automatic registration are obtained by using the pyramid-layered template matching technique. Finally, both the geo-referencing image and the image to be precisely registered are divided into a number of triangular regions by constructing the Triangulated Irregular Network (TIN) on them, and the high precise rectification and registration can be fulfilled triangular region by triangular region.

1. INTRODUCTION

The high-precision rectification and registration technique of multisensor, multiresolution and multitemporal remote sensing imagery is playing an important role in information fusion, change detection, map update and monitoring of environment and resources. Conventionally, two methods are used in image rectification and registration, which are the method using the polynomial model and the method using the satellite imaging model, such as the collinear transform. The latter is based on the relation between the image space and the ground space; It is the rigorous description of the geometric relationship of the imaging space; The accurate sensor position, sensor attitude and a Digital Elevation Model(DEM) are needed during the process. With the invention of the new kind sensors and the change of the imaging mode, it is getting more and more difficult to obtain the precise sensor position and sensor attitude information that vary continuously with time. At the same time, a DEM that can meet the needs is hard to acquire sometimes.

That is why the image rectification and registration method, which is based on the polynomial transform, is simple and has been used widely. However, with the improvement of the spatial resolution of the remote sensing imagery and the extensive application of remote sensing technology, this method can not meet the increasing needs of high-precision rectification and registration. How to realize the high-precision rectification and registration of multi-source remote sensing imagery has been becoming the problem urgently to be resolved. On the basis of the entire image been processed by the polynomial transform first, an automatic and high-precision rectification and registration technique dealing with multi-source remote sensing imagery and based upon the Triangulated Irregular Network (TIN) division is developed in this paper. This technique is composed of the following five steps (Figure 1):

(1) Apply the rough rectification to the uncorrected image by using the polynomial model.

(2) Automatically extract feature points distributed evenly over the roughly rectified image.

(3) Guided by the extracted feature points, obtain the homologous control points to be used in automatic registration by using the pyramid-layered template matching technique.

(4) Divide the geo-referencing image and the roughly rectified image into a number of triangular regions by constructing the Triangulated Irregular Network (TIN) over them.

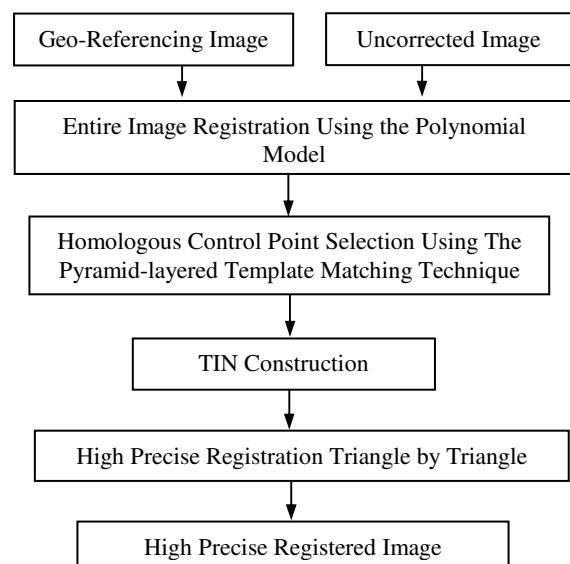(5) Fulfill the high precise registration triangle by triangle.

Fig.1 Workflow of automatic and high-precise rectification and registration of multi-source remote sensing imagery

2. ENTIRE IMAGE RECTIFICATION BY USING THE POLYNOMIAL MODEL

Registration is the process of establishing the geometric relationship between the original image and the image after correction, and transforming the original image with this geometric relationship. Assuming that the coordinates of an arbitrary pixel p before and after image rectification are x y and X Y respectively, then we have two reciprocal digital expressions:

$$X = F_x(x, y), \quad Y = F_y(x, y) \quad (1)$$
$$x = f_x(X, Y), \quad y = f_y(X, Y) \quad (2)$$

The former is the forward transformation equation used in the so-called direct method, while the latter is the backward transformation equation called the indirect method.

Before the process in this step, we assume that the original image has been undergone the necessary coarse processing, such as corrections for image distortion due to earth rotation, corrections for pixel size difference between x and y direction, corrections for satellite trajectory deflection, and corrections for atmospheric refraction and earth curvature etc.

While applying the rough registration to the entire image, if we neglect the influence of terrain undulation, the transformation function $F_x ¢ F_y ¢ f_x ¢ f_y$ can be transformed into the transformation between two planes, and at the same time, a polynomial function can be used. Take the 2nd order polynomial in backward transformation equation as an example:

$$x = a_0 + a_1 X + a_2 Y + a_3 XY + a_4 X^2 + a_5 Y^2$$
$$y = b_0 + b_1 X + b_2 Y + b_3 XY + b_4 X^2 + b_5 Y^2 \quad (3)$$

Control points used in establishing the transformation equation can be obtained by automatic image-to-image matching technique, which will be discussed in the following section, or it can be selected by human-computer interaction from the reference image. Generally, the rough rectification of the entire image needs four control points and we use the affine transformation to realize the rotation similarity between this two images[1].

