Extraction of Characteristics of Concrete Surface Cracks

Sang-Ho Ahn, *Members, KIMICS*

Abstract—This paper proposes a method that automatically extracts characteristics of cracks such as length, thickness and direction, etc., from a concrete surface image with image processing techniques. This paper, first, uses the closing morphologic operation to adjust the effect of light extending over the whole concrete surface image. After applying the high-pass filtering operation to sharpen boundaries of cracks, we classify intensity values of the image into 8 groups and remove intensity values belong to the highest frequency group among them for the removal of background. Then, we binarize the preprocessed image. The auxiliary lines used to measure cracks of concrete surface are removed from the binarized image with position information extracted by the histogram operation. Then, cracks broken by the removal of background are extended to reconstruct an original crack with the 5x5 masking operation. We remove unnecessary information by applying three types of noise removal operations successively and extracts areas of cracks from the binarized image. At last, the opening morphologic operation is applied to compensate extracted cracks and characteristics of cracks are measured on the compensated ones. Experiments using real images of concrete surface showed that the proposed method extracts cracks well and precisely measures characteristics of cracks.

Index Terms— cracks, closing morphologic operation, high-pass filtering operation, noise removal operations.

I. INTRODUCTION

Cracks occurring on a concrete structure are the basic factor that helps to decide soundness related with durability, usability and safety of the structure. In general, since people measure cracks with the naked eye examination, the process is time consuming and laborious. Also, storage of crack information and the subjectivity of an inspector may intervene in the measurement [1][2].

This paper proposes an automatic method that is able to detect cracks of a concrete structure and measure characteristics of cracks with image processing techniques. The proposed method takes a digitalized image for the surface of a concrete structure and uses various image processing techniques to highlight the information on cracks of concrete surface and measure characteristics of cracks as follows: the method, first, uses the closing morphologic operation to adjust the effect of light extending over the whole image. After applying the high-pass filtering operation, the method uses the block-based classification of intensity values for the removal of background and binarizes the preprocessed image. The auxiliary lines used to measure cracks of concrete surface are removed from the binarized image with position information extracted by the histogram operation and cracks impaired by the removal of background are extended with the 5x5 masking operation. And, the proposed method removes unnecessary information by applying three types of noise removal operations successively and extracts areas of cracks from the binarized image. At last, the opening morphologic operation is applied to compensate extracted cracks and characteristics of cracks are measured on the compensated ones.

This paper describes image processing techniques used to extract cracks of concrete surface in detail in Section 2, explains the measure of characteristics of cracks in Section 3, and reports experiment results in Section 4, followed by the conclusion.

II. EXRACTION OF CRACKS OF CONCRETE SURFACE

Considering features of a concrete surface image properly, the algorithm applies various image processing techniques to precisely extract areas of cracks from the image and measures characteristics of cracks such as length, width and direction, etc., on the extracted cracks. In this section, image processing techniques used to extract concrete surface cracks are described in detail.

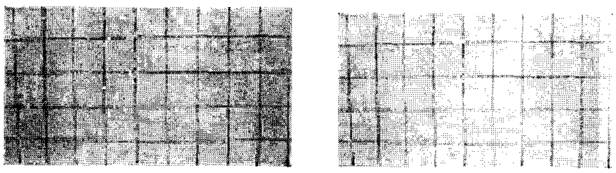
In an image taken by a digital camera, the direction and amount of light have a great influence on the background brightness. In particular, the low-level brightness of image makes a difficulty in the extraction of concrete surface cracks. This paper applies the closing morphologic operation to adjust the effect of light extending over the whole image, which performs the erosion operation and the dilation operation successively. The erosion and the dilation operations used in a grayscale image are described as Eq. (1) and (2), respectively [3].

Manuscript received May 21, 2007.

