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Research on Change Detection in Remote Sensing Images by using 2D-Fisher Criterion Function Method

Baoming Zhang, Ke Chen,Yang Zhou, Mingxia Xie, Hongwei Zhang
Remote Sensing Information Engineering Department, Zhen Zhou Institute of Surveying and Mapping, Zhen Zhou, China,
E-mail: zbm2002@vip.371.net, ck1702@163.com, zhouyang3d@163.com, xmx0424@yahoo.cn, hongwei0691@163.com

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ABSTRACT:

In this paper, 2D-Fisher criterion function was introduced to change detection in remote sensing images based on classic one dimension fisher criterion function, and this expanded the space of grey value from one-dimension to two-dimension and greatly improved the image noise-sensitivity. Meanwhile, in order to enhance the computing speed, we refined the solution method of 2D threshold in 2D-Fisher criterion function through transforming computing method from two-dimension threshold to two one-dimension thresholds and greatly reduced the detection time. Refined 2D-Fisher criterion function method was suitable not only for the change detection in remote sensing images, but also for other aspects in data processing.

1. INTRODUCTION

The auto extraction of change area is the key of the change detection of multi-temporal remote sensing image. It's easy to compute and has a fast computation speed. So how to find a threshold finding method with wide range of applications, good results of extraction and good performance of anti-noise becomes one of the main content of the research on remote sensing image change detection. Until now, domestic and foreign scholars have carried out extensive research on this problem and proposed kinds of methods to select threshold, for example，maximum variance between-class, maximum entropy method and so on. However, whether the maximum variance between-class or the maximum entropy method, its rule function only considers maximizing the variance between-class, in other words to maximize the degree of separation but without considering the discrete level in class within. And the two methods are only suitable when pixel number of change class and no change class are not different a lot. While the number of the two kinds of pixels is significantly different, neither one method is applicable.

A good remote sensing image change detection method should not only maximize the separation degree between change class and no change class, but also make the change class and no change class's dispersion degree minimum, that is, similarity of pixel in every class should be maximal. As we all know, in the pattern recognition theory, the Fisher criterion function can be used to get the best projection direction of feature vector. In this projection direction we can get the greatest distance between classes and the smallest distance in class. At this time, value of Fisher criterion function reached the maximum. Thus, Fisher criterion function is a good criterion to analyze the degree of class separation.

The classical Fisher criterion function method is introduced into remote sensing image change detection and extended its original one-dimensional space of gray value to the two-dimensional space, such as the gray value – mean neighborhood gray (G-Mean), gray value - the Medium value of neighborhood gray (G-Medium) and so on. 2D-Fisher criterion function method is bring forward to apply to the remote sensing image change detection. Because 2D-Fisher criterion function method for solving adaptive threshold is complex to compute, we try to improve remote sensing image change detection 2D-Fisher criterion function method proposed in this paper. So it can effectively de-noising, and achieve rapid change detection.

2. FISHER CRITERION FUNCTION METHOD

The essence of solving Fisher criterion function is to solve optimization problems, that means using a few linear combination (called the discriminant or canonical variate) $y_1 = a_1'x, y_2 = a_2'x, \cdots, y_r = a_r'x$ in p-dimensional vector $x = (x_1, x_2, \cdots, x_p)'$ (usually r is significantly less than p) to replace the original p variables $x_1, x_2, \cdots, x_p$, in order to achieve the reduced-dimensional purpose, and in the new projection space $y = a'x$, making the largest distance between the various classes and the smallest in one class. As is shown in Figure 1, for the two categories ω_n and ω_c, assuming that all classes are characterized by two-dimensional distribution (A, B part in Figure 1) and project them in straight line Y_1 and Y_2, you can clearly see that the separation between classes are particularly good at the direction of straight line Y_2.

