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An Automatic Registration Method for AVHRR Remote Sensing Images

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Abstract

Automatic registration is one of the key technologies for remote sensing image processing. Considering the influence of cloud points, the phenomenon of uneven distributed control points and other problems in the process of registration for the widely used AVHRR remote sensing images, an automatic registration method for AVHRR remote sensing images is proposed. In this method, the cloud points are detected firstly. Then, a Harris corner detection method with adaptive threshold is used to extract feature points in the overlapping region of the referenced image and the original AVHRR remote sensing image. After that, an automatic matching method based on image blocking and area constraints condition is adopted. Finally, the geometric precision correction is performed to realize the registration. Experimental result shows that this method can not only obtain even distributed control point pairs and avoid the interference of cloud points, but also improve the accuracy and efficiency of registration for AVHRR remote sensing images.

Keywords: *AVHRR remote sensing images; automatic registration; cloud points detection; adaptive threshold; even distribution; area constraints condition*

1. Introduction

NOAA AVHRR remote sensing image data has been widely used in many environmental research fields, such as detection of vegetation ecosystem, land cover, land use and detection of permafrost and grassland. At present, Level-1 AVHRR remote sensing images can be downloaded for free, and registration processing is necessary for more effectively usage [1].

There are two kinds of remote sensing image registration methods, manual and automatic. The manual method chooses control point pairs in referenced image and original image with visual observation to perform registration. Manual registration method is not only time-consuming but also difficult to ensure accuracy as a result of low spatial resolution of AVHRR remote sensing images. However, accessing control point pairs with automatic method is completely depends on the images themselves instead of manual intervention [2]. An automatic registration is divided into two main methods. One is based on region and another is based on feature [3]. The method based on feature is widely used, because it only uses parts of the image information and has certain robustness for occlusion and distortion in the image.

At present, the commonly used feature extraction methods include Moravec algorithm, Harris corner detection method, SIFT feature extraction method, *et al*. Li [4] *et al*., adopted SIFT feature extraction method to realize automatic remote sensing images registration. Lu [5] *et al*., utilized Harris feature corner to implement remote sensing images registration. There are many researches about remote sensing image automatic registration based on feature, but most of them did not consider the impact of cloud points in the remote sensing images. Because of the existence of the cloud points in AVHRR

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remote sensing images, some pixels around the cloud points are easy to be considered as control points, and it may bring adverse influence on the registration accuracy [1].

Harris algorithm is an effective corner feature extraction algorithm for image and the extracted feature points have good translation and rotation invariance. The threshold is the sole criterion for judgment of feature points when using Harris feature extraction algorithm, but the threshold is difficult to determine. Zhang [6] *et al.*, proposed a threshold iteration strategy to determine the threshold automatically, but it needs a pre-determined number of feature points while the condition is also hard to determine. Zhao [7] *et al.*, presented an adaptive-threshold formula to calculate the threshold automatically, but this method does not apply to the feature extraction of AVHRR remote sensing images. Meanwhile, the obtained control point pairs using by Harris corner detection method are easily gathered in the regions that have clear texture or edge information, but those regions with low information have few control point pairs. The uneven distributed control point pairs will affect the accuracy of registration subsequently.

Additionally, in the traditional registration method, each control points in AVHRR remote sensing images and referenced images should be calculated in the process of automatic matching. On the one hand, the amount of control points in AVHRR remote sensing images and referenced images can be hundreds or thousands, so the traditional method needs a lot of time to perform automatic matching. On the other hand, each control point in the referenced image needs to match all the control points in the AVHRR remote sensing image, so it may lead to generate mismatched control point pair. The mismatched control point pair means the two control points have a big difference in the image coordinates. The existence of mismatched control point pair will reduce the accuracy of registration.

This paper proposes an effective automatic registration method for AVHRR remote sensing images to solve the interference of cloud point in AVHRR images, the difficulty of determining the threshold of Harris corner detection, the uneven distribution of control point pairs and the low efficiency of automatic matching of control points.