Sang-Ho Ahn is with the School of Architecture, Silla University, Busan, 617-736, Korea,
(e-mail: shahn@silla.ac.kr).

$$(f \ominus g)(x) = \max\{y : g(z-x) + y \ll f(z)\} \quad (1)$$
$$(f \oplus g)(x) = \min\{y : -g(-(z-x)) + y \gg f(z)\} \quad (2)$$

Fig. 1(a) is an original image of concrete surface and Fig. 1(b) is an output image of the closing morphologic operation on Fig. 1(a), showing that the closing operation adjusts effectively the brightness of a concrete surface image.



(a) An original image (b) Result of closing morphologic operation

Fig. 1 Application of closing morphologic operation to an original image

The high-pass filtering operation cuts off low-frequency signals and embosses high-frequency signals in a digitalized image. Thus, the operation is mainly used to emboss a blurred image [4]. This paper applies the high-pass filtering operation to the brightness-adjusted image for the sharpening of boundaries of cracks. The high-pass filter mask used in this paper is shown as Fig. 2 and Fig. 3 shows the image sharpened by applying the high-pass filter mask to Fig. 1(b).

0	-1	0
-1	5	-1
0	-1	0

Fig. 2 A high-pass filter mask used in the proposed method

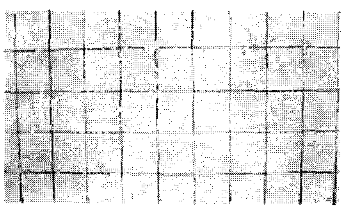
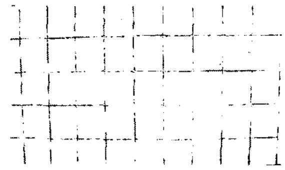


Fig. 3 Application of high-pass filtering operation to Fig. 1(b)

For the efficient extraction of cracks, this paper removes background signals and binarizes the preprocessed image with the block-based classification of intensity values. First, the sharpened image is divided to blocks of 30x30 pixels, and for each block, the average of intensity values is computed and intensity values below average are classified to 8 groups. And, the image is binarized by removing intensity values belong to a group having the highest frequency among 8 groups and converting pixels corresponding to remaining intensity values to black ones. Fig. 4(a) shows the image that displays each of 8 groups with 8 different colors, and Fig. 4(b) shows the image binarized by the proposed method.

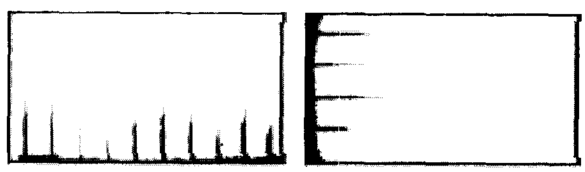


(a) Result of block-based classification of intensity values

(b) Binarized image by the removal of background

Fig. 4 Image binarization by the removal of background

In real situations, auxiliary lines are used in measuring cracks. They are crossed with 5 cm intervals on the surface of concrete structure. However, these lines make it hard to extract cracks by image processing techniques. We extract position information on auxiliary lines by the histogram operation and remove such lines from the binarized using extracted position information. In applying histogram operation, frequencies of black pixels are computed one by one in pixels by scanning the binarized image in the vertical and the horizontal directions and the average of frequencies is computed in each direction. And, for each direction, the areas with above average frequencies are decided by positions of cracks and pixels included in the areas are removed from the binarized image. Fig. 5(a) and 5(b) show the horizontal and the vertical histogram graphs, respectively, and Fig. 6 shows the image in which auxiliary lines are removed from Fig. 4(b).



(a) A vertical histogram graph (b) A horizontal histogram graph

Fig. 5 Vertical and horizontal histogram graphs indicating positions of auxiliary lines

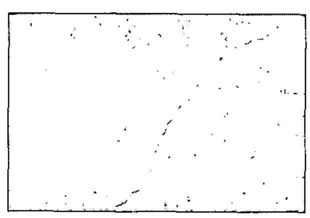


Fig. 6 Removal of auxiliary lines from Fig. 4(b) by the histogram operation

In the preprocessed image, cracks are broken by fine-grained gaps generated in the processing of background removal and binarization. So, to reconstruct broken cracks, this paper extends candidate areas which can be regarded as cracks as follows: after 5x5 mask is applied to each white pixel in the binarized image, if the number of black pixels in 25 pixels corresponding to the mask is over 1/3 of masked pixels, the central white pixel is converted to a black one. Fig. 7 shows the binarized image in which candidate crack areas are extended with 5x5 mask.

