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Fast Algorithm and Application of Wavelet Multiple-scale Edge Detection Filter

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Abstract

This paper focuses on the algorithm theory of the two-dimensional wavelet transform which is used for image edge detection. To simplify the algorithm, the author propounds to turn the two-dimensional dyadic wavelet to one-dimensional dyadic wavelet that can be divided into product. We can use the filter to achieve the wavelet multiple-scale edge detection quickly. Simultaneously, the process that the wavelet transform used for the multiple-scale edge detection is discussed in detail. Finally, the algorithm can be applied to vehicle license image detection and. Compared with the results of the Sobel, Canny and the others, this algorithm shows great feasibility and the effectiveness.

Keywords: Quick algorithm. Smoothing filter. License plate identification

1.Introduction

Wavelet analysis is a new and overlapping subject which has developed quickly in recent 20 years, and has been widely applied in the field of Image Processing. The flexibility and high efficiency of the wavelet multiple-scale detection makes it a method with more advantages in the field of edge detection.

With the development of modern life, the wide spread of private cars becomes an inevitable trend. To develop the Intelligent Transport System (ITS) becomes the main object to-be-achieved for the national Transportation Department. The Identification is one of the core technology to make the automation and intelligent of the traffic management, with Characters Edge Detection as its core. So this paper tries to analyze this core technology, and set up an effective process of multiple-scale edge detection with wavelet transform applied, and focuses on the Vehicle License Characters Edge Detection with the application of wavelet multiple-scale edge detection, so as to achieve an ideal effect.

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2.Hints wavelet transform and the theory of multiple-scale edge detection

Supposed that $\psi(x) \in L^2(R)$ and its Spectrum $\psi(\omega)$ meets the admissibility that $c_\psi = \int \frac{|\psi(\omega)|}{|\omega|^2} d\omega < \infty$, then $\psi(\omega)$ is called Basic Wavelet, which can be extended and shifted in order to form Wavelet bases $\psi_{ab}(x)$, that is

$$\psi_{ab}(x) = \frac{1}{\sqrt{a}} \times \psi(\frac{x-b}{a}) \tag{1}$$

The factorization of any function $f(x) \in R$ on Wavelet Bases $\psi_{ab}(x)$ is called the wavelet transform for $f(x)$, that is

$$W_f(a,b) = < f, \psi_{a,b} > = \int_{-\infty}^{+\infty} f(x)\psi_{a,b}(x)dx \tag{2}$$

In the formula above, a is Scaled Factor, which supposes the breadth of the wavelet in the Space-time Domain, as well as the frequency of the wavelet in the Frequency Domain, large scale is called lower frequency small wavelet, and small scale is called high frequency small wavelet; b is Shift Factor, which reflects the position of the wavelet in the Space-time Domain. Just like Fourier Transform, the coefficient of wavelet transform is the inner product of transformed function and each basis function. The amount of the inner product suggests the similarity between f and $\psi_{a,b}(x)$, that is the component weight of $\psi_{a,b}(x)$ in f. The algorithm of the inverse transform wavelet is:

$$f(x) = \frac{1}{C_\psi} \int_0^\infty \int_{-\infty}^\infty W_f(a,b)\psi_{a,b}(x)db\frac{da}{a^2} \tag{3}$$

Supposed that $\psi_a(x) = \frac{1}{\sqrt{a}}\psi(\frac{x}{a})$ suggests the wavelet base function with a scale of a, then the Flip Conjugate Wavelet can be defined as:

$$\overline{\psi}_a(x) = \psi_a^*(-x) = \frac{1}{\sqrt{a}}\psi_a(-\frac{x}{a}) \tag{4}$$

Then the wavelet transform of $f(x) \in L^2(R)$ can be taken as:

$$W_f(a,b) = f(x) * \overline{\psi}_a(x) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(x)\psi(\frac{b-x}{a})dx \tag{5}$$

This formula shows that signal $f(x)$ has passed a filter with an impulse response function of $\overline{\psi}_a(x)$. In the digital image, its large edge registers as broadside in the space domain, and low frequency in the frequency domain. This characteristic is similar with the wavelet of large scale. Therefore, with the presupposition of an appropriate choice of wavelet, the wavelet transform of large scale will have a positive response to large edge, as well as restrain small edge; on the contrary, the wavelet transform of small scale will have a positive response to small edge. Noise shows a characteristic of instantaneous mutation in the space domain, so the wavelet transform of large scale performs an excellent ability of noisy removal, and the wavelet transform of small scale has a larger response to noise.