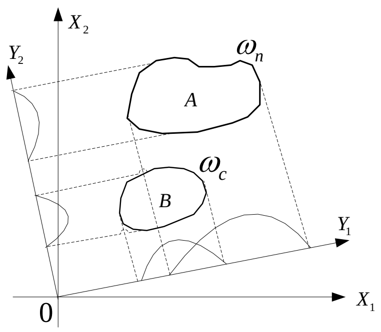


Figure 1． Projection of two-dimensional feature vector in a straight line

The bi-objective problem, namely class space will be the largest and the smallest category from, is transformed into single-objective optimization problem, that makes the formula 1 get a maximum.

$$\Delta(a) = \frac{SSTR}{SSE} = \frac{a'Ba}{a'Ea} \quad (1)$$

Where, $SSTR$ is the sum of squares between groups of y_{ij}, SSE is the sum of squares in the group y_{ij}, B is sum of squares between groups and sum of cross-product, E is sum of squares in group and sum of cross-product. This paper applies it to remote sensing image change detection process, so that pixels of change class and no change classes have the minimum dispersion in class and the maximum distance between classes (distance between the center of every class represent distance between classes), in change detection, we must consider the priori probability of change pixels and no change pixels, $P(\omega_c)$ and $P(\omega_n) = 1 - P(\omega_c)$,therefore, taking into account of the priori probability circumstance, the definition of Fisher criterion function is:

$$J(t) = \frac{|P(\omega_c)\mu_c - P(\omega_n)\mu_n|}{P(\omega_c)\sigma_c^2 + P(\omega_n)\sigma_n^2} \quad (2)$$

When t is the best threshold value, $J(t)$ gets maximum value, selection criteria of Fisher threshold is:

$$t^* = Arg \max_{0 \le t \le L-1} [J(t)] \quad (3)$$

3. 2D-FISHER CRITERION FUNCTION IN CHANGE DETECTION OF REMOTE SENSING IMAGES

As the classical Fisher criterion function method merely reflects the distribution of pixel's gray value, when SNR (signal to noise of the remote sensing image) is small, the one-dimensional grey level histogram of the difference images will have no noticeable wave crest and trough, so the threshold is difficult to select. Then if only according to one-dimensional grey histogram, the change detection, according to Fisher criterion function, will make a serious mistake. In view of this situation, in this chapter the classical Fisher criterion function will be introduced into the process of change detection, while the one-dimensional gray-scale space will be expanded. Taking full advantage of the neighborhood pixel spatial information, we put forward remote sensing image change detection 2D-Fisher criterion function method.

3.1 The basic principle of the 2D-Fisher criterion function method

Suppose two-dimensional space is a G-Mean space, $f(x, y)$ is the gray value at (x, y) point of different images, $g(x, y)$ is the average gray value in $k \times k$ adjacent area, (x, y) is the center, and

$$g(x, y) = \frac{1}{k^2} \sum_{m=-k/2}^{k/2} \sum_{n=-k/2}^{k/2} f(x+m, y+n) \quad (4)$$

$1 \le x \le m$, $1 \le y \le n$, m and n are the width and height of the changed image respectively, and k generally takes 3. The value of the two-dimensional histogram of changed image is expressed as the pixel gray value. The pixel number of the Neighborhood average gray value $g(x, y) = j$ is $(i, j = 0, 1, \cdots, L-1)$. Three-dimensional description is shown in Figure 2 and its projection to the plane is shown in Figure 3

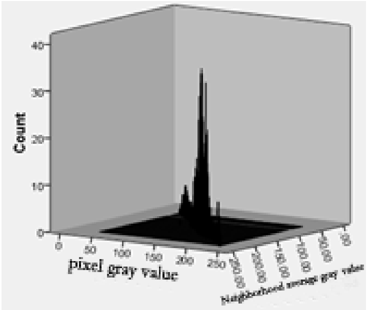


Figure 2. Three-dimensional description

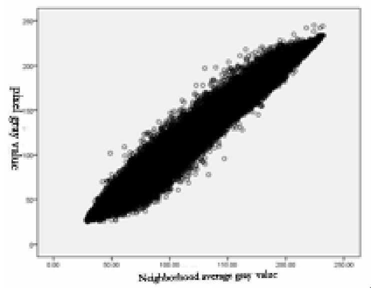


Figure 3. two-dimensional histogram display on plane

Difference image is divided into two parts, pixels changed and no changed. And their pixel gray value and the neighborhood average gray value is almost equal, so it is mainly distributed in the vicinity of the diagonal and the clustering phenomenon is apparent. Similarly, for noise in the difference image, the difference between pixel gray value and the average gray value in pixel's neighborhood area is large, so mainly in the non-diagonal part. In the difference image, the roughly distribution of changed pixels, no changed pixels and noise area in two-dimensional histogram is shown in Figure 4. It can be seen, regardless of high and low SNR of the difference image, selecting an appropriate threshold values to separate change class and no change classes, we can get a better test results. So it fully embodies the anti-noise performance after extending the original one-dimensional gray-value space to two-dimensional space.

