MULTI-SPECTRAL IMAGE INTER-BAND REGISTRATION TECHNOLOGY RESEARCH

Zhou Fang\textsuperscript{a,b}, Chunxiang Cao\textsuperscript{a}, Wanshou Jiang\textsuperscript{c}, Wei Ji\textsuperscript{a}, Min Xu\textsuperscript{a}, Shilei Lu\textsuperscript{d}

\textsuperscript{a}State Key Laboratory of Remote Sensing Science, Jointly Sponsored by the Institute of Remote Sensing Applications of Chinese Academy of Sciences and Beijing Normal University, Institute of Remote Sensing Applications, Chinese Academy of Sciences, PO Box 9718, Beijing 100101, China

\textsuperscript{b}Graduate School of the Chinese Academy of Sciences, Beijing 100049, China

\textsuperscript{c}State Key Laboratory of Information and Engineering in Surveying, Mapping and Remote Sensing(LIESMARS), Wuhan University, Wuhan 430072, China

\textsuperscript{d}Division of Ecological Environment, Department of Development Planning and Assets Management, State Forestry Administration, Beijing, 100714, China

ABSTRACT

Multi-spectral image refers to the use of multi-spectral sensors from the same object (target or region) to obtain the spectral range of more than one image. With the development of multi-spectral imaging technology, the existence of non-rigid mismatch among the original inter-band images requires a higher accuracy and faster registration. Here an automatic elastic registration method based on mutual information and thin-plate spline interpolation is presented, we carried out HJ-1A/B satellite Level 1 visible light inter-band images registration. This does not require other priori assumptions among multi-spectral image gray relationships, or the need for image segmentation and pre-processing (such as feature extraction, classification, etc.). Through the research about multi-spectral image inter-band registration, deviations may be controlled within an acceptable range, we can get more information about multi-spectral images.

\textbf{Index Terms}-Multispectral imaging, Image registration, Mutual information, Spline

1. INTRODUCTION

Multi-spectral image refers to the use of multi-spectral sensors from the same object (target or region) to obtain the spectral range of more than one image. Among the original inter-band images offset error is small, belonging to sub-pixel. The same target in different spectral characteristic parameters have a great change, its grayscale image differences may be significant. Deviations may still exist among Level 1 inter-band images which are handled by Ground Handling System, and after geometric correction, these deviations will become geometry distortions within Level 2 images, resulting in deviations become larger and difficult to correct.

For different spectral images, there is a big difference in gray properties, but for the same scene, the gray distribution has a certain similarity. Therefore, the pixel gray can be as random variables, we use gray distribution of statistical data as a registration measure function to achieve the multi-spectral inter-band image registration. This does not require other priori assumptions among multi-spectral image gray relationships, or the need for image segmentation and pre-processing (such as feature extraction, classification, etc.). Since most image registration methods are non-rigid, completely rigid images are rare. For the local existence of non-rigid deformation, rigid registration methods are not suitable for the local existence of non-rigid deformation.

2. METHODS

Automatic elastic registration method based on mutual information and thin-plate spline interpolation is presented here, we carried out HJ-1A/B satellite Level 1 visible light inter-band images registration. With one band image as reference image A(e.g. Red in this article), the remaining band images as image B(Green and Blue). The image A and image B along the X and Y directions are divided into four sub-block images. We use the normalized mutual information for image registration, then each sub-block images center point as a thin-plate spline interpolation marker to get two sets of corresponding feature points. The first registration image B1 was obtained after using thin-plate spline interpolation algorithm to transform the image pairs. Similarly, the image A and image B1 along the X and Y directions are divided into sixteen even sub-block images,

* Corresponding author (Email: cao413@irs.ac.cn)
getting second registration image B2. Finally, using the same methods, the image A and image B2 along the X and Y directions are divided into sixty-four even sub-block images, getting the final registration image B3.

