CRACK MEASURING SYSTEM BASED ON HIERARCHICAL IMAGE PROCESSING TECHNIQUE

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ABSTRACT

A prototype of crack detection and measurement system in which cracks are recognized and the length, width and distribution of cracks are measured has been developed for the purpose of assessment of the deterioration of concrete structures. In the system images of different resolution which are generated and hierarchically structured from fine to coarser are processed with a single spatial filter for crack detection rather than using a series of spatial filters for an image of single resolution.

Results show that 66 % of cracks of more than 0.1 mm width have been detected with width measurement accuracy of 0.08 mm RMS.

KEY WORDS: Image processing, Crack measuring, Edge detection, Spatial filter.

1.INTRODUCTION

To assess the deterioration of concrete structures, it is important to inspect cracks which can reveal useful information for a diagnosis of a degree of deterioration and also cause the other deterioration such as carbonation, etc. Recently a great deal of work has been put in the inspection that a shape of cracks is sketched out and a maximum width of each cracks is manually measured with crack-scale.

In order to save labor of the inspection, image processing technique is applied to recognition of a crack shape and to measurement of a width. In this processing the recognition and measurement should be performed with accuracy of 0.1 mm RMS, as targeting the cracks ranging from 0.1 to 3.0 mm in width. Hence a digital image examined in the process should be so fine that the resolution of image should be less than 0.025 mm per a pixel.

In case of such a resolution an aspect of 3.0 mm width crack shows a band-like area on the image, which is quite different from a line-edge aspect of 0.1 mm width crack. Detection of line-edge is usually carried out by means of spatial filtering. And the kernel size of filter is selected in proportion to the width of line-edge. For instance, a narrower line-edge demands a smaller kernel, and a wider like band area demands a larger. Consequently, a series of spatial filters must be prepared to detect a shape of cracks with a variety of width. And a larger kernel filter gives rise to obstruction of shortening a period of image processing.

Hierarchical image processing algorithm has been developed to detect cracks with a variety of width by means of a single spatial filter. The algorithm is divided into two sub-algorithm. One is edge detecting algorithm in which a series of images with different resolution are generated and structured hierarchically from fine to coarser. And a single spatial filter for line-edge detection works on images in the hierarchy. The other is crack measuring algorithm in which crack shapes derived from images of different resolution are combined and width of every crack is calculated.

2.HIERARCHICAL EDGE DETECTING ALGORITHM

Edge detecting process is combined with hierarchical image generating process in which a series of images are structured from fine to coarse in resolution.

2.1 GENERATION OF A SERIES OF IMAGES

A coarser image is generated from the original fine image by means of 'reduction in size by selecting the maximum value of pixels'. Fig. 1 shows a schema of the reduction to 1/5 in size. The reduced image is composed of the pixels selected under the condition with the maximum value remaining in each corresponding 5x5 area on the original fine image, because a pixel on crack has higher value than on concrete.

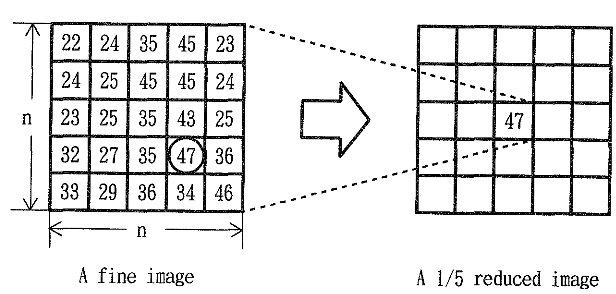


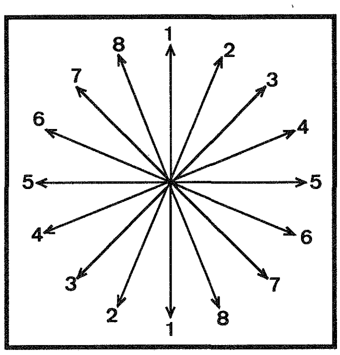
Fig. 1. Reduction in size by selecting maximum value of pixels

While cracks are reduced into 1/n scale on coarse image, the aspect of band-like cracks of n pixels in width generally turns into line-edge. Although the cracks of less than n pixels are reduced with the same manner, the skeletonized cracks are still remained by means of the maximum value selection. In the reduction, the aspect of cracks less than n pixels width on fine image can be transformed into line-edge on the coarse image, and hence the cracks can be detected with a single spatial filter in the hierarchy.

