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Parallel Research and Implementation of SAR Image Registration Based on Optimized SIFT

Quan Sun[1,2], Jianxun Zhang[1]*
[1]School of Computer Science and Engineering, Chongqing University of Technology, Chongqing, 400054, China,
[2]College Mobile Telecommunications Chongqing University of Posts and Telecom, Chongqing, 401520, China
*Corresponding author, e-mail: zjx@cqut.edu.cn

Abstract

A new SAR image registration method was Proposed based on improved SIFT algorithm. Which adopted multi-core system platform was used to overcoming the problem of high complexity algorithm of SIFT algorithm; According to the characteristics of SAR image, first of all, the source SAR image was enhanced in airspace, and finish the parallel extraction of feature points with the improved SIFT algorithm, then used Euclidean distance and the RANSAC algorithm to complete the matching of feature points and eliminate unmatching, finally realizes the SAR image registration. The experimental results show that the method can guarantee in the registration precision and reduce the complexity of the registration.

Keywords: *SIFT, airspace enhance, parallel optimization, SAR image registration*

1. Introduction

SAR (abbreviation of synthetic aperture radar) [1] image registration is the best matching of more than two images of the same scene that generated by the same or different sensor in the same or different times, that using spatial geometric transformation methods [2].

Currently image parallel processing methods can be broadly divided into parallel approach that based parallel cluster system [3] and based shared storage [4] technology. Of which the former use the manner of data-parallel to complete the parallel processing of the image by the message passing within the cluster system; the latter optimize the algorithm that through the shared storage to achieve the purposes of parallel calculation. OpenMP is a relatively mature shared storage technology that used for multi-threaded programming interface of shared memory parallel systems, and is a very completed set of guidance notes proposed by OpenMP Architecture Review Board.

SIFT (Scale In-variant Feature Transform) algorithm is the algorithm which making use of machine vision technology to detect and describe locality characteristics of image. SIFT algorithm was first published in 1999 and perfect which in 2004 by David Lowe. The algorithm have good robustness in a variety of performance in the case of the image scale invariance, rotation transformation and affine transformation of stability, etc.

We presented a better robustness method of SAR image parallel registration, which was based on a multi-core platform. When the image had been enhanced by method of histogram equalization, we used the parallel improved SIFT feature extraction algorithm to extract the feature of image, and completed the SAR image registration. The method had very good results in the effect of the registration, the computation speed and robustness.

2. SAR Image Registration Method

SAR image registration is the best matching of two or more images of the same scene that generated by the same or different sensor in the same or different times, that using spatial geometric transformation methods. Usually we select one of the two images as reference image and the other image as registration image, and match the registration image with the reference image. Taking into account the characteristics of SAR images, and the framework of the parallel registration algorithm based on SIFT we present follows:

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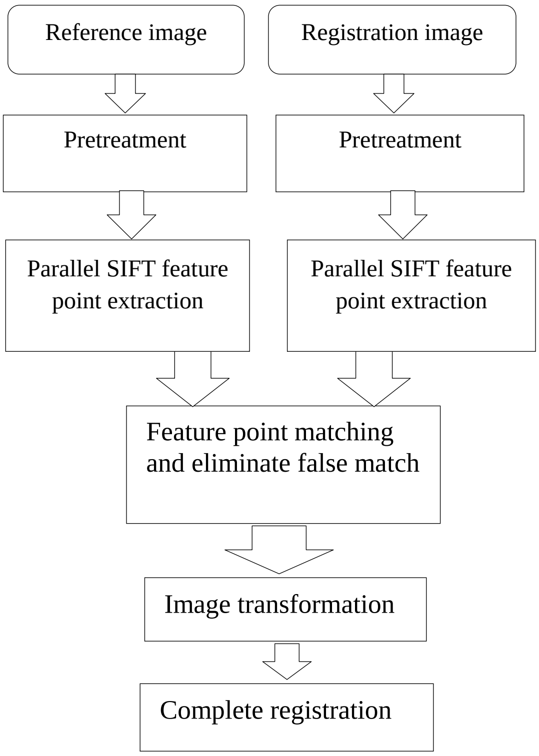

Figure 1. SAR Image Registration Algorithm Framework

3. Image Sources and Pre-processing

Due to uneven illumination, the factors such as terrain and sunshine will influence the image with uneven light and dark in the SAR image process [5], as shown in Figure 2, Figure 3. Interested characteristics in the lower light level area of SAR image, such as the target point and the boundary lines are not sufficiently clear, which will result in that the feature extraction algorithm can not identify the region of interest effectively which may lead to bad feature extraction effect or even failure.