![Flow chart of registration processing](image1)

2.1. Research Data

We obtained HJ-1A/B satellite Level 1 visible light images which mismatch among the bands. To facilitate study of algorithms, we intercepted the image of 512*512 subregion. The original image is shown in Figure 1, RGB channel images were extracted respectively.

![Original image, without inter-band registration](image2)

2.2. Normalized Mutual Information

Mutual information[1] for image registration key idea is that if two images reach matched, their mutual information reaches its maximum value. Studholme proposed a normalized mutual information measure[2], which allows a smoother registration function, can reduce the sensitivity of overlap between the image pairs, obtain higher registration accuracy.

The image gray value of A and B as two random variables a and b, the gray value of 0 to 255, the probability density function , respectively, and both of the joint probability density function , where

\[ H(a) = - \sum_a p(a) \log p(a) \]
\[ H(b) = - \sum_b p(b) \log p(b) \]
\[ H(a,b) = - \sum_{a,b} p(a,b) \log p(a,b) \]

\[ a,b \in [0,255] \]  \hspace{1cm} (1)

Normalized mutual information is defined as

\[ Y(A, B) = \frac{H(A) + H(B)}{H(A, B)} \]  \hspace{1cm} (2)

Mutual information image registration, the coordinate transformation using affine transformation model, the image after geometric transformation, the pixel coordinates and the original sampling grid is not completely coincident, the pixel gray values need to be recalculated, which requires the transformed image to resample and interpolate. We use trilinear partial volume distribution interpolation algorithm, referred to as PV interpolation method. Here we choose Powell[3,4,5] method for optimization method, rigid registration in the choice of markers is simplified to look for the optimal affine transformation parameters.

2.3. Thin-plate Spline Interpolation

Thin-plate spline is the only spline that is completely decomposed into affine and non-affine subspace, and its bending energy is determined by the second derivative of the mapping function[6]. One to one between the set of points ensuring the constraint conditions, by minimizing the bending energy function, joint solving the matching matrix and mapping parameters between the set of points. The deformed curved surface F with the function \( z = f(x, y) \), then the function should satisfy two conditions:

1) At each control point, \( f(x_i, y_i) = z_i, (i = 1, 2, \cdots, n) \)

2) Minimizing the bending energy function \( J(f) \)

Two-dimensional thin-plate spline energy function and basis function can be found in [7].

\[ J(f) = \int \left( \frac{\partial^2 z}{\partial x^2} + 2 \frac{\partial^2 z}{\partial x \partial y} + \frac{\partial^2 z}{\partial y^2} \right) dxdy \]

\[ U(r) = \begin{cases} r \log r, & r \neq 0 \\ 0, & r = 0 \end{cases} \]  \hspace{1cm} (3)

The Euclidean distance between \( P_i \) and \( P_j \) is

\[ r_{ij} = ||P_i - P_j|| = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \]  \hspace{1cm} (4)

Define the following matrixes:

\[ K = \begin{bmatrix} 0 & U(r_{12}) & \cdots & U(r_{1n}) \\ U(r_{21}) & 0 & \cdots & U(r_{2n}) \\ \vdots & \vdots & \ddots & \vdots \\ U(r_{n1}) & U(r_{n2}) & \cdots & 0 \end{bmatrix}_{n \times n}, P = \begin{bmatrix} 1 & x_1 & y_1 \\ 1 & x_2 & y_2 \\ \vdots & \vdots & \vdots \\ 1 & x_n & y_n \end{bmatrix}_{3 \times n} \]
where \( O \) represents a 3 \( \times \) 3 zero matrix. N-dimensional vector \( Z = (z_1, z_2, \cdots, z_n) \) indicates sequence of the control point \( Z \), denoted by \( n+3 \) dimensional column vector \( Y = (Z|0 \ 0 \ 0)^T \). N-dimensional vector \( W = (w_1, w_2, w_3, \cdots, w_n) \), and the coefficient \( a_1, a_2, a_3 \) can be obtained by solving the following linear equation:

\[
L(W|a_1, a_2, a_3)^T T = Y
\]

