CHINESE GEOGRAPHICAL SCIENCE
Volume 14, Number 3, pp. 263–268, 2004
Science Press, Beijing, China

EDGE DETECTION METHOD OF REMOTE SENSING IMAGES BASED ON MATHEMATICAL MORPHOLOGY OF MULTI-STRUCTURE ELEMENTS

LIN Hui[1], DU Pei-jun[2], ZHAO Chang-sheng[1], SHU Ning[3]
(1. Department of Territory Resource Information and Surveying Engineering, Xuzhou Normal University, Xuzhou 221116, P. R. China; 2. Department of RS and GIS, China University of Mining and Technology, Xuzhou 221008, P. R. China; 3. School of Remote Sensing and Information Engineering, Wuhan University, Wuhan 430079, P. R. China)

ABSTRACT: This paper puts forward an effective, specific algorithm for edge detection. Based on multi-structure elements of gray mathematics morphology, in the light of difference between noise and edge shape of RS images, the paper establishes multi-structure elements to detect edge by utilizing the grey form transformation principle. Compared with some classical edge detection operators, such as Sobel Edge Detection Operator, LOG Edge Detection Operator, and Canny Edge Detection Operator, the experiment indicates that this new algorithm possesses very good edge detection ability, which can detect edges more effectively, but its noise-resisting ability is relatively low. Because of the bigger noise of remote sensing image, the authors probe into putting forward other edge detection method based on combination of wavelet directivity checkout technology and small-scale Mathematical Morphology finally. So, position at the edge can be accurately located, the noise can be inhibited to a certain extent and the effect of edge detection is obvious.

KEY WORDS: Mathematical Morphology; multi-spectral'RS image; edge detection; multi-structure elements; wavelet transformation

CLC Number: TP79 Document code: A Article ID: 1002-0063(2004)03-0263-06

1 INTRODUCTION

Edge detection is widely used in such fields as fingerprint recognition, face recognition, ground artificial feature and natural landscape extraction including airport, massif, and flooded area. So it has got researcher's attention day by day. The edge includes abundant information that is very important attribute for obtaining the image characteristic by image recognition. We can delineate objects through edge detection, thereby achieve the goal of object recognition. In essence, image edge is the reflection of non-continuity in local image characteristics, which is often the line of demarcation of two different areas or boundary of two different objects. Multi-spectral remote sensing (multi-spectral RS) images possess abundant grey levels and plentiful information. Thus, those algorithms applied to edge detection in binary image successfully are difficult to meet practical requirements of edge detection in RS images, multi-spectral RS images in particular.

Mathematical Morphology is a science based on Set theory, in the meanwhile, is a kind of strong tool for geometrical morphology analysis and description. Since MATHRON and SERRA *et al.* put forward Mathematical Morphology, many experts and scholars have done a series of researches on its theories and applications, which results in its applications in many aspects. In recent years, Mathematical Morphology has been used in digital image processing and computer vision. And it arouses extensive interests of researchers and becomes one of the research hotspots in computer science. Generally speaking, Mathematical Morphology is becoming one kind of new theory and new method in fact for digital image processing and recognition (CHEN and BI, 2002; CUI, 2000)

Received date: 2003-11-12
Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 49971055)
Biography: LIN Hui (1973–), male, a native of Wugang City of Hunan Province, Lecturer, Master, specialized in photogrammetry and Remote Sensing image processing. E-mail: lin hui9995@sina.com

2 PRINCIPLE OF MATHEMATICAL MORPHOLOGY

Mathematical Morphology (also called image algebra) is the mathematical tool for image analysis based on shape. Its basic thought is to measure and detect corresponding shapes in an image in order to achieve the goal of analyzing and recognizing image by using structure element with some given forms. The application of Mathematical Morphology can simplify image data, maintain their basic characteristic in shape, and remove the irrelevant structure (CUI, 2000).

2.1 Basic Principle of Mathematical Morphology

The foundation of Mathematical Morphology is binary morphology, and its fundamental transforms include dilation, erosion, open, and close. Suppose binary image set is A, the structure element set is B (CUI, 2000), dilation operation (dilation) is defined as:

$$A \oplus B = \{x | [(\hat{B})_x \cap A] \subseteq A\} \tag{1}$$

where $\hat{B}$ is the map of B with reference to origin point, the set achieved from using B to dilate A is set of origin point location of B when at least a non-zero element intersects between displacement of $\hat{B}$ and A. x presents the displacement value of set A.

Erosion operation (erosion) is defined as:

$$A \ominus B = \{x | (B)_x \subseteq A\} \tag{2}$$

The set got from using B to erode A is set of origin point location of B when B is completely included in A.