That is why we need an image enhancement process. The image enhancement is the technology which using some kind of technology to highlight the key information of image and weaken (or eliminate) the irrelevant information at the same time according to the blur length of the source image to stress the purpose useful features of image [6]. In this paper, we used a method of histogram equalization to enhance the SAR image in airspace in order to improve the feature extraction accuracy of the SIFT algorithm.

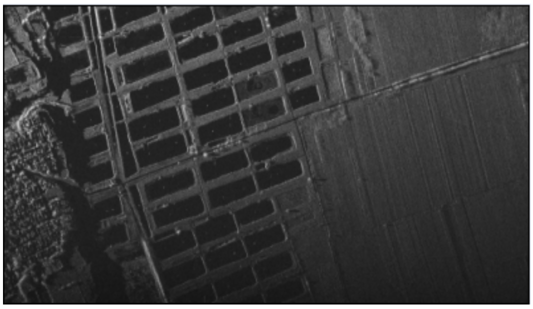

Figure 2. Reference Image

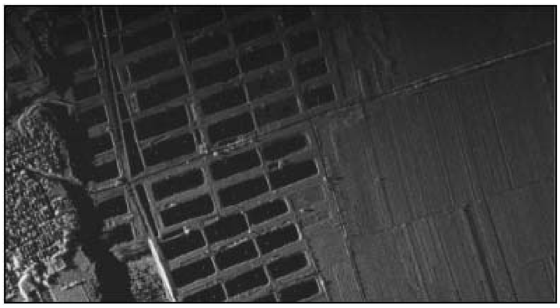

Figure 3. Registration Image

4. The SIFT Feature Extraction Algorithm

SIFT algorithm [7-9] have been widely used in the field of image processing, computer vision and stereo matching, which find the extreme points in the spatial scale and extract its position, scale and rotation invariant.

SIFT algorithm is divided into four steps: (1) the establishment of the Gaussian pyramid scale space of image and detection of extreme points; (2) the detection and localization of key points; (3) the descriptor calculation of the feature points; (4) to generate the feature descriptor.

Original image $I(x,y)$ in different factor of scale space σ convolute with the Gaussian kernel $G(x,y,\sigma)$:

$$L(x,y,\sigma) = G(x,y,\sigma) * I(x,y) \quad (1)$$

Thereinto, $G(x,y,\sigma) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$, (x,y) is the spatial coordinates of image pixel, the image scale space factor (or scale space coordinates) σ bigger the profile detail features of the image fewer.

The scale space have been established, in order to find a stable key point, we used the method of Difference of Gaussian to detect the extreme points in local position, and made use of different scale Gaussian differential convolute with the original image $I(x,y)$ to generate the Difference of Gaussian scale space(DOG scale-space):

$$\begin{aligned} D(x,y,\sigma) &= (G(x,y,k\sigma) - G(x,y,\sigma)) * I(x,y) \\ &= L(x,y,K\sigma) - L(x,y,\sigma) \end{aligned} \quad (2)$$

The coefficient K means the scale size. Firstly we convoluted the original image with the Gaussian kernel function of the different scale factor to obtain a different set of scale image, taken this set of image as the first layer of the image scale space. The first layer image had been down-sampled, and convoluted this set of image with the Gaussian kernel of different scale factor as the second layer of the generated image scale space. And repeat these steps until the image is smaller than a given threshold generated by the image scale space.

As a candidate point for the extreme points of the DoG space in 8 areas of the scale, in 9 areas of the upper and lower scales 26 areas points in all, and Taylor expansion at the candidate points expansions are as follows:

$$D(v) = D + \frac{\partial D^T}{\partial v} v + \frac{1}{2} v^T \frac{\partial^2 D}{\partial v^2} v \quad (3)$$

There into, $v = (x,y,\sigma)^T$ solve the equation above to get a sampling of key points, the sampled pixel and the exact coordinates of the sampling scale:

$$\hat{v} = -\frac{\partial^2 D^{-1}}{\partial v^2} \cdot \frac{\partial D^T}{\partial v} \quad (4)$$

5. Characteristics Extraction Based on Improved SIFT Algorithm

The analysis of the SIFT algorithm above show that the feature points location, the feature point descriptor generating and image down-sampling critical step of the algorithm is in a huge amount of calculation, which consume a relatively long time in the SIFT algorithm [10].

