Edge Detection of River in SAR Image Based on Contourlet Modulus Maxima and Improved Mathematical Morphology

Wu Yiquan (吴一全)[1,2,3,4,5*], *Zhu Li* (朱丽)[1], *Hao Yabing* (郝亚冰)[1], *Li Li* (李立)[1], *Lu Wenping* (卢文平)[2]

1. College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, 210016, P. R. China;
2. Engineering Technology Research Center of Wuhan Intelligent Basin, Changjiang River Scientific Research Institute, Changjiang Water Resources Commission of the Ministry of Water Resources, Wuhan, 430010, P. R. China;
3. Key Laboratory of the Yellow River Sediment of Ministry of Water Resource, Yellow River Institute of Hydraulic Research, Zhengzhou, 450003, P. R. China;
4. Key Laboratory of Port, Waterway and Sedimentation Engineering of the Ministry of Transport, Nanjing Hydraulic Research Institute, Nanjing, 210024, P. R. China;
5. State Key Laboratory of Urban Water Resource and Environment, Harbin Institute of Technology, Harbin, 150090, P. R. China

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Abstract: To cope with the problems that edge detection operators are liable to make the detected edges too blurry for synthetic aperture radar (SAR) images, an edge detection method for detecting river in SAR images is proposed based on contourlet modulus maxima and improved mathematical morphology. The SAR image is firstly transformed to a contourlet domain. According to the directional information and gradient information of directional subband of contourlet transform, the modulus maximum and the improved mathematical morphology are used to detect high frequency and low frequency sub-image edges, respectively. Subsequently, the edges of river in SAR image are obtained after fusing the high frequency sub-image and the low frequency sub-image. Experimental results demonstrate that the proposed edge detection method can obtain more accurate edge location and reduce false edges, compared with the Canny method, the method based on wavelet and Canny, the method based on contourlet modulus maxima, and the method based on improved (ROEWA). The obtained river edges are complete and clear.

Key words: synthetic aperture radar (SAR) image; river detection; edge detection; contourlet transform; modulus maxima

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1 Introduction

Synthetic aperture radar (SAR) has been drawn particular attention in target detection of river and sea water area, thanks to its special earth observation performance, which are of great value in topography, map matching, ship navigation and so forth[1]. Edge detection is an important step in river detection, for the edges and contours of river in SAR image carry important information and contain a large number of linear characteristics. It is also the premise of river seg-

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* **Corresponding author**: Wu Yiquan, Professor, E-mail: nuaaimage@163.com.

mentation, feature extraction, classification and recognition[2-3]. Moreover, automatic detection of linear boundaries is more difficult due to the existence of a large amount of coherent speckle noise. Therefore, the research on effective reduction of speckle noise in SAR image and accurate detection of water area edges is much valuable.

Due to the existence of a large amount of coherent speckle noise, the traditional edge detection methods based on the pixel level, which are sensitive to noise, cannot achieve good detection results. If the SAR image is processed by filtering before detection, the influence of noise on edge detection can be reduced, while some edge information, even some important information[4-5], are lost inevitably. The traditional methods of edge detection usually use differential operators. The classic edge detection operators are Prewitt operator, Sobel operator, Laplacian operator, Canny operator and so on. But the response of operators to the noise is often greater than the response to image edges, which will blur the detected edges, thus the traditional differential operators cannot achieve good results. At present, edge detection methods based on wavelet have been applied to edge detection of river in SAR images[6-7]. Hu, et al.[8] and Ge, et al.[9] proved that wavelet transform had good localization property of space and frequency. Moreover, most of the energy of original image was in the low frequency subband, and the energy of high frequency subband corresponded to the edge and contour of original image. This characteristic of wavelet can be used to analyze the strength of image signal's singularity and the location of singular points[10]. But it cannot detect line singularity effectively since the directivity of wavelet is limited. Besides, contourlet transform is a new extension to wavelet transform, and its greatest characteristic is multidirectional[11]. The basis function of contourlet transform is anisotropy, which makes contourlet transform have infinite directions in theory[12-13]. Contourlet transform also has the characteristics of multi-scale, space-frequency localization like wavelet[14]. Therefore, the edges of river in SAR image can be captured by using contourlet transform. On the other hand, although corrosion and dilation operators in morphology, which are applied to edge detection, can simplify image data and remove irrelevant structures, the edge signal obtained by the dilation operator is weak and blurry[15] and the edge signal obtained by the corrosion operator is more sensitive to noise, despite of its strong intensity. Hence, synthesizing respective advantages of the corrosion operator and the dilation operator can detect a weak edge and ensure an accurate edge position.