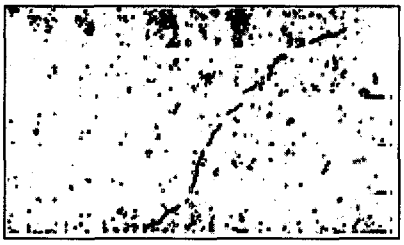
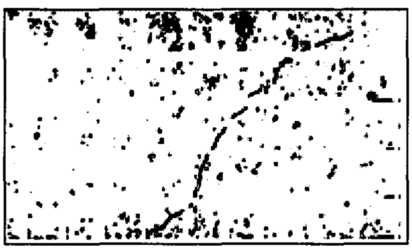


Fig. 7 Extension of candidate areas of cracks in Fig. 6

Thee types of noise removal operation are used successively to remove unnecessary noises except cracks and background. At the first step, by scanning the binarized image from left to right and from top to bottom, black pixels with only white neighboring pixels are removed as fine-grained noises. Fig. 8 shows the image in which fine-grained noises are removed from Fig.7 by the first type of noise removal operation.

At the second step, the glass labeling method is used to remove noises [5][6]. The method, first, scans adjacent pixels of a currently-selected pixel and labels black pixels among scanned ones, marking areas of interest. Then, for each labeled area, width and height are computed with the first and the last pixels of the area and if one of the two values is lower than 15, the threshold, the area is removed since being regarded as noises. In this paper, the threshold used in the glass labeling method was selected based on real experiments. Fig. 9 shows the image in which noises are removed by the proposed glass labeling method.



Pig.8 Removal of fine-grained noises from Fig.7

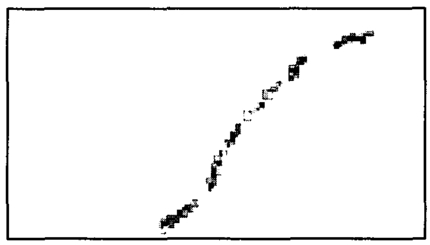
Fig. 9 Noise removal by glass labeling method

At the last step, noises are removed with the general features of crack areas. Based on real experiments, we regard an area with the following features among the remaining labeled ones as a noise and remove it: the ratio between width and height is less than 2 or the ratio of black pixels to total ones is greater than 65%. Fig. 10(a) and 10(b) show a type of noise and a type of crack among the labeled areas of interest, respectively. Fig. 11(a) displays all labeled areas of interest in Fig. 10, and Fig. 11(b) shows the image in which noises are removed from Fig. 11(a) with the features of cracks, showing candidate areas of crack finally extracted.

(a) A type of noise (b) A type of crack

Fig. 10 Comparison of types of noise and crack

(a) Remaining labeled areas in Fig. 9



(b) Noise removal by general features of crack in Fig. 9

Fig. 11 Removal of crack-like noises with general features of crack

In candidate crack areas, fine-grained cut-off and holes are generated in cracks by the processing for the removal of background and noises. This paper uses the opening morphologic operation to reconstruct spoiled cracks. In the opening morphologic operation, first, the dilation operation is performed to fill up holes on the inside of cracks, and next, the erosion operation to connect finely-broken cracks and recover thickness of cracks extended by the dilation operation. The dilation and the erosion operations in a binarized image are described as Eq. (3) and (4), respectively. Fig. 12 shows cracks finally extracted and compensated by the proposed method in Fig. 11(b).

