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(出版者 / Publisher)
法政大学大学院情報科学研究科

(雑誌名 / Journal or Publication Title)
法政大学大学院紀要. 情報科学研究科編 / 法政大学大学院紀要. 情報科学研究科編

(巻 / Volume)
10

(開始ページ / Start Page)
1

(終了ページ / End Page)
6

(発行年 / Year)
2015-03-24

(URL)
https://doi.org/10.15002/00011590

A Hierarchical Method for Satellite Image Co-Registration

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***Abstract*—As remote sensing image registration plays a quite important role in remote sensing image processing. Researchers are searching for an image registration method with high accuracy. In this paper, an automatic method for satellite image co-registration was proposed. This proposed approach got the candidate points on the reference image by introducing F-test and found out the corresponding points on the image to be registered using spatial correlation technique. After acquiring the ground control point pairs (GCPs), polynomial registration model was tried for the registration. The proposed method was applied to the satellite images.**

Keywords—remote sensing image; spatial correlation technique; image registration; candidate points; ground control point pairs;

I. Introduction

Image registration is an important research subject of computer vision and pattern recognition, no matter in remote sensing image processing, medical image analysis and some other research fields, it has a great application. Especially, in image fusion [1] and change detection [2], image registration is their precondition. The effect of image registration will product a significant influence on these processes.

In recent years, remote sensing image plays a very important and effective role in image processing. Remote sensing technology helps us be easier to acquire global comprehensive information. There are many superiorities in this research field, such as detection range is wider, speed is faster, and cycle is shorter. With the developing in this field, these advantages become more and more obvious. With different wavelengths remote sensors, we can obtain different information of the objective. By using image processing technique, we can combine these information together, and make information complementary with each other. It helps us to get much more plentiful and much more significant information of the objective. With the gotten information, we can accomplish image fusion and change detection analysis. However, when image data is recorded by sensors which are on satellites or aircrafts, it would contain some geometry distortions individually and geometry discrepancies between each other. And these disparities are always caused by the earth rotation during the procedure of image data acquisition [3][4]. In order to eliminate these distortions and discrepancies, image registration is needed and it helps us modify the images to keep consistence on the same coordinate. In remote sensing image field, as image registration is such important, a much faster, more precise and much more adaptive method of image registration is required. The fundamental principle of image registration (geometric calibration) is to directly use ground control points to do mathematic simulation of the remote sensing image geometric distortion in which includes twisting, scaling, rotation, shifting and some comprehensive actions. After all these operations, we can use an appropriate mathematical model to represent the correlation relationship between images before and after image registration.

For satellite imagery, as manually selected corresponding points image registration is always time consuming, laborious, inefficiency and sometimes not feasible, an automatic image registration algorithm is urgently required. In the procedure of image registration, ground control point pairs (GCPs) play the most important role [5] which are used to generate intensity matching functions and feature matching functions. Based on this situations, in this paper, we tried to propose an automatic method of satellite image registration. In this proposed method, the image registration process is carried out by the following steps:

1) Through hierarchical processing, we built up image pyramid which contains four layers.

2) By coarse image registration, we could evaluate the influence of rotation, scale and parallel shift between images.

3) Automatically detecting candidate points, finding corresponding points and generating ground control point pairs (GCPs).

4) With using polynomial registration model, we will get the result of image registration.

In the rest of the paper, we will discuss the principle we have used and describer the procedure of the proposed image registration method. Also we will provide some results that we have gotten from our preliminary experiment of the proposed image registration method. At last, we will make the conclusion with a discussion.

II. Principle

In this paper, we suppose that IMG1 has M*N pixels and IMG1 was the reference image and detected in temporal one. While IMG2 contains V*W pixels, and IMG2 is the image to be registered. What's more, IMG2 was detected in temporal two. The spatial resolutions of IMG1 and IMG2 are not quite the same and there are some distortions individually and discrepancies between IMG1 and IMG2. In the following, we will discuss the principles which we have used in the proposed algorithm in detail. Both of IMG1 and IMG2 are shown in Fig.1.

