Multifractal Based Country Road Information Extraction from Geoeye-1 Image

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Abstract—**A multifractal based approach to extracting road information is presented in this paper. As a case study, a Geoeye-1 image is used for the experiment. The result is compared with the results from Sobel operator, Roberts operator, Prewitt operator. It is shown that the proposed multifractal based method can extract different types of road information more effectively.**

Keywords-multifractal; Geoeye-1; country road; extraction

I. INTRODUCTION

The fast development of Chinese economy and increasing investment of road infrastructure construction force a frequent updating of road information. This demand is increasingly urgent with the popularization of navigation product. Aerial image has been a conventional data resource for road extraction, and automatic extraction of roads from digital images has been an active research subject for over two decades [1-4]. Various methods have been developed for road information extraction from aerial and satellite images. Conventional method of edge and road extraction is based on gradient operation (e.g. Sobel operator, Roberts operator, Prewitt operator and so on) or filter. With the increasing of spatial resolution, the high-resolution satellite image has been becoming an effective and efficient data resource and has motivated a sense of urgency for new technology of fast and accurate extraction road information, e.g. mathematical morphology, dynamic programming and snakes, segmentation and classification, multi-scale and multi-resolution, knowledge-based representation [5], fuzzy logic, neural networks [6, 7], genetic algorithms and so on. Generally, these methods may be listed by 2 categories, i.e. semi-automatic and automatic methods. While, Mena listed the main approaches on general method of road extraction developed at that time, and proposed a novel classification of these methods according to the preset objective, the extraction technique applied, the type of sensor utilized [8].

These methods have been adopted to extract various type of road, and each method is relatively effective for a type of road. However, this is not true for remote sensing image, which usually includes various type of roads. Thus a multifractal based method is proposed in this paper for extraction country road information. The literature on multifractal based country road extraction from high-resolution satellite image is spare.

II. FRACTAL AND MULTIFRACTAL OF NATURAL SURFACE

The concept of fractal was first proposed by Mandelbrot [9] and is used to describe the self-similar natural phenomena. Mandelbrot defined a fractal set as a set for which the Hausdorff dimension is greater than its topological dimension [10]. The fractal dimension is the most important parameter for a fractal system. However a single exponent (i.e. the fractal dimension) is not enough to describe the dynamics of complex nature, thus multifractal was proposed. The multifractal describes the concept that different regions of an object have different fractal properties [11]. Multifractal provides a quantitative description of a broad range of heterogeneous phenomena.

Fractal geometry is widely used in image analysis. The typical applications are texture analysis, image-compress and fractal simulation of nature landscapes. The natural and man-made landscapes show different fractal characteristic and have different fractal dimension, therefore, the fractal dimension can be used for extracting man-made landscapes, e.g. road information. However, as mentioned above, a single fractal dimension is not enough to describe various type of road, thus a multifractal based method is proposed.

There exist two options for description of multifractal i.e. measure based method ($\alpha \sim f(\alpha)$) and Rèny general dimension ($q \sim D(q)$) method. Correspondingly, a multifractal system can be described by the following parameters: mass exponent $\tau(q)$, general dimension $D(q)$, or singularity exponent -- Hölder exponent (α) and multifractal spectrum $f(\alpha)$. The measure based method is used in our experiment.

III. ROAD EXTRACTION BASED ON MULTIFRACTAL

A. Calculation of Multifractal Spectrum

Edge of road in an image is characterized by incontinuity and abrupt change of pixel gray. According to multifractal theory, this property can be described by singularity exponent -- Hölder (α). The Hölder exponent is related to local geometrical feature, and another parameter -- multifractal spectrum $f(\alpha)$, is related to the global geometrical feature, thus the α- $f(\alpha)$ parameters can highlight the main edges, and at the same time, ignore the unimportant edges, and effectively extract the road information. Therefore, if we can calculate the Hölder (α) and multifractal spectrum $f(\alpha)$ of an image, we can

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extract the road information. The computation of Hölder (α) and multifractal spectrum *f*(α) is described as follows:

1) Computation of probability measure

Probability measure can be thought of as the distribution of a random variable, and it means the distribution of gray value in an image in our experiment. Various methods have been developed for computing probability measure, and a modified method is proposed in this paper, this is:

$$p(\Omega) = \frac{I_\alpha(i,j)}{\sum \Omega(i,j)} \tag{1}$$

Where $I_a(i,j)$ denotes the gray value of the (i,j) pixel, $\Sigma\ \Omega\ (i,j)$ denotes the sum of gray value of all pixels in the window with the center of (i,j). For a specific size of the window, a probability measure can be calculated. Therefore, a series of probability measure is acquired. In our experiment, the size of the window is designed as 3 x 3 pixels, 5 x 5 pixels and 7 x 7 pixels respectively.