$$A \oplus B = \{A^C \ominus (-B)\}^C \quad (3)$$

$$A \otimes B = \{X : B + X \prec A\} \quad (4)$$

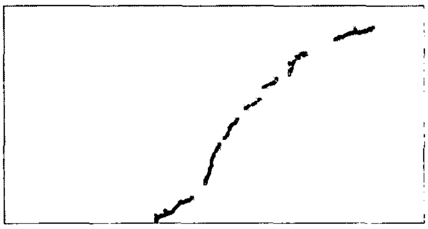


Fig. 12 Areas of cracks compensated by opening morphologic operation in Fig. 12(b)

III. ANALYSIS OF CHARACTERISTICS OF CRACKS

This paper analyzes cracks of concrete surface with pieces of cracks extracted by the proposed method, and so, characteristics such as length, direction and width are measured for each piece of crack. For each piece of crack, the length of crack is computed by scanning from the start pixel to the end pixel in the crack area. It is accumulated as 1 for a pixel of the horizontal or vertical direction and $\sqrt{2}$ for a pixel of the diagonal direction.

For each piece of crack, the direction of crack is measured in terms of an angle with Eq. (5) with reference to coordinates of the start and the end pixels, (x, y) and (x', y'). Fig. 13 shows two examples of the measurement of direction for cracks performed in this paper.

$$\angle(i) = \frac{180}{\pi} \times \tan^{-1}\left(\frac{y'(i) - y(i)}{x'(i) - x(i)}\right) \tag{5}$$

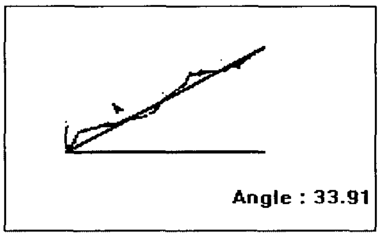


Fig. 13 Examples of the measurement of direction for cracks

The thickness of a crack is measured with length and direction of the crack. First, by regarding the direction of a crack as the gradient of the crack and using Eq. (6) and (7), the gradient of the crack is modified to become horizontality, so that it is easy to measure the thickness of a crack. Then, for the modified area of crack, by horizontally scanning pixel by pixel, thickness of black-pixel bands are measured in vertical pixel lines and the average of measured thickness is computed as the thickness of the crack. Fig. 14 shows two examples of the measurement of thickness for cracks.

$$x_2 = \cos(\theta)(x_1 - x_0) - \sin(\theta)(y_1 - y_0) + x_0 \tag{6}$$

$$y_2 = \sin(\theta)(x_1 - x_0) + \cos(\theta)(y_1 - y_0) + y_0 \tag{7}$$

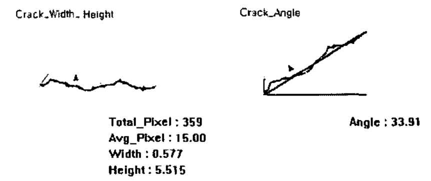


Fig. 14 Example of the measurement of thickness for cracks

IV. PERFORMANCE EVALUATION

The proposed method was implemented with Microsoft VC++ 6.0 tool and experiments for performance evaluation were performed on IBM-compatible PC with Intel Pentium-IV 2GHz CPU and 256MB RAM. 20 digital images of concrete surface firsthand taken with a digital camera were used in the experiments.

Fig. 15 shows two sample images and areas of cracks extracted from them by the proposed method and Table 1 shows measurement results of characteristics on 12 cracks labeled from A to L. Length and thickness in

