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Comparison Analysis on Present Image-based Crack Detection Methods in Concrete Structures

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***Abstract*—Crack detection is of particular crucial for safety and cost-effective maintenance of concrete structures. Many image-based detection methods have been highly proposed for their automation, objectivity and efficiency. However there are many difficulties in image-based crack detection for various reasons. In this paper, the present image-based crack detection methods are summarized and subdivided into four categories: integrated algorithm, morphological approach, percolation-based method, and practical technique. Experiment results and comparison analysis on the four categories of methods are presented.**

Keywords-crack detection; methods categorization; comparison analysis

I. INTRODUCTION

Cracks in concrete structures have many causes, such as poor repair, contractions due to rapid temperature decreases, fluctuations between contractions and expansions from temperature changes, and extra loads. They may affect appearance of concrete structures, and most importantly they may indicate significant structural distress or damage. How to detect cracks is an important task to adopt appropriate rehabilitation methods to repair the cracked structures. Recently, there has been an increasing interest in image-based crack detection in concrete structures for non-destructive inspection. However, there are many difficulties in image-based crack detection because of the random shape and irregular size of cracks, and various noises such as irregularly illuminated conditions, shading, blemishes, divots and concrete spall in the acquired images.

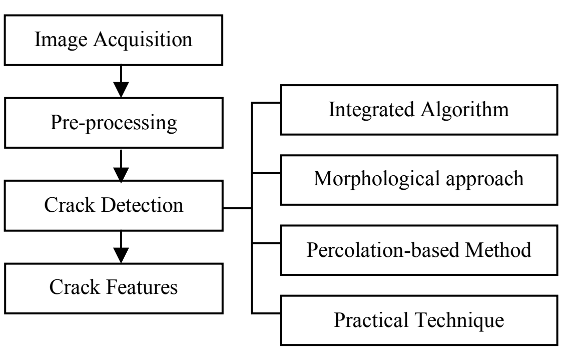

Figure 1. Flowchart of image-based crack detection

There have been many image-based detection methods proposed for the above mentioned reasons. These methods can be summarized and subdivided into four categories, namely integrated algorithm, morphological approach, percolation-based method, and practical technique. The flowchart of image-based crack detection is shown in Fig. 1. In this figure, the left column of the flowchart is explained in sequence, which is the basic procedure for crack detection and analysis. The four categories of methods are shown in the right column of the flowchart and described in the next sections.

II. REVIEW ON FOUR CATEGORIES OF METHODS

A. *Integrated algorithm*

Integrated algorithm [1-3] is composed of two steps. In the first step, some pre-processings are adopted to remove noises in the acquired images such as irregularly illuminated conditions and shading, and simultaneously to emphasize crack features. After image pre-processings, thresholding segmentation processing is used to separate cracks from the background in the second step.

Fujita's technique [1] can be categorized as one of integrated algorithms. In Fujita's technique, two pre-processings and one processing are used to detect cracks in concrete structures. Firstly, the subtraction pre-processing is used to remove slight variation like irregularly illuminated conditions and shading. Secondly, the line emphasis pre-processing is used to emphasize line structures associated with cracks against blob structures such as blemish. After two pre-processings, the Otsu's thresholding processing [4] is applied to separate cracks from the background. In the second step, the Otsu's thresholding technique selects a threshold based on integration of the gray-scale histogram. The performance of this algorithm is governed by the size of the median filter on the subtraction pre-processing and the parameters of the line emphasis pre-processing.

B. *Morphological approach*

Morphological approach [5-7] is based on mathematical morphology and curvature evaluation that detects crack-like patterns in a noisy environment. Mathematical morphology is based on set-theoretic concepts, on nonlinear superposition of signal, and on a class of nonlinear systems.

