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SAR Image Matching Algorithm Base on Improved Hu Invariant Moments

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Abstract

SAR image matching as a key technology is valuable in theory and practicality. Recent years, wide attention has been paid to cross-correlation algorithm and Hu invariant moments algorithm in the image matching field. The paper introduces concept of the two methods, and takes samples to analyze them to summarize the merits and faults. These two methods are not so effectual for SAR image matching. So based on the traditional Hu invariants moments algorithm, a new kind of improved Hu invariant moments algorithm is proposed. The experimental results prove that the improved method is stable and reliable under some variations for rotation in SAR image matching.

Keywords: *Cross-correlation; Hu Invariant Moments; Image matching; SAR image*

1. Introduction

Synthetic Aperture Radar (SAR) is an active microwave imaging system. It can work all weather and all time. Recent years, it is widely used in geological exploration, surface monitoring and military reconnaissance. It has become an important method to observe earth in high resolution. The technology of SAR has made considerable progress. The resolution of SAR image has reached to centimeters, which push the application of SAR image quickly. Developing the technology of SAR image processing and using mass data to get more information from SAR images become a hot spot issue in the field of SAR.

The technology of SAR image matching is one of the problems in the field of SAR image processing. It is widely used in image fusion, object identification and tracking. Nowadays, image matching methods can be mainly divided into two kinds: one is based on the gray value and the other one is based on the characteristic [1, 2]. The two methods are both popular now. And each method has its advantages and disadvantages.

The method based on the gray value usually uses the cross-correlation algorithm. The principle of this algorithm is easy to understand. And the accuracy of the algorithm is high. But the amount of calculation is huge. And the biggest fault is that the algorithm is sensitive to the conditions of image zooming, rotating, lighting, noising and small-scale perspective transformation. Because of the differences of emission source location, azimuth and height in SAR, there are rotations, zooming and metamorphoses in different SAR images. So cross-correlation algorithm is not so suitable for SAR image matching.

Comparatively speaking, the method based on the characteristic can extract some invariable information to match images. It can be used widely. So recent years, this method has become a keystone of image matching method. The method based on the characteristic usually includes Hu invariant moments algorithm and SIFT algorithm.

But because of severe speckle noises in SAR image [3], SAR image processing is more complicated than optical image processing. So the traditional image matching method is not perfect. In the paper, based on Hu invariants moments, a new kind of improved Hu invariant moments algorithm is proposed. The experimental results prove that the improved method is more stable and more reliable for SAR image matching.

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2. Cross-Correlation Algorithm

Cross-correlation algorithm was proposed in 1974. The algorithm uses the statistic correlation of information to match images. When the result of cross-correlation reaches the maximum, the matching image and the reference image get a best matching result [4]. Here is the specific process as follows.

Suppose $F = f(x, y)$ as the reference image whose size is $M \times N$. Suppose $G = g(x, y)$ as the matching image whose size is $m \times n$. $M \geq m, N \geq n$. We want to find an area in image F, which can match with image G. S is a two-dimensional matrix whose size is as same as image G.

$$S = s(i, j) = f(x + i - 1, y + j - 1) \quad i = 1, 2 \ldots, m \quad j = 1, 2 \ldots n \tag{1}$$

$\rho(i, j)$ is the related coefficient of S and G. $\rho(i, j)$ can be obtained as follow expression.

$$\rho(i, j) = \frac{\operatorname{cov}(S, G)}{\sqrt{D_s D_G}} \tag{2}$$

Where D_s and D_G are the variance of S and G respectively as follow expressions.

$$D_S = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (s(i, j) - \overline{S})^2 \tag{3}$$