Now we can construct the function:

\[
f(x, y) = a_1 + a_2 x + a_3 y + \sum_{i=1}^{n} w_i U(|P_i - (x, y)|)
\]

where \( a_1 + a_2 x + a_3 y \) is the transform part of the affine subspace, \( \sum_{i=1}^{n} w_i U(|P_i - (x, y)|) \) is the transform part of non-affine subspace. This function satisfies \( f(x, y) = z_i, (i = 1, 2, \cdots, n) \), and can make energy function \( J(f) \) minimum. At this point, the energy function is proportional to \( WKW^T \), \( J(f) \propto WKW^T \).

Marking the \( n \) pairs of corresponding control points \( p_i, q_i, (i = 1, 2, \cdots, n) \) on the two dimensional images of A and B, the function of the thin-plate spline model established by these control points can be decomposed into two sub-thin-plate spline function:

\[
 f_{x_i}(x, y) = (f_x(x, y), f_y(x, y))
\]

Where \( f_x(x, y) \) indicates \( X \)-direction thin-plate spline function, \( f_y(x, y) \) indicates \( Y \)-direction thin-plate spline function. It is noteworthy that in the process of construct thin-plate spline function, Matrix \( L \) is only related to the control point \( P_i \), therefore, in the constructor \( f_x(x, y) \) and \( f_y(x, y) \), \( L \) is the same. Only when we define \( n + 3 \) dimensional column vector \( Y = (Z|0 \ 0 \ 0)^T \), n-dimensional vector \( Z \) are set to the n-dimensional vector composed by the X and Y coordinates of \( q_i \).

3. RESULTS AND CONCLUSIONS

With the increasing numbers of image blocks, the mutual information between two images after registration is increasing, and the numbers of control points are also increasing, the representativeness of the required numbers of control points that reflect the local deformation in image are also increasing. However, with too many numbers of control points, the image registration is completely bound by the control points, the free elastic deformation is relatively small, leading to the decline in matching accuracy, the corresponding mutual information is also declining.

We carried out HJ-1A/B satellite Level 1 visible light inter-band images registration. The first registration image B1 was obtained after using thin-plate spline interpolation algorithm to transform the image pairs A and B. Similarly, the image A and image B1 along the X and Y directions are divided into sixteen sub-block images, getting second registration image B2. Finally, using the same methods, the image A and image B2 along the X and Y directions are divided into sixty-four sub-block images, getting the final registration image B3. Band 1 and 2, 3, followed by such algorithms to obtain the final registration results.

With red band image as reference image A, the green band images as image B, the blue band images as image C.

![Image B1 with 2x2 blocks](image1.png)
![Image B2 with 4x4 blocks](image2.png)
![Image B3 with 8x8 blocks](image3.png)

Figure 3 Procedure map between A and B

![Image C1 with 2x2 blocks](image4.png)
![Image C2 with 4x4 blocks](image5.png)
![Image C3 with 8x8 blocks](image6.png)

Figure 4 Procedure map between A and C
In order to check the registration accuracy, we calculate mutual information of the entire image after registration. With more and more sub-block images, the accuracy of registration indicated by the normalized mutual information (NMI) that is increasing (Table 1). Proved that the proposed layered mutual information and thin-plate spline method obtains an ideal non-rigid registration result.

Table 1 Image pairs normalized mutual information after registration

<table>
<thead>
<tr>
<th>Block numbers</th>
<th>NMI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before registration A&amp;B</td>
<td>1.05</td>
</tr>
<tr>
<td>2×2 blocks after registration</td>
<td>1.09</td>
</tr>
<tr>
<td>4×4 blocks after registration</td>
<td>1.12</td>
</tr>
<tr>
<td>8×8 blocks after registration</td>
<td>1.29</td>
</tr>
</tbody>
</table>

4. REFERENCES