IMAGERY TEXTURE ANALYSIS BASED ON MULTI-FEATURE FRACTAL DIMENSION

Jingxue Wang [a],*, Weidong Song [a], Feng Gao [b]

[a] School of Geomatics, Liaoning Technical University, Fuxin, Liaoning, 123000, China—xiaoxue1861@163.com, - song_wd@163.net

[b] Liaoning Environment Monitoring Center, Shenyang 123000, Liaoning, China

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ABSTRACT:

Texture is the important spatial structure information and primary feature of remote sensing imagery. It contains the surface information of imagery and the relationship with around environment. Firstly focusing on the basic principle of fractal, this paper adopts five different kinds of fractal algorithms to calculate the fractal dimensions of image texture towards the researching image, and gains five different fractal features. Secondly, according to the above obtained five fractal features, this paper makes the feature extraction under the principle of the transformation based on classibility criterion, and obtains two group new feature vectors. Finally, in the experiments, this paper carries on the image classification using the two new feature vectors, and gets the classification results. This paper adopts the fusion matrix to evaluate the precision of these classification results, and validates the feasibility, precision, and reliability of this method.

1. INTRODUCE

Texture is the important spatial structure information and primary feature of remote sensing imagery. It contains the surface information of imagery and the relationship with around environment. As carrying on the classification toward RS imagery, texture feature is one kind of common classification standard and judgment principle. Among the various methods of describing texture feature, the fractal algorithm is better than other traditional algorithms in the aspects of anti-noise and attention the macrostructure and the microstructure of imagery. Fractal algorithm mainly expresses the extent of self-similarity and the feature of roughness. Simultaneously, this algorithm can also detect the abundance details of imagery, and then obtain the better classification effect.

This paper focuses on the principles and techniques of image texture analysis, and validates the principles and methods with appropriate experiments. Firstly focusing to the basic principle of fractal, this paper adopts five different kinds of fractal algorithms to calculate the fractal dimensions of image texture towards the researching image, and gains five different images of fractal features. Secondly, according to the above obtained five fractal features, this paper makes the feature extraction under the principle of the transformation based on classibility criterion, and obtains new feature vectors in order to carry on the image classification. Finally, This paper adopts the fusion matrix to evaluate the precision of these classification results, and validates that the method proposed in this paper can obtain excellent classification results, and can guarantee the precision, the feasibility and the reliability of image classification.

2. FRACTAL FEATURE BASED ON THE TEXTURE OF IMAGE

2.1 Fractal Algorithm Based on The Discrete Fractal Brown Random Model

The Fractal Brown Motion is one kind of typical mathematics model to describe the random fractal feature in nature. And its definition is (Dongsheng Wang, 1995):

Set $\mathrm{B_H}(x)$ is a random Gauss field, and 0<H<1. If the $\mathrm{B_H}(x)$ satisfies this following formula:

$$F(y) = \mathrm{P_H}\left(\frac{\mathrm{B_H}(x+\Delta x) - \mathrm{B_H}(x)}{\|\Delta x\|^{\mathrm{H}}}\right) < y \tag{1}$$

Then we will call the $\mathrm{B_H}(x)$ as the Fractal Brown Motion. If the x and Δx in this formula are discrete values, then we can get the Discrete Fractal Brown Random field (abs. as DFBR field).

Taking the gray values of image as the third dimension $f(x, y)$ about the plane coordinates x and y, we can consider it as a discrete curving surface of gray, and this curving surface will satisfy the DFBR field partially. It can be expressed as:

$$S = \{x, y, f(x, y) \mid (x, y) \in G\}$$

As the $F(y)$ obeys the normal distributing $N(0,\sigma^2)$, then $E|B_H(x+\Delta x)-B_H(x)|^2 = C\|\Delta x\|^{2H}$. In this formula, C is a constant. Computing the *log* values of this equation, and we can get the following formula:

$$\lg E|B_H(x+\Delta x)-B_H(x)|^2 = 2H\lg\|\Delta x\| + \lg C \qquad (2)$$

After that, this fractal algorithm fits the data pairs $\{\lg E|B(x+\Delta x)-B_H(x)|^2, \lg\|\Delta x\|\}$ using the least square principle, and then calculates the value of H through the slope of fitted line. The fractal dimensional value D of image is defined as $D=N+1-H$, and when $N=2$, then $D=3-H$.
Setting (x_1, y_1) and (x_2, y_2) belong to the field G, then Δx represents the distance between (x_1, y_1) and (x_2, y_2). If the selection methods of them are different in field G, then it will obtain different forms of fractal dimensions. And the computation formulas of these fractal dimensions in different directions are shown as following (Sixian Wang, 1998):
(1) Horizontal fractal dimension D_1: In the gray image, if Δx is in the horizontal direction, and k is the positive integer, then

$$F_1(k) = \frac{\sum_{x=0}^{M-1}\sum_{y=0}^{N-k-1}|f(x,y)-f(x,y+k)|^2}{M(N-k)} \qquad (3)$$

(2) Vertical fractal dimension D_2: If Δx is in the vertical direction, then

$$F_2(K) = \frac{\sum_{x=0}^{M-K-1}\sum_{y=0}^{N-1}|f(x,y)-f(x+k,y)|^2}{N(M-k)} \qquad (4)$$

(3) Diagonal fractal dimension D_3: If Δx is in the diagonal direction, then

$$F_3(k) = \frac{\sum_{x=0}^{M-k-1}\sum_{y=0}^{N-k-1}|f(x,y)-f(x+k,y+k)|^2 + \sum_{x=0}^{M-k-1}\sum_{y=k}^{N-1}|f(x,y)-f(x+k,y-k)|^2}{2(M-k)(N-k)} \qquad (5)$$

(4) Integrated fractal dimension D_4:

$$F_4(k) = \frac{\sum_{x=0}^{M-k-1}\sum_{y=0}^{N-1}|f(x,y)-f(x+k,y)|^2 + \sum_{x=0}^{M-1}\sum_{y=k}^{N-k-1}|f(x,y)-f(x,y+k)|^2}{N(M-k)+M(N-k)} \qquad (6)$$

2.2 Box Dimension

Mr. Mandelbrot thinks that the surface having fractal feature will have the self-similarity (Mandelbrot B. B, 1982). If the limited set A is in the Euclidean space, then the fractal dimension of A (expressed by D) will satisfy the following equations:

$$1 = N_r r^D \quad \text{or} \quad D = \frac{\log(N_r)}{\log(1/r)} \qquad (7)$$

But it is difficult to calculate the fractal dimensions by these equations.

Mr. B.B.Chaudhuri proposed one algorithm to calculate the box-dimension. And the principle of this algorithm is:

Considering the image, whose size is $M\times M$, to be a 3D space, and the coordinate (x,y) represents one 2D plane, and the gray value of image represents the direction of Z axis. Then divides the 2D plane (x,y) into the grid with the size of $S\times S$ (s is the integer, and its scope is $1<s<M/2$), and we have $r=s/M$. In each grid, there are many boxes stacked one by one, whose volumes are all $S\times S\times S$. In the (i, j) grid, this algorithm endows the maximum and the minimum values in the gray surface to the box k and box l in the stacking. Then

$$n_r(i,j) = l-k+1 \qquad (8)$$

It is the box number of covering the image in the grid (i, j). And the total box number of covering the whole image can be calculated by formula (9):

$$N_r = \sum_{i,j} n_r(i,j) \qquad (9)$$

Changing the formula (8) into one kind of simple forms in order to calculate the gray values of image conveniently, like formula (10)

$$n_r(i,j) = \mathrm{int}(\max I_K/r) - \mathrm{int}(\min I_k/r) + 1 \qquad (10)$$

In this formula, I_k $(k=1,2,\ldots,n)$ refers to the gray value of n pixels in the unit area of $r\times r$.
The changing of r is caused by the changing of s, and the slope D can be calculated by fitting the $\log(N_r)-\log(1/r)$ using the least square principle. The accuracy of this algorithm to calculate the box dimension is excellent, especially as the change of image gray values in the neighboring field is great.
Mr. Dongsheng Wang proposed one kind of improved algorithm to calculate the box dimension:

$$n_r(i,j) = \mathrm{int}[(\max I_k - \min I_k)/r] + 1 \qquad (11)$$

This algorithm can cover the curving surface of image using the minimum number of cubic boxes, whose volume is also $S \times S \times S$. The cubic boxes will not be limited in certain fixed positions, and they can move up and down along the *Z* axis. This algorithm can reduce the number of boxes, and improve the extent of tightness to covering the curving surface. Therefore, it can increase the measuring precision of box dimension.