3. CONTROL POINT GENERATION BY AUTOMATIC IMAGE-TO-IMAGE MATCHING

The workflow of generating accurate control points by automatic image-to-image matching is depicted in figure 2; these points will be used in registration. First of all, adequate and evenly distributed feature points are extracted from the reference image (or the image to be registered) by feature detection technique. Then, homologous points, which will be used in registration and corresponding to the feature points in the image to be registered (or the reference image) are obtained automatically by pyramid-layered template matching. In order to ensure the feature points be detected and to keep the uniformity of the control point distribution, above all, the image should be divided into several rectangular regions, which have the same given size.
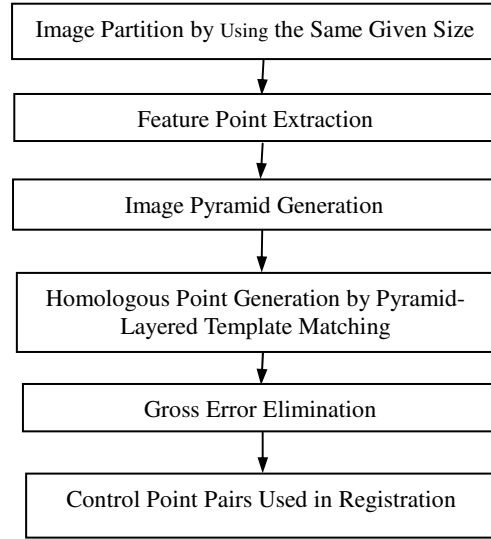

Fig.2 Generation of control points by automatic image matching

3.1 Feature Point Extraction

The extracted feature points are required to have a high positioning accuracy so that it can be used as the control points. Förstner operator is used in the extraction[2].

(1) Initial feature point extraction
Calculate the difference in the four neighbors of a pixel by Robert's gradient operator, that is to say, calculate the absolute value d_1, d_2, d_3, d_4 of grey difference on the up, down, left and right direction of pixel p c,r respectively.

$$\begin{cases} d_1 = |g_{c,r} - g_{c+1,r}| \\ d_2 = |g_{c,r} - g_{c,r+1}| \\ d_3 = |g_{c,r} - g_{c-1,r}| \\ d_4 = |g_{c,r} - g_{c,r-1}| \end{cases} \quad (4)$$

After the threshold T is selected, when the condition meets $M = mid\{d_1, d_2, d_3, d_4\} > T$, pixel p c,r can be determined as the initial feature point in this region.

(2) Feature point extraction
In the 3×3 window centered by the initial pixel p c,r, calculate the covariance matrix N and the roundness $q_{c,r}$ of the error ellipse according to the Förstner operator. Then, within the rectangular region, the point that is corresponding to the maximum value $Max(w_{c,r})$ can be regarded as the feature point according to the threshold value T_q of the roundness of the error ellipse.

$$Max(w_{c,r}) = \begin{cases} 0 & (q_{c,r} \leq T_q) \\ DetN/trN & (q_{c,r} > T_q) \end{cases} \quad (5)$$

$$N = \begin{vmatrix} \sum g_x^2 & \sum g_x g_y \\ \sum g_x g_y & \sum g_y^2 \end{vmatrix} \quad (6)$$

Where, g_x and g_y is the partial differential along the x and y direction respectively.

$$\sum g_x^2 = \sum_{i=c-1}^{c} \sum_{j=r-1}^{r} (g_{i+1,j+1} - g_{i,j})^2$$

$$\sum g_y^2 = \sum_{i=c-1}^{c} \sum_{j=r-1}^{r} (g_{i,j+1} - g_{i+1,j})^2$$

$$\sum g_x g_y = \sum_{i=c-1}^{c} \sum_{j=r-1}^{r} (g_{i+1,j+1} - g_{i,j})(g_{i,j+1} - g_{i+1,j})$$

$$q_{c,r} = 4DetN \big/ trN \qquad (7)$$

Where, *DetN* represents the determinant of the matrix *N*; *trN* represents the sum of the elements along the diagonal of the matrix *N*.