2) Mass exponent τ(q)

The mass exponent can be calculated based on the relation between the partition function and scale. The partition function is defined as follows:

$$\chi_q(\varepsilon) = \sum P_i(\Omega)^q \tag{2}$$

Where $P_i(\Omega)$ is the probability measure corresponding to the *i*th size of the window.

For a multifractal system, the partition function exhibits power exponential relation with scale ε, i.e.

$$\chi_q(\varepsilon) = \varepsilon^{\tau(q)} \tag{3}$$

Therefore $\ln(\chi_q(\varepsilon))$ is linearity with $\ln(\varepsilon)$ for a multifractal system, and the slope of the line is the mass exponent. Practically, we usually fit a least-squares regression line through the $\ln(\varepsilon)$ and $\ln(\chi_q(\varepsilon))$ data points, and the slope of the fitted line corresponds to the mass exponent $\tau(q)$. Fig. 1 illustrates the relation between $\ln(\varepsilon)$ and $\ln(\chi_q(\varepsilon))$ with various *q*.

3) Hölder exponent α

If the mass exponent $\tau(q)$ is computed, the Hölder exponent α can be calculated by (4):

$$\alpha = \frac{d\tau(q)}{dq} \tag{4}$$

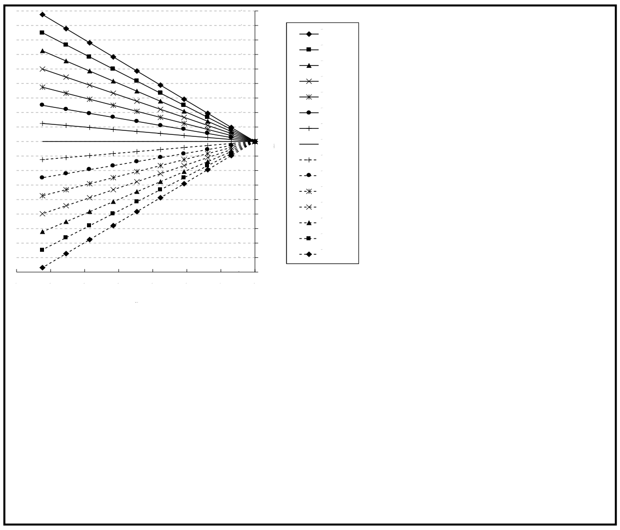


Figure 1. Relation between ln(ε) and ln(χq(ε)) with various *q*

4) Multifractal spectrum f(α)

Multifractal spectrum can be computed through mass exponent $\tau(q)$ and Hölder exponent α:

$$\tau(q) = \alpha q - f(\alpha) \tag{5}$$

B. Data Processing and Result Discussion

The Geoeye-1 image is used for our experiment. GeoEye-1 was launched on September 2008, it provides 0.41m panchromatic and 1.65 m multispectral imagery. However the imagery is blurred out to 0.5 m and 2 m for commercial users. Even so, the GeoEye-1 was the world's highest resolution commercial earth-imaging satellite at the time of its launch. The image used in this experiment is acquired in 2009, which has a coverage area of about 10km x 10km of Changping in northern Beijing. Due to the mass data, two 500 x 500 cropped panchromatic images which correspond to winding mountain road and country road are used for our experiment (Fig. 2).

a. Winding mountain road b. Country road

Figure 2. Different type of road in Geoeye-1 image

First, the image is preprocessed by median filter with a 9x9 window. Then the Hölder exponent α and multifractal spectrum *f*(α) of each image is computed. Fig. 3 and Fig. 4 illustrate the global multifractal characteristic of two images shown in Fig. 2. They show the obvious difference of multifractal spectrum for mountain road and country road.