The shape properties, connectivity and curvature are effectively used in morphological approach to detect cracks in an image consisting of complex background. Morphological approach can be divided into three steps. Firstly, improve the contrast of concrete image by enhancing the dark pixels from the background image. Secondly, perform crack enhancement described in mathematical morphology terms. At this step, a manual threshold on F value could result in cracks being segmented out from the image, but in most cases the image would be noisy thus requiring further treatment by curvature evaluation using a Laplacian filter. Finally, the third step in the detection process consists of applying a set of filters with linear structuring elements to remove the enhanced noise patterns. The final closing by a larger structuring element removes smaller and tortuous segments of cracks that are shorter than the structure element.

C. Percolation-based method

Percolation is a physical model based on the natural phenomenon of liquid permeation. Percolation-based crack detection method [8-9] is based on the assumption that cracks possess two characteristics, namely their shape being thinner than those of other textural patterns and their brightness being lower than that of the background. Unlike integrated algorithm which is only dependent on the brightness of crack, this method fully makes use of the shape information of crack which is extremely effective for unclear crack detection. The feature of this method is that it evaluates the central pixel in a local window according to a cluster former using the percolation process.

This method is a type of local image processing, and takes into account the connectivity among neighborhood pixels. If the focal pixel belongs to the crack pixels, the percolation region will grow linearly. On the other hand, if the focal pixel belongs to the background pixels, the percolation region will grow omnidirectionally. The shape of the percolation region depends on the characteristics of the focal pixel. Therefore the focal pixel can be evaluated to whether it belongs to a crack by characterizing the percolation region. In [8-9], the circularity F as a characteristic of the percolation region is expressed by the equation (1)

$$F=4\times C_{count}/(3.14\times C^2_{max}) \quad (1)$$

where C_{count} is the number of pixels in the cluster and C_{max} is the maximum length of the percolation region. The value of F ranges from 0 to 1. Whether the focal pixel belongs to a crack can be determined by calculating the value of F. If the shape of the percolation region is nearly circular, F is close to 1 and the focal pixel belongs to the background. On the other hand, if the shape of the percolation region is nearly linear, F is close to 0 and the focal pixel belongs to a crack.

For the acquired crack image, percolation processing is applied to every pixel in the image so that a binary image with cracks whose pixel value is 0 can be obtained.

D. Practical technique

In principle, a fully automated crack detection method would be desirable, and, given appropriate image quality, it might be possible to find the edges of cracks and detect them automatically. In fact, it is impossible to achieve this goal because of irregularity of cracks and various noises in concrete images. Practical technique [10-12] is a semi-automatic and semi-manual crack detection method which involves human intervention. This technique is based on the route-finder algorithm [10] whose purpose is to delineate the crack as a polyline. Once the polyline is defined, the crack is traced simultaneously and measurement of the crack is achieved.

The route-finder algorithm relies on the human operator interactively selecting two points, namely the start point and the end point on the crack with a mouse pointer. A straight line is drawn between the start point and the end point. A pre-defined distance along the straight line is move from the start point to the end point. The moving course is done by taking the profile of the pixel values perpendicular to the straight line. The profile is defined as an array of pixel values, lying on a straight line of a pre-defined length. The point with the lowest pixel value in the profile is taken as a crack point. The three points lying on the crack are joined together to form a three point polyline. The whole process is repeated until the entire crack has been delineated.

Once the crack has been delineated, an automatic algorithm to measure the width of the crack is possible. This width measurement algorithm starts with the polyline representation of the crack, and at the entire point of each polyline, a perpendicular profile is generated. Starting from the centre of the profile, the algorithm looks left and right until the profile reaches the threshold. The width is calculated as the distance from left to right. In this algorithm, the key step is the determination of the threshold. Reference [10] proposed the calculation of the threshold in equation (2)

$$\text{threshold} = \text{range}\times\text{gain}+\text{offset} \quad (2)$$

where the values of gain and offset are pre-defined. In [11] the value of gain was set to 0.5, and the value of offset was set to 0.

III. EXPERIMENTS AND COMPARISON ANALYSIS

A. Experiment results

In this section, some experiment results of the above four categories of methods are presented.