3.2 Homologous Point Generation by Pyramid-Layered Template Matching

After the feature points have been extracted from the image to be registered (or the reference image) by the Förstner operator, the homologous points of the feature points in the reference image (or the image to be registered) can be obtained by calculating the normalized standard correlation coefficient, which is described in the following equation. In order to speed the process, the pyramid-layered image searching mechanism is adopted in this period.

$$d(f,g) = \frac{\sum_{c=0}^{M-1} \sum_{r=0}^{N-1} (f(c,r) - \bar{f})(g(m+c,n+r) - \bar{g})}{\sqrt{\sum_{c=0}^{M-1} \sum_{r=0}^{N-1} (f(c,r) - \bar{f})^2 \sum_{c=0}^{M-1} \sum_{r=0}^{N-1} (g(m+c,n+r) - \bar{g})^2}} \qquad (8)$$

Where, $f(c,r)$ is the grey value of the pixel (c,r) in the template image; $g(m+c,n+r)$ is the grey value in the matching image, where (m,n) is the centre of the searching area, (c,r) is the searching extent; $\bar{f}, \bar{g}$ is the mean value of the pixels in each window. Take the feature points extracted from the image to be registered as an example.

(1) Generate the pyramid image series of the image to be registered *f* and the reference image *g* respectively, which are f_i and g_i. (i=1,2,…N, for example, N=3). Map the feature points onto the image series f_N.

(2) Begin with i=N, in image g_N, calculate the value $d(f,g)$, which is corresponding to the feature points in image f_N. The homologous points are the points corresponding to the maximum value of $d(f,g)$. Map these homologous points onto the layer i-1, i.e. g_i-1, and let i=i-1.

(3) In the layer *i*, within the rectangular extent of W×H in image g_i, calculate the homologous points corresponding to the feature points according to the algorithm in step (2), until i=1.

(4) All the feature points and the corresponding homologous points construct the control point pairs.

3.3 Gross Error Elimination

Because the entire original image has been roughly registered, the horizontal and vertical deviation value Δx_i and Δy_i of the control point pairs should be less than the threshold T_1 and T_2. Thus, the following method is adopted to eliminate the mismatched control point pairs.

Assuming that the number of control point pairs is n, each control point pair is constituted by $f(i,j)$ and $g(k,l)$, then we have

the following expressions describing the mean square errors of the horizontal and vertical deviation:

$$\sigma_x = \frac{1}{n-1} \sqrt{(\Delta x_m - m_x)^2}, \quad \sigma_y = \frac{1}{n-1} \sqrt{(\Delta y_n - m_y)^2} \qquad (9)$$

Where, $m_x = \frac{1}{n} \sum_{i=1}^{n} \Delta x_m, \qquad m_y = \frac{1}{n} \sum_{m=1}^{n} \Delta y_m,$

$$\Delta x_m = k - i, \quad \Delta y_m = l - j \quad , (i,j,k,l,m = 1,2,\cdots,n) \qquad (10)$$

Let $T_1 = 3\sigma_x \ and \quad T_2 = 3\sigma_y,$

while it meets $\Delta x_i > T_1 \ and \quad \Delta y_i > T_2$ the control point pair $f(i,j)$ and $g(k,l)$ can be considered as the mismatched points.

4. HIGH PRECISE REGISTRATION TRIANGLE BY TRIANGLE

After the control point pairs have been automatically collected, the reference image and the image to be registered can be divided into several triangular regions by TIN, which is constructed by the control points. The affine transformation model can be applied in each triangular region to fulfill the precise registration.

4.1 TIN Construction

Among the different methods constructing TIN, Delaunay TIN, which is constructed by Thiessen Polygon method is close to optimum. Because the control points are obtained after the image has been divided into several rectangular regions which have the same given size, the situation that four points are concyclic may occur, and this cannot meet the condition to construct Delaunay TIN. The Minimum-Distance method is simple and has better executive efficiency, it is adopted to construct TIN in this paper.

(1) Determination of the Initial Triangle
Find the closest two points in the control point set, then find another point that is closest to the connection line of the two points but is not collinear with the two points. The initial triangle can be determined by the three points.

(2) TIN Generation by Triangle Expansion
Triangle Expansion starts from the first edge of the first triangle. Assuming that the vertexes of the triangle are p_1, p_2 and p_3, and the first edge is $p_1 p_2$ (See figure 3), it is obviously that the expanded point $q(x',y')$ should not be the point located at the same side of the line $p_1 p_2$, just like the point p_3, and also not the point on the line $p_1 p_2$. The straight line equation is:

$$F(x,y) = y - Ax - B \qquad (11)$$

If $F(x',y') > 0$, (x',y') is located at the positive zone of the line; if $F(x',y') = 0$, (x',y') is located at the line; if $F(x',y') < 0$, (x',y') is located at the negative zone of the line. So, when

$$F(x_3,y_3)F(x',y') < 0 \qquad (12)$$

$q(x',y')$ is the point that possibly to be expanded.

