Method for extracting crack area on structure surface based on digital image processing technology

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Abstract. According to the characteristics of the surface crack of the wall structure, the method of extracting and marking the surface crack area of the wall mechanism is studied by using the digital image processing technology. In this paper, the wall structure crack is taken as the research object, firstly, the nonlinear Bilateral Filters algorithm is used to suppress the noise and smooth the image; then the crack edge is extracted by Canny operator, all the crack edges are closed by mathematical morphology opening operation, and some non-crack contours are eliminated; finally, the non-crack area is deleted to realize the real mark of crack connected region. The analysis of the experimental results shows that the method proposed in this paper can realize the safe line monitoring of the cracks in the wall structure and mark the area where the real cracks are located.

1. Introduction
The surface crack of the structure is of great significance and value to the safety factor of the structure and the maintenance and repair of the structure. Common building structure cracks include road cracks, bridge cracks, wall structure cracks, and airport runway cracks. The main reasons for the formation of cracks in the wall structure are the uneven settlement of the building; the temperature of the concrete is not well controlled, and the tensile stress of the concrete with excessive temperature difference inside and outside the wall produces cracks on the surface; dry shrinkage cracks are formed by improper maintenance and management in the later stage [1].

In recent years, machine vision technology has developed rapidly, and has been well applied in the field of structural crack recognition, such as Li Q.[2] and other researches on ceramic tile surface crack detection combined with principal component analysis and digital image processing; Li L F. et al.[3] proposed a bridge crack detection algorithm based on image processing and suitable for complex backgrounds; Jahanshahi et al.[4] proposed a feasible method for automatic defect detection based on image processing for bridge structures, and realized crack detection and detection through depth perception. Quantification; Tran Hiep Dinh et al.[5] proposed an automatic peak detection algorithm for image segmentation, which is suitable for specific crack detection problems. Digital image processing technology can obtain the actual status of the object to be detected without the need for staff to go to the scene, and the detection accuracy is high, the recognition range is wide, and it provides a new solution for the extraction and marking of the crack area of the wall structure.

In response to the requirements of wall structure surface crack detection, this paper proposes the use of classic Canny operator edge detection and mathematical morphology opening operation to extract the wall structure crack area, and further proposes to delete the small area of non-wall crack area and mark the real wall crack connected area, so as to make the crack area more visible. The daily
inspection of the wall structure can be replaced by UAV technology to eliminate the hidden danger of the building structure in advance.

2. Image preprocessing

2.1. Gray image histogram
In digital image processing, the grayscale range can be obtained by observing the gray image histogram. The grayscale range can be used to measure the image contrast. The larger the grayscale range, the higher the contrast [6]. Figure 1 is a gray scale image, and Figure 3 is a three-dimensional surface image composed of grayscale values, where \( X \) and \( Y \) are pixel coordinates and \( Z \) is the grayscale value of the corresponding pixel. It can be seen from Figure 3 that the distribution is extremely uneven. Figure 2 shows the gray histogram of the crack image. The frequency of pixel appearance shows a single peak shape. The traditional image threshold segmentation method is not ideal for extracting cracks.

\[
I_{p}^{bf} = \frac{1}{W_p} \sum_{q \in \Omega_p} G_s \left( I_p - I_q \right) G_s(p - q)\left[I_q\right]
\]

\[
W_p = \sum_{q \in \Omega_p} G_s \left( I_p - I_q \right) G_s(p - q)
\]

Figure 4(a) is the original picture of the wall structure cracks before filtering, and Figure 4(b) is the effect picture obtained by bilateral filters. Compared with the original picture, it is obvious that the effect of removing non-crack elements in the original picture is obvious.
3. Wall crack image edge detection

In order to obtain more real and effective crack information, it is necessary to extract the edge of the crack. The purpose of edge detection is to identify the points with obvious brightness change in the crack image. There are many applications of edge detection algorithm [9-11]. At present, the application effect of Canny operator edge detection algorithm is better in crack detection.

