Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 154 (2019) 610–616

Procedia Computer Science

www.elsevier.com/locate/procedia

8th International Congress of Information and Communication Technology, ICICT 2019

Research on Crack Detection Algorithm of the Concrete Bridge Based on Image Processing

Yun Wang[a], Ju Yong Zhang[a**], Jing Xin Liu[a], Yin Zhang[a], Zhi Ping Chen[a], Chun Guang Li[a], Kai He[a], Rui Bin Yan[a]

[a]*School of Mechanical Engineering, Hangzhou Dianzi University, Hangzhou and 310018,China*

Abstract

The appearance and development of cracks in the concrete bridge will seriously affect the safe use of bridge buildings. In order to better satisfy the crack detection requirement, this paper comes up with an image preprocessing scheme combining multiple adaptive filtering and contrast enhancement based on the image processing technology of concrete crack, which can improve the removal effect of background noise and obtain the characteristic vein information of tiny cracks. Then we designed a local adaptive algorithm of Otsu threshold segmentation and integrated with modified Sobel operator for removing isolated noise spots, so as to extract the crack edge information and improve the positioning accuracy of the crack boundary. Furthermore, according to the image feature of the bridge crack edge, the target crack is identified as well as classified and the feature data is calculated. The results of case analysis show that the data processing precision of the detection algorithm can reach 0.02mm, which can satisfy the actual engineering detection requirements of concrete bridge crack.

Keywords: Concrete bridge, Crack detection, Image processing, Algorithm improvement

1. Introduction

In order to ensure the safe operation of a reinforced concrete bridge, it needs regular detection and timely maintenance, which concrete crack detection is one of the important items of bridge detection. And the digital image

* Corresponding author: Juyong Zhang; Tel.:13735525761;
E-mail address:zhang_juyong01@163.com

1877-0509
10.1016/j.procs.2019.06.096

processing has become an important technology of concrete bridge detection, scholars have done a lot of research about the crack image detection technology, such as Yao et al. [1] design a climbing robot for bridge crack detection, as well as realize the identification and classification of the crack image. But the detection precision of the video image is not enough, and the application cannot be popularized in engineering practice. And for improving the transmission quality of image data, the terrestrial laser scanning (TLS)[2] technology processes and evaluates the crack images obtained by laser scanning. Liu et al. [3] optimized the robust processing effect of the crack image by using the method based on multi-scale morphological enhancement and crack characteristics on the concrete surface, but the image edge after morphological processing was prone to distortion. In order to ensure the accuracy of data calculation, an image matching method based on optical flow and sub-pixel [4] was used to detect the width of concrete shear crack. Talab et al.[5] filtered and de-noised the concrete image using the Sobel operator, and then performed otsu threshold segmentation to complete the crack edge detection. Although it was proved that the Sobel operator has a higher consistency in the crack image detection of the concrete bridge [6]. However, the crack edge treated by Sobel operator is thicker, which will affect the accuracy of data extraction. To predict the depth of concrete crack, Adhikari et al.[7] established a neural network model according to the crack width and variational characteristics. But it could not accurately predict the depth information of concrete bridge crack. Due to image acquisition environment of bridge cracks is more complex, the surface of the concrete structure may be not only accompanied by the interference information, such as stain and potholes but also made local images difficult to segment by the uneven illumination. As a result, some conventional bridge detection equipment and crack image processing methods are difficult to be applied to crack detection of concrete bridges.

For these reasons, this paper studies the processing scheme and algorithm improvement in the three process modules of image preprocessing, crack edge detection and feature information extraction. In order to not only improve the accuracy and convenience for detection, but also realize the automatic safety detection of concrete bridge crack, further algorithm research and instance verification are carried out for the image processing technology of concrete bridge crack under the complex background, and its detection steps are shown in Fig. 1.