After the points that are possibly expanded have been obtained by equation (12), using the law of cosines, equation (13), we

can get the point that will be expanded, which is corresponding to the maximum C.

$$\cos C = (a^2 + b^2 - c^2)/2ab \quad (13)$$

When the first edge of the triangle k has been expanded, apply the same method to expand the other two edges; then turn to the $k+1$ triangle until all the points have been gone through.
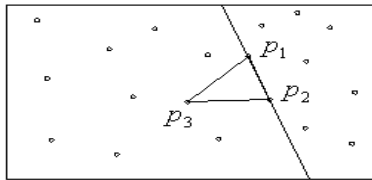

Fig. 3 Straight line judgment method

4.2 Fulfill Registration Triangle By Triangle

Within each triangle pair, construct the regional rectification model using the affine transformation, equation (14), together with the coordinates of the vertexes of the two triangles. Then fulfill the high precise registration of the two images triangle by triangle.

$$\begin{cases} x = a_0 + a_1 x + a_2 y \\ y = b_0 + b_1 x + b_2 y \end{cases} \quad (14)$$

After the regional rectification model has been established, the key point of this rectification method is to judge which triangle that the point to be rectified is located in. In order to speed the process, we can judge if the point is located in the circumrectangle of the triangle. If it is true, we can further judge if the point is located within the triangle.

5. EXPERIMENTS AND CONCLUSIONS

Using the method presented by this paper, the software that realizes the high precise rectification and registration of multi-source remote sensing imagery has been developed in VC++ language, based on personal computer, and this software has been successfully used in land use and land cover change detection based on multi-temporal remote sensing imagery and dynamic land use monitoring based on TM 30m multi-spectral data and SPOT 10m panchromatic data. Figure 4,5 and 6 are the experimental results using the high precise TIN rectification method presented by this paper.
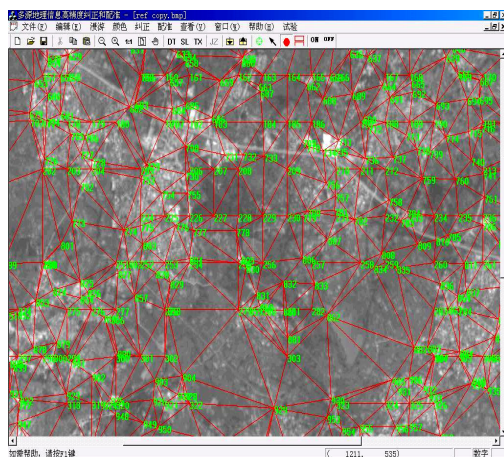

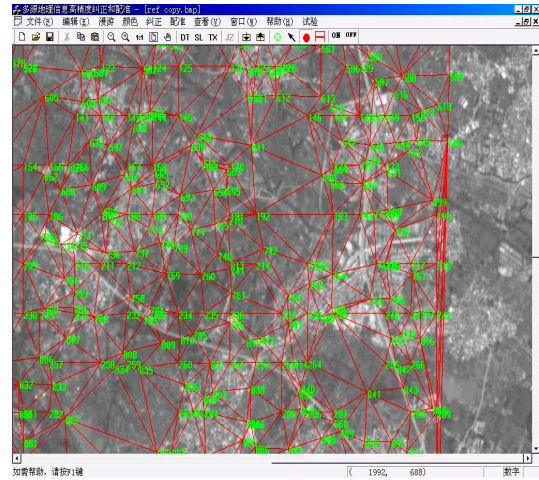Fig.4 TIN constructed on the geo-referencing image

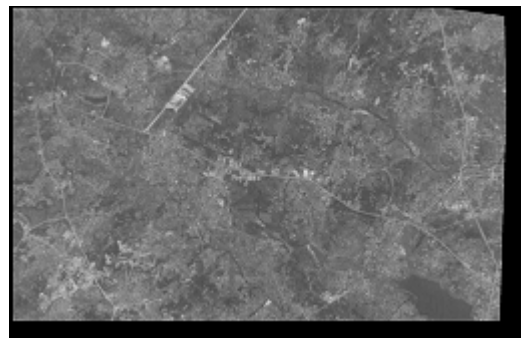Fig.5 TIN constructed on the image to be rectified

Fig.6 The rectified result

Experimental results and practical work show that the approach presented by this paper is simple and applicable without employing DEM, satellite ephemeris data and orientation information of the sensor, and it is an effective method to realize the high precise rectification and registration of multi-source remote sensing imagery. Because of the speciality of the radar imaging mode, the method presented by this paper is not applicable to radar imagery. In addition, after the control points have been selected by human-computer interaction, the high precise registration of the thematic data and the image data can be fulfilled by TIN rectification developed in this paper.

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