Combining the advantages of edge detection method based on differential operator, method based on wavelet transform and method based on mathematical morphology, we propose an edge detection method of the river in SAR image based on contourlet modulus maxima and improved mathematical morphology. Firstly, SAR image of river is decomposed into a low frequency component and high frequency components by contourlet transform. Secondly, modulus maximum and improved mathematical morphology are used to detect high frequency sub-image edges and low frequency sub-image edges, respectively. Finally, the edges of high frequency sub-image and the edges of low frequency sub-image are fused to get the final edges of the river in SAR image.

2 Edge Detection of Contourlet Modulus Maxima

2.1 Contourlet transform

The schematic diagram of the structural principle of the discrete contourlet transform, referred to as pyramidal direction filter banks (PDFB), is shown in Fig. 1. It consists of two steps, i. e., Laplacian pyramid (LP) decomposition and directional filter banks (DFBs). It uses LP filter to achieve image multi-scale decomposition and decomposes each low frequency component into a low frequency component and a high frequency component; then two-dimensional (2D) DFBs are used for each level of high frequency component, which are achieved by LP decomposition. As a result, the image contour can be captured, and the image decomposition of multi-scale and multi-direction can be accomplished. Through contourlet transformation, a low frequency component and high frequency components that distribute on multi-scale and multi-direction can finally be obtained.

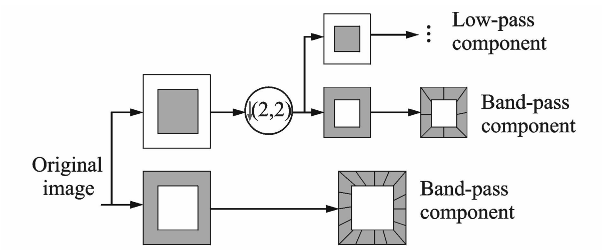

Fig. 1 Schematic diagram of contourlet filter banks

2.2 Edge detection of modulus maxima

Based on the study on modulus maxima edge detection of wavelet transform, high frequency sub-image obtained by contourlet transform can be processed in the same way. Wavelet modulus maxima can be obtained by combining the wavelet transform with first-order derivative extremum detection. For a 2D smoothing function φ, which satisfies $\iint_{R^2} \varphi(x,y)\mathrm{d}x\mathrm{d}y = 1$, where R^2 represents a 2D space, the partial derivative of x and y can be given by

$$\begin{cases} \phi_1(x,y) = \partial\varphi(x,y)/\partial x \\ \phi_2(x,y) = \partial\varphi(x,y)/\partial y \end{cases} \tag{1}$$

Assuming an image $I(x,y)$, then its wavelet transform is

$$\begin{cases} W_1^l(x,y) = I(x,y) * \phi_1(x,y) = \\ \qquad l\dfrac{\partial}{\partial x}(I * \varphi^l)(x,y) \\ W_2^l(x,y) = I(x,y) * \phi_2(x,y) = \\ \qquad l\dfrac{\partial}{\partial y}(I * \varphi^l)(x,y) \end{cases} \tag{2}$$

where l is the scale of wavelet transform; and $*$ denotes convolution operation. In Eq. (2), the modulus of wavelet is proportional to the gradient vector of $I(x,y)$, and the edge point of images is actually the inflection point of $(I * \varphi^l)(x,y)$, namely, the extremum value of first-order derivative of $(I * \varphi^l)(x,y)$. In scale l, wavelet modulus can be defined as

$$M^l(x,y) = \sqrt{|W_1^l(x,y)|^2 + |W_2^l(x,y)|^2} \tag{3}$$

The argument of wavelet transform is the angle of the gradient vector and the horizontal direction of $I(x,y)$. It can be defined as

$$A^l(x,y) = \arg(W_1^l(x,y) + \mathrm{i}W_2^l(x,y)) \tag{4}$$

It is the direction whose partial derivative changes fastest. The wavelet edge detection is just searching the local modulus maxima of wavelet along the gradient direction in the scale of l. Because the grayscale of the image has an obvious step change at edge, which means the modulus value is too large, and the appropriate threshold can be selected. If the value is greater than the threshold, it can be judged as an edge point. Consequently, the extraction of the edge information of original image can be achieved.

Basic principles of the wavelet modulus maxima and contourlet transform are the same, but they are different in determining the image edge direction. The modulus maxima detection method based on wavelet transform determines the gradient direction of edge and curve through calculating the angle of the gradient vector and the horizontal direction. Filter banks of contourlet transform are inseparable. And the coefficients of each directional subband have already contained enough direction information.

Assuming the modulus of $C_k^l(x,y)$ to be $|C_k^l(x,y)|$, its edge direction is expressed as $\arg[C_k^l(x,y)]$, and this direction can be determined uniquely. Therefore, in the method of contourlet modulus maxima, one only needs to compare $|C_k^l(x,y)|$ with the modulus of adjacent elements of $\arg[C_k^l(x,y)]$ in the vertical direction to determine whether the pixel is the local modulus maxima or not.