The edge of image refers to the set of pixel's gray-scale step change or roof change around the image. So to find out the edge information of the image is called edge detection. Usually, the amplitude variation of which the digital image goes parallel with the edge is smooth，and that of which the digital image goes perpendicular to the edge is sharp. Under the condition of 2-D, the algorithm of edge detection can be used to find out the spatial location of the edge by calculating the localized mode maxima of the 2-D image signal $f(x,y)$'s gradient vector.

Two 2-D wavelets with directionality, which are used to calculate the two partial derivatives of the image signal, are respectively the partial derivatives of the 2-D smooth function $\theta(x, y)$:

$$\psi^x(x, y) = -\frac{\partial\theta(x, y)}{\partial x}, \psi^y(x, y) = -\frac{\partial\theta(x, y)}{\partial y} \tag{6}$$

Supposed that the integral of $\theta(x, y)$ on x-y plane, and that the integral convergences rapidly to 0, then $\theta(x, y)$ can be defined as wavelet generating functions . The result of scale transformation forms a series of wavelet:

$$\psi_j^x(x, y) = 2^{-j}\psi^x(2^{-j}x, 2^{-j}y), \psi_j^y(x, y) = 2^{-j}\psi^y(2^{-j}x, 2^{-j}y) \tag{7}$$

Wavelet transform is defined by two components:

$$W^x f(2^j, x, y) = (f(u, v), \psi_j^x(u - x, v - y)) = f * \overline{\psi}_j^x(x, y) \tag{8}$$

$$W^y f(2^j, x, y) = (f(u, v), \psi_j^y(u - x, v - y)) = f * \overline{\psi}_j^y(x, y) \tag{9}$$

In the formula

$$\overline{\psi}_j^x(x, y) = \psi_j^x(-x, -y), \quad \overline{\psi}_j^y(x, y) = \psi_j^y(-x, -y) \tag{10}$$

Any binary wavelet transform can be defined as the functions below:

$$Wf(2^j, x, y) = \{W^x f(2^j, x, y), W^y f(2^j, x, y)\}_{j\in Z} \tag{11}$$

In order to ensure the completeness and stability of the binary wavelet transforms, the necessary and sufficient condition is required as below:

If two positive constant of A and B is existed, the $\forall(\omega_x, \omega_y) \in R^2 - \{(0,0)\}$ is :

$$A \le \sum_{j=-\infty}^{\infty} |\hat{\psi}^x(2^j\omega_x, 2^j\omega_y)|^2 + |\hat{\psi}^y(2^j\omega_x, 2^j\omega_y)|^2 \le B \tag{12}$$

In the formula of (12), $\hat{\psi}^x$ and $\hat{\psi}^y$ suggest 2-D Fourier transform of ψ^x and ψ^y respectively. $\{\psi^x, \psi^y\}$ which meets the requirement of the formula above is called dyadic wavelet, within which wavelet reconstruction $\{\tilde{\psi}^x, \tilde{\psi}^y\}$ exists whose Fourier transform meets the condition below:

$$\sum_{j=-\infty}^{\infty} 2^{-2j}[\hat{\tilde{\psi}}_j^x(2^j\omega_x, 2^j\omega_y)\hat{\psi}^{x*}(2^j\omega_x, 2^j\omega_y) + \hat{\tilde{\psi}}_j^y(2^j\omega_x, 2^j\omega_y)\hat{\psi}^{y*}(2^j\omega_x, 2^j\omega_y)] = 1 \tag{13}$$

