Multi-scale Edge Detection of Wood Defect Images Based on the Dyadic Wavelet Transform

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***Abstract*—Multi-scale feature of wavelet and the theory of wavelet transform modulus maxima were researched. A method about multi-scale edge detection based on dyadic wavelet transform was proposed in order to solve the contradiction between noise suppression and edge continuity when wood defect image detected edge. A fast multi-scale edge detection algorithm was constructed when the image and filter do convolution and applied to the wood defect image edge detection. The method was verified by computer simulation. The experimental results show that the method can detect image edge continuously and clearly and can suppress noise effectively. The method is better than the traditional edge detection algorithms and is suitable for wood defect image edge extraction.**

Keywords-dyadic wavelet transform; multi-scale; edge detection; wood nondestructive testing

I. INTRODUCTION

The image edge is the most basic feature of the image. It carries much valuable boundary information and is the basis of analyzing and understanding the image. The contour of the image is available through the edge detection which has a direct impact on the image-processing quality. A lot of the traditional edge detection operators have been proposed such as Robert operator, Sobel operator, Prewitt operator, etc. But these operators have so many problems that can not reach the ideal edge detection. For example: the edge position is inaccurate and noise interference is more serious [1].

Wavelet theory has brought new theories and methods in image processing. Wavelet multi-scale feature and the theory of wavelet modulus maxima are used to detect the image edge [2]. When wood defect image is obtained by nondestructive testing system, it has the contradiction between noise suppression and edge continuity in extracting edge of wood defect image because factors, which are camera system quality, the light conditions, input devices, increase the image noise to a certain extent. Based on the above issues, a method about Multi-scale edge detection of wood defect images based on the dyadic wavelet transform is proposed to get rid of noise effectively and keep the edge straight in this paper.

II. MULTI-SCALE EDGE DETECTION BASED ON DYADIC WAVELET TRANSFORM

A. Dyadic Wavelet Transform

1) Wavelet transform: If $\psi(t) \in L^2(R)$, and Fourier transform $\hat{\psi}(\omega)$ satisfies the admissibility condition

$$c_\psi = \int_{-\infty}^{+\infty} \frac{\left|\hat{\psi}(\omega)\right|^2}{|\omega|} d\omega < +\infty \tag{1}$$

So $\psi(t)$ is a basic wavelet or mother wavelet.

Mother wavelet $\psi(t)$ flexes and translates, we will get wavelet basis function

$$\psi_{a,b} = \frac{1}{\sqrt{|a|}} \psi\left(\frac{t-b}{a}\right) \tag{2}$$

a is a scale factor b is a shift factor

For a given basic wavelet $\psi(t)$, Function the $f(t) \in L^2(R)$,the continuous wavelet transform is expressed as

$$WT_f(a,b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{+\infty} f(t) \psi^*\left(\frac{t-b}{a}\right) dt = \left\langle f, \psi_{a,b} \right\rangle \tag{3}$$

$WT_f(a,b)$ is the wavelet transform coefficients of $f(t)$

2) Dyadic wavelet and dyadic wavelet transform: In the continuous wavelet transform, $a = 2^j$ $j \in Z$, but b is still taking a continuous value, we will get dyadic wavelet:

$$\psi_{2^j,b}(t) = 2^{-j/2} \psi\left[2^{-j}(t-b)\right] \tag{4}$$

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Function $f(t) \in L^2(R)$, dyadic wavelet transform is expressed as

$$WT_f(2^j, b) = \int_{-\infty}^{+\infty} f(t)\psi^*\left[2^{-j}(t-b)\right]dt \quad (5)$$

Dyadic wavelet transform is the trade-offs of continuous wavelet transform and discrete wavelet transform. Because it is discrete only for the scale factor, but the shift factor in the time domain remains a continuous change and has the translation invariance. Thus its magnitude has also the translation invariance. There is great significance for the edge detection [3].

B. Multi-scale Edge Detection

The image edge point can be determined by detecting two-dimensional wavelet transform modulus maxima point. The wavelet transform at various scales proposes the edge information of image, so it is called multi-scale edge. Modulus maxima curves are formed when the edges are connected by following boundary under the scale. Wavelet transform is able to analyze image into many multi-scale components and use corresponding time-domain or airspace to sample step for different scales. Thus, it is able to focus on any small detail constantly. Wavelet transform possesses multi-scale feature and just can be used to image edge detection.

Multi-scale edge detection algorithm is defined that: at different scales, the spatial location of image edge is found by calculating local maxima of module which is the mode of $\nabla f = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}\right)$. $f(x, y)$ is the image signal. ∇f is Gradient Vector. The direction of ∇f points out the fastest direction of the image gray-value change [4].

Two-dimensional smooth function $\theta(x, y)$

If $\theta(x, y) \geq 0$ $\iint_{R^2} \theta(x, y) dxdy = 1$ $\lim_{x,y\to\pm\infty} \theta(x, y) = 0$

Mark: $$\theta_s(x, y) = \frac{1}{s^2}\theta\left(\frac{x}{s}, \frac{y}{s}\right) \quad (6)$$

For $f(x, y) \in L^2(R^2)$, $(f * \theta_s)(x, y)$ is the image which is smoothed by $\theta_s(x, y)$, s>0, s is a smooth scale.

