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Pavement Crack Detection Based on Fractional Domain Adding Window and Contrast Enhancement

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Abstract: The efficiency and accuracy of traditional artificial pavement crack detection are low. In this paper, the crack image is transformed into the fractional domain, and the fractional domain denoising is realized by windowing. Then, the fractional homomorphic filtering algorithm is used to enhance the contrast and obtain the highest contrast image under the optimal order. Finally, edge detection and threshold segmentation are performed on the image, and the crack edge is smoothed by doing or calculating, and then the crack characteristics in the crack image are effectively extracted by image morphology operation. Compared with the fractional frequency domain processing method and the improved HC method, the accuracy of the method is increased by 5.84 % and 4.5 %, and the recall rate is increased by 5.58 % and 3.52 %, respectively. It shows that the method has better detection effect and higher recognition rate in pavement crack detection.

Keywords: Crack Detection; Fractional Fourier Transform; Fractional Domain Adding Window; Contrast Enhancement; Homomorphic Filtering

1. Introduction

Pavement cracks will lead to a decline in the carrying capacity of the road, if not timely detection and maintenance, will bring serious hidden dangers to traffic safety. In recent years, fractional Fourier transform has been applied to the field of image recognition by some scholars because it has the particularity of transform order and can simultaneously reflect the characteristics of time domain and frequency domain. Wang[1] used two-dimensional fractional Fourier transform to transform the crack image from the airspace to the fractional domain. Through the region removal and enhancement of the spectrum image, the effect of removing background noise was achieved, which provided convenience for crack extraction.

In reality, when the crack is located in the complex road background or the uneven illumination of the collected crack image will affect the extraction of cracks. At this time, it is necessary to highlight the crack area by contrast enhancement. Homomorphic filtering algorithm is widely used in image contrast enhancement because of its ability to weaken low frequency and enhance high frequency. In view of the limitation that Fourier transform can only transform images from spatial domain to frequency domain in homomorphic filtering algorithm, Zhang[2] combined homomorphic filtering with multi-level wavelet decomposition to enhance the contrast of images. Jiang[3]also improved homomorphic filtering algorithm by replacing Fourier transform with wavelet transform the wavelet transform to enhance the contrast of the uneven brightness crack image, so as to highlight the crack area.

Based on the above research, unlike the traditional method that processes the image in a single domain, this paper conducts denoising and contrast enhancement on the crack image in the fractional domain, namely, both in the spatial domain and the frequency domain, and proposes a pavement crack detection method based on fractional domain windowing and contrast enhancement to extract the crack area in the crack image. In this method, the fractional Fourier transform is used to window the crack image in the fractional domain, and the improved homomorphic filtering method is used to further enhance the contrast of the denoised image in the fractional domain. Finally, the purpose of effectively extracting crack features is achieved.

2. Adding window functions and removing noise in fractional domain

2.1 Fractional Fourier transform

Fractional Fourier transform has the characteristics of concentrated information. When the transform order p_1 , p_2 reaches 0.7, the information in the center 1/4 interval of the fractional domain has been concentrated to more than 90 %. Continue to increase the values of the information contained in the frequency domain increases the amplitude and space will be sharply reduced, even negative growth. Therefore, by comparing the results of different orders of fractional Fourier transform on transverse crack, longitudinal crack, block crack and mesh crack image sets, it is found that when the value p_1 , p_2 is 0.83, the spectrum image processing can get better results. The original image and the spectrum image under 0.83 order are shown in Figure 1.

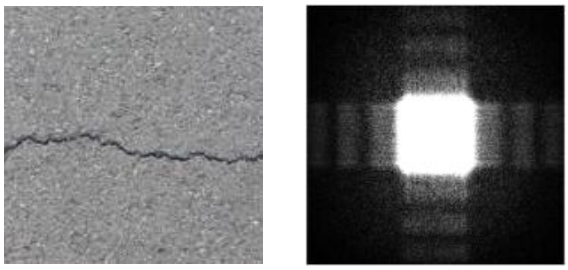


Fig.1 Original image and spectrum image

2.2 Adding window functions in fractional domain

2.2.1 Design of window function

In order to better remove the noise information in the original crack image, the following two conditions should be met when processing the spectrum image : (1) The region with higher central pixel value should be retained to the greatest extent. (2) Retain less areas near the edge with lower pixel values.

In order to meet these two conditions at the same time, this paper uses the method of adding window functions in Fractional domain to process the spectrum diagram. The regions with more information of fracture characteristics in the center of the spectrum map are retained. The remaining regions are processed using the ascending chord window function[4], making the regions closer to the edge less reserved. Design window function as shown in (1).

$$W(n)=\begin{cases} a-(1-a)\cos\left(\dfrac{2\pi n}{N-1}\right), 0\le n<m_1 \\ 1, m_1\le n\le m_2 \\ a-(1-a)\cos\left(\dfrac{2\pi n}{N-1}\right), m_2<n\le N \end{cases} \tag{1}$$

Among (1) , N is the size of the spectrum, and m_1 , m_2 represent the starting point and end point of the reserved center area respectively, and a represents the parameters that control the attenuation speed of pixel value in the edge area, and $0\le a\le 1$.