Open operation (open) is defined as:

$$A \bullet B = (A \ominus B) \oplus B \tag{3}$$

Close operation (close) is defined as:

$$A \bullet B = (A \oplus B) \ominus B \tag{4}$$

Edge detection formula is:

$$d(A) = A - (A \ominus B) \tag{5}$$

where d is the edge point set.

2.2 Grey Mathematical Morphology

Because practical image is mostly grey image, binary morphology theory needs to be popularized to grey level morphology. Thus it can deal with the gray and color images effectively. We must popularize the function space of the image from two-dimensional plane to three-dimensional space, accordingly function value from {(0),(1)} to [0, 255], assuming $f(x, y)$ is input image function, $b(i, j)$ is structure element function. The following expression can be inferred (WANG *et al.*, 2003; ZHANG *et al.*, 2002).

Grey dilation definitions is:

$$(f \oplus B)(x, y) = \max\{f(x-i, y-j) + b(i, j) \in B,\ f(x-i, y-j) \in f\} \tag{6}$$

where x and y is the row number and column number of original input image matrix respectively, i and j is the row number and column number of multi-structure element matrix respectively.

The grey dilation operation is to choose maximum value of $f+b$ in the field determined by the structure element. If the values of structure element are positive, grey value of output image will be higher than that of input image, grey value of dark detail area which is close to the pixels with higher grey value will be enhanced, the output image will show the weakened or eliminated dark detail, and the range of the bright area will be dilated. Dilation operation can be used for elimination of the dark detail and enhancement of the bright area edge according to its characteristics.

Grey erosion definition is:

$$(f \ominus B)(x, y) = \min\{f(x+i, y+j) + b(i, j) \in B,\ f(x+i, y+j) \in f\} \tag{7}$$

Erosion operation is to choose minimum value of $f-b$ in the field determined by the structure element. If the values of structure element are positive, grey value of output image is lower than that of input image. But its influence is weakened under the situation that bright detail size in input image is less than the structure element size, at the same time, the weakened degree depends on grey value around the bright detail area, and the shape and amplitude of structure element. The appearance of the output image shows that grey value of brighter detail of edge part will decrease, and the brighter area edge will shrink. The definition of open-close operation of grey image is similar to those of binary morphology, the definition of open and close operation expressed by b and f is:

$$f \bullet b = (f \ominus b) \oplus b,\ f \bullet b = (f \oplus b) \ominus b \tag{8}$$

3 EDGE DETECTION ALGORITHM BASED ON GREY MATHEMATICAL MORPHOLOGY

3.1 Selection of Operation Structure Element

The operation structure element is a basic operator of Mathematical Morphology of an image, all processes involving in the morphology of the image are finished by it. So reasonable selection of operation structure element directly influences the effect and quality of image processing. When edge detection is carried out by traditional morphology method, it only uses a "structure element". Because "structure element" has very close and important relation with image edge detection, furthermore in fact the image edge is various, if a "structure element" is applied to image, it can only get a type of the edge. In order to detect all kinds of edges, multi-structure elements are proposed to detect edge.

While multi-structure elements are adopted to detect edge, because of the diversity of edge in image and the obvious influences of structure element to edge detection, typical and enough structure elements should be selected for edge detection. In morphology, there is not regular method as guidance, so repeated trials and precious experience is necessary in general (HO and CHIN, 1995; LEE *et al*., 1987).

In fact, structure element is a grey "morphology" within a small window, that is to say, when the size of the window is fixed, only determining the value of each point in the window is enough. Generally speaking, structure element core is regarded as permissible value of grey difference in non-edge area, and elements around core have determinant function on judging whether edge exists between present point and its adjacent point while detecting edge by their mutual size and relative size of core. Structure element value is generally determined by combing specific target with experiment effect. As for the size of the window, in morphological transform of edge detection, generally 3×3, 5×5 and 7×7 windows are used. Among them, 3×3 window is commonly used, which has the characteristic of high operation speed and fine and smooth edge detection. In addition, the larger window will bring the loss in precision of edge detection. Due to edge variety in the whole image, with respect to structure element value, central symmetrical structure element value should be chosen generally, and the value of cores of structure element is a little greater than value of its surrounding point.

Using multi-structure elements can detect various edges, and at the same time, image noise is filtered. Four kinds of structure element with the form of 3×3 are defined for edge detection here, and they can be shown by Fig. 1 (LIANG and LI, 1999; NI *et al*., 2003).