2. The Basic Process of Automatic Registration Method for AVHRR Remote Sensing Images

The proposed automatic registration method for AVHRR remote sensing images has been divided into seven steps, including calculation of overlapping region, cloud points detection, image enhancement, Harris corner feature extraction with adaptive threshold, automatic matching of control based on image blocking and area constraints method, least squares matching, gross error elimination and geometric precision correction. The process is shown in Figure 1. All the steps are shown as follows.

Step 1, the overlapping region in the referenced image and original AVHRR remote sensing image is calculated according to latitude and longitude information. Calculation of automatic matching in the overlapping region can effectively reduce computational complexity of registration. Here, the latitude and longitude information is expressed by Albers projected coordinate system;

Step 2, the OSTU method is adopted to compute cloud region segmentation threshold and then the cloud points can be marked by this threshold;

Step 3, considering the low contrast of the original AVHRR remote sensing images or referenced images, a histogram equalization method is used to enhance the two images. This method not only can improve the image contrast but also can highlight the feature of image object;

Step 4, a Harris corner detection method with adaptive threshold is performed to extract feature points (control points) in the two images;

Step 5, an automatic matching method of control points based on image blocking and area constraints is performed. There are two steps in the process of automatic matching, the first step is the coarse matching and the second step is the precise matching. The maximum correlation coefficient method is used to perform the coarse matching and the least squares method is used to perform the precise matching in this paper;

Step 6, a gross error elimination method is utilized to get rid of the control point pairs that have large error (mismatched control point pair). Here, least squares polynomial fitting method is used to eliminate gross error;

Step 7, the geometric precision correction is performed using by dataset of control point pairs and the original AVHRR remote sensing image. Here, the transformation of spatial position for each pixel in the original image is completed by creating a polynomial geometric correction model. And then, the bilinear interpolation method is used to resample for each pixel.

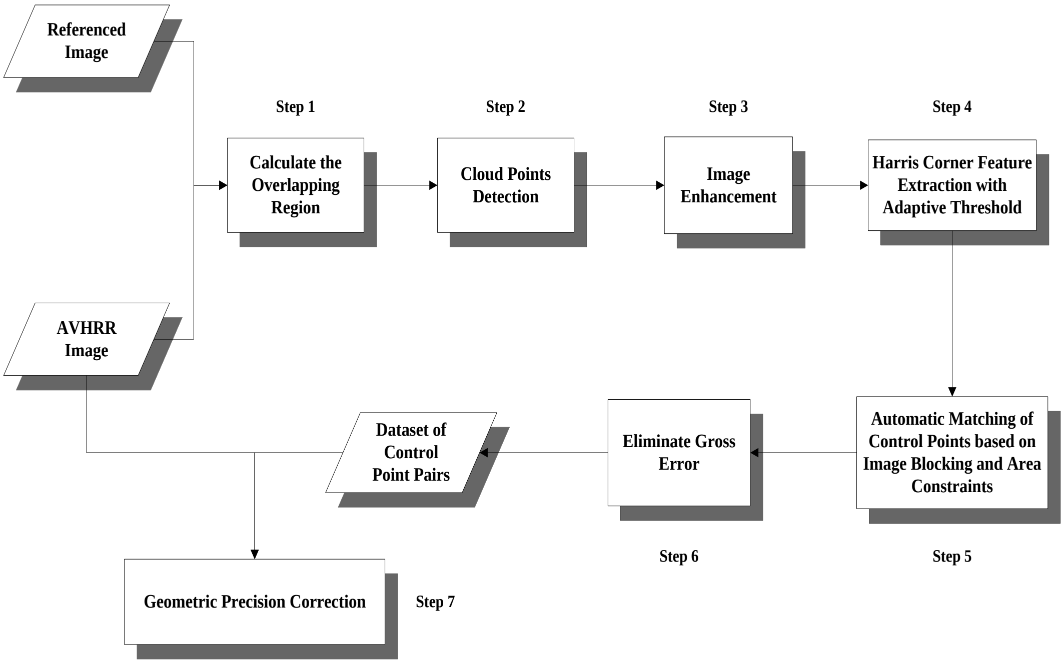

Figure 1.The Process of Automatic Matching for AVHRR Remote Sensing Images

3. The Key Algorithms and Improvements

In the proposed automatic registration method for AVHRR remote sensing images, cloud points detection, Harris corner feature extraction with adaptive threshold and automatic matching of control points based on image blocking and area constrains are main research contents in this paper. The following will describe the key algorithms and improvements.