To the serial SIFT algorithm, the algorithm will locate feature point direction and generate feature point descriptor with each of the detected feature points in the scale space; however, only a small part of the feature points will be exploited up in the subsequent calculations [11]. Which will waste a huge number of computing resources, increase the complexity of the algorithm greatly. In order to reduce the complexity of the algorithm, we use the parallel improved SIFT algorithm to extract the feature point.

Firstly, we detect the feature point of all scales group. The detected feature point will be screened in the subsequent steps of the feature point direction position and the generation of feature point descriptor: Therefore, in order to reduce the amount of calculation, we filter the unwanted feature point in subsequent processing after the feature point detection phase, which can greatly reduce the amount of calculation. The 5×5 template of screening selected operator was defined as follows:

$$M = \begin{bmatrix} \alpha & \alpha & \alpha & \alpha & \alpha \\ \alpha & \alpha & \alpha & \alpha & \alpha \\ \alpha & \alpha & \alpha & \alpha & \alpha \\ \alpha & \alpha & \alpha & \alpha & \alpha \\ \alpha & \alpha & \alpha & \alpha & \alpha \end{bmatrix} \quad (5)$$

There into, $\alpha = 1$. We use the template to determine whether there is only one detected feature point in the template. If it was true, we retained this feature point and determined the next point. If there were two or more feature points in the template, compared the significant of the feature points and select the most significantly point, the formula of significant comparative as follows:

$$H(x_i, y_i) = \sum_{(x,y)\subset M} \exp\left\{-\frac{I(x_i, y_i) - I(x, y)}{T}\right\} \quad (6)$$

There into, $I(x_i, y_i)$ is the pixel value of the detected feature point; $I(x, y)$ is the pixel value of the feature points within the template; (x_i, y_i) is the pixel coordinate; In this paper the threshold value of the gray-scale difference $T = 20$. The screening condition is as follows, where K is the number of feature points of the template:

$$\max_{1 \le i \le K} \{H(x_i, y_j)\} \quad (7)$$

While use the improved SIFT algorithm for feature extraction, we also optimize the parallel of the improved algorithm in order to minimizing the processing time complexity.

6. Matching Feature Points and Eliminate the False Match

Usually we match two images based on the similarity between the characteristics of feature points. There are many similarity measurement methods, such as block distance, Hausdorff distance [12], Euclidean distance and Mahalanobis distance. Euclidean distance is selected in this article to complete the similarity measurement and the feature points initial matching.

We get a set of matched feature points after the initial feature matching. Since the SIFT algorithm is a local feature points extraction algorithm which can not take the overall distribution of the feature points into account. Therefore, mismatching may occur when feature points initially matched. The matched feature points conform to the motion model between the reference image and registration image are called inside point, the points do not conform to are called outside point, outside point must be clear in order to prevent it from interfering the estimation of motion model parameters. We use RANSAC method to eliminate false matching and improve the matching accuracy.

RANSAC (RANdom Sample Consensus) [13] proposed by Fischler and Bolles in 1981, whose basic idea is that design search engine for the problem firstly, and then use this engine to remove the different values between the input data and the estimated parameters, finally use the correct data to parameter estimation when the parameters estimating is needed.

7. Experimental Results Analysis

AMD dual-core 64-bit CPU PC was used as hardware platform in this experiment and VC6.0 combined with the OpenMP multi-threaded programming for software development platform. Firstly, we processed the source image with airspace enhancement method. Then the parallel improved SIFT algorithm was used to extract the feature point of SAR image, and the extracting effect of improved SIFT algorithm was contrasted with the serial SIFT algorithm. Finally, after matching feature points, eliminate mismatching and transformation, the SAR image registration was completed.

7.1. The Feature Extraction Effect Comparison

Due to uneven illumination, the factors such as terrain and sunshine will cause the image to produce uneven light and dark in the SAR image process, as shown in Figure 2, Figure 3. Interested features in the SAR image of the lower light level area, such as the target point and the boundary lines are not clear enough, which will result in that the feature extraction algorithm can not effectively identify the region of interest which can lead to bad feature extraction effect or even failure. In this paper, we used the method of histogram equalization to enhance the SAR image in airspace in order to improve the feature extraction accuracy of the SIFT algorithm.