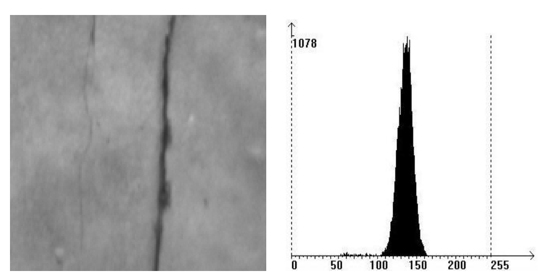

Figure 2. Original concrete image and its histogram

Fig. 2 represents the acquired original concrete image taken with a digital camera containing 256 possible gray levels, ranging from 0 for black to 255 for white and its histogram. The crack detection results of this image using the above mentioned methods are shown in the following.

Fig. 3 shows the crack detection result using Fujita's technique. The left picture of this figure is the result of two pre-processings, and the right image is the final processing result using the Otsu's thresholding technique.

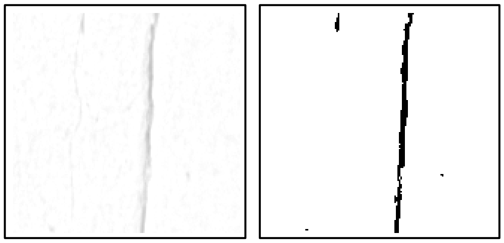

Figure 3. Results of Fujita's technique

The two images in Fig.4 are the results of morphological approach using different structuring elements.

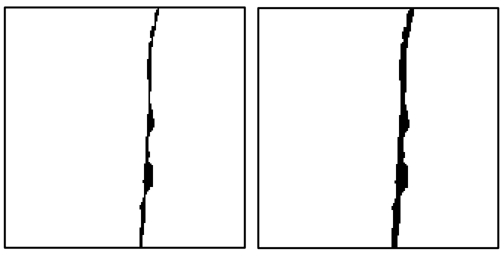

Figure 4. Results of morphological approach

Fig. 5 and Fig. 6 illustrate the percolation of crack region and background region with different iteration steps, respectively. In Fig. 5, the focal pixel belongs to a crack and the value of F is close to 0. On the other hand, in Fig. 6, the focal pixel belongs to the background and the value of F is close to 1. Fig. 7 shows the ultimate crack detection result.

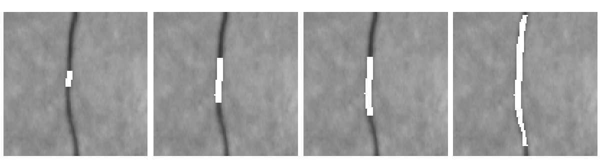

Figure 5. Percolation of crack region

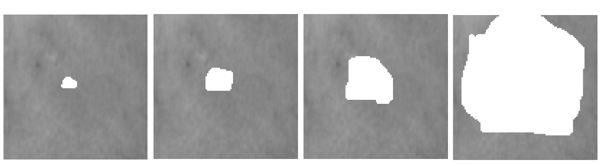

Figure 6. Percolation of background region

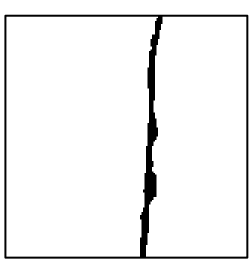

Figure 7. Result of percolation-based method

Fig. 8 illustrates the crack detection process of the route-finder algorithm used in practical technique with different iteration steps. Fig. 9 is the ultimate crack detection result using this method.

