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Mensuration of Concrete Cracks Using Digitized Close-Range Photographs

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ABSTRACT: The elements of concrete structures suffering from chemical reactions tend to be an expansion phenomenon, which leads to cracks. The concrete structures of inferior quality caused by cracks have much influence on the structures' durability and strength. The non-contact measurement is employed because of the physical limitations in manual measurements. This paper deals with semi-automatic crack feature extraction from digital close-range images to infer the relationship between concrete expansion and crack width. Only few manual seed points are required on crotches of crack features. Then, the shape and position may be illustrated with automatic feature extraction in two-dimensional image space. In the process of crack tracing, a Gaussian filter is applied in advance to smooth the noise along crack profiles to improve the reliability and precision. Subsequently, the edges of cracks are determined by computing the gradient of the crack profiles. The edges of cracks detected by the proposed method will be compared with the one digitized by manual operations.

1. INTRODUCTION

In civil engineering, concrete structures of good quality should be durable. In reality, effects of inferior environmental conditions decrease the endurance. AAR (Alkali-Aggregrate Reaction) found by Stanton (Dolar-Mantuani, 1983) produces cracks on concrete structures because of its chemical reactions. The cracks due to expansion pressure of AAR on concrete structures are adopted by contact mensuration in a traditional method. According to the "Crack-Scale", the traditional mensuration is operated by human to determine and locate the width and the position of cracks. The sample lines with scaled width are taken to match the width along the track of cracks. However, this kind of time-consuming operation does not result consistently. Thus a non-contact measurement is proposed to cope with the physical limitations in manual operations. Because fully automatic methods are still far to reach, semi-automatic methods with human operator are used to increase the precision of identifying of crack width and location. These semi-automatic methods are associated with a minimum human interpretation. Only few human operations are involved and the crack features can be extracted precisely. We input few seed points as rough tracks on crotches of crack features, then all crack tracks are located first and subsequently the crack edges are determined depending on the located tracks. In the process of crack tracing, a Gaussian filter (Roberts & Mullis, 1987) is applied in advance to smooth the noise along crack profiles to improve the reliability and precision. The edges of cracks are determined by computing the gradient of the crack profiles. We develop an interactive program to handshake with the operator to make this whole operation friendlier. Furthermore, if time series photographs are taken, we can infer the relationship between concrete expansion and crack width.

1.1 Experimental procedures and methods

When AAR occurs, it has been 6~12 years passed in natural environment. In order to speed up the reaction time, we use high alkali-contained test concrete object and put it in high temperature and high wet atmosphere environmental conditions to make cracks happen quickly. We adopt "Potential Alkali Reactivity of Aggregates (Chemical Method)" (ASTM C 1260-94) to simulate the situation and take the concrete crack images on schedule. Our proposed scheme is shown in figure 1.

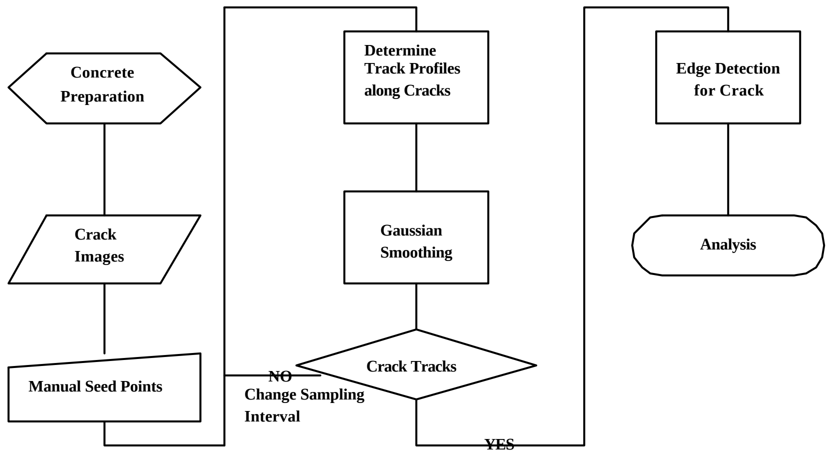

Figure 1. Scheme Procedure

2. IMAGE GEOMETRY ANALYSIS

A non-metric camera i.e., Rlleifiex 6008, is used in this investigation. The camera calibration must be carried out in advance.