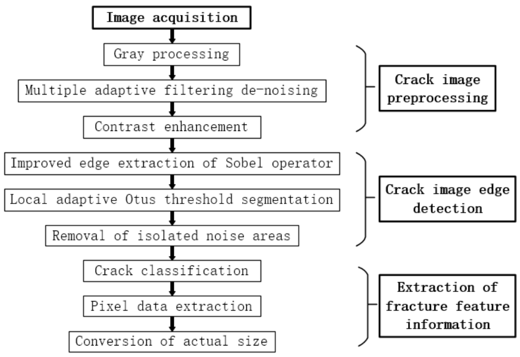

Fig. 1.The detection process of image cracks on concrete Bridges

2. Image Preprocessing of Concrete bridge Cracks

After graying the bridge crack image is obtained through image acquisition, the most critical gray-level information of the bridge crack is reserved as shown in Fig. 2. In order to highlight the edge of crack and eliminate useless interference, the median filter is usually adopted to remove noise. It has a significant effect on processing salt and pepper noise but is not applicable to process signals which contain a large number of overlapping noise. As a nonlinear smoothing filter, adaptive filter changes the output result by calculating the local variance of pixels within the filter window and has a very good adaptability on removing the kinds of superimposed noise. In addition, the appropriate template selection of filter window size will have a great impact on the processing efficiency of the internal pixel.

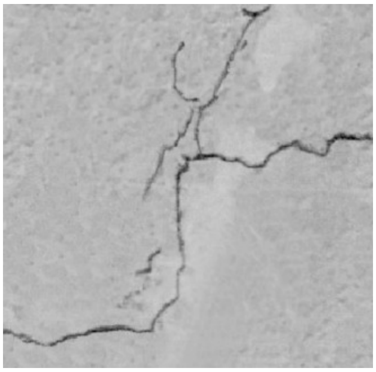

Fig. 2. Crack image of the concrete bridge

In the experiment, a primary adaptive filter and contrast enhancement was carried out for the original gray image through the 3 x 3 graphics window. The processing image is shown in Fig. 3. (a). However, the high-frequency noise in image background is close to the gray value of crack. As a result, the de-noising effect after the primary filtering process is undesirable. For this reason, the filtering window can be properly amplified and the high-frequency noise in small areas can be further smoothed out. In this paper, the adaptive filtering is used for multiple times, and the filtering window is amplified appropriately each time. Furthermore, the size of the window is adjusted according to the statistics of gray level in the retrieval window. For the image of concrete bridge cracks, the clear processing results can be obtained after two or three times of this filtering. In the experiment, the optimal smooth denoising effect was obtained by using the continuous filtering with three groups of windows: 2 x 2, 3 x 3 and 4 x 4. And then, after contrast enhancement, as shown in Fig. 3. (b), it can be clearly seen that the processed image removes a large amount of background noise and retains the detailed information of the target crack to the maximum extent.

(a) primary filtering and enhancement (b) three groups of multi-window filtering and enhancement

Fig. 3. The results after adaptive filtering and contrast enhancement

Through a series of contrast experiments, it was found that the image processed by the above-mentioned multi-window adaptive filter had a more obvious gray interval boundary, that is the gray value of the target crack was lower (between 0 and 255 x 0.1), while the gray value of the background region was higher (between 255 x 0.6 and 255). These results suggest that the above filtering process will effectively weaken the irrelevant noise signal in the gray image and observably distinguish the crack feature without special pollution condition. So in order to improve the processing efficiency, these two intervals of gray values are polarized through the contrast stretching, as well as the gray values in the middle interval are uniformly divided and nonlinearly mapped. These are carried out to enhance the output of dark values and strengthen the detailed feature texture information of the target crack. The linear transformation formula of image grayscale is as follows:

$$g'(x,y)=\begin{cases}0, & f(x,y)<255\times 0.1\\ \dfrac{f(x,y)-255\times 0.1}{255\times 0.5}, & 255\times 0.1\le f(x,y)\le 255\times 0.6\\ 255, & f(x,y)>255\times 0.6\end{cases} \tag{1}$$

In this formula, the $f(x,y)$ is gray value of each pixel after filtering, and the $g'(x,y)$ is the gray value after transformation.