3. FEATURE EXTRACTION BASED ON THE CLASSIBILITY CRITERION

The principle of feature extraction is to extract the new feature vector *d* from the original feature vector *D*, and in generally the dimension of *D* is bigger than the dimension of *d*. Furthermore, the new feature vector should satisfy the function condition that the total dispersion of various categories will be the smallest. By this way, the extracted secondary feature not only gets rid of the relativity among the original features, contains the main features of the seven kinds of fractal dimensions in the largest extent, but also can describes the texture information of image well and truly, improves the precision of classification.

In order to extract one group effective feature for image classification from various features, it needs to establish an accurate standard or criterion to judge the validity of these features for image classification, and this is the transformation based on classibility criterion (Song Weidong, 2007).

In the given feature space, whose dimension is *D*, we should extract *d* features to guarantee that they can apart the categories as far as possible. It means that we should extract a feature vector x^* , which has *d* features, and makes the average distance *J*(*x*) between each sample in the *C* categories reach the maximum, which is to say that $J(x^*) = \max J(x)$. And the computation of *J*(*x*) can be expressed as the following formula:

$$J(x) = \frac{1}{2}\sum_{i=1}^{c} P_i \sum_{j=1}^{c} P_j \frac{1}{n_i n_j} \sum_{k=1}^{n_i} \sum_{l=1}^{n_j} d(x_k^{(i)}, x_l^{(j)}) \tag{12}$$

In this formula, n_i refers to the number of training samples of the w_i category in set S, and P_i refers to the pre-probability of the i category. If P_i is unknown, it can be instead by w_i / n . In many situations, the Euclidean distance is convenient to analyze and calculate. By the following formula (13), the distances among categories will reach the maximum, and the distances in the categories will reach the minimum after the transformation (Jingxue Wang, 2007):

$$d(x_k^{(i)}, x_l^{(j)}) = [(x_k - x_l)^T (x_k - x_l)]^{\frac{1}{2}} \tag{13}$$

4. EXPERIMENTS

In experiments, focusing on the SPOT5 panchromatic image as the researching object, and through the lucubrating to the fractal principles and the fractal features of texture, this paper adopts the fractal dimensions in different directions based on the DFBR and the box dimension as the fractal features of texture images, extracts the feature vectors of texture, and then creates the corresponding fractal images. After that, this paper extracts new feature vectors from the above fractal features using the principle of feature extraction, and uses these feature vectors into the image classification. Finally, it evaluates the precision of classification results.

4.1 Computation of Fractal Dimension Based on Multi-Scale and Multi-Feature

In the experiments of computing the fractal dimension, it needs to obtain the fractal dimensions from the training samples of the various categories at first. This paper selects twenty training samples from each category, and calculates the texture features of these categories using different fractal algorithms, and then obtains the average fractal values of them. The results are shown as the following Table 1:

Category	Discrete Fractal Brown Model (DFBM)				Box Dimension
	Horizontal Fractal Dimension	Vertical Fractal Dimension	Diagonal Fractal Dimension	Integrated Fractal Dimension	Fractal Dimension
Vegetable Plot	2.7902	2.8237	2.8560	2.8644	2.6584
Resident Area	2.8644	2.8382	2.8437	2.8693	2.7497
Cropland	2.5830	2.7967	2.7420	2.8025	2.0551

Table 1. Texture fractal feature values of different categories

In order to classify the image using the fractal principles, it needs to know the fractal dimension of each pixel. Similarly, this paper calculates the fractal dimensions of the SPOT5 panchromatic image utilizing the above mathematics models, and obtains five different fractal images. In the computation of fractal dimensions, this paper adopts the linear regression based on the least square method to calculate the fractal dimensions in the different window sizes. Through the computation analysis and comparison, it can be concluded that the effect of linear regression will reach the best state when the size of selected window is 9×9 pixels. And the computed fractal dimensions will fluctuate in a relative steady range.