Therefore,

$$f(x, y) = \sum_{j=-\infty}^{\infty} 2^{-2j}[W^x f(2^j, x, y) * \tilde{\psi}_j^x(x, y) + W^y f(2^j, x, y) * \tilde{\psi}_j^y(x, y)] \tag{14}$$

$\{\psi^x, \psi^y\}$ is the first-order partial derivative of smooth function $\theta(x, y)$, therefore, a conclusion can be made: two components of 2-D dyadic wavelet transform are equivalent to those of gradient vector when the signal $f(x, y)$ has been smoothed, that is:

$$\begin{pmatrix} W^x f(2^j, x, y) \\ W^y f(2^j, x, y) \end{pmatrix} = 2^j \begin{pmatrix} \frac{\partial}{\partial x}(f * \overline{\theta}_j)(x, y) \\ \frac{\partial\theta}{\partial y}(f * \overline{\theta}_j)(x, y) \end{pmatrix} = 2^j \nabla(f * \overline{\theta}_j)(x, y) \tag{15}$$

the positive ratio of modulus of the gradient vector $\nabla(f * \overline{\theta}_j)(x, y)$

$$Mf(2^j, x, y) = \sqrt{|W^x f(2^j, x, y)|^2 + |W^y f(2^j, x, y)|^2} \tag{16}$$

The intersection angle of gradient vector and the horizontal direction is

$$\mathrm{A}f(2^j,x,y)=\begin{cases}\alpha(x,y), W^x f(2^j,x,y)\geq 0\\ \pi-\alpha(x,y),\ \ W^x f(2^j,x,y)<0\end{cases} \tag{17}$$

In the formula

$$\alpha(x,y)=\tan^{-1}\left(\frac{W^y f(2^j,x,y)}{W^x f(2^j,x,y)}\right) \tag{18}$$

Therefore, multiple-scale edge detection by the use of dyadic wavelet transform can be realized by finding out the local maximum of $Mf(2^j,x,y)$, of which the intersection angle of the two components suggests the direction of the edge.

3.Multiple-scale edge detection algorithm by the filter

In the practical application, the operation of 2-D convolution is complicated, so this paper puts forward a method in order to simplify the arithmetic: to transform the 2-d dyadic wavelet of edge detection into the separable product of 1-D dyadic wavelet. The Fourier transforms are:

$$\hat{\psi}^x(\omega_x,\omega_y)=H(\frac{\omega_x}{2})\hat{\varphi}(\frac{\omega_x}{2})\hat{\varphi}(\frac{\omega_y}{2}) \tag{19}$$

$$\hat{\psi}^y(\omega_x,\omega_y)=H(\frac{\omega_y}{2})\hat{\varphi}(\frac{\omega_x}{2})\hat{\varphi}(\frac{\omega_y}{2}) \tag{20}$$

In the formulas above, $\hat{\varphi}(\omega)$ is the low-pass filter, and $H(\omega)=-j\sqrt{2}e^{-j\omega/2}\sin(\omega/2)$ is high-pass filter. Supposed that the scale function meets the two-scaled equation (21),

$$\hat{\varphi}(\omega)=\prod_{n=1}^{+\infty}\frac{G(2^{-n}\omega)}{\sqrt{2}}=\frac{1}{2}G(\frac{\omega}{2})\hat{\varphi}(\frac{\omega}{2}) \tag{21}$$

Supposed that the scale function of m-time is:

$$\hat{\varphi}(\omega)=e^{\frac{js\omega}{2}}\left(\frac{\sin(\omega/2)}{\omega/2}\right)^{m+1},\ \ \varepsilon=\begin{cases}0,\text{ if } m \text{ is odd}\\ 1,\text{ if } m \text{ is even}\end{cases} \tag{22}$$