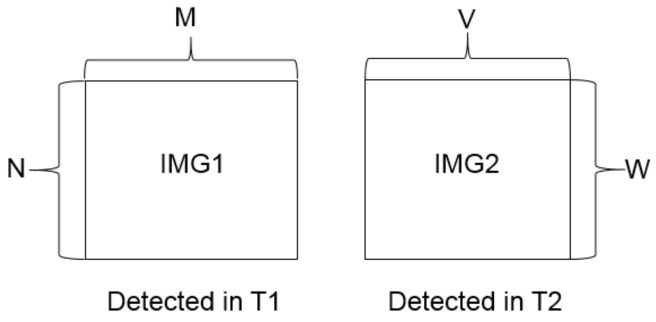

Fig. 1. Images to be processed

A. Hierarchical Processing

As the resolution of the original images are very high, and it is inconvenience to calculate at the beginning of our research, we introduced the hierarchical processing into our research to help us establish the image pyramid [6][7]. In our research, totally we reduced the original image into four layers as shown in Fig.2.

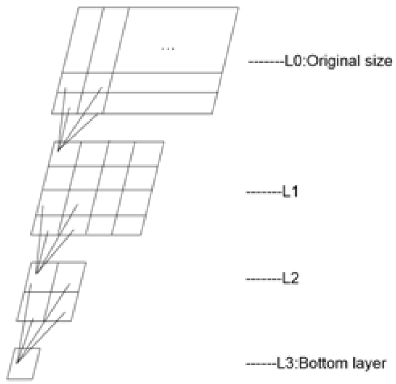

Fig. 2. Hierarchical processing

During hierarchical processing, geometry disparities are reduced to a half in the compressed image layer. In order to get the compressed image, we made four neighborhood pixel densities compress into one pixel [8]. There are mainly two important steps in the reduce procedure. One step is low pass filter and the other one is down-sampling of interlaced separated columns. With the two procedure, we would get the second layer and by repeating this process, we got four layers in the end. In every layer, image resulted from the formal layer image by low pass filtering process, the resolution and sampling point density were reduced comparing with the formal layer image. The formulation for us to get the down-layer image is:

$$L_{(n+1)} = \sum_{m=-2}^{2}\sum_{n=-2}^{2} W(m,n)\,L_n(2i+m, 2j+n), (i \le \frac{N}{2}, j \le \frac{M}{2}) \quad (1)$$

Where, $L_0(m,n)(m \le M, n \le N)$ is the original image, M, N are the number of the row and column of the image. $W(m,n) = W(m)*W(n)$ is a low pass filter, and its size is 5*5.

We started our research mainly on the bottom layer, and after making the bottom layer images registered, we would go to up-layer until we accomplished the image registration of the original images. As the images which we researched on are from the same satellite, we assumed the original images have been done radiometric calibration and we just considered the geometric calibration which is also named registration.

B. Coarse Image Registration

Based on the characteristics of the reference images and the image to be registered which were from the same satellite, we didn't consider about the influence from the atmospheric condition and ground condition. However, as we have talked about in the previous, there still exited some variances such as rotation, shifting, scale and so on. These differences would inevitably generate some influences during the procedure of image registration [9].

In order to make clear the effect of the mainly variances, such as rotation, shifting and scale which can be generally expressed by a first order polynomial formula. Based on this fact, we did a coarse image registration by using affine transformation. The basic affine transformation formulation is:

$$\begin{cases} v = a_0 + a_1 x + a_2 y \\ w = b_0 + b_1 x + b_2 y \end{cases}, \quad (1)$$

Where (x, y) is the axis of the based image (reference image) while (v, w) is the axis of the image which is to be registered. And $a_0, a_1, a_2, b_0, b_1, b_2$ are the coefficients of the basic affine transformation formulation.