In horizontal direction 4 kinds of structure elements are as follows respectively:

$$\begin{aligned} &B_1=((-1,1),(0,0),(1,-1)) \\ &B_2=((0,1),(0,0),(0,-1)) \\ &B_3=((-1,-1),(0,0),(1,1)) \\ &B_4=((0,0),(1,0),(2,0)) \end{aligned} \tag{9}$$

In perpendicular direction 4 kinds of structure elements are as follows respectively:

$$\begin{aligned} &B_1=((-1,1),(0,0),(1,-1)) \\ &B_2=((0,0),(0,1),(0,2)) \\ &B_3=((-1,-1),(0,0),(1,1)) \\ &B_4=((-1,0),(1,0),(1,0)) \end{aligned} \tag{10}$$

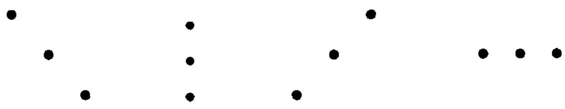

Fig. 1 Four kinds of structure elements

3.2 Grey Mathematical Morphology Algorithm for Edge Detection

Edge in an image has three important characteristics: 1) the change of grey does not present continuity; 2) different texture feature appear on both sides of the edge; and 3) grey of pixel on edge has directionality. So three factors described above should be taken comprehensively into consideration in order to detect edge information in the complicated image effectively. Classical differential operator generally detects non-continuity of local characteristics of an image at first, then, links these discontinuous edge pixels to form complete boundary. But because noise has also the characteristic of changing fast in grey, there is a defect of promoting noise with differential operator detecting edge. If reducing noise, perhaps target information is often gotten rid together. However, remote sensing image often has the characteristics of steady transition in grey and much noise, so the edge detection result of differential operator is not very ideal. Mathematical Morphology may select the structure element and transform way intentionally to weaken or strengthen some kinds of specific object. In RS image processing, differential gradient operator always combines with the threshold value technology to detect image edge. Like the situation of differential gradient operator, morphology gradient operator can be also combined with threshold value to finish edge detection. In grey morphology image processing, at present, many kinds of gradients have already been put forward.

If dilation operation is adopted, edge detection algorithm is as follows (HENK, 1994):

$$\begin{aligned} G_d(x,y) &= f(x,y)\oplus b(x,y)-f(x,y) \\ &= \max_{(i,j)} f(x-i,y-j)-f(x,y) \\ &= \max_{(i,j)} (f(i,j)-f(x,y)) \end{aligned} \tag{11}$$

where G_d indicates edge detection algorithm. If erosion operation is adopted, edge detection algorithm is :

$$\begin{aligned} G_d(x,y) &= f(x,y)-f(x,y)\oplus b(x,y) \\ &= f(x,y)-\max_{(i,j)} f(x-i,y-j) \\ &= \max_{(i,j)} f(x,y)-f(i,j)) \end{aligned} \tag{12}$$

Although edge and noise of the image has the attribute of suddenly gradient change, they have different morphology edge, thus, while detecting edge, these pixels whose grey change greatly only need be determined, then the pixel is judged according to multi-structure element so as to determine whether it is edge or noise. If it is noise, it will be filtered, otherwise retained as edge. It is unnecessary to perform Mathematical Morphology operation for each pixel of the whole image, which will reduce a large amount of unnecessary operation. Based on considerations to RS image with great gray change, abundant information content, complicated background noise and great density of edge, the morphology edge detection algorithm of the multi-structure element is realized by the following steps (LEE *et al.*, 1987; LIANG and LI, 1999; NI *et al.*, 2003):

Step 1: selecting pixel of sudden change in grey gradient by utilizing differential method of adjacent pixel.

Step 2: performing erosion operation of binary morphology of multi-structure element in order to eliminate noise and detect edge of image.

Step 3: obtaining the edge image.

While pixels with sudden change in grey gradient are chosen, edge threshold in strategy based on vision model is adopted, which is more effective than fixed threshold. It can be expressed by the following equation:

$$\Delta I=\begin{cases} C & I\leqslant a \\ \alpha & a\leqslant I\leqslant b \\ \beta\, 10^{\frac{10}{156-I}} & I>b \end{cases} \tag{13}$$

where a is grey maximum in dark area, b is grey minimum in bright area, I is grey of background brightness, α, β and C are also unknown parameters; ΔI is the predetermined threshold value. Here only 256 grades of grey.

