PAPER • OPEN ACCESS

Road crack edge detection based on wavelet transform

To cite this article: Xiaoliang Zhou *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **237** 032132

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

This content was downloaded from IP address 181.214.36.74 on 19/03/2019 at 17:12

IOP Conf. Series: Earth and Environmental Science **237** (2019) 032132 doi:10.1088/1755-1315/237/3/032132

Road crack edge detection based on wavelet transform

Xiaoliang Zhou[1], Lamei Xu[1] and Jing Wang[1*]

[1] School of automation, Wuhan University of Technology, Wuhan, Hubei, AH533, China

[*]Corresponding author's e-mail: 948529792 @qq.com

Abstract. In this paper, the edge detection of road surface crack images is studied. The traditional edge detection algorithms such as Gaussian-Laplacian and Canny operator are used to extract the edge of the crack. The experimental results show that the edge extraction is not complete and sensitive to noise. Therefore, the modern wavelet analysis method is adopted to extract the complete and accurate crack edges.

1. Introduction
The most important thing before the measurement of pavement cracks is to find the boundary contour of the crack and calculate it with the boundary as the mark. Therefore, it is vital to extract the crack boundary. In the digital image processing, according to the character of the edge, the edge is defined as the set of points of those pixels whose gray values have changed around the pixel. The edge of the target area in the image is reflected by the gray level step change or discontinuity. The general summary of the edge can be roughly divided into categories: (1) step edge, which is that the gray values of the pixels on both sides of the edge are very different. (2) ridged edge, which is that the gray values near the edge are large, and the gray value on both sides of the edge is gradually reduced[1].

The derivative of a pixel in a certain direction in the image can be represented by a gradient, which describes the direction in which the rate of change is greatest in a neighbourhood. So the gradient is a description of the first derivative. The image grayscale can be expressed as $f(x,y)$ and the gradient at the position (x,y) can be expressed as a vector. Then the gradient can be expressed as

$$\nabla f(x,y) = [G_x, G_y] = [\frac{\partial f(x,y)}{\partial x}, \frac{\partial f(x,y)}{\partial y}] \tag{1}$$

Remarks: G_x denotes gradient in the directions of x. G_y denotes gradient in the directions of y. In the digital image processing, for the convenience and speed of computer processing, the gray value is the quantized digital quantity, and the differential is used instead of the differential when calculating the gradient. Thus the gradient can be expressed as

$$\left|\nabla f(x,y)\right| = \left|f(x,y) - f(x+1,y)\right| + \left|f(x,y) - f(x,y+1)\right| \tag{2}$$

Based on this theory, a variety of traditional edge detection algorithms have been developed [2].

2. Traditional edge operators

2.1. Gauss-Laplacian operator

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

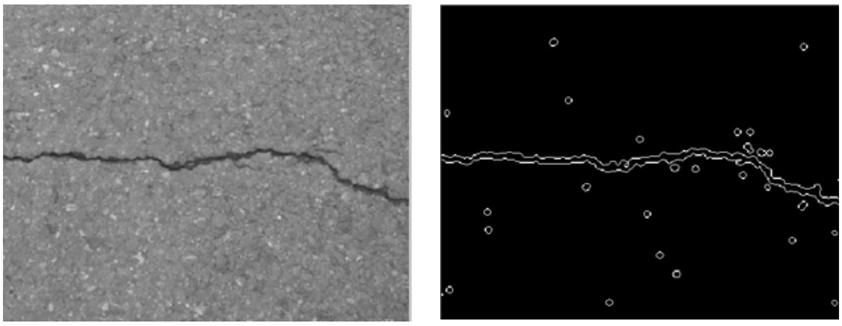

Figure 1. Original image and filtered image by Laplacian

The Laplacian operator belongs to the second-order differential operator. The detection principle is to detect the fine edge by the zero-crossing point of the second derivative. The expression of the Laplacian operator is

$$\nabla^2 f(x,y) = [\frac{\partial^2 f(x,y)}{\partial x^2}, \frac{\partial^2 f(x,y)}{\partial y^2}] \tag{3}$$

In actual digital image processing, the second-order differential operator is replaced by a second-order difference, so the above equation can be expressed as

$$\nabla^2 f(x,y) = f(x+1,y) + f(x-1,y) + f(x,y+1) + f(x,y-1) - 4f(x,y) \tag{4}$$

The matrix corresponding to the Laplacian operator is

$$\nabla^2 f(x,y) = \begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix} \tag{5}$$

The Laplacian operator has a good effect on the detection of thin lines and isolated points, but it loses the edge direction information and often produces double edges. The method is very sensitive to noise and has an enhanced effect on noise. Therefore, before using the Laplacian operator for edge detection, it must be smoothed and then edge-detected. It shows the result in figure 1.