3 Edge Detection Operator Based on Improved Mathematical Morphological

The four basic operations of mathematical morphology include erosion, dilation, opening operation and closing operation.

Let $f(x,y)$ be a gray image, $g(x,y)$ a structural element in a given 2D space, then the dilation operator of edge detection can be given by

$$E_d(x,y)=(f \bullet g)(x,y)-f(x,y) \quad (5)$$

The erosion operator of edge detection can be expressed as

$$E_e(x,y)=f(x,y)-(f * g)(x,y) \quad (6)$$

The opening operator of edge detection can be expressed as

$$E_{ed}(x,y)=(f * g)(x,y) \bullet g(x,y)-f(x,y) \quad (7)$$

The edges obtained by the dilation operator are weak, thus being liable to be blurry. The edges obtained by the erosion operator are strong, but more sensitive to noise. An improved edge detection operator can be achieved by combining the operators mentioned above.

Let

$$E_{min}(x,y)=\min\{E_d(x,y),E_e(x,y)\} \quad (8)$$

$$E_{max}(x,y)=\max\{E_d(x,y),E_e(x,y)\} \quad (9)$$

$$E_{dec}(x,y)=E_{max}(x,y)-E_{min}(x,y) \quad (10)$$

The improved edge detection operator can be obtained from Eq. (11)

$$E(x,y)=E_{ed}(x,y)+E_{dec}(x,y) \quad (11)$$

However, in order to reduce the noise sensitivity to operators more effectively, Eq. (11) is further modified and finally results in Eq. (12). A weighting factor is added to the operator, and edge blurriness and sensitivity to noise can thus be reduced by adjusting this factor.

$$E(x,y)=E_{ed}(x,y)+\lambda E_{dec}(x,y) \quad (12)$$

where $0 \leqslant \lambda \leqslant 1$.

In addition, the selection of structural elements also has influence on the results of edge detection. The window sizes of commonly used structural elements are generally 3×3, 5×5, 7×7, etc. Taking the edge detection result and the running time into account, a 3×3 window serves as structural element in this paper.

4 Procedure of Proposed Edge Detection Method

Weighted fusion of the high frequency sub-image and the low frequency sub-image are performed to obtain clear river edges with accurate positioning under the combination of the advantages of contourlet modulus maxima and improved mathematical morphology.

The edges of low frequency and high frequency sub-images are denoted as $L(x,y)$ and $H(x,y)$, respectively. Then the fused image $F(x,y)$ can be obtained according to Eq. (13).

$$F(x,y)=\alpha L(x,y)+\beta H(x,y) \quad (13)$$

where α and β are the weighting factors which satisfy $\alpha+\beta=1$.

The procedure of the proposed edge detection method is as follows:

Step 1 N-layer contourlet decomposition is carried out on each SAR image to obtain a low frequency component and high frequency components.

Step 2 The low frequency sub-image is processed by using the improved mathematical morphology method to detect the weak edges and ensure accurate location, thus the edges of low frequency sub-image $L(x,y)$ can be achieved.

Step 3 To search for modulus maxima of contourlet coefficients in each high frequency sub-image, and to set the non-modulus maxima to 0 for obtaining the edges of high frequency sub-image $H(x,y)$.

Step 4 According to Eq. (13), the edges of high frequency sub-image and low frequency sub-image are fused to form a new coefficient matrix. As a result, the final edge image $F(x,y)$ can be obtained.

5 Experiment Results and Discussion

To verify the effectiveness of the proposed edge detection method based on contourlet modulus maxima and improved mathematical morphology, a large number of experiments on different SAR images are conducted. Experimental results are compared with the related methods such as the Canny method, the method based on wavelet and Canny (denoted as WCM)[16], the method based on contourlet modulus maxima (denoted as CMM)[17], and the method based on improved ratio of exponentially weighted averages (ROEWA) (denoted as IROW)[18]. The experiments are conducted in the following environment: Intel(R) Core(TM) 2, 1.80 GHz, 2 GB memory, Matlab 7.11. The parameters of the proposed method are set as follows: the 3 LP levels and 16 directions are used at the finest level. In the LP stage the authors choose the "9-7" filters partly, while in the DFB stage the authors use the "pkva" filters. Due to space limitations, three SAR images of river are selected to illustrate the proposed method.

In Figs. 2—4, sub-images (a) are the original images. Sub-images (b—f) are the edge detection results of three SAR images of river by the Canny method, WCM[16], CMM[17], IROW[18], and the proposed method, respectively. The running time of the five methods is compared, as listed in Table 1.