Here the following reference picture is the comparation between the feature extraction effect of the image before enhancement and after:

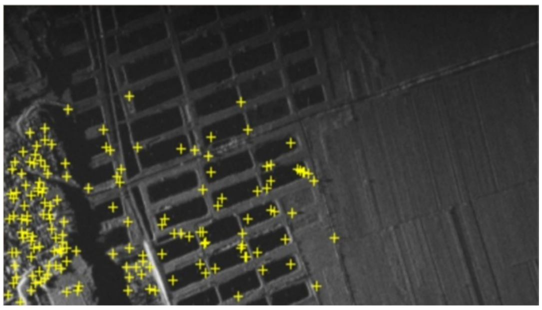

Figure 4. Feature Extraction Effect of Reference Image

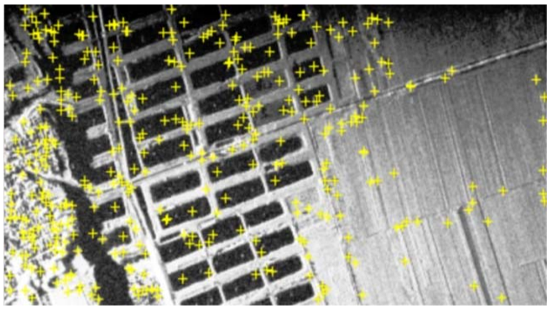

Figure 5. Feature Extraction Effect of Enhanced Reference Image

From Figure 4, the extracted feature point number is 155, and the Figure 5, the extracted feature point number is 412. As is showed in the figures, the feature point can only be successfully extracted in left-down part of the original image where the light is preferably, the extracted feature point of the image after enhancement is more uniform than the former, and the number of the feature points is 2.66 times of the former.

7.2. The Feature Extraction Experiments Comparation

The feature extraction cost the largest proportion of the entire SAR image registration process time. Serial SIFT algorithm and parallel improved SIFT algorithm were used respectively to extract feature of the source image and the enhanced image, and the algorithm feature extraction time has been compared, as shown in the following table:

Table 1. Feature Point Extraction of Original Image Time Comparison

Time	Reference image(ms)	Registration image(ms)
SIFT	2953	2875
Parallel improved SIFT	1180	1153

Table 2. Feature Point Extraction of Enhanced Image Time Comparison

Time	Enhanced reference image(ms)	Enhanced registration image(ms)
SIFT	4968	4781
Parallel improved SIFT	2078	1998

The following is the performance optimization assessment of the parallel algorithm. The parallel optimization assessment mainly includes two aspects of the speed-up ratio and time complexity. The speed-up ratio expression as follows:

$$S_p = \frac{T_s}{T_p} \tag{8}$$

There in, T_s is the computation time of the serial algorithm, T_p is the time consumed by the parallel algorithm, p is the number of processor.

Set the number of processors for p, the number of feature points is N, and the time complexity of the serial SIFT algorithm is $O(N)$. Because of the p processor set up sharing stack feature point access operation at the same time, the time complexity is $O(\log_p N)$.

The characteristic direction and feature descriptor of the feature point in the characteristics stack have been calculated by the parallel algorithm. The average acceleration ratio of the algorithm is 2.4, and the time complexity has been decreased about 50%. The algorithm screens the initial detected feature point before the feature point direction position and the characteristics descriptor formation steps, so it is reasonable that the speed ratio is more than the number of processors.

7.3. SAR Image Registration Results

The two figures of Figure 2 and Figure 3 differ in light and shade due to the illumination conditions. The registration experimental results of the two figures as follows:

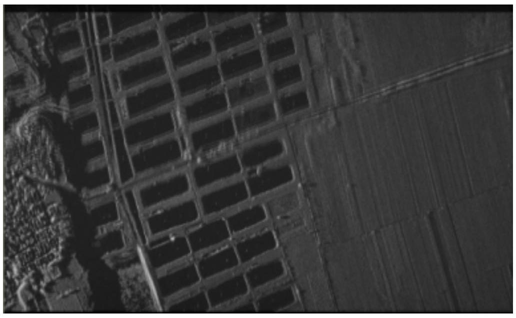

Figure 6. Results of SAR Image Registration

From the Figure 6, the results of the registration algorithm meet the registration requirements.

8. Conclusion

The article proposes a new method of SAR image parallel registration which has better robustness. Due to uneven illumination, the factors such as terrain and sunshine will cause the image to produce uneven light and dark in the SAR image process. Firstly, we process the SAR image with method of airspace enhancement to improve the accuracy of registration. Then we use the parallel improved SIFT algorithm to parallel extract the feature point on the multi-core platform, and the efficiency of the registration has been improved in a large extent. Experimental results show that the efficiency of improved SIFT algorithm is about 2.4 times of the traditional SIFT algorithm. The method greatly reduces the time complexity of registration computing on the basis of guaranteeing the precision of registration.

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