In this process of coarse image registration, we manually selected three pairs of points. As the destination of the coarse image registration is to eliminate some effects from rotation, shifting and scale, we need not to get the control points with high precision. However, the more precise of the control points, the better effect we will get.

C. Parallel Shift Distance

In order to get the parallel shift distance between the images, we did another image process which would help us reduce some variances between the images. And the process we called XOR operation. Before doing XOR operation, firstly we translated the original images into binary images. During image binarization processing, we applied OTSU algorithm [10] in image segmentation procedure. OTSU algorithm has a good performance that it is sensitive to noise and target size. By using this algorithm, we could get a quite good segmentation effect.

OTSU Algorithm: For one image, assume the threshold between the foreground and background is t, the ratio of foreground points is W0, mean value is U0, the ratio of background points is W1, and average value is U1.Then we calculate the mean value of the total image is:

$$U = W0*U0 + W1*U1, \quad (2)$$

And we can establish the objective function as:

$$G(t) = W0*(U0-U)^2 + W1*(U1-U)^2, \quad (3)$$

$G(t)$ is the expression of the variance between classes when the threshold value is t. With using OTSU algorithm, we could get the maximum value of $G(t)$, and at the same time, when $G(t)$ got the maximum, we considered t was the optimal threshold value.

By introducing OTSU algorithm into our research, we got the binary images, then through applying morphological expansion functions, we translated one image to the other. As a result, we successfully did XOR operation with the two images and got the parallel shift distance between the multi-temporal images. And the XOR operation processing also helped us reduce some disparities between the images.

D. Image Merge

Multispectral image can fully display different characteristics of different objectives, and this feature is conducive to recognize different types and forms of the objectives, for example, the forest, the soil, the rocks and so on. As multispectral remote images have different spectral bands, and there are also some correlations among the bands. In order to get as much information as possible of the objective, in our research, we did image merge to combine three bands of the RGB image and one band of near-infrared image together. And we introduced K-L transformation (principle component analysis) to process with the given images. K-L transformation [11] helped us reduce the data volume and keep the main information of each band. After getting each band of multispectral images, we merged them and did some other processes to get a new image for the following process. In the new image, we combined useful information together, and reduced the repetitive information. Through image merge process, we significantly reduced the total amount of data and enhanced the amount of the information in the new image, what's more, it helped us reduced some unnecessary computations.

E. Detection of Candidate points

It is widely known that the precision of image registration is determined by the accuracy of GCPs. As the result of coarse image registration is not so good especially reflected on the effect of precision, we proposed an approach to automatically generate the GCPs. With the purpose of generating GCPs, we should find the candidate points at first. During the process of detecting candidate points, we introduced F-test into our research, and F-test is a kind of statistical method [12][13]. And in Fig.3 shows the masks we have set during the procedure of corner detection.

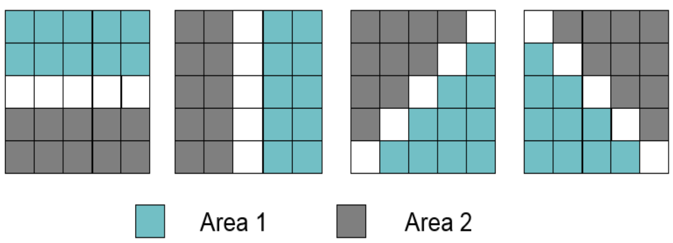

Fig. 3. Masks for edge detection

So as to search for the corner points, we defined the cross points of these two edges as the corner points. And if we detected that the mean values of densities in area1 and area2 have a great difference with each other, we considered the edge was found. Then we tried to find the cross points of each two edges, in our process, we defined the cross points of two edges as the corner points. Also we considered the corner points were candidate points. The formulation of F-test we have defined in our research is:

$$F_0 = \frac{N(\mu_1 - \mu_2)^2}{(v_1 + v_2)}, \quad (4)$$

Where, N is the total number of pixels in the defined mask, μ_1, μ_2 are the mean values of the pixels in area1 and area2, v_1, v_2 are the variances of the pixels in area1 and area2.In order to minimize the influence of the errors, we carefully chose the threshold which was theoretically derived as 2.