3.1. Cloud Points Detection based on OSTU Method

In 1979, N. Otsu proposed minimum within-class variance criteria method to select the best threshold [8]. And this method is applicable to the image have obvious bimodal histogram [13]. In AVHRR remote sensing images, the pixels which belong to cloud region have big values but the pixels that belong to underlying surface have small value. The contrast between cloud region and underlying surface region is very obvious and the image generally contains a bimodal gray-level histogram. Thus we choose this method to extract segmentation threshold of cloud region，and then we use the obtained threshold to mark those cloud points. The basic calculation formula of OSTU method can be expressed as follows.

$$\sigma^2 = \omega_1 \omega_2 (\mu_1 - \mu_2)^2 \quad (1)$$

Where

$$\omega_1 = \sum_{i=0}^{t} p_i \quad (2)$$

$$\omega_2 = \sum_{i=t+1}^{M-1} p_i \quad (3)$$

$$\mu_1 = \sum_{i=0}^{t} ip_i / \omega_1 \quad (4)$$

$$\mu_2 = \sum_{i=t}^{M-1} ip_i / \omega_2 \quad (5)$$

$$p_i = n_i / N \quad (6)$$

$$N = \sum_{i=0}^{M-1} n_i \quad (7)$$

Here: σ^2—the between-cluster variance;

ω_1—the appearance probability of gray levels whose value is smaller than or equal to the threshold *t;*

ω_2—the appearance probability of gray levels whose value is larger than the threshold *t*;

μ_1—the average of gray levels whose value is smaller than or equal to the threshold *t*;

μ_2—the average of gray levels whose value is larger than or equal to the threshold *t*;

p_i—the appearance probability of each gray level in one image;

n_i—the number of pixels whose gray level is *i*;

N—the total number of pixels in one image;

M—the gray levels of one image;

t—the optimal threshold to be calculated.

The threshold *t* is computed starting from 0 to *M*-1, and then we calculate the between-cluster variance for each new threshold. The greater the between-cluster variance, the greater difference between the background and objectives in the image is. Finally, the value of *t* that has the maximum of between-cluster variance is elected to be the final threshold.

In this paper, a between-cluster variance represents the degree of difference between the cloud regions and underlying surface regions in AVHRR remote sensing images. And the threshold *t* calculated by OSTU method is expressed as the segmentation threshold of cloud region. We judge the segmentation threshold commonly varies from 300 to 550 with a large number of experiments and compress the calculation range from 0-1024 to 300-550.This improvement can not only greatly reduce the amount of calculation, but also ensure the accuracy of the threshold. Then, we compare the value of each pixel in the image with the threshold obtained by OSTU method and judge those pixels which are greater than the threshold as cloud points. And we mark these cloud points at last.

3.2. Harris Corner Feature Extraction Method based on Adaptive Threshold

Harris corner detection method [9] proposed by C. Harris and M. Stephens in 1988 was a kind of feature extraction method based on signal. This method was inspired by the signal processing of autocorrelation function, and then the M matrix associated with autocorrelation function was given. The eigenvalue of the M matrix was the first-order curvature of autocorrelation function. A pixel with high curvature in both X direction and Y direction was considered to be a feature point [10]. The feature points extracted by Harris method have good rotation invariance and translation invariance, and are very suitable for registration of remote sensing images. Harris corner detection calculation uses the following equations.

$$M = Gauss(x,y) \otimes \begin{bmatrix} I_x^2 & I_x I_y \\ I_x I_y & I_y^2 \end{bmatrix} \quad (8)$$

and

$$R = Det(M) - kTrace^2(M) \quad (9)$$

Here: I_x—the gradient of X direction for one pixel;
I_y—the gradient of Y direction for one pixel;
Gauss(x,y)—the template of Gaussian filter;
R—the interest value in each pixel;
Det—the determinant of a matrix;
Trace— the trace of a matric;
k—a constant，the value varies from 0.04 to 0.06.