2.2. Canny operator

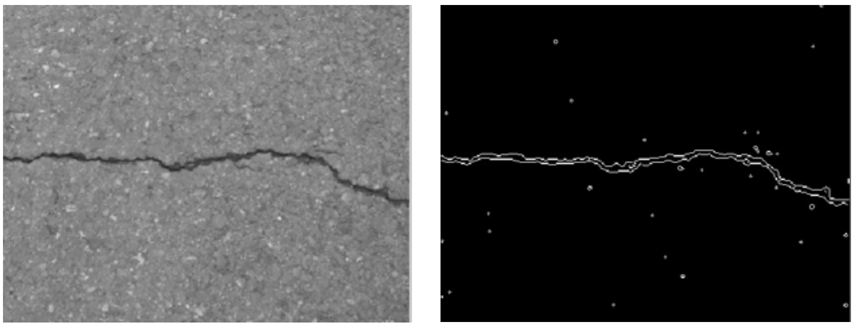

Figure 2. Original image and filtered image by Canny

Canny algorithm is implemented in four steps: (1) Gaussian filtering the image to filter out noise in the image; (2) Calculate the size and direction of the gradient using the first-order differential operator for the filtered image; (3) Suppress non-local maxima of the gradient; (4) Use a dual threshold simultaneous action to detect and join the pixels to form an edge. In contrast, the performance of the

Canny operator is much better. It not only extracts the complete continuous edges like the Laplacian Gaussian operator, but also has finer edges and smoother effects on noise. It shows result in figure 2.

3. Crack detection based on wavelet analysis

In the road surface crack image, the crack is generally thin, and the small noise of the road surface has an influence on the detection target. Therefore, the wavelet analysis method is used to extract the edge. The basic idea is that the road image is decomposed by the wavelet packet. Then the crack signal is transformed into the high-frequency and high-amplitude wavelet coefficients. The noise signal is transformed into the high-frequency and low-amplitude wavelet coefficients. The image background signal is converted to the low frequency band. The crack image is then reconstructed from the statistical characteristics of the coefficients of the wavelet transform of the image in different frequency bands [3].

The wavelet transform is developed on the basis of the Fourier transform. Although the Fourier transform can better express the spectrum of the signal, it can only reflect the total intensity of a certain frequency component contained in the signal, and cannot provide time localized information about frequency components. Gabor proposed a short-time Fourier transform, which is implemented by windowing the time domain signal. The formula for performing the Fourier transform on $f(t)$ is

$$F(\omega)=\int_{-\infty}^{+\infty} f(t)\mathrm{e}^{-j\omega t}\mathrm{d}t \tag{6}$$

For the Fourier transform of $f(t)$ windowed, the high window function is $g(t)$, then the transformation formula is

$$G(\omega,\tau)=\int_{-\infty}^{+\infty} f(t)g(t-\tau)\mathrm{e}^{-j\omega t}\mathrm{d}t \tag{7}$$

This method maps the one-dimensional signal $f(t)$ into a two-dimensional function $G(\omega,t)$ on the time-frequency domain plane. Thus, $g(t)$ acts as a time limit and $\mathrm{e}^{-j\omega t}$ acts as a frequency limit. But this time window is fixed-scale. Since the same window is used for all frequencies, the resolution is the same in all parts of the time-frequency domain. The wavelet transform overcomes the fixed resolution.

All wavelets are obtained by scaling and shifting the basic wavelets. The basic wavelet is a real-valued function with special properties, which is damped oscillation, and usually decays very quickly. It mathematically satisfies the zero mean condition and spectrum condition.

$$\int_{-\infty}^{+\infty} \psi(t)\mathrm{d}t=0 \tag{8}$$

$$C_{\psi}=\int_{-\infty}^{+\infty} \frac{|\psi(\omega)|^2}{\omega}\mathrm{d}\omega<\infty \tag{9}$$

The basic wavelet also has good attenuation properties in the frequency domain. A family of wavelet basis functions can be generated by the basic wavelet function by the parameter a and the parameter b as shown in the following equation (10).

$$\psi_{a,b}(t)=\frac{1}{\sqrt{a}}\psi(\frac{t-b}{a}) \tag{10}$$

The continuous wavelet transform of a continuous function $f(t)$ is defined as.

$$Wf(a,b)=\int_{-\infty}^{+\infty} f(t)\psi_{a,b}(t)\mathrm{d}t=\frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} f(t)\psi(\frac{t-b}{a})\mathrm{d}t \tag{11}$$

The essence of the wavelet transform is to represent the arbitrary function $f(t)$ as a superposition of its projections over $\Psi_{a,b}(t)$ with different parameters a and parameters b. By adjusting the scale expansion parameter a and the translation parameter b, wavelets with different time-frequency widths can be obtained to match any position of the original signal and the purpose of time-frequency localization analysis of the signal is achieved.