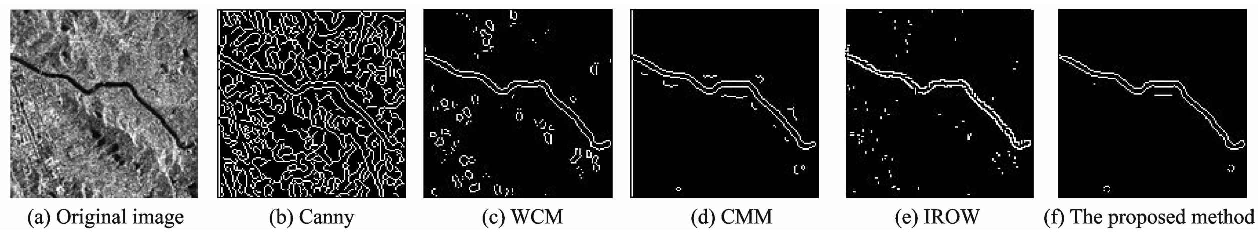

Fig. 2 Edge detection results of river in SAR image 1

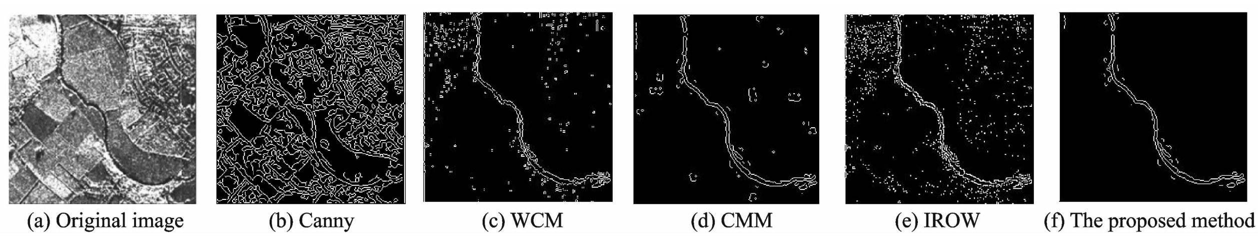

Fig. 3 Edge detection results of river in SAR image 2

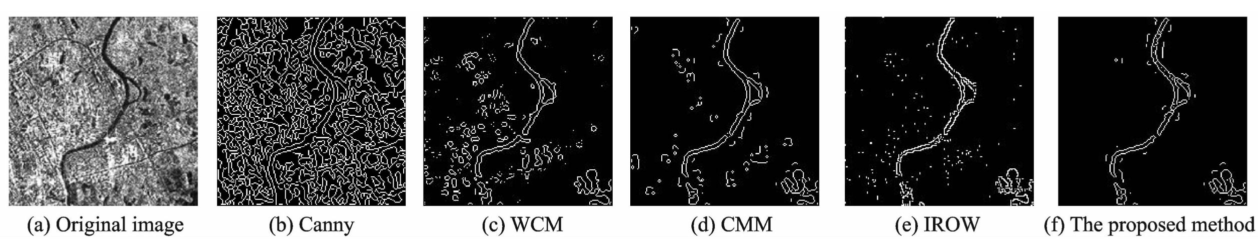

Fig. 4 Edge detection results of river in SAR image 3

Table 1 Comparison of five methods in running time

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Method	Fig. 2	Fig. 3	Fig. 4
Canny	0.54	0.67	0.61
WCM[16]	1.42	1.45	1.25
CMM[17]	1.63	1.72	1.60
IROW[18]	2.78	2.83	2.59
The proposed method	1.48	1.57	1.55

It can be seen that the edge images detected by the proposed method have better effect than those of other three methods. From Fig. 2 to Fig. 4, it clearly shows that the Canny method cannot detect the edges of river, while the WCM method, the IROW method and the CMM method can roughly extract the edges of river in SAR images. However, there exists too much noise as well as false edges. Overall, all the four methods cannot represent river edges accurately. It can be seen from the experiment results (f) in Fig. 2 to Fig. 4 that the final edges extracted by the proposed method are almost completely consistent with the riverbank, illustrating good continuity. The proposed method based on contourlet modulus maxima and improved mathematical morphology can achieve superior results and also reduce false edges, compared with the Canny method, WCM, CMM, and IROW methods.

In Table 1, although the running time of the proposed method is almost the same as those of WCM and CMM, the edge detection performance of the proposed method is the best.

6 Conclusions

An edge detection method based on contourlet modulus maxima and improved mathematical morphology is proposed to detect rivers in SAR images. A SAR image of river is firstly decomposed into a low frequency component and high frequency components through contourlet transform. Then the improved mathematical morphology method is used to detect low frequency sub-image edges, while the method of contourlet modulus maxima method is applied to the high frequency sub-image to detect edges. Consequently, noise can be suppressed effectively. Finally, the weighted fusion of high frequency and low frequency sub-images are carried out, then the river edges of SAR image are obtained. The proposed edge detection method can achieve more accurate edge location and reduce false edges. And the obtained river edges are complete and clear, compared with the Canny method, WCM, CMM, and IROW methods.

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