3. The Edge Detection of Concrete Bridge Crack

After the above denoising and contrast enhancement, a relatively clear and ideal grayscale image is obtained. In order to further identify and analyze the characteristics of concrete cracks, the bridge cracks need to be accurately extracted and segmented from the image. In this case, the Otsu algorithm with good segmentation effect is adopted, which is also known as the method of maximum classes square error. However, concrete bridges always exist the uneven surface areas and the staggered surface of space characteristics. The imaging of crack surface may generate a significant difference in image brightness due to uneven illumination, which will affect the threshold segmentation of the whole crack image. Therefore, it is not feasible to use the conventional threshold segmentation method directly and we need to improve the algorithm.

In order to improve the detection accuracy on the edge of the bridge crack, the improved threshold segmentation algorithm of local adaptive Otsu is combined with Sobel edge gradient detection in this paper. Furthermore, the convolution kernel templates of extended 8-directional isotropic Sobel operator calculate the gradient amplitude $G_i(x,y)$ and direction angle θ of each pixel, as well as the local optimal threshold T_i in crack image. Then these gradient values of each pixel in the area were binarized by the threshold. And the steps to improve the algorithm are as follows:

(1) First, the gray variance σ^2 and the gray mean u of the whole image are calculated, and the local gray variance threshold is $t=k\sigma^2$, where k is the coefficient constant.

(2) Then a window template with 20 x a height of image pixels is built to slidably retrieve the image pixel by pixel from left to right and calculate the local gray variance S^2 in each window template.If $S^2\ge t$, we perform the steps (3) and (4), otherwise the step (5).

(3)We obtain each gray level L_i in the window image, and respectively divide the window image into two parts according to the local threshold L_i in order from small to large. Next, we need to calculate the gray means and the probabilities of its occurrence. Among them, the mean grayscales of the two parts of the image are u_1 and u_2 , as well as probabilities of gray levels in the two groups are ω_1 and ω_2 . Then the interclass variance of the two groups under the gray level is: $d(k)=\omega_1(u_1-u)^2+\omega_2(u-u_2)^2=\omega_1\omega_2(u_1-u_2)^2$

(4) The interclass variance under each local threshold of the image window $d_i(k)$ is solved respectively, and its maximum value is taken as the segmentation threshold of local maximum variance (as shown in $T=\max(d_i(k))$) to binarize the pixel points in the window template. That is, when the maximum gradient value of the pixel point $G_i(x,y)$ is greater than the threshold value of maximum interclass variance T_i , the pixel point is retained as the crack edge and its pixel value is set to 0. Otherwise, the pixel point is filtered as background noise and its pixel value is set to 1.

(5) If S^2 is less than the initial threshold value t, it indicates that the gray contrast in the image window is very low and the high-frequency information is absent. Then it is regarded as the background area and its pixel value is set to 1.

After the above steps, the image segmentation effect of crack area is shown in Fig. 4. The improved edge detection algorithm not only realizes the optimal threshold calculation under local Windows but also reflects the information relationship between pixels and their spatial neighborhood. It avoids the influence of the contrast difference caused by the uneven illumination and the spatial structure. Moreover, the gradient amplitude of each pixel after the processing of the expanded Sobel operator is discriminated by the threshold value, and the local variation of each region is treated differently to realize the adaptive threshold segmentation of local bridge deck background and crack target.

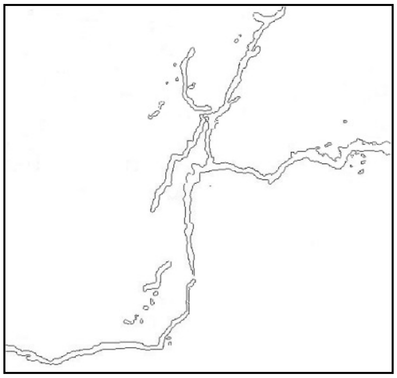

Fig. 4. The improved edge segmentation results

However, due to the interference information of concrete bridge surfaces, such as stains and potholes, there are still a few isolated noise spots in the binary image after edge segmentation. Therefore it is necessary to further identify and eliminate residual noise spots according to the area characteristics and linear characteristics of cracks, so as to ensure the subsequent accurate extraction of crack feature data.