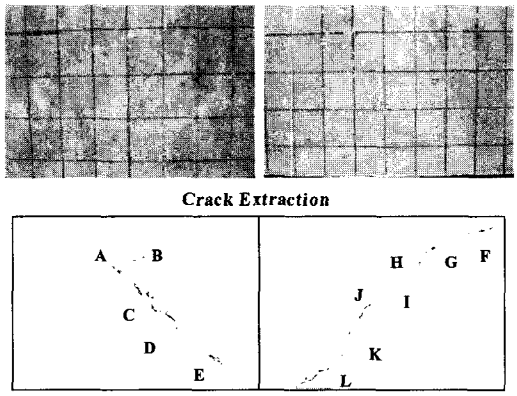


Fig. 15 Two sample images of concrete surface and areas of cracks extracted

Table 1 Measurement results of characteristics for cracks in Fig. 15

Crack	Length(cm)	Thickness(cm)	Direction(°)
A	2.254	0.346	55.33
B	2.200	0.192	36.47
C	3.537	0.377	42.24
D	5.612	0.454	48.33
E	3.753	0.231	24.20
F	5.012	0.385	19.27
G	3.551	0.269	50.27
H	2.285	0.269	36.10
I	2.381	0.308	31.12
J	3.070	0.423	52.13
K	5.086	0.538	67.31
L	5.515	0.577	33.91

Table 1 mean real-world distance values computed by multiplying the number of pixels measured from a crack to the real-world distance per pixel. Experiment results show that the proposed method extracts cracks precisely from the concrete surface image, while small pieces of broken cracks were removed as if noises in the processing for the removal of noises and the exact whole length of a crack could not be computed.

V. CONCLUSIONS

This paper proposed a novel method that automatically measures various characteristics of cracks by applying image processing techniques to a digital image of concrete surface. This paper used the closing morphologic operation to adjust the effect of light extending over the whole image of concrete surface. After applying the high-pass filtering operation for the sharpening of boundaries of cracks, this paper removed background with block-based classification of intensity values and binarized the preprocessed image. The auxiliary lines used to measure cracks were removed from the binarized image with position information extracted by the histogram operation and cracks finely broken by the removal operation of background are extended to reconstruct an original crack with the 5x5 masking operation. This paper removed unnecessary information by applying three types of noise removal operations successively and extracted areas of cracks from the binarized image. At last, the opening morphologic operation was applied to compensate extracted cracks and characteristics were measured on finally-extracted cracks.

Experiments using real images of concrete surface showed that the proposed method extracts concrete surface cracks fairly well and measures characteristics of cracks precisely. On the other hand, small pieces of broken cracks were removed as if noises in the noise removal process and then, the exact whole length of a crack could not be computed.

In the future, we would like to extend our approach to more noisy scenes or image with auxiliary lines.

REFERENCES

[1] B. Y. Lee, Y. Y. Kim and J. K. Kim, "Development of Image Processing for Concrete Surface Cracks by Employing Enhanced Binarization and Shape Analysis Technique," Journal of the Korea Concrete Institute, Vol.17, No.3, pp.361-368, 2005.

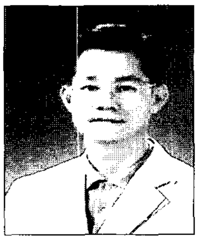
[2] Y. S. Kim, C. T. Has, " An Algorithm for Automatic Crack Detection, Mapping and Representation," KSCE Journal of Civil Engineering, Vol.4, No.2, pp.103-111, 2000.

[3] Milan, S., Vaclav, H., Roger, B., Image Processing, Analysis and Machine Vision, Chapman & Hall Computing, 1993.

[4] David A. F., Jean, P., Computer Vision A Modern Approach, Prentice Hall, 2003.

[5] Parker, J. R., Algorithm for Image Processing and Computer Vision, John Wiley & Sons, Inc., 2000.

[6] K. B. Kim, K. B. Sim, S. H. Ahn, "Recognition of Concrete Surface Cracks using The ART1-based RBF Network," Lecture Notes in Computer Science, LNCS 3972, pp.669-675, 2006.



Sang-Ho Ahn

Received the M.S. and Ph.D. degrees in Department of Architectural Engineering from Pusan National University in 1985 and 1997, respectively. Since 1997, he has been a professor in School of Architecture, Silla University, Busan, Korea. His research interests are in the area of Crack Image Analysis and Concrete Rehabilitation.