4 EDGE DETECTION ALGORITHM BASED ON WAVELET TRANSFORMATION

Wavelet analysis is superior to Fourier transformation theory. It possesses good localization features in the field of time and frequency, and because it adopts gradually precision sample step-distance in the field of time or frequency, it can focus on arbitrarily details of the target's object, and is praised as the microscope on mathematics. In the course of wavelet analysis, isolated bizarre indexes of signal can be determined by attenuation velocity while scale-parameter of wavelet transformation becoming small in the point. Because of above-mentioned characteristics, it is effective considerably when images edge is detected by wavelet transformation. Because resolution value of signal's wavelet transformation varies as frequency in the field of time-space, namely, lower-frequency is rough, higher-frequency is precise, so signal can be separated from noise by certain way. Wavelet transformation is sensitive to bizarre characteristic, which make it much suitable for images edges and details detection.

Suppose $\varphi(x)\in L^2(R)$ and $\varphi(x)$ satisfies

$$C_\varphi=2\pi\int_{-\infty}^{+\infty}\left|\varphi(\widetilde{\omega})/\widetilde{\omega}\right|^2 \mathrm{d}\widetilde{\omega}>\infty,$$

when $\int_{-\infty}^{+\infty}\varphi(x)\,\mathrm{d}x=0$, $\varphi(x)$ is called wavelet.

Define wavelet transformation formula of function $f(x)$ is:

$$\varphi f(a,b)=(C_\varphi|a|)^{-1/2}\int_{-\infty}^{+\infty} f(x)\varphi\left|\frac{x-b}{a}\right|\mathrm{d}x \tag{14}$$

where a is expansion and contraction factor, b is displacement factor, C_φ is wavelet coefficient.

Accordingly inverse transformation is

$$f(x)=(C_\varphi)^{-1/2}\int\int_{-\infty}^{+\infty} a^{-2}\,\varphi f(a,b)\left(|a|^{1/2}\times\varphi\left|\frac{x-b}{a}\right|\right)\mathrm{d}a\mathrm{d}b \tag{15}$$

The following expression can be derived through expansion and contraction and horizontal movement:

$$\varphi_{a,b}(t)=a^{-1/2}\varphi((t-b)/a) \tag{16}$$

Wavelet weight of higher-frequency corresponds narrow portion while $a>1$, wavelet weight lower-frequency corresponds wide portion while $a<1$, which make wavelet transformation become powerful tool in realizing signal localization in the field of time and frequency. Multi-scale edges detection through wavelet transformation is described as follows. At first, $\theta(x,y)$ indicates a Gauss smoothing function.

Assuming:

$$\begin{aligned} \theta_2^j(x,y)&=\theta(x/2^j,y/2^j)/4^j \\ \varphi_{2j}^1(x,y)&=\varphi^1(x/2^j,y/2^j)/4^j \\ \varphi_{2j}^2(x,y)&=\varphi^2(x/2^j,y/2^j)/4^j \end{aligned} \tag{17}$$

Conducting convolution processing:

$$\begin{aligned} W_{2j}^1 f(x,y)&=f*\varphi_{2j}^1(x,y) \\ W_{2j}^2 f(x,y)&=f*\varphi_{2j}^2(x,y) \end{aligned} \tag{18}$$

Then, $W_{2j}^1 f(x,y)$, $W_{2j}^2 f(x,y)$ consist of an array of binary wavelet series, $j\in N$.

Under 2^j scale, the determinant of gradient vector is:

$$M_2^j=\left(\left|W_{2j}^1 f(x,y)\right|^2+\left|W_{2j}^2 f(x,y)\right|^2\right)^{1/2} \tag{19}$$

The argument is:

$$A_{2j}f(x,y)=\tan^{-1}\left[\left|W_{2j}^2 f(x,y)\right|/\left|W_{2j}^1 f(x,y)\right|\right] \tag{20}$$

Gradient direction directs to the direction where determinant is maximum value, so if detecting local maximum value of wavelet transformation coefficient determinant following gradient direction, then may obtain edge point of images.

5 EXPERIMENTS AND ANALYSIS

The original image used in the experiment is a Landsat TM image with the size of 250×250 in a given area of Wuhan (capital of Hubei Province), China (Fig. 2).

Fig. 2 Original TM image

Sobel algorithm, LOG algorithm, Canny algorithm and 4 kinds of 3×3 structure elements proposed in this paper are used to detect edges in original image respectively, and the results are shown in Fig. 3. From the four-edge image we can directly find out that detected edge number is small in Fig. 3a and Fig. 3b, and their completeness is bad and is disturbed seriously by noise. On the contrary, edge continuity is good in Fig. 3c and Fig. 3d, also their completeness is dominant. Compared with Fig. 3d, edge in Fig. 3c is thick, and with much noise. As far as connection of edge is concerned, Fig. 3d is the best, and feature detail is embodied most distinctly. In addition, the outline edge of water body is detected completely, which has advantageous in RS image analysis and interpretation.