2.1 Camera calibration

The measure objects in our research are time-series concrete plates. Because the measure objects' surfaces are flat enough, they may be regarded as two-dimensional (2-D) plate. Due to the consideration of test objects, the calibration field is also simplified to two-dimensional. In the calibration, we use 2-D Projective Transformation (Wolf & Dewitt, 2000). Lens distortion parameters including radial and tangential parts (Kraus, 1993) are also considered in the transformation to compensate the systematic errors.

2.2 Tilt displacement modification

Target objects regarded as 2-D plate is shown in Figure 1. Equation 1 formulates the 2-D Projective Transformation (Wolf & Dewitt, 2000).

$$x = \frac{a_1 X + b_1 Y + c_1}{a_3 X + b_3 Y + 1} \qquad \text{eq. (1)}$$
$$y = \frac{a_2 X + b_2 Y + c_2}{a_3 X + b_3 Y + 1}$$

where x and y are image space coordinates and X and Y are object space coordinates. Object space distances are measured and referenced to the first stage image. The picture is scanned as 2500 dpi digitized image, thus one pixel is represent for 0.0079 mm in object space. After the determination of the parameters for the mapping function, we are able to do resampling on the original image and produce the modified image.

3. CRACK DECTECTION

By visual inspection, we assure that cracks show the properties that radiometric reaction of cracks is darker than its neighborhoods. Starting from this, we make the following assumptions in our method when cracks are to be traced.

1. The smallest grey level across the crack profiles is regarded as the initial position of the crack profile.
2. The profiles' widths of cracks are located in a certain range.
3. Cracks are continuous but non-linear for crack tracing from given seeds.

Our proposed method has three components. Those are "Prediction of a Crack Position", "Noise Removal" and "Conditions of Stop Tracing".

1. Prediction of a Crack Position

The manual seed points are put in crotches of cracks point to point. The end point will be taken as an initial point in the next detection process. The tracing process starts with the first and the second seed point. There is one reference line connected by these two points. An sampling interval is chosen along the reference line and the first smallest grey level point is determined and shown as P1 in Figure 2. A Gaussian filter (Roberts & Mullis, 1987) is applied to smooth the grey level along the line vertical to the reference. A new reference line is formed by the first seed point and P1. In the same way, a sampling interval along the new reference line detects P2 shown in Figure 3. Iteratively, the former point predicts the next point until the end condition is met.

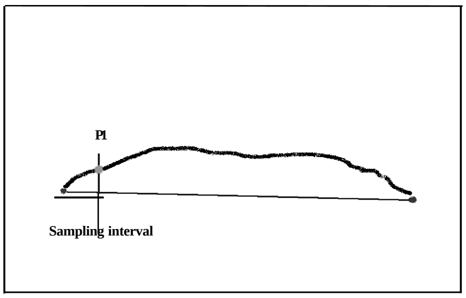

Figure 2. Crack Track P1

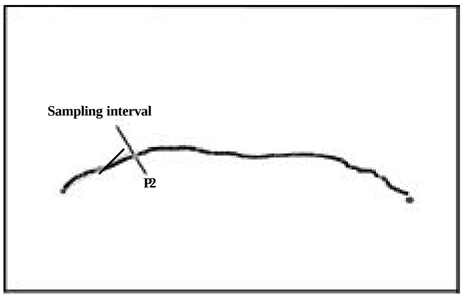

Figure 3. Crack Track P2

2. Noise Removal

Positions with grey level data of cracks' profiles provide one-dimensional information. We use Gaussian function to smooth the effects of noises. The Gaussian function is expressed as

$$G(x) = \frac{1}{\sqrt{2\pi}\,\sigma} e^{\frac{-x^2}{2\sigma^2}} \qquad \text{eq. (2)}$$

where σ is used for determine the one-dimensional Gaussian mask window size and convolution is processed to deal with data smoothing.