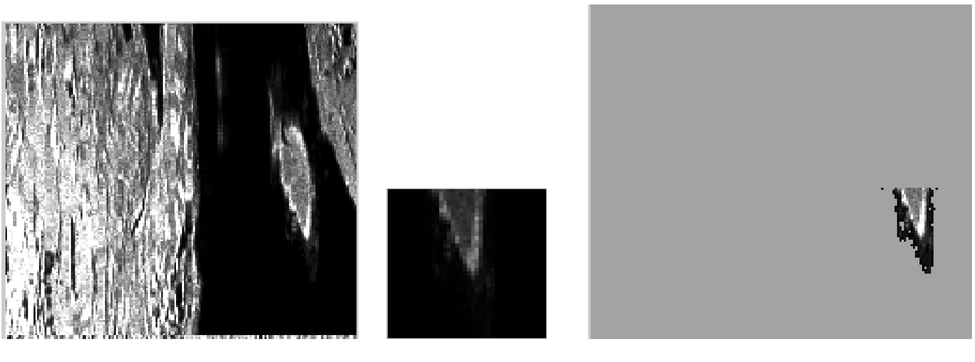
$$D_G = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (g(i, j) - \overline{G})^2 \tag{4}$$

$\operatorname{cov}(S, G)$ is the covariance of S and G.

$$\operatorname{cov}(S, G) = \frac{1}{mn} \sum_{i=1}^{m} \sum_{j=1}^{n} (S(i, j) - \overline{S})(g(i, j) - \overline{G}) \tag{5}$$

Where $\overline{S}$ and $\overline{G}$ are the mean of the gray value of image S and image G.

Theoretically, when $\rho(i, j) = 1$, image G and image F match at the point (i, j).



a) Reference Image b) Matching Image c) The Position for Matching Result

Figure 1. The Result of Image Matching by Cross-Correlation Algorithm

Figure 1 is the result of image matching by cross-correlation algorithm. Both image a) and image b) are real SAR images. The image a) in Figure 1 is the reference image. And the image b) is the matching image. By cross-correlation algorithm, we can find the position where the matching image is in the reference image. From the image c), we can easily see that we get a right result of matching images.

Cross-correlation algorithm is mainly used for matching images without rotating. The algorithm is accurate when the two images are in the same direction. Even if the gray value of matching image changes, the algorithm still can get a right result. And the algorithm is not sensitive to the noise of the image.

But the algorithm still has some disadvantages. We notice that the algorithm is very sensitive to conditions of image zooming, rotating, lighting and small—scale perspective transformation [5]. For example, if the matching image rotates an angle, the cross-correlation algorithm is not useful. And another disadvantage is the amount of calculation is huge when the image is big. It is inefficiency. So we want to find a better algorithm to match images.

3. Hu Invariant Moments Algorithm

In 1962, a scientist named Hu proposed a continuous function invariant moments which can be used to identify an area shape. When an image moves or rotates, the invariant moments won't vary. Now this algorithm has become one of the most popular methods to match images [6].

We suppose that the gray value of a digital image is stored in a two-dimension matrix. Based on the theory of Hu invariant moments, we can calculate seven invariant moments of the matching image. The seven invariant moments can be described as follows.

Suppose $G = g(x, y)$ as the matching image whose size is $m \times n$. Its $p+q$ moment is:

$$M_{pq} = \sum_m \sum_n m^p n^q g(m, n) \tag{6}$$

The $p+q$ central moment of $g(m,n)$ is:

$$u_{pq} = \sum_m \sum_n (m - \overline{m})^p (n - \overline{n})^q g(x, y) \tag{7}$$

Where $\overline{m}$ and $\overline{n}$ are the gravities of the area：

$$\overline{m} = M_{10} / M_{00}, \qquad \overline{n} = M_{01} / M_{00}$$

The normalized central moment of $g(x, y)$ can be expressed as follows.

$$\mu_{pq} = \frac{u_{pq}}{u_{00}^r} \tag{8}$$

Where $r = (p+q)/2 + 1$, $p + q = 2, 3 \ldots$.