Generally, feature points are extracted through comparing the interesting value of each pixel calculated by Equation (9) with one threshold. The pixel whose interest value is greater than the threshold can be considered as a feature point. So the size of the threshold selection is very important. On the one hand, if the threshold is too small, feature points may easily cluster together. On the other hand，if the threshold is too big, feature points may be very few.

The gray-level range of AVHRR remote sensing image is generally 0-1023. Normalizing to 256 gray-level range will lose a lot of useful information and it may reduce the number of feature points. So we need to use Harris corner feature extraction method under the condition of original gray- level. Plenty of experiments show that interest value range obtained by using equation (8) and (9) is very wide and the magnitude of both maximum positive value and minimum negative value are easy to reach 100000. At the same time, we also take advantage of interest value relations in all pixels to seek for an adaptive solution on the premise of interest value equations.

We present an adaptive threshold calculation equation for AVHRR remote sensing images with a large number of experiments. The equation is described as follow:

$$\rho = \varepsilon * R_{max} \quad (10)$$

Here: R_{max}—the maximum interest value of all pixels in the new image resulting from the
Gaussian filter;

ε—the empirical coefficient, and the value varies from 0.0001 to 0.001.

Experiment shows that reasonable number of feature points can be extracted in the AVHRR remote sensing images by using the equation above. One result is shown in Figure 2.

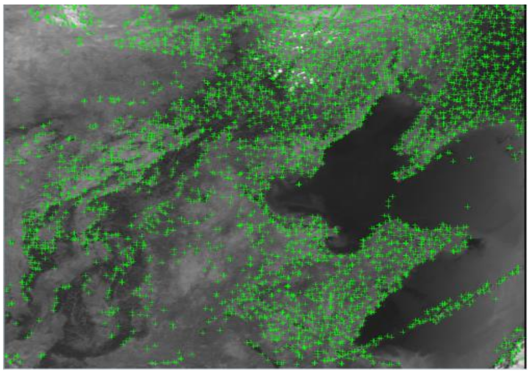

Figure 2. Result of Harris Corner Feature Extraction Method based on Adaptive Threshold

3.3. The Correlation-coefficient Matching based on Area Constraints Condition

The basic idea of area constraints firstly estimates the maximum position error of the original AVHRR remote sensing images in the process of registration. Secondly, the idea seeks a point of the AVHRR remote sensing image whose coordinate of the image is the same as each control point in the referenced image. Then, a registration window is established in the original image. In the window, length of the radius is the maximum position error and the center is the spatial coordinates obtained by above step. Finally, the matching of control points is completed in the window. The specific steps of the correlation-coefficient coarse matching based on area constrains are as follows. The intuitive description is shown in Figure 3.

(1) In the original AVHRR remote sensing image, the point $X(m, n)$ whose location is the same as the control point $Y(m, n)$ in the referenced image is found firstly;

(2)A registration window (size is $l \times l$) is established, its radius is the maximum position error and center is $X(m, n)$. With a lot of matching experiment and analysis, the numerical value 10 is selected as the empirical value of the radius and the size of window is set as 20×20;

(3)The value of correlation-coefficient is set as ρ_{thre}. With the maximum correlation coefficient matching method, the correlation-coefficients are calculated between the control point $Y(m, n)$ in the referenced image and each control point $X(m_i, n_i)$ (*i* represents the amount of control points in the registration window) in the registration window of the original AVHRR remote sensing image. Then, the maximum of correlation-coefficient is compared with ρ_{thre}. If the maximum is greater than ρ_{thre}, the control point $Y(m, n)$ in the referenced image and the control point in the registration window can be considered as a control point pair.

The calculation scope of matching in the original AVHRR remote sensing image can be transformed from the whole image into a window of 20×20 size by using area constrains condition. This method not only can reduce the amount of calculation and improve efficiency of registration, but also can solve the problem of the existence of mismatch and improve the accuracy of registration to a certain extent.