Then

$$H(\omega)=\sqrt{2}e^{-j\omega/2}[\cos(\omega/2)]^{m+1} \tag{23}$$

Supposed that dyadic wavelet transform is uniformly sampled under all scales, and that sample interval is 1, then the coefficient of the discrete wavelet is:

$$d_j^x(n,m)=W^x(2^j,n,m),\ d_j^y(n,m)=W^y(2^j,n,m) \tag{24}$$

And the original image signal can be defined as:

$$a_0(n,m)=\langle f(x,y),\phi(x-n)\phi(y-m)\rangle \tag{25}$$

With $j\geq 0$, the image signal is :

$$a_j(n,m)=\langle f(x,y),\phi(x-n)\phi(y-m)\rangle \tag{26}$$

In order to achieve 2-D discrete dyadic wavelet transform with the use of wave filter, this paper indicates the algorithm of 2-D dyadic wavelet transform in the form of discrete convolution as following:

$$a_{j+1}(n,m)=a_j*\bar{h}_j(n)\bar{h}_j(m) \tag{27}$$

$$d^x{}_{j+1}(n,m)=a_j*\bar{g}_j(n)\delta(m) \tag{28}$$

$$d^y{}_{j+1}(n,m)=a_j*\delta(n)\bar{g}_j(m) \tag{29}$$

a_{j+1} is the result of a_j being low-pass filtered horizontally and vertically; d^x_{j+1} and d^y_{j+1} are the results of a_j being high-pass filtered horizontally and vertically. Large edge of the digital image registers as broadside in the space domain, and low-frequency in the frequency domain, the characteristic of which is similar with the wavelet of large scale. Therefore, the wavelet transform of large scale should be chosen in order to extract the large edge information of the image; conversely, the wavelet transform of small scale should be chosen in order to extract the small edge information to highlight details of the image. Noise shows a characteristic of instantaneous mutation in the space domain, so the wavelet transform of large scale performs an excellent ability of noisy removal, and the wavelet transform of small scale has a larger response to noises.

4.Gaussian smoothing filter

In the practical application, digital images usually contain all kinds of additive and multiplicative noise, so the image should be undergoing the smoothing processing. For an image, the smoothing filter is usually designed under the direction of 2-D zero mean discrete Gaussian function. This paper chooses the weight for a linear smoothing filtering in accordance with the shape of Gaussian function, so as to remove the noise in the image.

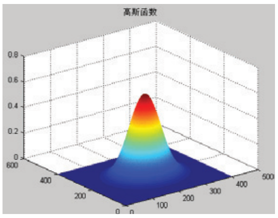

Fig.1 Gaussian function.

Gaussian function (figure 1) has a characteristic of separability, which can effectively bring the realization of a large Gaussian filter. Any large Gaussian filter can be realized by reusing the small Gaussian filter, which simplify the calculating of large Gaussian filter as well as enhance the application value of the Gaussian smoothing filter. The result of filtering is shown in figure2 below.

Fig.2 A photo after Gaussian smoothing filtering.

We can see from above that Gaussian smoothing filter can not only filter noise during the process of images, or smooth the pixel within the smoothing field, but also preserve the boundary contour for the smoothness of image edge detection.

5.The designed process of the multiple-scale edge detection filter

The concrete process of the algorithm of multiple-scale edge detection programmed in MATLAB 7 is shown in figure 3. The main steps are:

Step 1 The image should be passed through Gaussian smoothing filter in order to reduce the noise of the image;

Step 2 Design a wavelet multiple-scale edge detection filter. The most important thing in edge detection is to define the coefficient of spline filter in accordance with the characteristics of detected image; the number of point of the filter selected determines the amount of computation. The filter selected should be with appropriate number of point according to the resolution of the processed image, so as to avoid unnecessary computation. Impulse response function (IRF) with a large amount of points is usually used to process images with high resolution, on the contrary, the use of IRF with a small amount of points can enhance the edge detection. Besides, IRF with a small amount of points can be used to detect images with several sharp edges, and vice versa.