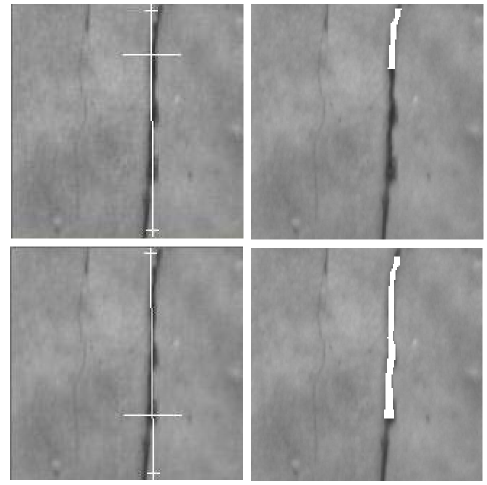

Figure 8. Process of the route-finder algorithm

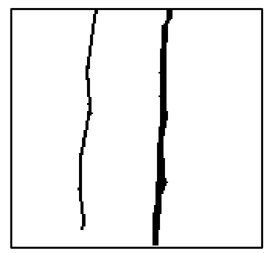

Figure 9. Result of practical technique

B. *Comparison analysis*

Integrated algorithm consists of some pre-processings to remove various noises and one thresholding segmentation to separate cracks from the background. It is effective especially for removing shading. The performance of pre-processing is dependent on the size of the median filter and the parameters of the line emphasis. However, the Otsu's thresholding technique is effective in an ideal image in which the histogram has a deep and sharp valley between two peaks representing cracks and background, respectively, so the integrated algorithm is highly dependent on the performance of the two pre-processings. In practical applications, the size of the median filter and the parameters of the line emphasis are not easily selected, which lowers the efficiency of this technique.

The shape properties, connectivity and curvature are fully used in morphological approach. It achieves a very small proportion of false detection and performs better than the Otsu's techniques, but as shown in Fig. 4, some micro-cracks in the images are missed. Because the performance of morphological approach is dependent on the size of the structuring element and degree of rotation, different structuring elements would produce different results as shown in Fig. 4. This method can be used to distinguish between cracks, holes, laterals and joints, but the crack pixels are not detected precisely. If cracks are too close to each other, there is false detection. Some cracks are not detected mostly in very low contrast and sometimes in images which have shadow due to irregularly illuminated conditions in the concrete image.

Connectivity of the neighborhood pixels and the shape information are fully taken account of in percolation-based method. Whether the focal pixel belongs to a crack can be distinguished by determining the shape of the percolation region. It is effective for unclear crack detection. However, because it is a local image processing, the processing time required for crack detection is long especially for large-size concrete images. Also, as shown in Fig. 7, some micro-cracks are still missed.

The practical technique based on the route-finder algorithm is dependent on the operator selecting the start point and the end point of the crack in the concrete image. This technique is a semi-automatic crack detection method. In comparison with other methods, this method can detect micro-cracks as shown in Fig. 9. Although it involves human intervention, this technique is characterized by its nonparametric and unsupervised nature and is effective for crack detection in most of the concrete images with various noises.

In processing time during the course of crack detection, integrated algorithm and morphological approach are better than percolation-based method and practical technique. In comparison with practical technique, the processing time of percolation-based method is long. For large-size concrete images, percolation-based method is not an optimal method. Although the processing time of integrated algorithm and morphological approach is shorter than that of practical technique, these two methods would produce false detection results especially for the concrete images with various noises. For micro-crack detection, practical technique can achieve the best detection result of the four categories of methods. In general, practical technique is the most advantageous of the four categories of crack detection methods. It is suitable for most of the crack detection in concrete structures.

IV. CONCLUSION

The present image-based crack detection methods are summarized and subdivided into four categories, namely integrated algorithm, morphological approach, percolation-based method, and practical technique.

Integrated algorithm, morphological approach, and percolation-based method are all automatic in crack detection, while practical technique based on route-finder algorithm is semi-automatic. Integrated algorithm is especially suitable for pre-processing such as shading correction, and its performance is highly dependent on the size of the median filter and the parameters of the line emphasis. Morphological approach performs better than the Otsu's techniques, but the crack pixels are not detected precisely and some micro-cracks in concrete images will be missed. Percolation-based method is suitable for unclear crack detection, while, because it is a type of local image processing, the processing time required for crack detection is long especially for large-size concrete images. Although it is a semi-automated crack detection method which involves human intervention, practical technique can achieve excellent performance in various concrete images.

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