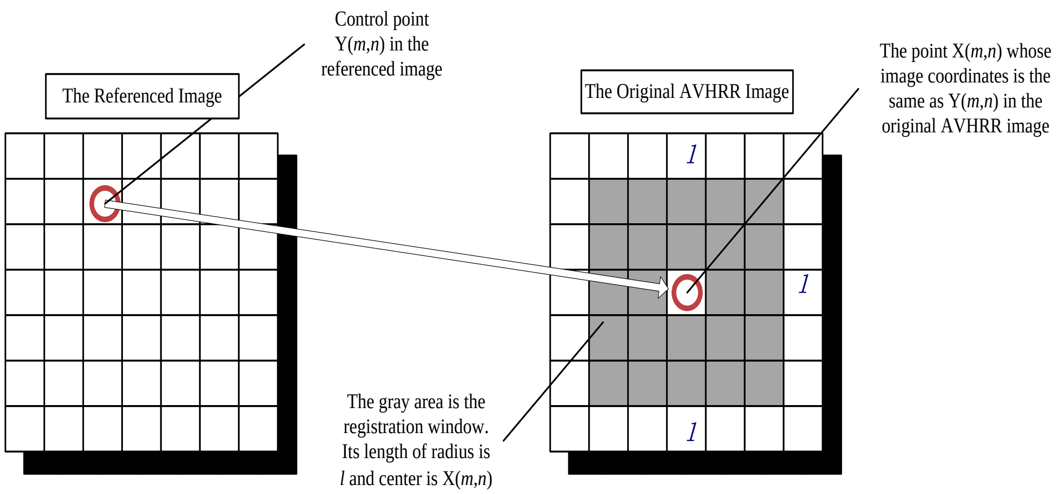

Figure 3. Schematic Diagram of Area Constrains Condition

3.4. Extraction Strategy of Control Point Pairs based on Image Blocking and Cloud Point Detection Method

The proposed extraction strategy of control point pairs has two steps. In the first step, we divide X (the referenced image) and Y (the original image) into sub-blocks by using image blocks method at first. Theoretically, the more sub-blocks, the easier to extract even distributed control point pairs. Then, we divide the overlapping region into m × n sub-blocks. For the region containing M rows and N columns, the row length is M/m and the column length is N/n in a sub-block. But the length should not be too small. And then we should mark X_i (a sub-block in referenced image) and Y_i (a sub-block have the same geographical position with X_i in original image, $1 \le i \le m \times n$), and consider them as a sub-block pair.

In the second step, we firstly select X_i and Y_i to perform match with the maximum of correlation-coefficient method. This method need to compute the correlation-coefficient between a template to be matched in the original image and the small window in referenced image and can find the position of maximum correlation-coefficient by moving the small window in the referenced image. The template to be matched is the region whose geographical position is close and size is same with the small window. Then, with the results of cloud detection, we present an inequality to rule out the interference of cloud point for the matching. This inequality is described as follows.

$$\theta > (m \times n)*10\% \quad (11)$$

Here, the θ represents the number of cloud points in a template to be matched. If the θ over 10% of the template size, it means there exist lots of cloud points. Therefore, this calculation of correlation-coefficient can be abandoned to avoid the cloud point interference. On the contrary, it is necessary to calculate the correlation-coefficient for those templates that do not meet the inequality (9). We select μ_i (the maximum correlation-coefficient) in a sub-block pair and treat the corresponding feature point pair as a candidate control point pair. Then, we set a global threshold μ_g that varies from 0.55 to 0.75. The value is adjusted based on the quality of AVHRR remote sensing images. After that we compare μ_i with μ_g, If $\mu_i \ge \mu_g$, then the corresponding candidate control point pair can be selected as final control point pair, if not, the corresponding candidate control point pair should be eliminated. Finally, each sub-block pair should be calculated by the method mentioned above.

4. Experiment and Analysis

In this paper, we firstly perform the automatic matching experiment of control points based on cloud point detection method. And then, we accomplish the automatic matching experiment respectively based on image blocking technique and area constrains condition. Finally, we complete the automatic registration experiment for one AVHRR image combined with multiple methods mentioned above. All the experimental data are derived from the website of Chinese national satellite meteorological center. The original image is an AVHRR remote sensing image in 2004 and the referenced image is a MODIS remote sensing image of China. The experimental environment is VC++6.0.

Experiment 1 performs an automatic matching with cloud detection method, and compares it with an automatic matching without dealing with the cloud points. The results of the two experiments are shown in Figure 4.a and Figure 4.b.