2.2.2 Determination of the optimal value

It can be seen from Fig. 2 that with the increase of a value, the smaller the attenuation rate on both sides of the window function is, the more reserved the edge region of the corresponding spectrum diagram is. The purpose of using two-dimensional fractional Fourier transform windowing method to process crack image is to extract crack information and remove noise information. Therefore, there is an optimal a value, so that the ratio R^a reaches the maximum. $Crack$ represents the number of pixels in the crack area of the image, and $Noise$ represents the number of noise pixels.

$$R_{max}^{a} = \frac{Crack}{Noise} \quad (2)$$

2.3 Removing noise in fractional domain

When the traditional Fourier transform is used to process images, the image can only be transformed from spatial domain to frequency domain. However, when the image is difficult to identify its characteristics in both spatial and frequency domains, the Fourier transform will no longer be applicable. In view of this limitation, this paper introduces the fractional Fourier transform with transform order, and combines the fractional Fourier transform with homomorphic filtering algorithm[5] to enhance the image contrast in the fractional domain. The enhancement effect is stronger than the traditional frequency domain enhancement. The process of fractional order homomorphic filtering enhancement algorithm is as follows:

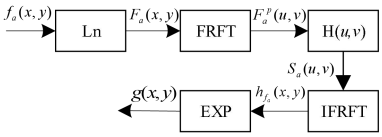


Fig.2 Fractional homomorphic filtering enhancement process

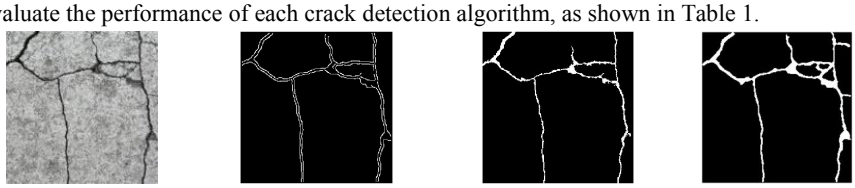
The purpose of using fractional homomorphic filtering to process crack image is to highlight the crack characteristics in the dark and improve the contrast of crack image. Therefore, there is an optimal order to maximize the contrast of the image after fractional homomorphic filtering.

2.4 Fracture feature extraction

Crack image extraction is to extract the crack characteristics from the background. Canny edge detection algorithm[6] can accurately detect the real edge of the crack, but it may also identify the background noise as the edge. Otsu threshold segmentation method[7] can effectively separate the fracture characteristics from the background, but the edge of the binary fracture image will have more pixels missing or even disconnected, that is, the overall extraction effect is good, and more details can be extracted, but the edge extraction effect is poor. In this paper, Canny edge detection results and Otsu threshold segmentation results are either calculated.

3. Experimental simulation and result analysis

This method is compared with the crack extraction results of Wang ' s fractional frequency domain processing method[1] and Zhong ' s improved HC aboriginality detection method[8], as shown in Figure 3, and the accuracy, recall and F-measure are calculated to evaluate the performance of each crack detection algorithm, as shown in Table 1.



(a)Original figure (b)Wang's method (c)Zhong's method (d)Our method

Fig.3 Comparison of detection results of various algorithms

It can be seen from Fig. 3 that for the regions with small crack width, the method in this paper can remove the noise and retain the crack characteristics with complete and continuous edges, while the effect of removing the noise by the two methods is poor, and the extracted crack characteristics are discontinuous. For the mesh region with high complexity, the first two methods can only extract the outer mesh contour, and cannot extract the details inside the mesh, while the method in this paper can completely extract the region with more details of the crack.

Table1 Performance comparison of various algorithms

Method	Accuracy	Recall	F-measure
Wang ' s method	87.91%	89.89%	88.89%
Zhong ' s method	89.25%	92.22%	90.71%
Our method	93.75%	95.74%	94.73%

According to the experimental results in Table 1, each evaluation index of the three crack detection methods is higher than 85 %, which has good accuracy. Compared with the fractional domain processing method and the improved HC method, the accuracy of the proposed method is increased by 5.84 % and 4.5 %, and the recall rate is increased by 5.58 % and 3.52 %. Based on the above comparison of crack extraction effect and evaluation index of each algorithm, the proposed method has better crack extraction effect, higher robustness and better performance.

4. Conclusion

Aiming at the pavement crack detection under complex background, this paper proposes a pavement crack detection method based on fractional domain windowing and contrast enhancement, and compares the algorithm with the fractional frequency domain processing method and the improved HC method qualitatively and quantitatively. The simulation results show that the method in this paper has good effect on removing background noise and extracting crack feature, and can effectively improve the recognition rate of cracks.

References

[1] Wang YH, Chen R. Image recognition method of pavement cracks based on fractional fourier transform and spectral enhancement [J]. Computer Applications, 2020, 40(S1): 189-194.

[2] Zhang XM, Shen LS. Wavelet-based homomorphic filter for image contrast enhancement [J]. Chinese Journal of Electronics, 2001, 29(4): 531-533.

[3] Jiang JR. Research on detection method and identification of pavement cracks based on image analysis[D]. Nanjing University of Posts and Telecommunications, 2016.

[4] Li ZJ, Zhang CB, et al. Application of improved cosine window in harmonic analysis of virtual instruments[J]. Modern Electronic Technology, 2018, 41(15): 108-113.

[5] Oppenheim AV, Schafer RW. Nonlinear filtering of multiplied and convolved signals. Proc. IEEE, 1968(56): 1264-1291.

[6] Yu HC, Mu PA. Application of adaptive Canny algorithm in edge detection of steel plate defects [J]. Software Guide, 2018, 17(4):175-177.

[7] Li SW, Li LC. Application of adaptive OSTU algorithm in ship edge detection and Its FPGA implementation [J]. Software Guide, 2019, 18(6): 176-180.

[8] Zhong AE. Research on pavement crack recognition technology based on image processing [D]. Hubei: Wuhan University of Science and Technology, 2020.