F. Generate Ground Control Point Pairs

In the previous, as we have gotten candidate points on IMG1, following what we had to do was to find the corresponding points on IMG2. In our algorithm, we introduced spatial correlation technique [14]. We set masks on IMG1 and IMG2, and the masks for estimating position of corresponding point are shown in Fig.4. Here, the sizes of mask1 and mask2 are the same.

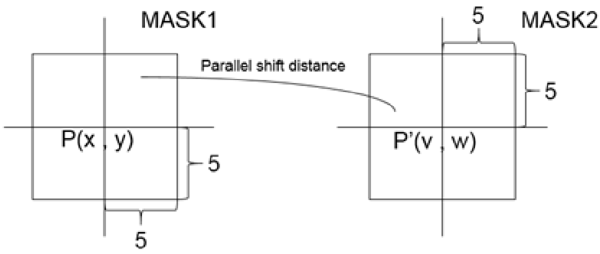

Fig. 4. Masks for estimating position of corresponding point

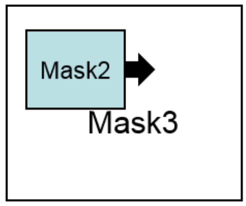

Fig. 5. Masks for defining searching area

Masks for defining searching area is shown in Fig.5. We set mask3 around P', and we used moving mask2 to search all the pixels in mask3.Importantly, we introduced spatial correlation technique [14] in this process. We used correlation coefficient r to help us estimate the linear relationship between them. After searching, we found the maximum of the correlation coefficients and corresponding point P'', and we regarded P and P'' as a pair of corresponding pair/GCP. When we found the precise corresponding points, we draw a scatter diagram of the densities in mask1 and mask2. It will help us to estimate the similarity of spatial structure of both of the images. If it shows us a linear relationship in the scatter diagram, it indicates that the points correspond to each other well. The following formulations are for calculating correlation coefficient:

$$r = \frac{S_{12}}{\sqrt{S_{11} S_{22}}}, \tag{5}$$

$$S_{ij} = \sum_{k=0}^{n} (D_{ik} - \mu_i)(D_{jk} - \mu_j), \tag{6}$$

Where, n means the number of pixels in mask1 and mask2, D means pixel density and μ means the average density value.

G. Geometry Transformation Based on GCPs

In order to register the images based on the GCPs, as polynomial expansion model is simple and intuitive, we introduced polynomial expansion model [15], into our research.

General polynomial registration model is:

$$\begin{cases} u = a_0 + (a_1 x + a_2 y) + (a_3 x^2 + a_4 xy + a_5 y^2) + \\ \qquad (a_6 x^3 + a_7 xy^2 + a_8 x^2 y + a_9 y^3) + \cdots \\ v = b_0 + (b_1 x + b_2 y) + (b_3 x^2 + b_4 xy + b_5 y^2) + \\ \qquad (b_6 x^3 + b_7 xy^2 + b_8 x^2 y + b_9 y^3) + \cdots \end{cases}, \tag{7}$$

Where, (x, y) is the pixel axis of IMG1 and (u, v) is the pixel axis of IMG2. $a_i, b_j (\mathrm{i, j} = 0,1,2,\cdots(\mathrm{N}-1))$ are the coefficients of polynomial expansion model.

The coefficients of polynomial expansion model are determined by weighted least square method. The weighting depends on two factors, certainty and applicability.