From this point of view, the rate of reduction which is suitable to detect the cracks ranging from 0.1 to 3.0 mm in width can be estimated at 1/30.

2.1.1 Line reserving smooth filter In course of reduction, however, misdetection of fine cracks arise from various stains which are often observed on concrete surface, such as mud, small holes, exfoliation and so on. The reason for the misdetection is that the pixels corresponding to such stains have rather high value than the pixels on fine cracks and work as noise. In order to reduce miscomputation, the original image is preprocessed with a line reserving smooth filter shown in Fig. 2. A certain noise whose length is less than the size of filter can be smoothed in the preprocessing, while the cracks seem to be linear structures still remain.

And furthermore, to prevent an increase in undetectable fine cracks affected by residual noise, a series of images is gradually reduced into 1/2 size step by step till the coarsest image which resolution is intended to detect the target cracks (see Fig. 3).



On each point of an image, a line reserving smooth filter finds out the maximum of mean values on each line of 8 directions.

Fig. 2. A line reserving smooth filter

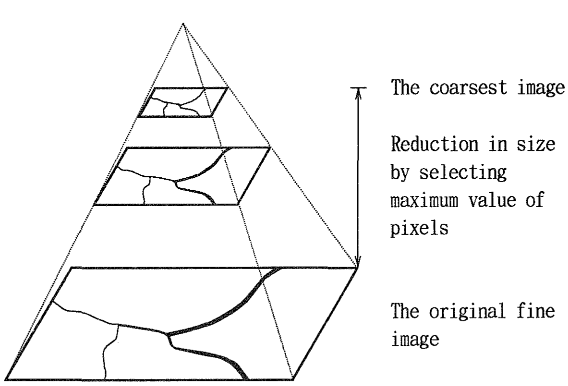


Fig. 3. A series of images structured hierarchically

2.2 Edge detection

After generating a series of images, edge detection is performed on the hierarchical images. The edge detection is divided into five stages; line-edge filtering, thresholding, noise reduction, thinning and vectorization (see Fig. 4).

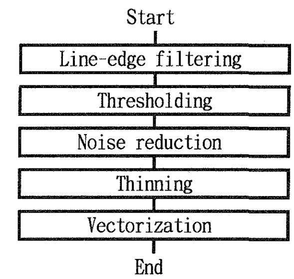


Fig. 4. The flow chart of line edge detection in hierarchical edge detecting algorithm

2.2.1 Line-edge filtering Suzuki (1985)'s Directional Contrast Filter is convoluted on the image to detect line-edge ranging from 1 to 5 pixels in width.

2.2.2 Thresholding A threshold value is determined by computation of an average on the filtered image, following which the image is thresholded into a binary image. The pixel of value more than the threshold is regarded as a part of pixels on cracks.

2.2.3 Noise reduction A small lump of pixels is removed as a noise, which length and area to be eliminated are previously determined.

2.2.4 Thinning A linear chain of pixels which is prospected to construct a crack is skeletonized to determine the position of a crack.

2.2.5 Vectorization A series of coordinates of each chaining pixel which represents position vector on the binary image compose a set of crack. In the vectorization, the coordinates are calculated by tracing along the skeleton. And then, several sets of crack which are extracted from a finer image are combined with the sets from the coarsest image. While the combination is carried out, the sets from a finer are weighted.

3.HIERARCHICAL CRACK MEASURING ALGORITHM

The crack vectors extracted from the coarsest image are positioned roughly rather than from the fine image, and hence they lead to rough-measurement of crack width.

Detailed positioning and precise measurement can be achieved by means of mapping coarse vectors onto a finer image. The mapping operation with measuring crack width is carried out step by step on each hierarchical image shown in Fig. 5, which turns back the way of image reducing process. As the execution is finished on the fine original image, the detailed crack vectors and precise width can be generated. At the end of crack measurement processing, coordinates of crack vectors and scale of width are rectified using to the fiducial points arranged on concrete.