5 CONCLUSIONS AND PROSPECTS

RS image processing by Mathematical Morphology has the characteristics of simplicity in form and rigorousness in mathematics, and has the unique advantage of describing image morphology feature

a. Based on sobel algorithm

b. Based on log algorithm

c. Based on canny algorithm

d. Based on multi-structure element

Fig. 3 Images of edge detection

quantitatively, so it offers powerful means for carrying out image processing based on morphology detail. Mathematical Morphology mainly chooses the corresponding structure element by adopting the combination of dilation, erosion, and open and close to process image. Mathematical Morphology has extensive applications in RS image processing and there are a lot of practical algorithms. But it is an important problem to select structure element in each kind of algorithm (PEI and CHEN, 1995).

Based on above-mentioned experimental results and compared with classical edge detection algorithms, the algorithm proposed in the paper has very good capability to detect edge because the image edge is much clearer and the characteristic is more obvious. But noise-resistant ability of grey morphology image processing is low. If there is much noise in image, the result of image edge detection will be influenced. In order to overcome this disadvantage, we put forward a new edge detection method by adopting the combination of wavelet transformation and Mathematical Morphology. That new method makes full use of the advantages of wavelet transformation, decomposes the RS image firstly in order to obtain the detail of high frequency quantity. Because the sizes of the structure element are different, the characteristics of images edge detected are different. Though the noise-eliminated ability of the structure elements of small size is weak, it can detect the more precise edge detail. On the contrary, the noise-eliminated ability of the structure element of the large size is strong, but the edge is relatively thicker. So we can combine wavelet transformation with gray Mathematical Morphology, take full advantage of wavelet transformation, and utilize the structure element of small size to perform dilation and erosion operation, therefore, we can obtain better characteristics and detail of RS image edge (PEI and CHEN, 1991; TAO *et al.*, 2002).

REFERENCES

CHEN Lan-lan, BI Du-yan, 2002. The application of Mathematical Morphology in image process [J]. *The Journal of Computer Application*, 8: 8–20. (in Chinese)

CUI Yi, 2000. *Image Process and Analysis—Mathematical Morphology Method and Its Applications* [M]. Beijing: Science Press, 98–111. (in Chinese)

HENK J A M Heilmans, 1994. *Morphological Image Operators* [M]. New York: Academic Press, Inc., 361–371.

HO C P, CHIN R T, 1995. Decomposition of arbitrarily shaped morphological structuring elements [J]. *IEEE Transaction on Pattern Analysis and Machine Intelligence*, 17(1): 2–15.

LEE J, HARALICK R M, SHAPIRO L G, 1987. Morphology edge detection [J]. *IEEE Transaction on Robotic Automation*, 3(4): 142–156.

LIANG Yong, LI Tian-mu, 1999. The application of image edge detection with multidirection morphological structuring elements [J]. *Journal of Yunnan University (Natural Science Edition)*, 21(5): 392–394. (in Chinese)

NI Chong-jia, WANG Bo-ping, LIU Wen-qi, 2003. Morphology edge detection based on multi-scale and multi-structure element [J]. *The Journal of Science and Engineering University of Kunming (Science and Engineering Edition)*, 28(4): 164–166. (in Chinese)

PEI S-C, CHEN F-C, 1991. Subband decomposition of monochrome and color images by Mathematical Morphology [J]. *Opt. Eng.*, 30(8): 921–933.

PEI S-C, CHEN F-C, 1995. Hierarchical image representation by Mathematical Morphology subband decomposition [J]. *Pattern Recogit. Lett.*, 16: 183–192.

TAO Hong-jiu, LIU Jian, TIAN Jin-wen, 2002. Edge detection of RS image based on Wavelet Transform and Mathematical Morphology [J]. *Infrared and Laser Project*, 31(2): 154–157. (in Chinese)

WANG Yu, WANG Chen, LIU Ji-ping, 2003. A algorithm of edge detection of RS image based on Mathematical Morphology [J]. *The Journal of Institute of the Post and Telecommunications of Chong Qing*, 15(2): 57–60. (in Chinese)

ZHANG Xiang, LIU Mei-jie, CHEN Li-wei, 2002. Edge detection method on the basis of Mathematical Morphology [J]. *The Journal of University of Electronic Science and Technology of Cheng Du*, 31(5): 492–495. (in Chinese)