III. PROCEDURE

As the principles we have explained in previous, and in our research, the images which we have to process are multispectral and multi-temporal. Based on this situation, firstly, we applied hierarchical processing in our research. And we established an image pyramid with four layers. After we got the right result of the bottom layer images, we went up layers until we accomplished image registration of the original images. In the following procedure, we coarsely registered the image based on manually selected points pairs and affine transformation. We found that the effect of coarsely image registration was not so good with processing remote sensing images. It required us to propose a much more precise approach to do image registration. In order to be easier to do image registration, firstly through the XOR operation with the images, we could found the shift distance between the multi-temporal images. As we have known that there is some different information which contained in different spectral band of multispectral images. In order to get information of the objective as much as possible and eliminate the repetitive information, we should merge different spectral bands together. For image registration, as we know, to acquire the ground control point pairs is the most important procedure. Its precision will directly determinate the effect of the last result of image registration. Considering of this, in our research, we found the candidate points (corner points) on IMG1 which was based on F-test. As there are too many candidate points, we detected the candidates which were on the island. As we did not need so many points, we uniformly chose some of them and the uniformly chosen some points from the candidate points and the chose points will present the shape of the island. After that, we searched the corresponding points on IMG2 with using spatial correlation technique [16]. After generating the GCPs, we had tried to introduce polynomial expansion model method, thus for confusing with concepts of it, now, the result which I have gotten was not satisfied the requirement of image registration, and I should pay much attention on this subject.

As what we have talked about in the procedure, the flowchart of the proposed method is just as Fig.6. And in the following, we will explain specify process procedures of the proposed method.

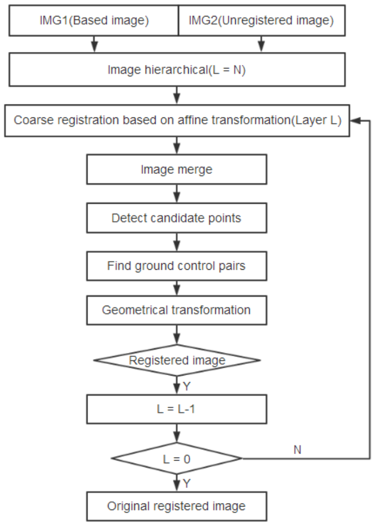

Fig. 6. Flowchart of the proposed method

1) As the original images contain too much data to process, by introducing hierarchical processing, we got the image pyramid, as we can see in Fig.3. In order to save calculating time, at the begging of our research, we mainly paid much attention on researching the bottom layer. When we got the anticipated result of our proposed method, we went up layer until we got the registered result of the original images.

2) Coarse image registration processing is based on manually selected control point pairs and affine transformation. This process helped us verify the mainly different factor of the remote sensing images which were from the same satellite is parallel shift.

3) As we have known that parallel shift is the mainly difference between the images from the same satellite, in order to clarify the parallel shift distance between the satellite images. In this processing, we introduced in OTSU algorithm in the operation of image binarization. After we got the binary images, we did XOR operation with the images, and at last we detected the parallel shift distance. Not only did it help us reduced some unnecessary computation, but also helped us find the excepted corresponding points.

4) Generate candidate points on IMG1.In order to automatically find the corner points, we introduced F-test theory and by defining the corner points as the cross points of two edges, we got the candidate points of the whole image. However, the objective which we focused on was the island. As the island is an integral whole, we extracted the shape of the island from the binary image and overlapped the shape with the whole image which had been done generated candidate points operation, we got all of the candidate points which are just on the island.

5) Find the corresponding points on IMG2.As there are many candidate points on the island of IMG1, and we wanted to find points which could stand for the objective. In this procedure, we used homogenization choice method to find some points from the candidate points. Then by applying parallel shift distance, we easily found the expected (coarsely) corresponding points. And we introduced spatial correlation technique to search the much more precise corresponding points and generate the ground control points pairs (GCPs).

6) In order to accomplish the image registration, we introduced polynomial expansion model.

In our research, for saving time, we kept the process procedures automatically. Also the automatically image registration method will help us improve the precision of image registration.