We can use vector $\Phi_G = [\varphi_1, \varphi_2 \ldots \varphi_7]$ to express the seven moments of matching image. $\varphi_1, \varphi_2 \ldots \varphi_7$ are as follows.

$$\varphi_1 = \mu_{20} + \mu_{02} \tag{9}$$

$$\varphi_2 = (\mu_{20} - \mu_{02})^2 + 4\mu_{11}^2 \tag{10}$$

$$\varphi_3 = (\mu_{30} - 3\mu_{12})^2 + (\mu_{03} - 3\mu_{21})^2 \quad (11)$$

$$\varphi_4 = (\mu_{30} + \mu_{12})^2 + (\mu_{03} + \mu_{21})^2 \quad (12)$$

$$\varphi_5 = (\mu_{30} - 3\mu_{12})(\mu_{30} + \mu_{12})[(\mu_{30} + \mu_{12})^2 - 3(\mu_{03} + \mu_{21})^2] + (3\mu_{21} - \mu_{03})(\mu_{21} + \mu_{03})[3(\mu_{30} + \mu_{12})^2 - (\mu_{03} + \mu_{21})^2] \quad (13)$$

$$\varphi_6 = (\mu_{20} - \mu_{02})[(\mu_{30} + \mu_{12})^2 - (\mu_{21} + \mu_{03})^2] + 4\mu_{11}(\mu_{30} + \mu_{12})(\mu_{21} + \mu_{03}) \quad (14)$$

$$\varphi_7 = (3\mu_{21} - \mu_{03})(\mu_{30} + \mu_{12})[(\mu_{30} + \mu_{12})^2 - 3(\mu_{03} + \mu_{21})^2] + (3\mu_{12} - \mu_{30})(\mu_{21} + \mu_{03})[3(\mu_{30} + \mu_{12})^2 - (\mu_{03} + \mu_{21})^2] \quad (15)$$

Traverse the reference image to get $S(i, j)$ which has the same size as the matching image. So the size of $S(i, j)$ is $m \times n$. Calculate the seven invariant moments of $S(i, j)$. Then Store the result in $\Phi_F(i, j)$. Calculate the distance between victor $\Phi_F(i, j)$ and Φ_G as follows.

$$DD(i, j) = \left\|\Phi_F(i, j) - \Phi_G\right\| = \sqrt{\sum_{k=1}^{7} (\varphi_k(i, j) - \varphi)^2} \quad (16)$$

Theoretically, when $DD(i, j) = 0$, it means at the coordination in reference image the seven invariant moments of $S(i, j)$ is as same as the seven invariant moments of the matching image. So it shows that image G and image F can match at the coordination (i, j).

The flow chart of Hu invariant moments algorithm is as Figure 2.