In order to implement the fast calculation of the computer, discrete wavelet transform is used. Let the scale parameter $a = a_0{}^m$ and the translation parameter $b = nb_0 a_0{}^m$, thus it can conclude a discrete wavelet function

$$\psi_{m,n}(t) = \left|a_0\right|^{-m/2} \psi(a_0{}^{-m}t - nb_0) \tag{12}$$

Then the discrete wavelet transform can be expressed as

$$Wf(a,b) = \int_{-\infty}^{+\infty} f(t)\psi_{m,n}(t)\mathrm{d}t = \left|a_0\right|^{-m/2} \int_{-\infty}^{+\infty} f(t)\psi(a_0{}^{-m}t - nb_0)\mathrm{d}t \tag{13}$$

4. Multi-resolution analysis

Multiresolution analysis describes a function as the limit of a series of approximation functions. Each approximation function is a smooth approximation of the original function and is an increasingly fine approximation function. As the scale changes from large to small, it can be decomposed from coarse to fine at various scales. In the large-scale space, the target observed under the far lens can only see the rough outline of the target; in the small-scale space, the target part can be observed corresponding to the target observed under the lens [4-5].

Multi-resolution analysis of images using wavelet transform can show different effects at different scales: when the wavelet function scale is large, the smoothing suppression ability of noise is enhanced, and the ability to detect edge details is weak; when wavelet When the function scale is small, the ability to suppress noise is weakened, but the ability to detect edge details is enhanced. Therefore, in the traditional method, the target edge can only be detected under the same template scale. The multi-scale wavelet analysis edge detection can use the mutation point singularity detection method to distinguish the image edge and suppress the noise. The wavelet transform detection has a large superiority.

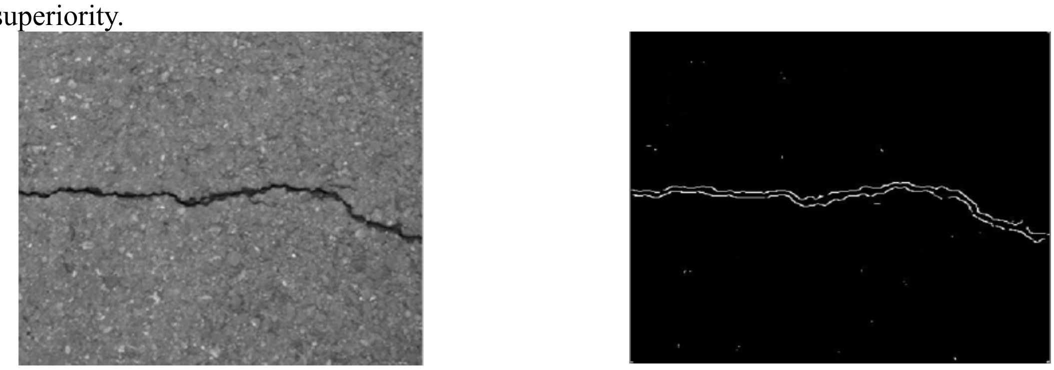

Figure 3. Original image and filtered image by wavelet transform

Based on the above-mentioned wavelet transform multi-resolution idea, in the detection of pavement crack edges, we can use wavelet transform to decompose the road crack image. For an image, its edge details, grayscale jumps, and noise appear as high-frequency components of the image in the frequency domain, while large-area background regions and slowly varying portions appear as low-frequency components in the frequency domain. Based on this characteristic of the image, after the wavelet transform on the road crack image, the wavelet coefficient of the high frequency value of the high frequency segment approximates the crack signal, and the wavelet coefficient of the low frequency value of the high frequency segment approximately represents the noise signal. The low-band wavelet coefficients approximate the background stationary signal. Then the image edges are reconstructed according to the statistical characteristics of the wavelet coefficients of the images in different frequency bands to complete the crack detection. It shows the result in figure 3.

5. Conclusion

The traditional method of pavement crack detection is introduced. The limitation of traditional edge detection method in pavement crack detection is demonstrated, especially in terms of anti-noise ability. The order edge operator is not ideal in terms of continuity, and the second-order operator is more sensitive to noise. Then a modern edge detection method is proposed. The wavelet detection method can obtain ideal results for edge detection of pavement images. Wavelet analysis adds edge detection to very effective de-noising function, and under the multi-scale multi-resolution decomposition, it improves the precision of edge detection, and more complete and accurate edge crack are obtained.

References

[1] Kelvin. (2000) Designs and implementation of automated systems for pavement surface distress survey. Journal of Infrastructure Systems, 6(3)：24-32.
[2] X.M. Sun, J.P. Huang and W.Y. Liu. (2011) Decision model in the laser scanning system for pavement crack detection. Optical Engineering, 50(12):1-10.
[3] Z.X. Cheng. (1998) Wavelet Analysis Algorithm and Application: Xi'an Jiaotong University Press, Xi'an.
[4] X.W. Bao. (2012) Application of Wavelet Transform in Image Edge Detection. Electronic Design Engineering, 20: 160-162.
[5] Y.Q. Zhang. (2013) Image Denoising Algorithm for High Speed Road Crack Based on Gradient Enhanced Diffusion. Computer Science, 40: 288-290.