IV. Experiments and Discussion

Based on the principle and procedure described in previous, for measuring the performance of the proposed method which is called a hierarchical method for satellite image co-registration, we applied it into our experiment. And in our experiment, the algorithm was developed under the platform of MATLAB 2012b.In our preliminary experiment, a set of images that we have used are from the same satellite, also they are multi-temporal and multispectral images of Ishigakijima. And the sizes of the images of temporal one are 5330*4328 pixels (1 band image) and 5330*4328*3 (3 bands image) pixels, and the sizes of the images of temporal two are 5359*4443 pixels (1 band image) and 5359*4443*3 pixels (3 bands image).In this section, we will display some preliminary result of our research. In Fig.6 shows the bottom layer of the hierarchical operation and the color images have 3 spectral bands while the gray images have 1 spectral band. And Fig.7 (a) shows the images of temporal 1 while Fig.7 (b) shows the images of temporal 2.

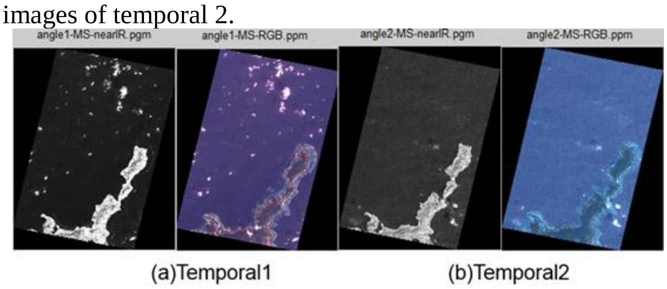

Fig. 7. Bottom layer of hierarchical operation

Through coarse image registration, we have gotten the information that the influence of rotation and scale is very small, in this experimentation we have not taken them into consideration. For the bottom layer the parallel shift distance we have detected is (-5, -4) and the effect of image XOR operation is shown is Fig.8.

After we got the parallel shift distance, we merged the 3 bands image and 1band image, and the result we got from image merge process is shown in Fig.9 and Fig.10.

Fig.11 (a) shows the result of candidate points' detection of whole image ones selected only and Fig.11 (b) shows the candidate points on the island. As there are still 1149 candidate points on the island of the bottom layer and it is too many for us processing. We uniformly selected 31 candidate points which could simply describe the shape of the island from 1149 candidate points. The uniformly chosen candidate points are shown in Fig.11 (c).

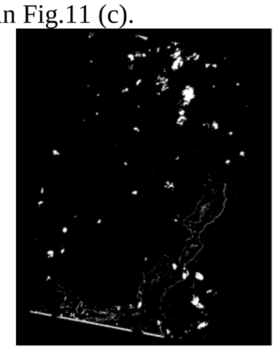

Fig. 8. The effect of XOR operation

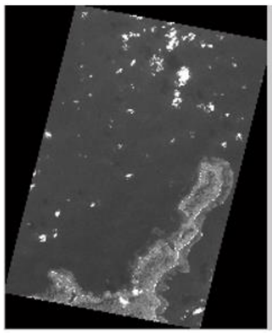

Fig. 9. Temporal 1 merged image

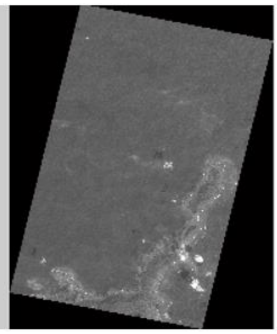

Fig.10. Temporal 2 merged image

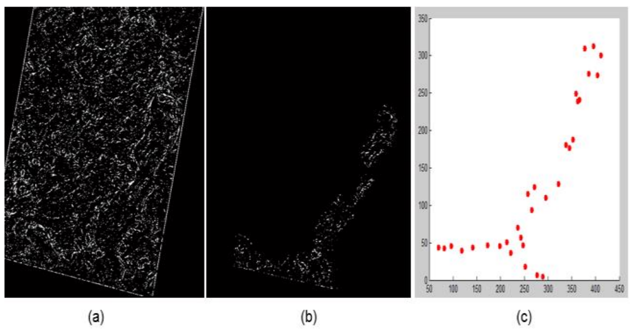

Fig.11. The candidate points of the whole image ones selected only (a); The candidate points on the island (b); The uniformly chosen candidate points (c)