John Canny et al. [12] proposed the classical Canny edge detection operator on the basis of a systematic summary of the existing edge detection algorithms. Under certain assumptions about the signal and filter, the optimal filter is obtained by numerical calculation method, and the performance of various filters is compared [13]. The generation equation of Gaussian filter kernel of size (2k+1)×(2k+1) is given by the following formula:

$$H_{ij} = \frac{1}{2\pi\sigma^2} \exp\left(-\frac{(i-(k+1))^2+(j-(k+1))^2}{2\sigma^2}\right), 1 \leq i, j \leq (2k+1)$$  \hspace{1cm} (3)

The amplitude and direction of the gradient are calculated by the finite difference of one-dimensional partial derivative:

$$G = \left(G_x^2 + G_y^2\right)^{1/2}$$  \hspace{1cm} (4)

$$\theta = \arctan\left(\frac{G_y}{G_x}\right)$$  \hspace{1cm} (5)

According to the gradient direction, non-maximum value suppression is performed on the gradient amplitude, and finally double threshold processing and connecting edges are used.

Figure 5 is the boundary image extracted by the Canny operator. The crack edges are roughly extracted, but some crack areas appear discontinuous and non-crack boundaries. At the same time, some holes and burrs left on the surface during construction are also extracted. These non-crack information interfered with the final crack identification.

4. Mathematical morphology operation processing

Mathematical morphology is a nonlinear filtering method. By describing the basic features and structure of the image, the image processing problems such as noise suppression, feature extraction and edge detection are solved. The commonly used transformation has a unique advantage in detecting the edge of the image [14].

4.1. Opening operation and closing operation

Opening operation and closing operation are a combination of expansion operation and erosion operation. Opening operation is the first erosion operation and then the dilation operation, and the closing operation is the first dilation operation and then erosion operation. Opening operation can remove the bright areas smaller than the structural elements in the image, and other details are not affected; Closing operation can fill the dark areas in the image smaller than the structural elements, and other gray-scale details are also unaffected. Open operation and the closing operation can be used in combination to filter out the noise in the original image, or to remove the interference part of the target object in the binary image[15].

Erosion operation and dilation operation are defined as:

$$A \ominus S = \{x \mid (S)_x \subseteq A\}$$  \hspace{1cm} (6)

$$A \oplus S = \{x \mid (B)_x \subseteq A \neq \emptyset\}$$  \hspace{1cm} (7)

Opening operation and closing operation are defined as follows:

$$A \circ S = (A \ominus S) \oplus S$$  \hspace{1cm} (8)
Some of the crack regions proposed by the Canny operator edge detection algorithm have discontinuous and non-crack boundaries, so the non-crack boundaries need to be removed. In this paper, opening operation of mathematical morphology is used, and the result is shown in figure 6. From the treatment results, it can be seen that some small non-crack edges have been removed, the real crack area has not been affected, and all the edges of the crack area have been closed well.

\[ A \cdot S = (A \oplus S) \ominus S \]  

(9)

5. Delete small areas and mark connected areas

After opening operation of mathematical morphology, a small number of non-crack elements are removed directly, and all the crack edges are closed after crack image processing, forming a connected region. Because of the continuity of cracks in the wall structure, it can be considered that the isolated small connected area is not the crack area. Delete the isolated small areas, get the final crack areas of the wall structure, and mark these areas.

The area of all elements in the crack image is represented by the number of pixels occupied by the elements. The core idea of deleting isolated small areas is to replace all white small area pixel values (255,255,255) with black pixel values (0,0,0), so that white isolated small areas become black and are deleted.

The core idea of the method is to find the contour of the target element of the binary image, sort the outline according to the ascending or descending order of the pixel area, set the pixel area threshold of the outline to be deleted, and delete the contour region which is less than the threshold. Finally, the rectangular boundary of the crack outline is obtained, and the marked wall crack connected region is obtained by drawing the rectangular boundary mark of the outline. The detailed algorithm flow chart is shown in figure 7.