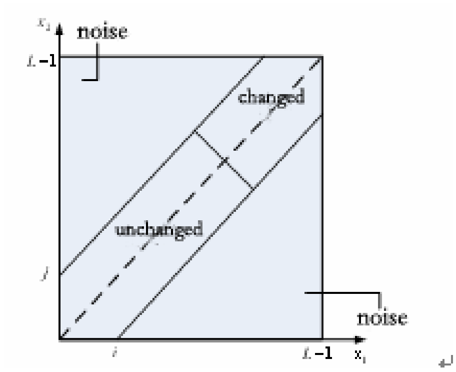


Figure 4. distribution of changed and no changed pixels and noise area Difference image.

The two-dimensional joint probability density of Pixel gray value and its neighbourhood average gray-scale is as follows:

$$p_{ij} = \frac{N(i,j)}{N}, \quad p_{ij} \ge 0, \sum_{i=0}^{L-1}\sum_{j=0}^{L-1} p_{ij} = 1 \tag{5}$$

Given any two-dimensional threshold value, the corresponding changed class and no changed class are ω_c and ω_n. Their gray and average neighborhood gray are:

$$P(\omega_{ni}) = \sum_{i=0}^{s-1} p_{ij}, \; j = 0,1,\cdots,L-1 \tag{6}$$

$$P(\omega_{nj}) = \sum_{j=0}^{t-1} p_{ij}, i = 0,1,\cdots,L-1 \tag{7}$$

$$P(\omega_{ci}) = \sum_{i=s}^{L-1} p_{ij}, \; j = 0,1,\cdots,L-1 \tag{8}$$

$$P(\omega_{cj}) = \sum_{j=t}^{L-1} p_{ij}, i = 0,1,\cdots,L-1 \tag{9}$$

The corresponding mean and variance vectors:

$$\mu_c = \left(\mu_{ci}, \mu_{cj}\right)^T \quad \mu_n = \left(\mu_{ni}, \mu_{nj}\right)^T \tag{10}$$

$$\sigma_c^2 = \left(\sigma_{ci}^2, \sigma_{cj}^2\right)^T \quad \sigma_n^2 = \left(\sigma_{ni}^2, \sigma_{nj}^2\right)^T \tag{11}$$

And

$$\mu_{ni} = \frac{\sum_{i=0}^{s-1} iP(\omega_{ni})}{\sum_{i=0}^{s-1} P(\omega_{ni})}, \mu_{nj} = \frac{\sum_{j=0}^{t-1} jP(\omega_{nj})}{\sum_{j=0}^{t-1} P(\omega_{nj})} \tag{12}$$

$$\mu_{ci} = \frac{\sum_{i=s}^{L-1} iP(\omega_{ni})}{\sum_{i=s}^{L-1} P(\omega_{ni})}, \mu_{cj} = \frac{\sum_{j=t}^{L-1} jP(\omega_{nj})}{\sum_{j=t}^{L-1} P(\omega_{nj})} \tag{13}$$

$$\sigma_{ni}^2 = \frac{\sum_{i=0}^{s-1}(i-\mu_{ni})^2 P(\omega_{ni})}{\sum_{i=0}^{s-1} P(\omega_{ni})}, \sigma_{nj}^2 = \frac{\sum_{j=0}^{t-1}(j-\mu_{nj})^2 P(\omega_{nj})}{\sum_{j=0}^{t-1} P(\omega_{nj})} \tag{14}$$

$$\sigma_{ci}^2 = \frac{\sum_{i=s}^{L-1}(i-\mu_{ci})^2 P(\omega_{ci})}{\sum_{i=s}^{L-1} P(\omega_{ci})}, \sigma_{cj}^2 = \frac{\sum_{j=t}^{L-1}(j-\mu_{cj})^2 P(\omega_{cj})}{\sum_{j=t}^{L-1} P(\omega_{cj})} \tag{15}$$

According to Equation 2, we can derive that 2D-Fisher criterion function is:

$$J(s,t) = \frac{\sqrt{\left(P(\omega_{ci})\mu_{ci} - P(\omega_{ni})\mu_{ni}\right)^2 + \left(P(\omega_{cj})\mu_{cj} - P(\omega_{nj})\mu_{nj}\right)^2}}{P(\omega_{ci})\sigma_{ci}^2 + P(\omega_{cj})\sigma_{cj}^2 + P(\omega_{ni})\sigma_{ni}^2 + P(\omega_{nj})\sigma_{nj}^2} \tag{16}$$