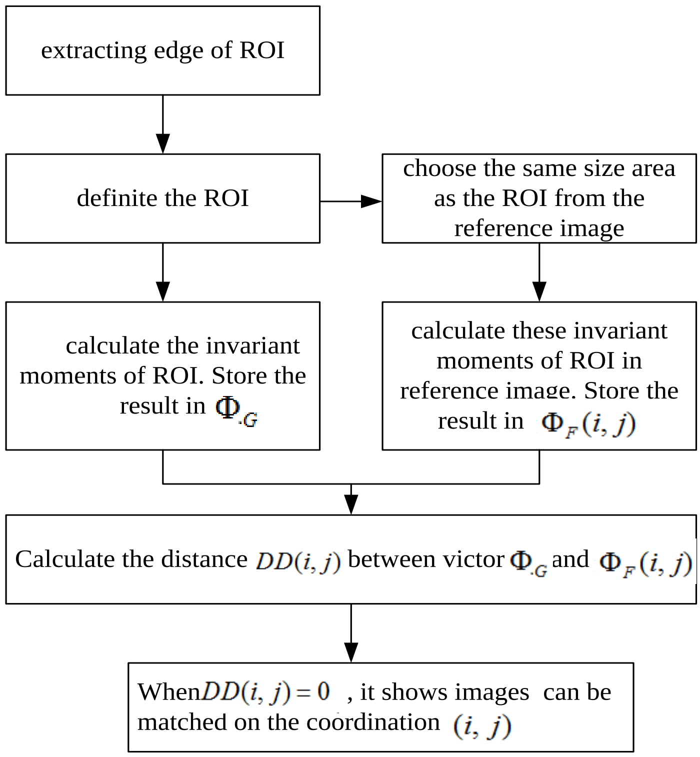


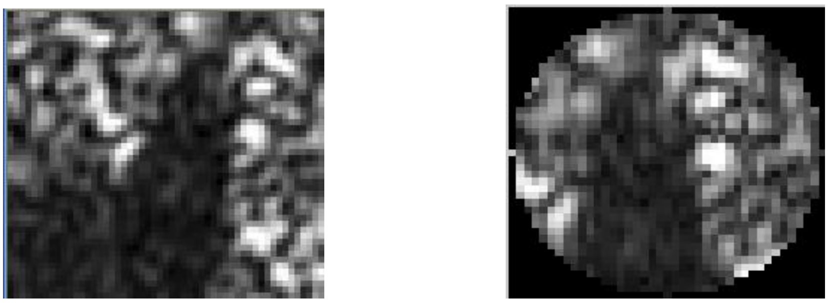
Figure 2. The Flow Chart of Hu Invariant Moments Algorithm

4. Improved Hu invariant Moments Algorithm

In theory, Hu invariant moments algorithm is more flexibility than cross-correlation algorithm. So its application is more extensive. But Hu invariant moments algorithm needs to definite a closed area of interested (ROI). In general, we can definite a closed area based on the edge. So we should extract edge of a ROI firstly. There are many methods to extract edge, such as Roberts, Laplacian, Canny and so on. But there are more speckle noises in SAR image, so these methods of edge detection sometimes can't work well. The problem makes Hu invariant moments algorithm more difficult to use. To solve the problem, we can consider the whole matching image as the ROI. Then we can calculate the invariant moments of the whole ROI. Then we choose the same size area as the ROI from the reference image and calculate these invariant moments of the area.

Obviously, the ROI is a quadrate closed area by using this method. And when the image rotates some angles the pixels in a quadrate closed area are changed. And the invariant moments are changed too. So if the images rotate, we can't get a correct result by this method. So we try to use a round closed area instead of using the quadrate closed area. And the center of the circle is the center of the ROI. Because we know that a round area will not be changed when the image rotates. Then we calculate the invariant moments of the round closed area. Store the result in Φ_F . Then we choose the same size area as the ROI from the reference image and calculate its invariant moments. Store the result in $\Phi_G(i, j)$. At last, we can calculate $DD(i, j)$.

From figures below, image a) in Figure 3 is the matching image. And we can consider image b) in Figure 3 as the ROI. It is a round area. So when it rotates, the area won't change.



a) Matching Image b) The Result of Choosing a Closed Area

Figure 3. The Way to Choose a Closed Area

Then according to Hu invariant moments algorithm as above, we hope to find coordinate (i, j). At this point we can make $DD(i, j) = 0$. It means the circular area whose center is (i, j) has the same invariant moments as the ROI in matching image. So the circular area whose center is (i, j) can match with the ROI in matching image. Therefore, we can accomplish image matching.

But after experiment, we find that when the matching image rotates we can't find a coordinate (i, j) to make $DD(i, j) = 0$. After analyzing, we find the reason is the digitized image. When a digitized image rotates, the gray value in a pixel will change. It can be easily seen as the figure below. We know that each pixel is a quadrate area. When the image on the left side rotates, the gray value in a small quadrate area is not same as the gray value on the right side. So we can't find an area whose invariant moments are same as ROI in the matching image.

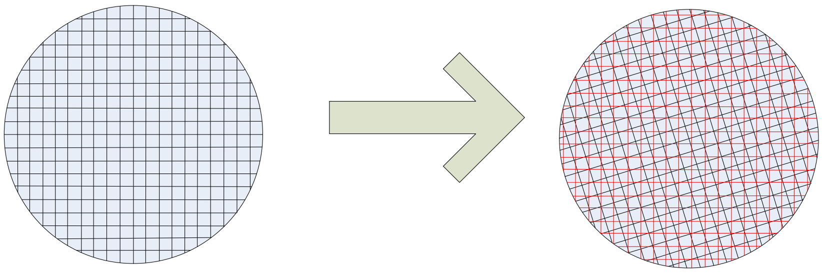


Figure 4. The Reason of the Digital Error

To solve the problem which is brought because of the digitized image, we can sequence $DD(i, j)$ from small to large. When $DD(i, j)$ is the minimum, (i, j) is the matching coordinate of matching image and reference image.