3. **Conditions of Stop Tracing**

There are two situations for a crack detection process to stop its operation:

(i) The distance between the track point and the last seed point is smaller than a sampling interval.

(ii) The number of detected track points is larger than three times of the distance between two seed points.

If the condition of stop tracing is (ii), it must be wrong during the process. At this time, we need to change the sampling interval. If the procedure stops at (ii) three times, it means that the input initial and the next seed point are out of range or the seed points are not along cracks at all. We should add a manual seed point between those two points.

3.1 Edge detection of cracks

It is recognized that the variation of grey levels in the direction along edges changes little and the variation is significant in the direction perpendicular to edges. The sudden variation in grey level will produce a peak or a trough in its first differential space. Therefore, we use the differential operator for edge detection. The peak or the trough leads to the local-maximum or local-minimum value which is the crack edge. A second order polynomial function is used for sub-pixel interpolation. Processing the image grey level, one-dimensional data are acquired and the sampling range can set to be 4~5 times of the crack width, as shown in Figure 4. The local extreme values of image gradient and edges of cracks may be located automatically.

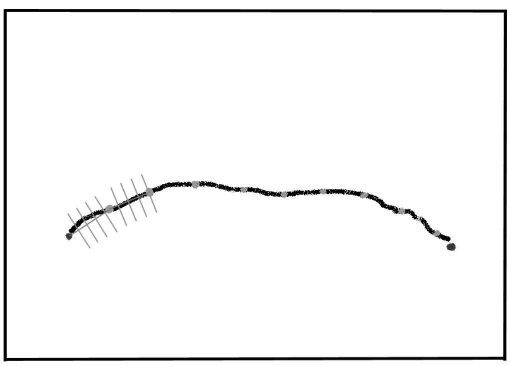

Figure 4. Edge Detection of Cracks

4. EXPERIMENT RESULTS WITH CRACK IMAGES

The experiment results are shown in Figure 5 and Figure 6. The computed data produced by the algorithm of method are compared with the results using traditional measure method using “Crack-Scale”. The crack widths are not constant. Therefore, we select 5 different types of cracks each was measured by 7 operators. The comparisons for the traditional method and the proposed scheme are shown in Table 1.