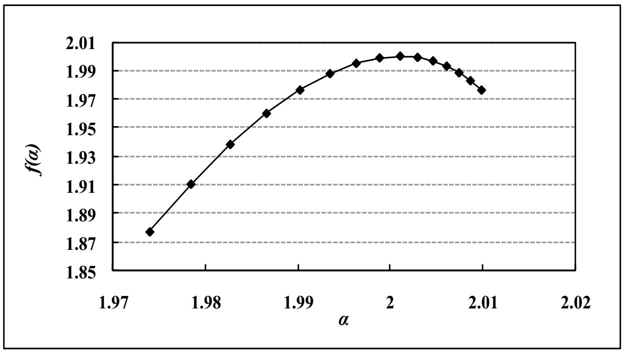


Figure 3. Mulatifrctal characteristic of Fig. 2 (a) image

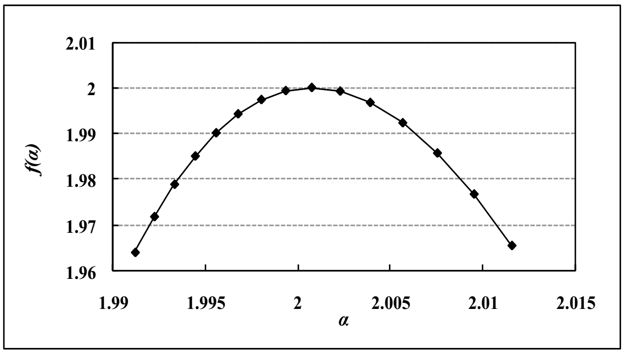


Figure 4. Mulatifrctal characteristic of Fig. 2 (b) image

At the same time, the multifractal spectrum of each pixel is also computed. In order to compare the multifractal spectrum of road and non-road pixels, 4 pixels are selected from the images, and their multifractal spectrum are shown in Fig. 5, Fig. 6, Fig. 7 and Fig. 8. It can be seen from the figures, that the multifractal spectrum of road pixels change abruptly at some α (Fig. 5 and Fig. 7), while that of the non-road pixels change smoothly (Fig. 6 and Fig. 8).

Because the multifractal spectrum of a road and non-road pixels is different, the α and *f*(α) can be used for road information extraction. Fig. 9 and Fig. 10 show the results of road extraction by parameter α and *f*(α), some other results are also presented to validate the multifractal based method.

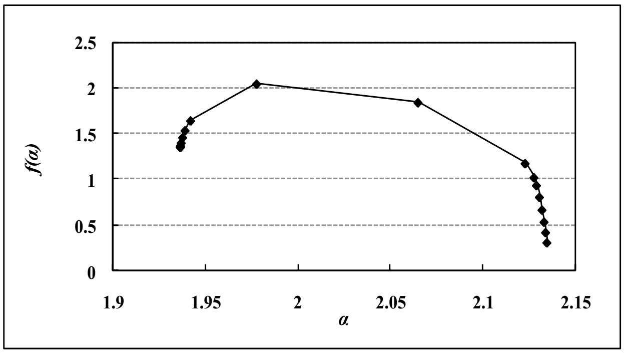


Figure 5. Mulatifrctal characteristic of a road pixel in Fig. 2 (a)

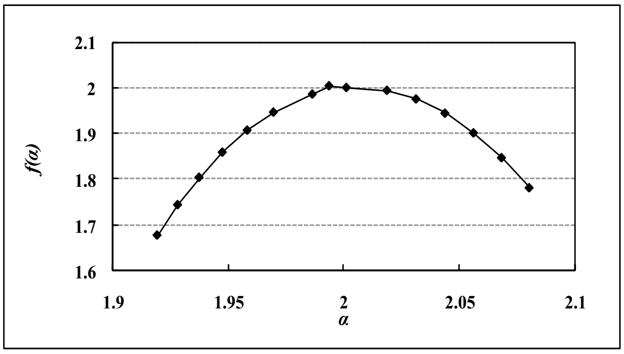


Figure 6. Mulatifrctal characteristic of a non-road pixel in Fig. 2 (a)

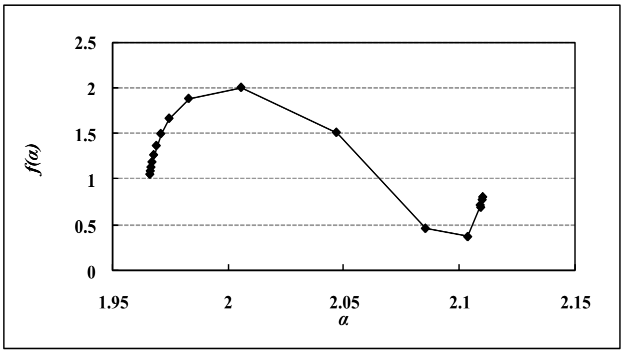


Figure 7. Mulatifrctal characteristic of a road pixel in Fig. 2 (b)