Two-dimensional wavelets are defined by $\theta(x, y)$:

$$\psi^1(x, y) = \frac{\partial\theta(x, y)}{\partial x} \quad (7)$$

$$\psi^2(x, y) = \frac{\partial\theta(x, y)}{\partial y} \quad (8)$$

Mark: $$\psi_s^1(x, y) = \frac{1}{s^2}\psi^1\left(\frac{x}{s}, \frac{y}{s}\right) \quad (9)$$

$$\psi_s^2(x, y) = \frac{1}{s^2}\psi^2\left(\frac{x}{s}, \frac{y}{s}\right) \quad (10)$$

Then

$$W^1 f(s, x, y) = \iint_{R^2} f(u, v)\frac{1}{s}\psi^1\left(\frac{u-x}{s}, \frac{v-y}{s}\right)dxdy$$
$$= (f * \overline{\psi}_s^1)(x, y) \quad (11)$$

$$W^2 f(s, x, y) = \iint_{R^2} f(u, v)\frac{1}{s}\psi^2\left(\frac{u-x}{s}, \frac{v-y}{s}\right)dxdy$$
$$= (f * \overline{\psi}_s^2)(x, y) \quad (12)$$

$W^1 f(\mathrm{s}, x, y)$ and $W^2 f(\mathrm{s}, x, y)$ are two components of wavelet transform on scale s of $f(x, y)$.

Meanwhile $\overline{\psi}_s^k(x, y) = \frac{1}{s^2}\psi_s^k(-x, -y)$ k=1, 2. (13)

While, Two components of dyadic wavelet transform on scale $s = 2^j$ of function $f(x, y)$:

$$\begin{pmatrix} W^1 f(2^j, x, y) \\ W^2 f(2^j, x, y) \end{pmatrix} = 2^j \begin{pmatrix} (f * \overline{\psi}_s^1)(x, y) \\ (f * \overline{\psi}_s^2)(x, y) \end{pmatrix}$$

$$= 2^j \begin{pmatrix} \frac{\partial}{\partial x}(f * \overline{\theta_{2^j}})(x, y) \\ \frac{\partial}{\partial y}(f * \overline{\theta_{2^j}})(x, y) \end{pmatrix} = 2^j \nabla(f * \overline{\theta_{2^j}})(x, y) \quad (14)$$

The module of $\nabla(f * \overline{\theta_{2^j}})(x, y)$ is proportional to

$$Mf(2^j, x, y) = \sqrt{\left|W^1 f(2^j, x, y)\right|^2 + \left|W^2 f(2^j, x, y)\right|^2} \quad (15)$$

The angle between Gradient Vector and horizontal direction is $Af(2^j, x, y)$

$$Af(2^j, x, y) = \begin{cases} \alpha(x, y), W^1 f(2^j, x, y) \geq 0 \\ \pi - \alpha(x, y) W^1 f(2^j, x, y) < 0 \end{cases} \quad (16)$$

Meanwhile $$\alpha(x, y) = \tan^{-1}\left(\frac{W^2 f(2^j, x, y)}{W^1 f(2^j, x, y)}\right) \quad (17)$$

The knickstelle of $\nabla(f * \overline{\theta_{2^j}})$ corresponds to local modulus maxima of $Mf(2^j, x, y)$ which is on the direction of $Af(2^j, x, y)$ .So multi-scale edge detection which uses the dyadic wavelet transform is detecting maximum point of $Mf(2^j, x, y)$ along the direction of $Af(2^j, x, y)$. The location of the maxima gives a multi-scale edge of image [5].

III. DYADIC WAVELET TRANSFORM ALGORITHM WOOD DETECT IMAGE

Two-dimensional discrete dyadic wavelet transform can be achieved by convolution of filter. Wood defect image and the digital filter do convolution.

RSA [6]:

S_{2^j} is wood defect image, H, G, L are the digital filters, H_j, G_j, L_j are discrete filters which are obtained by inserting $2^j - 1$ zeros into H, G, L on scale 2^j.

j=1 $S_{2^j} = f(x, y)$

While (j<J)

$S_{2^{j+1}} = S_{2^j} * (H_j, H_j)$

$W^1_{2^j} f(x, y) = S_{2^j} * (G_j, L_j)$

$W^2_{2^j} f(x, y) = S_{2^j} * (L_j, G_j)$

j=j+1

End of while

$W^1_{2^j} f(x, y)$ is horizontal high-frequency (edge) information of image on scale 2^j . $W^2_{2^j} f(x, y)$ is perpendicular high-frequency (edge) information of image on scale 2^j . $Mf(2^j, x, y)$ is obtained by $W^1_{2^j} f(x, y)$ and $W^2_{2^j} f(x, y)$ on scale 2^j . Local minimization of $Mf(2^j, x, y)$ constitutes the edge of wood defect image on scale 2^j .