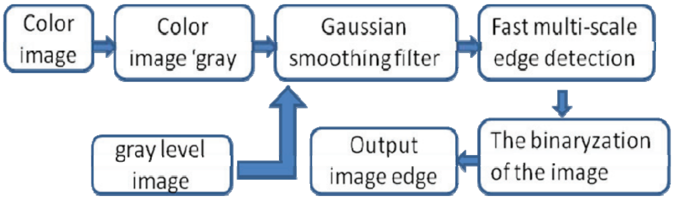

Fig.3 The process of edge detection

Step 3 The digital image binary conversion. It is to select a threshold value, and when the luminance value of the gray level image's pixel is less than the threshold value, its pixel value is supposed to be 0; reversely, its pixel value is supposed to be 255. Figure 4 shows a comparison of images before and after binary conversion.

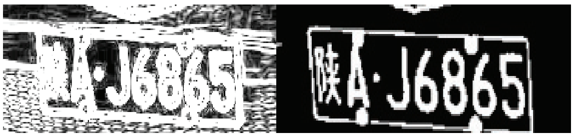

Fig.4 Images before and after binaryzation.

Small scale wavelet transform has a high precision in edge detection, but it also has a strong response to noise, so it can detect some edges of the background details; however, the result of large scale wavelet transform detection has slight shift of the edge, while it can restrain noise and edges of the background details. After a comparison of edges detected by large scale and small scale wavelet transform detection, the edge of the shorter chain length can be removed according to the chain length of the edge. In the practical application, the size of scale is usually selected according to practical situation. Small scale wavelet edge detection, which can get a satisfied edge detection result without set a threshold value artificially, has a precise reflection of detail information and an overall profile, and has an excellent ability to reduce noise and preserve the edge, with a high application value for the edge detection of the target image.

6.The application of multiple-scale edge detection filter---- edge detection of vehicle license image

Edge is the basic feature of the image, so edge detection is the important content of image processing. So far, edge detection has become one of the most popular subjects in the field of machine vision, playing an important role in engineering. This paper applies edge detection in the edge detection of vehicle license image according to the characteristics of wavelet multiple-scale edge detection.

The application of multi-scale edge detection filter into the Automatic License Plate Identification System for the vehicle license position can effectively detect the character information of the license plate image. Factors in daily life, such as interference of environment, weather and artificial factors, and difference of colors or positions of license plates, make the work of license plate identification more difficult. Multi- scale edge detection filter put forward in this paper can effectively detect character information even if images of license plates are taken in a bad environment, of low quality, or have complicated characters on the plate. As is shown in figure 5 and 6, license plates with a complicated character, with images of load noise, and with blurry edges can see clearly that wavelet multi-scale edge detection offers a more continuous, more distinct, and more accurate edge information.

Fig.5 Detection of a complicated character“鲁”

Fig.6 Edge detection of the image of load noise

With a comparison of results of wavelet multi-scale edge detection method and the traditional method from figure 7 to 8, we can see clearly that detection with transition’s Sobel method and Canny method leads to too many fake edges, a blurry profile, and character information that cannot be correctly identified. However, wavelet multiple-scale edge detection, which detects the character information of license plate more accurately and fewer fake edge, provides a favorable condition for the coming character identification and feature extraction of license plates. It will provide a technical gist for the standardization of transport management, and promises a prospect of wide application.

Fig.7 Detection of array

Fig.8 Edge detection with Sobel and Canny method

7.Conclusion

This paper focuses on the algorithm theory of the two-dimensional wavelet transform which is used for image edge detection. The author propounds to simplify the algorithm and improve calculating speed, which is to use the filter to turn the two-dimensional dyadic wavelet to the separative product of one-dimensional dyadic wavelet, so as to enhance the efficiency of the edge detection. Simultaneously, the algorithm can be applied to vehicle license image detection. Compared with the results of the Sobel, Canny and the others, the feasibility and the effectiveness of this algorithm can be seen clearly.

Finally, it should be illustrated that vehicle license character detection has a certain requirement of images' quality, so it is difficult to identify the character of the license plate which is severely interfered by some factors. Therefore, the algorithm should be further optimized in order to get more accurate edge information.

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