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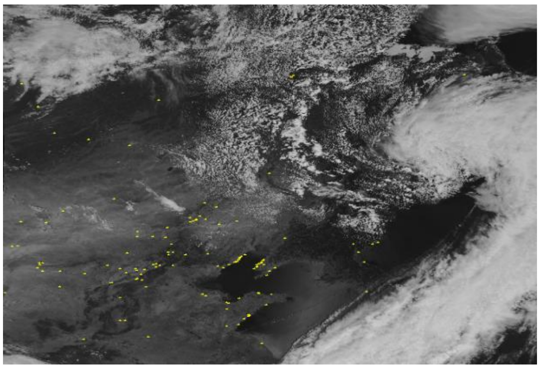

Figure 4.a. Ruling Out the Interference of Cloud Points In the Image

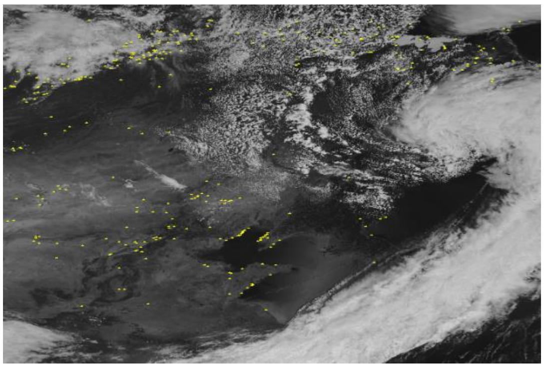

Figure 4.b. Without Ruling Out the Interference of Cloud Points In the Image

It can be found that there are more control points in Figure 4.b than them in Figure 4.a at the edge of cloud region. But these extra points are not real control points and we call them as pseudo control points. In fact, parts of pixels on the edge of cloud region due to the interference of cloud points may have a large interest value when using Harris corner detection method to extract feature points. As a result, these pixels can be easily considered as control points. And then these pseudo feature points may be extracted as pseudo control points after matching. The accuracy of automatic registration will be reduced with lots of pseudo control points. But the Figure 4.a shows that these pseudo control points around the edge of cloud region can be effectively eliminated with dealing with cloud points. Ruling out the interference of cloud points will improve the accuracy of automatic registration.

Experiment 2 performs two matching experiments with image blocking and the one without image blocking. The size of the block is 20×20, and then the images are divided into 400 sub-blocks. The results of the two experiments above are shown in Figure 4.a and Figure 4.b.

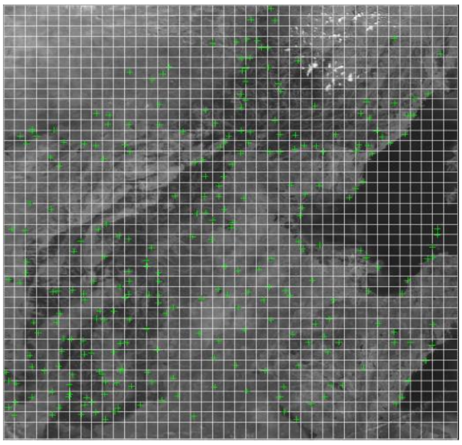

Figure 5.a. Control points of Relatively Even Distribution

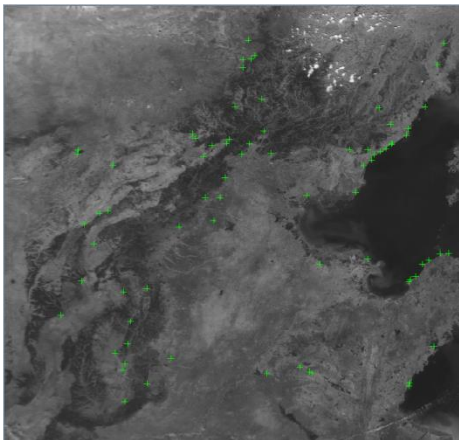

Figure 5.b. Control points of Uneven Distribution

It can be found that the whole distribution of control points in Figure 5.b is not even. In Figure 5.b, control points are clustered in the regions which have rich information of edge and texture while the regions with less information have few control points. But the Figure 5.a shows that more control points can be extracted by image blocking method and the distribution is also relatively even.