Figure 8 is the process image of traversing the image pixels, deleting the small non-crack area and marking the final real crack area image after sorting. It can be seen from the image that the small non-crack areas are all deleted, and the real crack areas are finally marked by a complete frame.

Figure 7. Algorithm flowchart for deleting small area and marking connected areas.
6. Summary
In this paper, the bilateral filters algorithm is used for image preprocessing, and then the edge detection of the preprocessed wall crack image is carried out by Canny operator, and the rough outline of the crack edge on the image is extracted, at the same time, part of the crack region discontinuity and non-crack boundary are extracted, and then the mathematical morphology opening operation is used to process a small number of non-crack region contours directly, and the image processing method closes all the crack edges. Finally, the algorithm is written to delete the non-crack area, and the connected region of the crack area of the wall is marked with a rectangular box. It can realize the surface crack image extraction and crack area marking of the wall structure, which greatly improves the inspection efficiency of the hidden danger of the wall structure, and has high practical value. Of course, the algorithm of this paper also has some shortcomings, such as wall cement block, paint falling off, wall discoloration and stains may reduce the accuracy of crack area extraction and crack area marking, which will be the focus of future research.

Conflicts of Interest
The author declares that there are no conflicts of interest regarding the publication of this paper.

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References
[1] Li L X. (2014) Analyze the prevention and control measures of wall cracks in civil construction. Heilongjiang Science and Technology Information,09:243.
[2] Li Q, Zeng S., Zheng S G., Xiao Y S., Zhang S W., Li X L. (2020) Machine Vision Based Detection Method for Surface Crack of Ceramic Tile.Laser & Optoelectronics Progress, 57:51-57.
[3] Li L F., Sun R Y. (2019) Bridge crack detection algorithm based on image processing under complex background. Laser & Optoelectronics Progress, 56: 061002.
[4] Jahanshahi M R., Masri S F., Padgett C W., et al. (2013) An innovative methodology for detection and quantification of cracks through incorporation of depth perception. Machine vision and applications, 24: 227-241.
[5] Dinh T H., Ha Q P., La H M. (2017) Computer vision-based method for concrete crack detection. In:International Conference on Control. Thailand. pp. 1-6.
[6] Li Y N.,Wang P.,Xiao J H. (2019) An Image Style Transfer Algorithm Based on Multi-dimension Histograms Matching.Computer and Modernization, 02:15-18+26.
[7] Tomasi C. (1998) Manduchi R.Bilateral filtering for gray and color images In:IEEE International Conference on Computer Vision.WashingtonD. pp.839-846.
[8] Chen P.,Jiang Z B.,Optical Communication Technology. (2019) Application of bilateral filter in OTDR.http://kns.cnki.net/kcms/detail/45.1160.TN.20200722.1010.002.html.
[9] Wang B J., Zhao H Q., Liu C. (2018) An improved edge detection algorithm based on canny operator. Science and Technology Innovation. 27:13-14.

[10] Wang F B., Sun H Y., Tu P. (2019) Visual Inspection for Extended Edge Belt Tearing Based on SVM. China Mechanical Engineering. 30:455-460.

[11] Yang X F., Zhao L., Du J J. (2018) The Pipeline's Crack Detection Algorithm Based on Improved Median Filtering and Morphology. Computer Integrated Manufacturing Systems, 35:81-85+180.

[12] Canny J. (1986) A computational approach to edge detection, In: Proceedings of Transactions on Pattern Analysis and Machine Intelligence. TPAMI. 6: 679-698.

[13] Zhang Y., Zhao Y Y., Li G X., Zheng Z Z., Zhang S. (2020) Research Progress on Edge Detection Technology of Images. Computer & Digital Engineering. 48:1176-1184+1232.

[14] Hu L., Chang X., Ji F. (2018) New research progress of image edge detection methods. Modern Electronics Technique. 41:32-37.

[15] Lu F., Zhang J S., Huang G. (2018) Mathematical Morphology Analysis of Weld X-ray Images. Hot Working Technology. 48:212-214+219.