Crack measuring process is divided into five stages; mapping crack vectors, thresholding, noise reduction, detailed positioning and measurement of crack width (see Fig. 6).

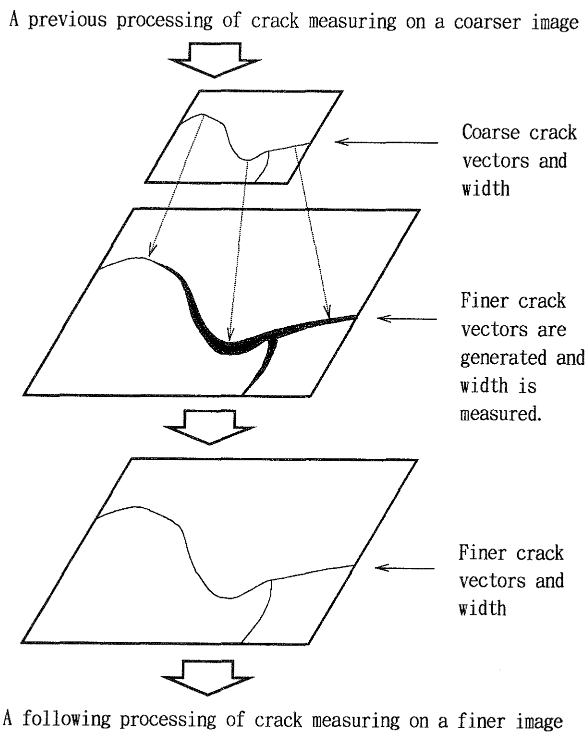


Fig. 5. A schema of hierarchical crack measuring

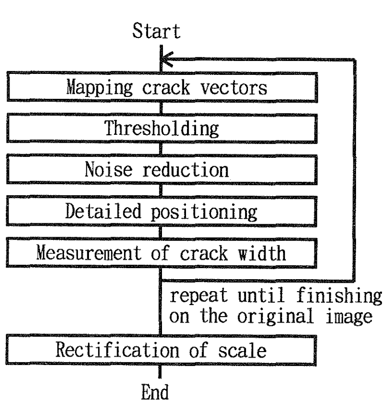


Fig. 6. The flow chart of hierarchical crack measuring algorithm

3.1 Mapping crack vectors

Each vector of cracks is mapped onto the image one step finer than the present image. Because the ratio of resolution between these images is 2:1, the location of mapped vector has an ambiguity in area of 2x2 pixels (see Fig. 7).

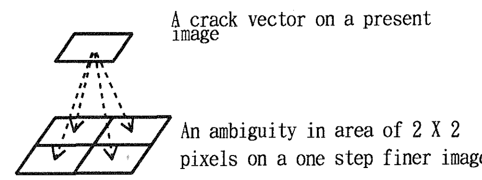


Fig. 7. Ambiguity of mapping

3.2 Thresholding

A threshold value is determined by the method based on discriminating and least squares criteria suggested by Ohtsu (1980), following which the finer image is thresholded into a binary image.

A threshold value of each crack vector is calculated in an elliptical target shown in Fig. 8, which the major axis of the ellipse is directed along the crack. In order to accomplish an adequate calculation, the length of the minor axis is determined to be twice or three times of the crack width which has been computed on the present image.

It is noted that the initial crack width on the coarsest image can be determined from the number of execution times required in thinning process.

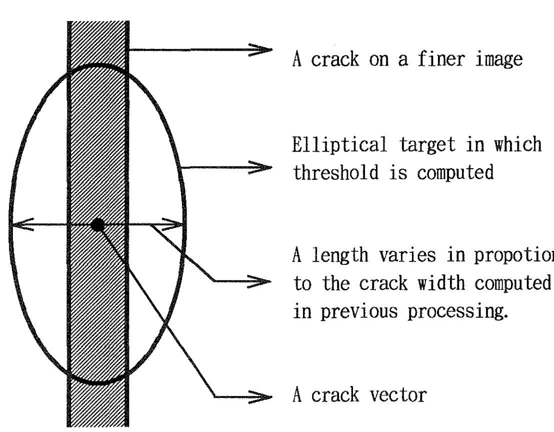


Fig. 8. An elliptical target for thresholding

3.3 Noise reduction

Fig. 9 shows an example of small isolated holes in the thresholded area. These holes, which usually prevent detailed positioning of crack vectors and precise measurement of crack width, must be filled.