When $J(s,t)$ reaches the maximum the corresponding Split point should be the best change detection threshold, then the 2D-Fisher threshold selection rule is:

$$(s^*, t^*) = Arg \max_{\substack{0 \le s \le L-1 \\ 0 \le t \le L-1}} \left[J(s,t)\right] \tag{17}$$

3.2 The improvement of 2D-Fisher criterion function

2D-Fisher criterion function can make use of the gray information of a single pixel and related information of pixel's neighborhood space. The considering scope is extended from a single point gray value into the point and its neighborhood gray-spatial information. Relative to the classical one-dimensional Fisher criterion function, anti-noise performance has been greatly improved in the process of image change detection. According to the basic principles and formulas of 2D-Fisher criterion function, it can be known that along with the increasing of solution space dimension, the entire solution space need to traverse when to find the optimal threshold is $\left[0, L-1\right] \times \left[0, L-1\right]$.At this time, computing time is too long, and real-time is bad. To some extent, it limits the 2D-Fisher criterion function method in the practical application of remote sensing image change detection. Therefore, the following content will consider how to improve the timeliness of 2D-Fisher criterion function method.

In order to improve the speed of remote sensing image change detection of 2D-Fisher criterion function, it can be considered from two aspects to improve the proposed 2D-Fisher criterion function: for one thing, narrow the solution space of 2D-Fisher criterion function; for another, transform the two-dimensional threshold into two one-dimensional thresholds. The following will discuss these two mentioned-above aspects.

1） Narrow the scope of the original solution space, so as to achieve the purpose of improving the speed of detection.

Since the extraction of the change area is similar to the two types of clustering problem, to maximize the distance between classes, the initial cluster centers generally select the point where the rule function value is the largest. Because it is two types of clustering, the initial cluster centers always select the two points where the function gets two largest values. In specific clustering process, the optimal threshold value will fall

between two points. According to this theory, the specific solving steps are as follows:
Step 1: To obtain two-dimensional histogram of difference image;
Step 2: According to two-dimensional histogram to Select k extreme points from the difference image, as is shown in Figure 5 (usually make $k=6$);
Step 3: Obtain the corresponding values of each extreme point in the 2D-Fisher criterion function.
Step 4: Select the two extreme points (s_1,t_1) and (s_2,t_2) corresponding to the largest two function value, (s_1,t_1) as the center and (s_2,t_2) as the vertex to make a rectangle. As shown in Figure 6, namely, the area of red rectangle $\left[s_1-|s_1-s_2|, s_1+|s_1-s_2|\right]\times\left[t_1-|t_1-t_2|, t_1+|t_1-t_2|\right]$ is the improved scope of the solution space.
From the above analysis we can get that the improved solution space is the original solution space. $\dfrac{\left[s_1-|s_1-s_2|, s_1+|s_1-s_2|\right]\times\left[t_1-|t_1-t_2|, t_1+|t_1-t_2|\right]}{[0,L-1]\times[0,L-1]}$

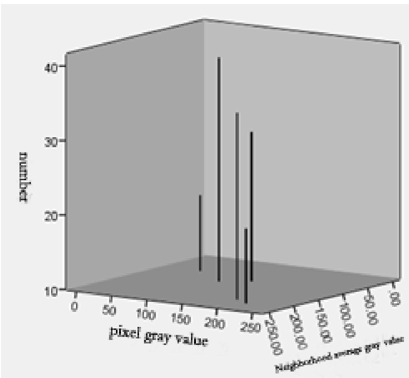


Figure 5. The selection of maximum in two-dimensional histogram

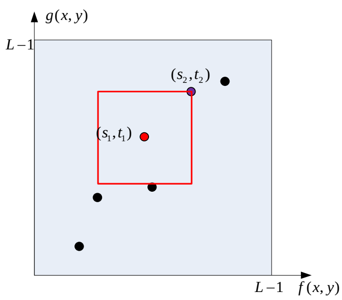


Figure 6. Improvement of solution space

2) Transform two-dimensional threshold into two one-dimensional thresholds, so as to achieve the purpose of improving the speed of detection

Respectively make use of each pixel gray value and neighbourhood spatial information, according to the classical Fisher criterion function method, to solve the optimal gray threshold value s^* and the best neighborhood threshold t^*, both of which constitute the two-dimensional threshold (s^*,t^*) of remote sensing image change detection. Then according to the two-dimensional threshold (s^*,t^*), do change detection of the difference images.