The results of discrete dyadic wavelet transform are related to the filters. In this experiment, the second B-spline wavelet filter and wood defect image are chosen to do convolution. The filter coefficients are shown in TABLE Ⅰ [7]:

TABLE I. FILTER COEFFICIENT

n	-1	0	1	2
H	0.125	0.375	0.375	0.125
G		0.5	-0.5	
L	-0.0869	0.5789	0.5789	0.0869

IV. RESULTS AND ANALYSIS

Wood defect image is obtained by new dual-focus X-ray wood nondestructive testing equipment in the experiment. Fig. 1 shows the original image. As the image contrast is low and there are many noises, many details of detection have been submerged in the background. So, the image needs to be pre-processed. The image is preprocessed by histogram equalization, filtering and so on to make the details of wood defect image clear.

The dyadic wavelet multi-scale edge detection algorithm (that is: the image and digital filter do convolution by quadratic B-spline wavelet.) is used to detect the wood defect image [8](Fig. 4). The results show that the algorithm can not only eliminate and control noises effectively but also detect the edge continuously and clearly. The algorithm avoids emerging false-edge and shows the outline of the edge of wood defect image rightly. At the same time, the traditional edge detection operator such as Sobel operator (Fig. 2), Canny operator (Fig. 3) are used to detect the wood defect image. The results show that Sobel operator has good real-time but detect the edge incoherently and eliminate noises badly [9]. Canny operator is affected by noise seriously. The edge information is submerged completely in the noise in order that unable to identify the edge accurately.

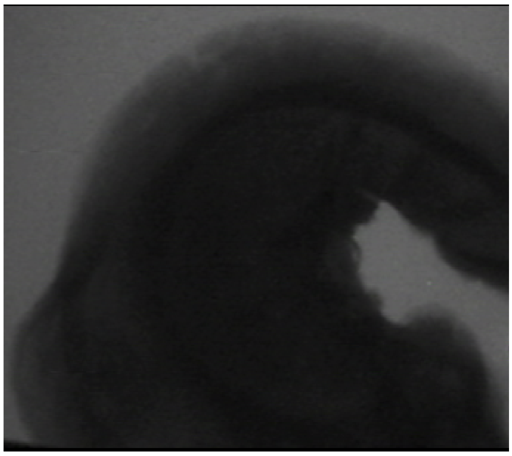

Figure 1. Wood defect original image

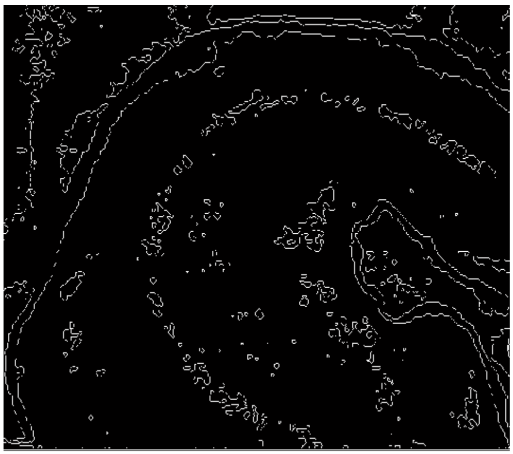

Figure 2. Sobel operator defected image.

V. CONCLUSION

Based on wavelet multi-scale features and wavelet transform modulus maxima theory, dyadic wavelet transform is used for wood defect image to multi-scale edge detection. This method is better than those traditional operators at the edge of the continuity and the noise suppression. The method is fast, accurate and obvious. The method provides a new way for the wood defect image edge detection.

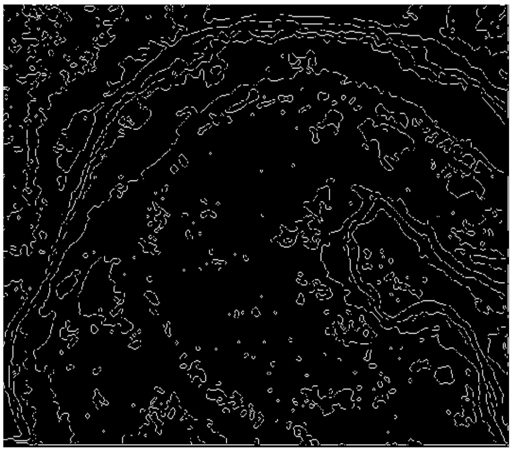

Figure 3. Canny operator defected image.

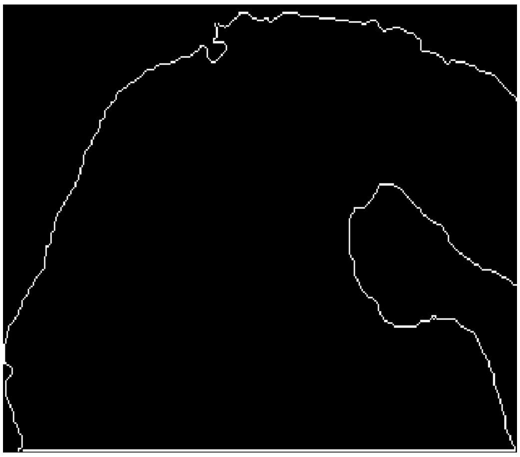

Figure 4. Dyadic wavelet transform defected image.

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