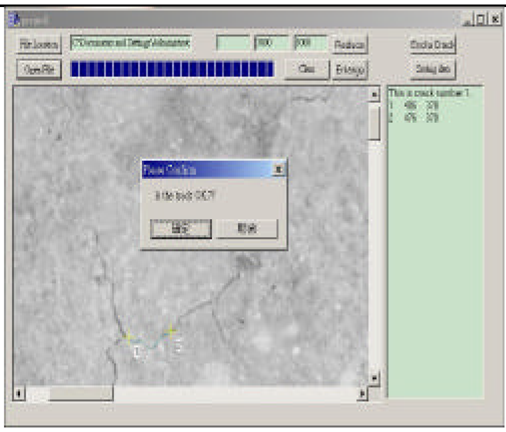

Figure 5. Tracing for Cracks

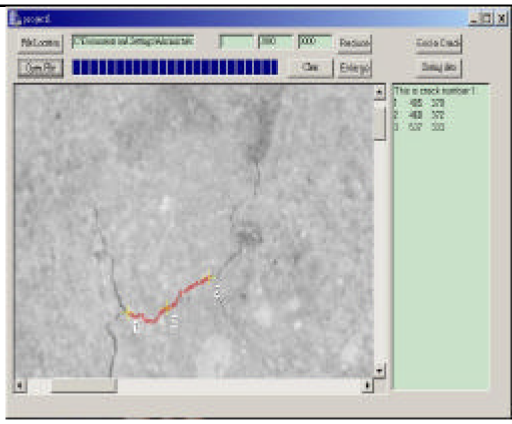

Figure 6. Edge Detection of Cracks

Table 1. The Test results

	Example 1	Example 2	Example 3	Example 4	Example 5
Crack-Scale mean (A)	0.371	0.193	0.113	0.264	0.593
RMSE	0.0452	0.0416	0.0328	0.0639	0.0728
Data from Algorithm (B)	0.395	0.237	0.152	0.261	0.632
|A-B|	0.024	0.044	0.039	0.003	0.039

The identifying error is not avoidable in a traditional measure way. The consistency is hard to maintain in a certain range even testing the same crack. The difference between our algorithm and traditional method is below 0.05mm, which is with the same order of the RMSE by manual operations.

4.1 Relationship Between Crack Width and Concrete Expansion

The increase of the expansion makes the widths of cracks larger and larger. The relationship between crack widths and the concrete expansion are observed in laboratory and measured continually. It is found that when the expansion is reach 0.4~0.6%, the cracks start to appear on concrete objects. Figure 8 shows the relationship between the expansion and time stage of concrete objects.

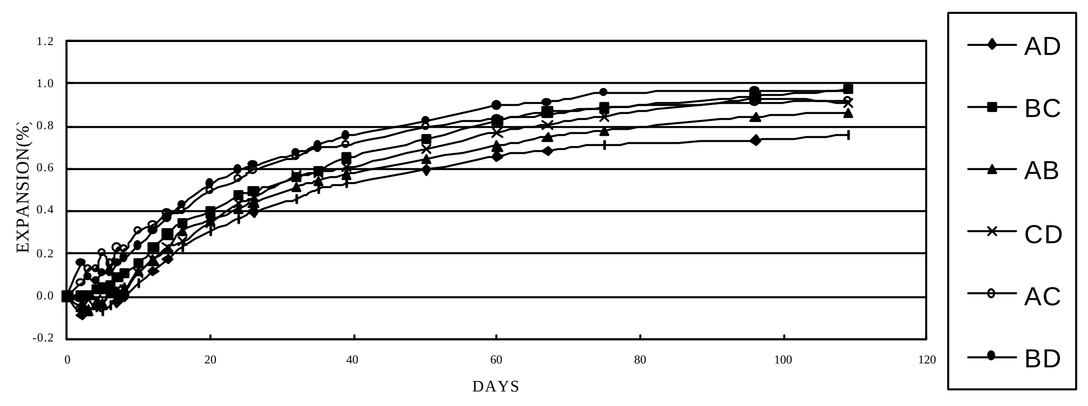

Figure 8 The Relationship Between Expansion and Concrete Objects Time Stage

We measure the expansion value from the set screws and compared with the widths of cracks computed by the algorithm (7 time series image data, 26, 35, 50, 60, 67, 75, 96 days). We gain the relationship between the sum of cracks' widths per unit length and the expansion. We use the Least Squares regression to fit the function between crack's width and expansion. It's shown as eq. (3), the correlation coefficient is 0.705.

$$Y=1.4218X+0.4116 \qquad \text{eq. (3)}$$

where Y is expansion value (%), X* is the sum of cracks' widths per unit length (%),

5. CONCLUSIONS

This paper has developed a scheme to measure and carry out the edge detection for concrete cracks. Following conclusions are made:

1. The widths of cracks change from place to place. Thus we suggest a non-contact measure method to improve the traditional time-consuming mensuration.
2. Kinds of reasons cause the unobvious or discrete situation of cracks. The semi-automatic procedure might be a good solution. It forces tracks of cracks in a small range of seed points and may not lead to wrong tracks caused by noises. High precision is reached from semi-automatic process. It is easy to implement for further investigations.
3. The edge detection module of cracks has been developed. It can be applied in other kinds of concrete structures' cracks caused by any reasons, not only by AAR.

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