4. Feature Data Extraction of Concrete Bridge Crack

4.1 Recognition and classification of target cracks

After the above processing, all the interfering information in the image has been removed, and the intact edge segmentation of each target crack is completed. Then, after the pixel of the binary image is inverted, the image matrix is projected horizontally and vertically by using the projection method, according to the characteristics that pixel value of the continuous crack edge line is 1 and the bridge surface background is 0. Now, let the horizontal and vertical projection lengths of the target crack are ΔX and ΔY. The rows and columns pixel values are summed and stored in the array, where the horizontal and vertical projection values at each location point are X_i and Y_i. According to the two groups of feature data, the crack types of concrete bridge are divided into transverse, longitudinal, inclined and reticular cracks. The criterion is as follows:

(1) The length-width ratio $\Delta Y / \Delta X$ of image cracks is calculated on the basis of the actual characteristic size of concrete bridge cracks. If the numeric value is less than 0.3, it is considered as a transverse crack, and if the value is greater than 3, it is regarded as a longitudinal crack. Otherwise, the next step to discriminate is required.

(2) According to the trend features of the actual bridge crack, the numeric values of two projection arrays in the horizontal and vertical directions are respectively retrieved. If more than half of the numeric values in the array are greater than 5, it indicates that the projection of the crack edge in both directions overlaps in many places, then it is regarded as a reticular crack. Otherwise, it is regarded as an inclined crack.

4.2 The extraction of crack pixel data

Because the two edge lines of the crack in the binary image present approximately parallel characteristics, the feature data of the identified image crack can be extracted according to one of the edge lines. As the normal direction of each pixel point (x_i, y_i) on one crack edge line $u(x, y)$, the edge gradient direction θ can be calculated by the expanded Sobel operator. And then the crossed point coordinates (x_i', y_i') of the normal and another edge line $v(x, y)$ are obtained, as shown in Fig. 5. The crack width of each pixel point on the crack edge line is calculated by $\Delta d_i = \sqrt{(x_i - x_i')^2 + (y_i - y_i')^2}$ and its maximum value $d_{\max} = \max(\Delta d_i)$ is taken as the maximum crack width.

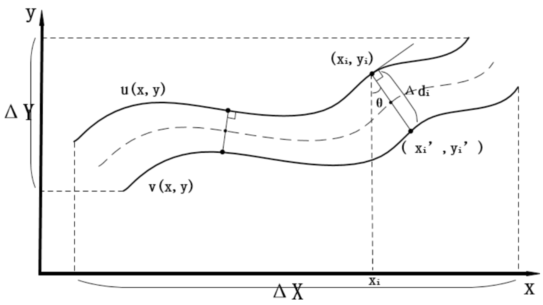

Fig. 5. The data detection of crack edge

The crack binary image after edge segmentation is a single-pixel crack boundary that is composed of edge pixels with the maximum gradient. Therefore, the number of pixel points on the edge of each crack region can be counted as the circumference of each crack. We take half of the circumference of the crack as the length of the crack, due to the width at the end of the crack is negligible compared with the length. The average width is dividing the sum of the crack width at each pixel position by the crack length. And the fracture rate of crack image is calculated by dividing the total number of pixels in the region surrounded by the crack edges by the sum of pixels in the whole image area.

5 Case analysis

Through case analysis and comparison, it can be seen that the result obtained by using the conventional crack image processing method [7] is shown in Fig. 7. (a). The crack contour has multiple discontinuities and is accompanied by some noise spots which cannot be fully processed. Such segmentation results will seriously affect the calculation accuracy of the subsequent feature data. However, in this paper, after improving the de-noising method and segmentation algorithm in the process, the extracted crack edge image is shown in Fig. 7. (b). It can be clearly seen that the fracture edge is relatively complete and continuous, and more accurate texture feature information of crack edge details is provided.