So the flow chart of Hu invariant moments algorithm is improved as Figure 5. Compared with the traditional Hu invariant moments algorithm, there are two more steps. One is to definite a round area as a ROI. The other is to sequence $DD(i, j)$ to find the minimum in $DD(i, j)$. The two steps increase the amount of the calculation. But they make the algorithm more effectual.

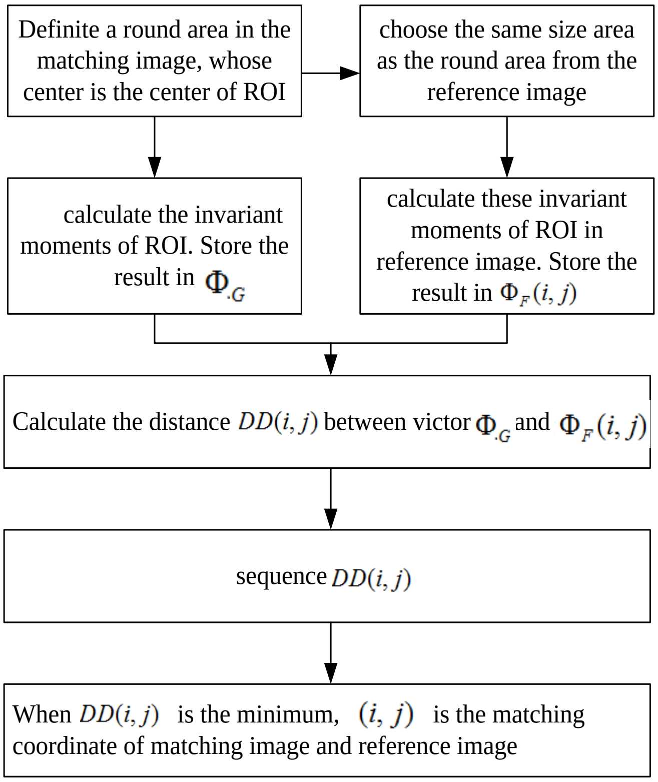
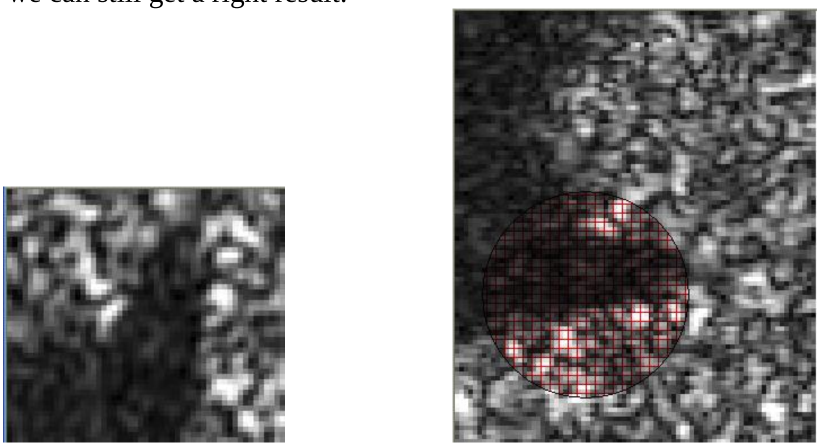


Figure 5. The Flow Chart of Improved Hu Invariant Moments Algorithm

Using the improved Hu invariant moments algorithm, we can match images. For example, image a) in Figure 6 is the matching image and image b) in Figure 6 is the reference image. Both of them are real SAR images. After calculating, we can find an area in the reference image. And the area is the matching result. We can find that the matching image and the reference image have some angles. But by using the improved algorithm, we can still get a right result.



a) Matching Image   b) Matching Result

Figure 6. Matching Result by using the Improved Hu Invariant Moments Algorithm

5. Conclusions

This paper proposes a new kind of improved Hu invariant moments algorithm. The improved Hu invariant moments algorithm can choose a closed area in the reference image automatically based on the size of ROI in the matching image. Then calculate the distance of the invariant moments between ROI and the closed area in the reference image to get the minimal distance. From this, we can get the position of image matching in reference image. This algorithm can be used when matching image and reference image have a certain angle. At last, the experiment shows the algorithm is effectual.

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