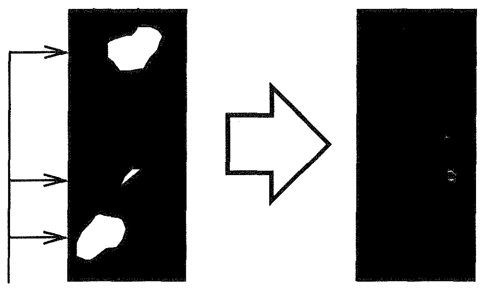


Fig. 9. Noise reduction by filling small holes

3.4 Detailed Positioning

Each vector of cracks must be centered in thresholded area, as the location of mapped vectors have ambiguity. Fig. 10 shows a schema of positioning process. In this processing location of a crack vector is shifted into the midpoint between both sides of intersection which are determined by the cross section at right angle of crack direction. Furthermore, the vector mapped on an isolated area is moved to the area on which the majority of vectors have been mapped.

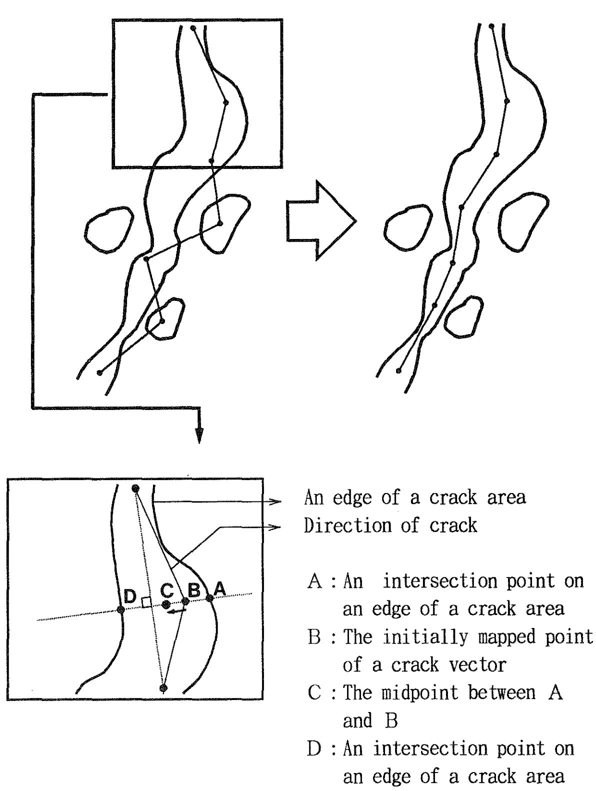


Fig. 10. A schema of detailed positioning by centering

3.5 Measurement of crack width

Crack width are measured at the location of each crack vector, which is defined as a diameter of an inscribed circle of the thresholded area shown in Fig. 11.