(a) Contour extraction of the canny algorithm (b) Contour extraction of the improved algorithm
Fig. 6. Comparison between the improved algorithm and the traditional algorithm

The images collected by the CCD camera only contains plane pixel information. In order to obtain the distance conversion, this paper uses the distance measurement method to realize the conversion between pixel information and actual physical data. According to the principle of lens optical imaging, the size information of the actual crack can be obtained by pixel detection of the image crack. In order to verify the effectiveness of the algorithm for extracting crack feature information, the feature information results obtained from 10 crack images of the concrete surface taken at the test site after calculation are shown in Table 1 below:

Table 1. The data extraction of each crack image

the serial number of crack images	The length l_i/px	The average width d_{mean}/px	Maximum width d_{max}/px	Absolute error of maximum width E_d/mm	the fracture rate of crack image η/%
①	1483	13.416	17.205	0.01	5.47
②	1197	9.534	11.487	0	3.14
③	1241	9.724	12.203	0	3.32
④	1173	12.938	14.472	0	4.18
⑤	872	12.185	13.935	0	2.93
⑥	1039	13.095	15.629	0	3.72
⑦	1394	11.912	16.374	0.01	4.61
⑧	1641	9.287	13.528	0	4.19
⑨	1427	9.813	12.973	0	3.85
⑩	934	10.940	14.625	0	2.81

After the conversion of distance dimensions, the maximum pixel width of each group of cracks is compared with the actual measured value. The absolute error between them is controlled within 0.02mm, as shown in table 1. Therefore, the processing results meet the actual engineering requirements of bridge crack detection. This method can provide technical support for non-destructive automatic detection of bridge surface cracks.

5 Conclusion

Aimed at the actual situation of concrete bridge surface crack based on image detection, the parameters of crack characteristic achieve a more accurate extraction. In this paper, the improvements have been made in the denoising, contrast enhancement, edge segmentation, crack recognition and data extraction of crack images detection. Finally, the results of preliminary experiment show that the obtained image cracks are highly consistent with the real ones, and the calculation accuracy of the characteristic data meets the need for engineering detection. Therefore, the improved algorithm is feasible in the real-time automatic detection of concrete bridge cracks.

Acknowledgements

This work is supported by the Basic Public Welfare Research Project of Zhejiang Province (LGF18E070001) and the Innovative Practice Base Project From the Mechanical Engineering Academy of Hangzhou Dianzi University (JDR201728).

Reference

[1].Yao, C., et al. A bridge crack image detection and classification method based On climbing robot. 2016: TCCT.

[2].Valença, J., et al., Assessment of cracks on concrete bridges using image processing supported by laser scanning survey. Construction and Building Materials, 2017. 146: p. 668-678.

[3].Liu, X., Y. Ai and S. Scherer, Robust image-based crack detection in concrete structure using multi-scale enhancement and visual features. 2017.

[4].Yang, Y., et al., Image analysis method for crack distribution and width estimation for reinforced concrete structures. Automation in Construction, 2018. 91: p. 120-132.

[5].Talab, A.M.A., et al., Detection crack in image using Otsu method and multiple filtering in image processing techniques. Optik - International Journal for Light and Electron Optics, 2016. 127(3): p. 1030-1033.

[6].Xu xuejun and zhang xiaoning, Crack detection technology of concrete bridge based on digital image. Journal of Hunan university (natural science edition), 2013(07): 34-40.

[7].Adhikari, R.S., O. Moselhi and A. Bagchi, Image-based retrieval of concrete crack properties for bridge inspection. Automation in Construction, 2014. 39: p. 180-194.

[8].Li wenbo and Yang baochun, Detection of crack width of concrete bridge based on image processing technology. Hunan transportation technology, 2015(01): 119-122.