Then we picked up one candidate points as P from the 31 candidate points and calculated out the coarsely the corresponding points as P' based on parallel shift distance which we have gotten, by setting mask1 on IMG1 around P and mask2 on IMG2 around P’, the sizes of mask1 and mask2 are 11*11. Then we set mask3 whose size is 30*30. By using spatial correlation technique, we calculated out the correlation coefficients, and we regarded the point having the maximum correlation coefficient as P’’. We draw out scatter diagram of pixel densities in mask1 around P and mask2 around P’’ to evaluate the correlation between IMG1 and IMG2 [8].In Fig.12 (a), the scatter diagram was taken out between pixel (363, 247) on IMG1 and pixel (358, 243). The two pixels we got were calculated based on parallel shift distance. And the effect was quite good, the correlation coefficient is 0.8118. In Fig.12 (b), the scatter diagram was taken out between pixel (433, 281) on IMG1 and pixel (423, 286) on IMG2. The two pixels we got were from using spatial correlation technique, and the correlation coefficient is 0.9986. The linear characteristic is quite obviously.

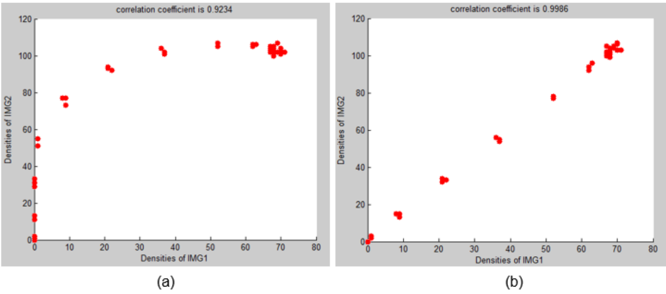

Fig.12. Density scatter diagram obtained at a point (a), and one at the correct point (we regard the point giving the maximum correlation coefficient is the correct corresponding point) (b)

In addition, TABLE I. shows us some detected parameters during the procedure of generating GCPs.

TABLE I. DETECTED PARAMETERS

Parallel Shift	[-5, -4]
Processing Time(s)	183
No. of GCPs	24
Average Correlation coefficient	0.883

V. CONCLUSIONS

For the researchers who works on remote sensing image field, they know the difficulty to accomplish the image registration process with a high accuracy. In our research, we proposed a hierarchical method for remote sensing image, and specific discussed about the method we have proposed. The critical factor in the proposed approach is using F-test to detect candidate points and using spatial correlation technique to find the corresponding points and generate the ground control point pairs (GCPs).By introducing these theories into our research, it improved the precision of image registration and eliminated the influence from manual which will take in some discrepancies. Also the image we got after the process of image registration have a quite good correlation with the based image. As it become much easier to implement the image registration, the effective also becomes much better. The proposed method helps us solve the problems which are contained in the high resolution image registration procedure in the following: (1) manually selecting the ground control point pairs which is laborious and quite time consuming; (2) with using hierarchical method, we can process with the large volume data of high resolution remote sensing images much easier. However, as we have not get the coefficients of the polynomial registration model, we have not completely accomplished the image registration. And there are many diversities of remote sensing image and remote sensing image usually is complicated, and in our preliminary experiments, we just processed with the date which is from the same remote sensor satellite. For this shortness, in the future research, firstly, we should accomplish the image registration by using polynomial registration model and do many more experiments to estimate the proposed method. And through doing some optimized operations to make sure the efficiency and robustness of the proposed approach.

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