4.2 Feature Extraction and Image Classification

Considering that the texture features of vegetable land and resident area are similar in certain degree, this paper carries on the secondary extraction to the five group fractal features, and classifies the image using these new features. The extracted secondary feature not only gets rid of the relativity among the original features, contains the main features of the seven kinds of fractal dimensions in the largest extent, but also can describes the texture information of image well and truly, improves the precision of classification.

In this experiment, it extracts the feature vectors towards sixty samples based on the principle of classibility criterion, and gets the graph of discrete samples. Analyzing from this graph, it can be concluded that these three kinds of categories have the divisibility in the direction of *x* and *y* axes. This paper classifies the image using the extracted secondary features, and obtains the graph of classification results, which is shown as Figure 2. In this figure of classification results, the differences among these categories are obvious, and the total precision of classification is very high.

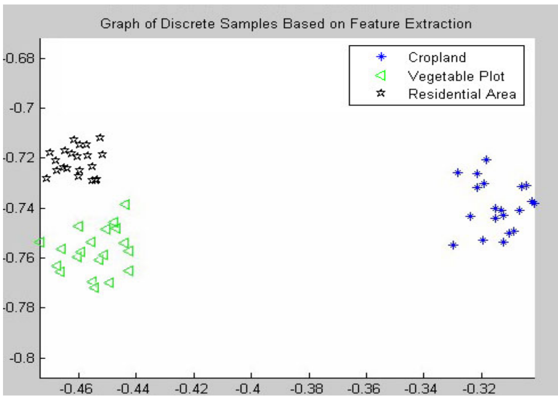

Figure 1. Graph of discrete samples based on feature extraction

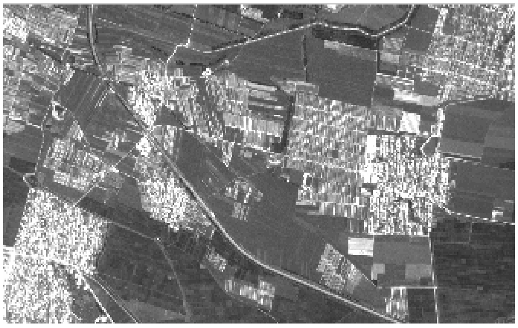

Figure 2. Original RS image

Figure 3. Classification results map

4.3 Precision Evaluation of Classification Results

In general, there is no one method can check the classification of every pixel in the whole image one by one and judge whether it is right or wrong, but have to evaluate the errors of classification using some samples. And the ways of sample selection are usually random. This paper takes the present land use map, whose region is covered by RS image, as the reference, and selects 600 samples randomly in this region, constructs the corresponding confusion matrix to carry on the precision evaluation to the classification results, and the computed total precision is 89.67%. The fusion matrix is shown as the Table 2:

Sample		Reference Categories				User's Accuracy	The Total Classification Precision
		Vegetable Plot	Resident Area	Cropland	Sum		
Classified Categories	Vegetable Plot	**182**	18	10	210	86.67%	89.67%
	Resident Area	26	**166**	2	194	85.57%	
	Cropland	6	0	**190**	196	96.94%	
	Sum	214	184	202	**538**		
Producer's Accuracy		85.05%	90.22%	94.06%			

Table 2. The confusion matrix and the precision of classification results

5. CONCLUSION

This paper carries on the classification towards the SPOT5 image utilizing the fractal principle and the feature extraction algorithm in pattern recognition, and the computed total precision of classification reaches 89.67%. Saying from the effect of classification and the evaluated precision, it can realize the effective classification on the objects categories with the feature vectors extracted from multiply fractal features, and improve the precision of classification. Simultaneously, it validates the feasibility, precision and reliability of this classification algorithm based on the multi-feature fractal dimensions.

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