Experiment 3 performs the automatic matching experiment based on area constrains condition and then compares the matching result with the result without area constrains condition. The contrast is shown in Table 1.

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Table 1. The Contrast of Computation Time in the Two Experimental Results (Unit: second)

The original image data	Computation time of matching without area constrains condition	Computation time of matching with area constrains condition
An AVHRR image in 2004	1860.118	60.035
An AVHRR image in 2005	1544.244	52.195
An AVHRR image in 2006	1731.156	59.492

As shown in Table 1, it can be found that automatic matching using by area constrains condition will greatly reduce the computation time. Thus, the automatic matching based on area constrains condition can improve efficiently of registration.

Experiment 4 performs two automatic registration experiments, one is based on the proposed registration method in this paper and another is based on traditional registration method.

Precision analysis method for the two experiments is as follows. Firstly, we select twenty even distributed pixels which have obvious feature in reference image. Secondly, we should find the corresponding twenty pixels which have the same location with the selected pixels of reference image in the two corrected images through the experiments above. Thirdly, we calculate the error of the X direction, Y direction and distance for the twenty pixels in the two corrected images. The obtained experimental data are shown in Table 2. Finally, we calculate mean error and root-mean-square error of the X-direction, Y-direction and distance and analyze them.

Table 2. Error Statistics of the Twenty Pixels in the Two Experimental Results

The points in reference image	Not using the corresponding method mentioned in this paper			Using the method mentioned in this paper		
	Error of X-Direction	Error of Y-Direction	Error of Distance	Error of X-Direction	Error of Y-Direction	Error of Distance
1	1	1	1.4	0	1	1.0
2	2	1	2.2	0	1	1.0
3	0	1	1.0	0	1	1.0
4	0	1	1.0	1	0	1.0
5	0	1	1.0	0	1	1.0
6	0	2	2.0	0	1	1.0
7	3	0	3.0	2	0	2.0
8	0	1	1.0	0	1	1.0
9	1	1	1.4	1	0	1.0
10	1	2	2.2	0	1	1.0
11	1	0	1.0	1	0	1.0

12	1	0	1.0	1	0	1.0
13	1	1	1.4	0	1	1.0
14	1	1	1.4	0	1	1.0
15	1	0	1.0	0	0	0.0
16	0	1	1.0	1	1	1.4
17	1	2	2.2	0	1	1.0
18	1	2	2.2	0	1	1.0
19	1	1	1.4	1	1	1.4
20	0	1	1.0	1	0	1.0

Analyze the data in the Table 2, we can get the error analysis results. The result is shown in Table 3. It can be seen that both the mean error and root-mean-square error obtained by the proposed method are less. The experimental results show that using the proposed method can improve the accuracy of automatic registration for AVHRR remote sensing images.

Table 3. Error Analysis

Error Type	Not using the corresponding method mentioned in this paper			Using the method mentioned in this paper		
	X-Direction	Y-Direction	Distance	X- Direction	Y- Direction	Distance
Minimum error	0.0	0.0	1.0	0.0	0.0	0.0
Maximum error	3.0	2.0	3.0	2.0	1.0	2.0
Mean error	0.80	1.0	1.49	0.45	0.70	1.04
Root-Mean-Square error	0.77	0.65	0.60	0.60	0.47	0.35

5. Conclusion

An automatic registration method for the widely used AVHRR remote sensing images is studied here. The OSTU method is adopted to calculate the threshold of cloud region and the cloud points can be marked with this threshold. An adaptive threshold formula suitable for AVHRR remote sensing images is presented to solve the problem that the threshold is difficult to determine in Harris corner detection algorithm. The automatic matching of control points based on image blocking and area constrains condition is performed. Automatic matching method based on area constrains condition can not only reduce the amount of calculation of matching but also eliminate the existence of mismatch to a certain extent. Even distributed control point pairs can be obtained using by image blocking method so that the phenomenon of uneven distribution can be effectively solved. Meanwhile, the interference of cloud points can be eliminated with the marks of cloud points. The experiment of automatic registration shows that the accuracy and efficiency of automatic registration for AVHRR remote sensing images can be improved.

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