In method 1), the improvement of solution space of 2D-Fisher criterion function is the original solution space $\dfrac{\left[s_1-|s_1-s_2|, s_1+|s_1-s_2|\right]\times\left[t_1-|t_1-t_2|, t_1+|t_1-t_2|\right]}{[0,L-1]\times[0,L-1]}$.

However, we need to traverse the entire image to obtain the two-dimensional joint probability density of pixel gray value and its neighborhood spatial information according to the two-dimensional histogram. After that, it has nothing to do with the image size itself. The number of run times (one run means the process of calculating all kinds of probability, the mean and variance each time) of the original solution space for solving is $(1+2+\cdots+256)\times(1+2+\cdots+256)$ (Assuming gray-scale of the image is 256). After improved, the number is $4|s_2-s_1||t_2-t_1|$. In the Intel Pentium Dual 2.0 CPU, 2G memory environment, the time one run required is probably 0.0384 s. Since the two extreme values fall mostly on both sides of the middle-class gray, suppose that $(120,120)$ is the maximum point, and $(129,129)$ is the second, the time is 12.4416 s the best two-dimensional threshold required. It can be known that no matter how narrow the solution space is, the solution time can not satisfy the needs of practical applications. Therefore, we chose method 2).

3.3 The specific process to improve 2D-Fisher criterion function method.

The specific process of remote sensing image change detection makes use of the improved 2D-Fisher criterion function method (taking two-dimensional space of choosing G-Mean for example):
Step 1: According to the pixel gray values and formula 4, obtain the grey level histogram of the difference image and the histogram of the mean value of gray scale in 3×3 neighbourhood area.
Step 2: On the histogram, as well as neighborhood average gray histogram, take advantages of classical Fisher criterion function method to get the one-dimensional optimal threshold s^* and t^* and the two-dimensional threshold (s^*,t^*) respectively.
Step 3: According to two-dimensional threshold, analyze the various elements to generate the results of image change detection.

For (x,y)
If (($f(x,y)\ \ge s^*$) && ($g(x,y)\ \ge t^*$))
Then $(x,y)\subset\omega_c$
Else
$(x,y)\subset\omega_n$

(s^*,t^*) is the optimal threshold of image change detection.

4. EXPERIMENT AND ANALYSIS

In the above sections, through the Fisher criterion function in the pattern recognition theory, we propose the remote sensing image change detection method: 2D-Fisher criterion function. Then, we will use the simulation data and real data experiments to validate the effectiveness of the change detection algorithm proposed in this chapter.

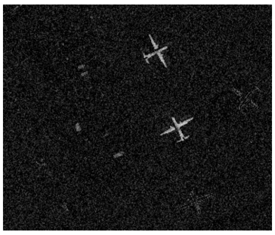
The experimental environment is Intel Pentium Dual 2.0 CPU, 2G memory. First is the simulation experiment. The remote sensing simulation images of multi-phase are constituted by an airport image and the corresponding changed image, as shown in Figure 7. Make linear transformation on the original image to simulate another phase of the remote sensing data, and then add two aircraft on the simulation image to make the changed area.

(a) Phase 1 Original simulation image

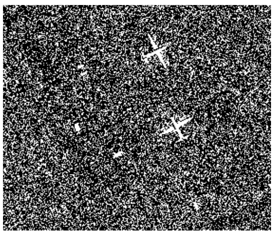
(b) Phase 2 Original simulation image

Figure 7. the simulation image at different time but in the same area

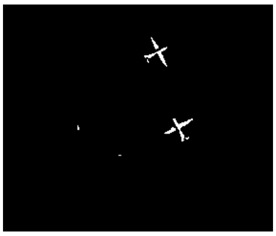
The following plus noise (Gaussian noise)in the difference image of the original simulation image, let SNR=10,according to One-dimensional Otsu, One-dimensional Fisher, two-dimensional Otsu, and two-dimensional Fisher, do change detection test on the image with noise. The comparison is shown in Figure 8.