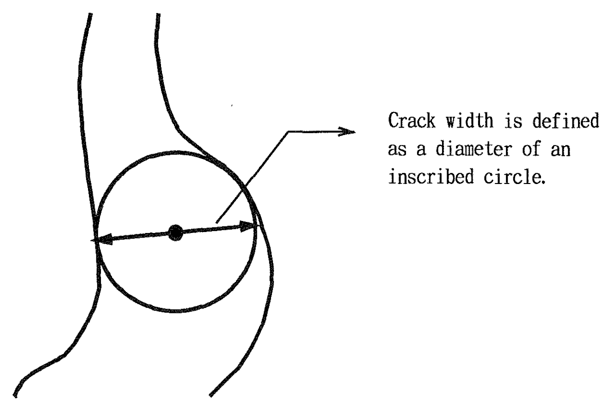


Fig. 11. A definition of crack width

4. THE TEST OF THE ALGORITHM

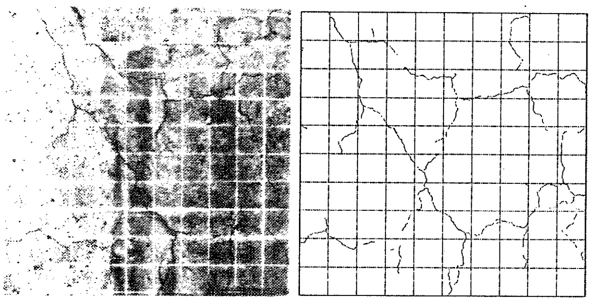
Hierarchical image processing algorithm has been examined with 18 samples of concrete crack images. In the test the resolution of finest image is 0.025 mm per a pixel. Results of the measurement can be evaluated by the two indices. One is an index of extraction which is a ratio the length of extracted cracks to the total length of existing cracks. The other is RMS error in crack width measurement.

Table 1 shows the summary of results, and Fig. 12 shows one of the coarsest image examined and its outcome of crack measurement. The result shows that the crack recognition has been achieved in the mean of extraction ratio 66 % and the width measurement done with accuracy of the mean of RMS error 0.08 mm.

Table. 1 The summary of results of the test

sample No.	length of traced crack (cm)	length of extracted crack (cm)	an index of detection (%)	RMS error (mm)
1	38.63	31.00	80.2	0.11 (20)
2	41.47	23.12	55.8	0.07 (20)
3	25.65	20.49	79.9	0.06 (20)
4	183.27	103.77	56.6	0.14 (20)
5	209.99	123.50	58.8	0.04 (19)
6	301.75	245.90	81.5	0.17 (38)
7	290.82	67.83	23.3	0.05 (20)
8	156.24	105.75	67.7	0.05 (19)
9	428.60	210.64	49.1	0.06 (33)
10	71.22	51.78	72.7	0.04 (16)
11	63.06	53.50	84.8	0.08 (20)
12	55.07	38.99	70.8	0.05 (20)
13	30.36	27.81	91.6	0.11 (20)
14	46.87	40.16	85.7	0.05 (20)
15	31.27	20.22	64.7	0.08 (20)
16	25.16	19.29	76.7	0.09 (20)
17	39.75	22.02	55.4	0.06 (20)
18	31.33	12.29	39.2	0.05 (20)
mean value			66.4	0.08

*) Number in () indicates the number of samples.



The coarsest image — computed crack pattern in 5 cm meshes

computed items
Total length of crack : 210.64 cm
Density of crack : 842.56 cm/m^2
Mean of crack width : 0.29 mm

Fig. 12. The coarsest image examined and its outcome (sample No. 9)

5. DISCUSSION

In the present examination 34 % of cracks are undetected. It is realized that most of undetected cracks are little contrast to the concrete due to a certain stains around them. The line-edge filter should be more sensitive in such a condition consequently. In order to make the filter sensitive, thresholding in edge detecting algorithm needs to be improved. In particular a method of calculating threshold value should be changed suitably according to a condition around the crack.

The measurement of crack width has been accomplished with accuracy of the mean of RMS error 0.08 mm, which is attained the goal of this study intended. In order to achieve more precise measurement of crack width, it is needed that a resolution of the original image should be more fine.

6.CONCLUSION

To assess the deterioration of concrete structures, an algorithm employed in a prototype of crack measurement system based on hierarchical image processing technique has been examined with 18 samples of concrete crack images. The algorithm can be executed to detect and measure the cracks ranging from 0.1 to 3.0 mm in width, in which a series of images are generated and structured hierarchically from fine to coarser, and a single spatial filter is used for crack detection.

As a result, 66 % of existing cracks on the samples have been detected and measurement of crack width has been performed with an accuracy of 0.08 mm RMS. It is clear that the edge detecting algorithm should be improved to prevent from misdetection of cracks which are little contrast to concrete due to a certain stains. The condition around cracks, however, are changed so much in places that no useful algorithm can be prepared practically to apply to detecting every crack influenced by every stain.

It is concluded that the algorithm examined in this study is useful to the crack measurement system, although a improvement of algorithm should be necessary to eliminate such misdetection.

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