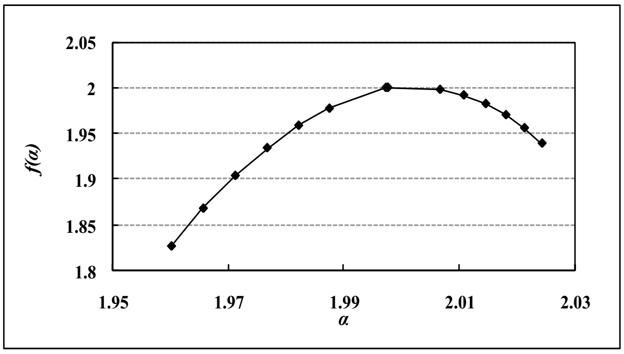
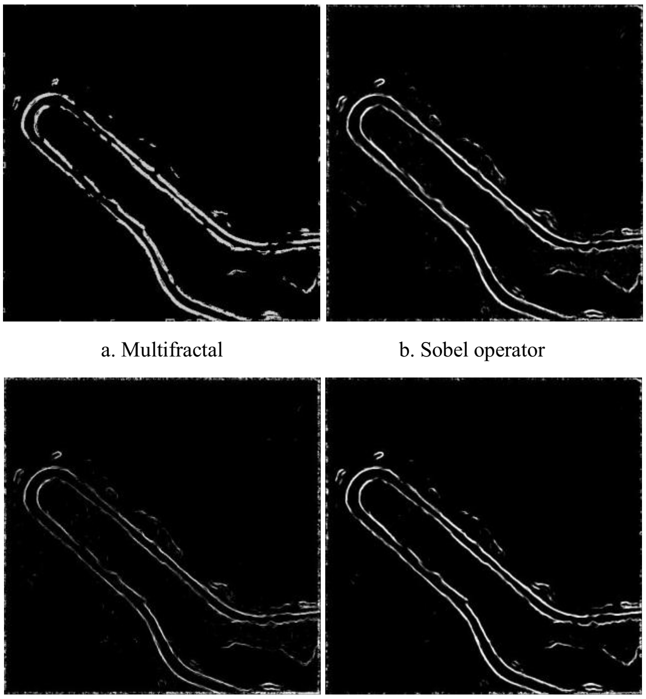


Figure 8. Mulatifrctal characteristic of a non-road pixel in Fig.2 (b)

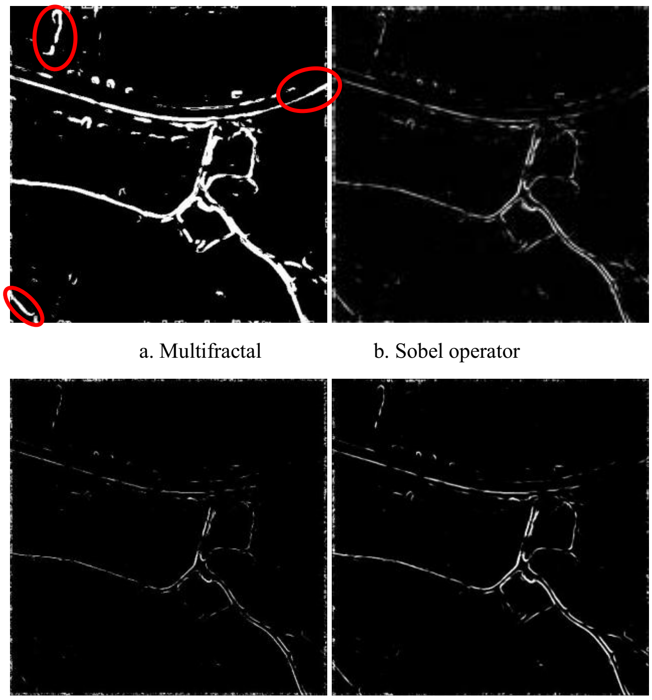
It can be seen from Fig. 9 and Fig. 10, that generally speaking, the multifractal based method is effective for extraction of different type of road information. Especially, we can see from the Fig. 10, that our method can extract road information that the other method ignore, e.g. as illustrated by ellipses in Fig. 10.



a. Multifractal b. Sobel operator

c. Roberts operator d. Prewitt operator

Figure 9. Winding mountain road extraction based on different method



a. Multifractal b. Sobel operator

c. Roberts operator d. Prewitt operator

Figure 10. Country road extraction based on different method

IV. CONCLUSION

The multifractal based method is adopted to extract country road information from high resolution Geoeye-1 satellite image. Because that the Hölder exponent α and multifractal spectrum *f*(α) can depict local and global feature of an image respectively, the proposed approach can outstand main road and ignore unimportant texture. The primary experiment and comparison with Sobel operator, Roberts operator and Prewitt operator validate the effectiveness of the presented approach.

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