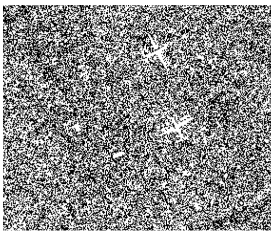
(a) Difference image with noise (SNR=10)



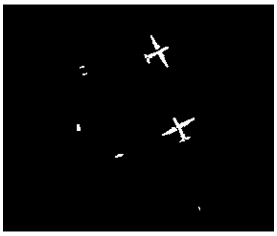
(b) Result of One-dimensional Otsu ($s^* = 28$)



(c) Result of two-dimensional Otsu $(s^*,t^*) = (28,105)$



(d) Result of One-dimensional Fisher



(e) Result of 2-D Fisher (before improvement) $(s^*,t^*) = (19,73)$

(f) Result of 2-D Fisher (after improvement) $(s^*,t^*) = (18,67)$

Fig.8 results compare of change detection with noise

From fig.8 we can see that improved 2D-Fisher change detection algorithm can effectively detect the changed area in the difference image with noise. Its anti-noise is superior to the classical one-dimensional Otsu, one-dimensional Fisher, and has the pretty same performance as pre-2D-Fisher criterion function method and two-dimensional Otsu method, namely, neighbourhood information are obvious for Removal of Gaussian noise. From the result of two-dimensional Otsu method we can see that this method is not very complete for the extraction of the aircraft, namely, existing problems of missing detection. The time occupied by two-dimensional change detection method is shown in Table 1.

Algorithm	2D-Otsu	2D-Fisher (before improvement)	2D-Fisher (after improvement)
Time of detection	57.19 s	74. 51 s	0. 68 s

Table 1 The Time of every two-dimensional change detection methods

In order to further verify the effectiveness of the proposed method in this chapter, the actual remote sensing images in an area of two-phase is chosen to do the experiment. The experimental data is SPOT panchromatic image with registration and relative radiometric correction, and is a region in 1987 and 1992 provided by ERDAS. The spatial resolution is 10m, region size 512 × 512 pixels and 256 gray levels. Experiments are carried out using the above method, in which select (gray value, neighborhood gray-scale median) space as two-dimensional space of 2D-Fisher criterion function method. The result is shown in Figure 9

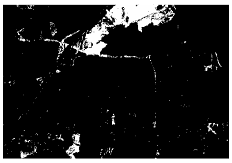
(a)Remote Sensing Image in 1987

(b)Remote Sensing Image in 1992

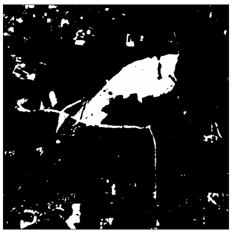
(c) The difference image

(d)Result of One-dimensional Otsu

(e)Result of Two-dimensional Otsu



(f)Result of One-dimensional Fisher



(g) Result of 2-D Fisher (before improvement)

(h) Result of 2-D Fisher (after improvement)

Fig.9 the results of real image change detection

The time occupied by two-dimensional change detection method in the image change detection process is shown in Table 2.

Algorithm	2D-Otsu	2D-Fisher （before improvement ）	2D-Fisher （after improvement ）
Time of detection	14. 46 min	75.24 *s*	0. 79 *s*

Table 2 the time occupied by two-dimensional change detection method in the image change detection process

Experimental results show the excellent of the change detection method based on the improved 2D-Fisher criterion function, whose superior anti-noise, and speed could have been fully embodied, whether in the simulation experiment or on the actual image. And, it's able to meet the needs of practical application of remote sensing image change detection in effect of real-time and change detection.

5. SUMMARY

The classical Fisher criterion function is introduced into the remote sensing image change detection. The approach based on 2D-Fisher criterion function method is proposed. Remote sensing image change detection 2D-Fisher criterion function method extended the one-dimensional gray value space of the classical Fisher criterion function to two-dimensional space, such as (G-Mean), (G-Medium), etc. Among them, the choice of two-dimensional space is based on the specific circumstances of the actual images. For example, G-Mean has a good effect of removing Gaussian noise, while G-Medium are obvious for the salt and pepper noise. In the process of the solution, the two-dimensional threshold, we split it into two one-dimensional thresholds, and the detection speed is greatly improved.

The 2D-Fisher criterion function method takes into account of the anti-noise and detection speed of the change detection process, making the method much more suitable for practical application needs of remote sensing image change detection. Experiments show that the improved 2D-Fisher criterion function method of remote-sensing image change detection is superior to the classical one-dimensional Otsu method, one-dimensional Fisher criterion function method in the anti-noise, and is far superior to the Two-dimensional Otsu in the speed of change detection.

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