An Automated Measuring System of Cracks in Concrete Which Uses Image Processing Techniques and Artificial Intelligence Theory

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Abstract

The measurement of cracks in concrete surfaces is a procedure undertaken to diagnose deterioration and the prospective life of concrete structures. The authors have been studying a measuring system which uses computer image processing to reduce labor requirements and increase reliability. In this study crack data were first defined and then a data processing method which combines general-purpose image processing techniques with artificial intelligence theory was developed in order to extract crack patterns from concrete surface data and measure crack length, direction and width. It was found that crack measurements can be processed automatically or with the aid of simple manual operations.

I. Introduction

This paper describes a system manufactured for automatic crack measuring which consists of small , light-weight image gathering apparatus and a general-purpose image processing apparatus based on image processing algorithms which were developed previously. A test application of the system is also described.

The manufactured system under discussion is expected to be used together with a robot traveling on a wall, as shown in Fig. 1. It will enable efficient work and information processing at the site. Therefore, multiple equipment combinations have been prepared to satisfy differing requirements for accuracy and measurement scope depending on the situation. Moreover, the software enables the extraction of crack patterns and the measurement of length, width and direction of cracks without specialized knowledge of image processing on the part of its operators.

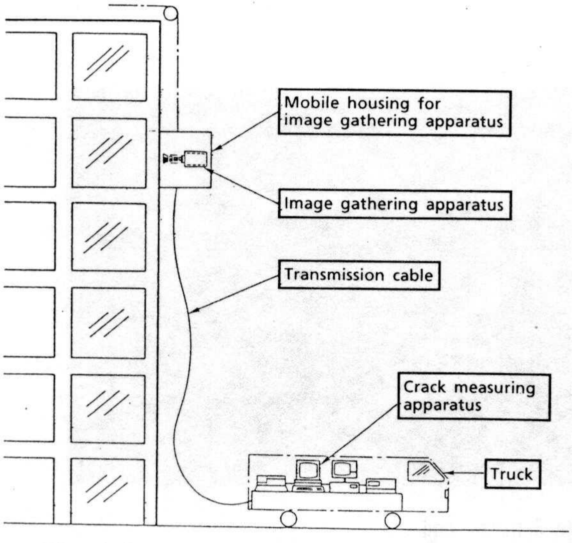


Fig. 1 Components of Concrete Crack Measuring Work

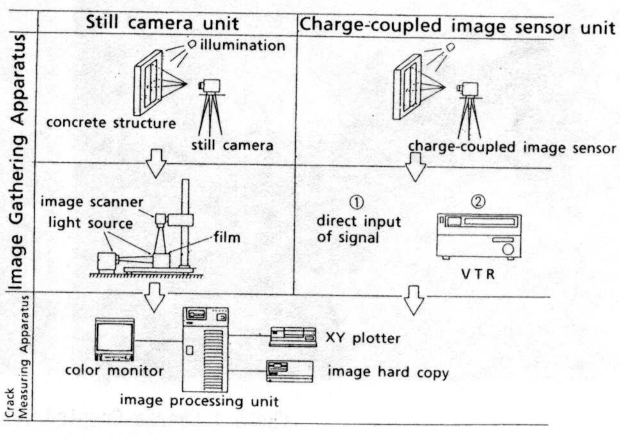


Fig. 2 Configuration of Measuring System

II. Overview of Measuring System

As shown in Fig. 2, the measuring system is composed of an image gathering apparatus and a crack measuring apparatus. An image gathering apparatus which uses a charge-coupled image sensor and a crack measuring apparatus with an image scanner are shown in Photo 1.

1. Image Gathering Apparatus

An image gathering apparatus is used to capture and collect images of cracks in concrete surfaces. For this system we adopted both still camera and charge-coupled image sensor units as means of providing data for the crack measuring apparatus (image processing unit).

(1) Still camera unit

An image captured on film by a 6 cm x 6 cm still camera is input into an image processing unit via an image scanner. This method allows for high resolution but has the disadvantage of consuming much time in the processes of photographing, developing and data inputting.

(2) Charge-coupled image sensor unit

There are two methods for utilizing this unit. One method is to input an image captured by a charge-coupled image sensor directly into the image processing unit, and the other is to first store an image obtained on videotape and later transfer it from a VTR into the processing unit.

The direct input method is inferior in resolution to the method which employs a still camera, but has the advantage of making it possible to input an image into the processing unit immediately. The VTR image storage method permits great flexibility in measuring work because it is not necessary to locate the image processing unit at the measuring site, though resolution is lower than with the direct input method.

2. Crack Measuring Apparatus

The crack measuring apparatus consists of a minicomputer-based general-purpose image processing unit and its peripheral equipment. The apparatus extracts crack patterns from concrete surface image data provided by the image gathering apparatus and measures their length, direction and width.

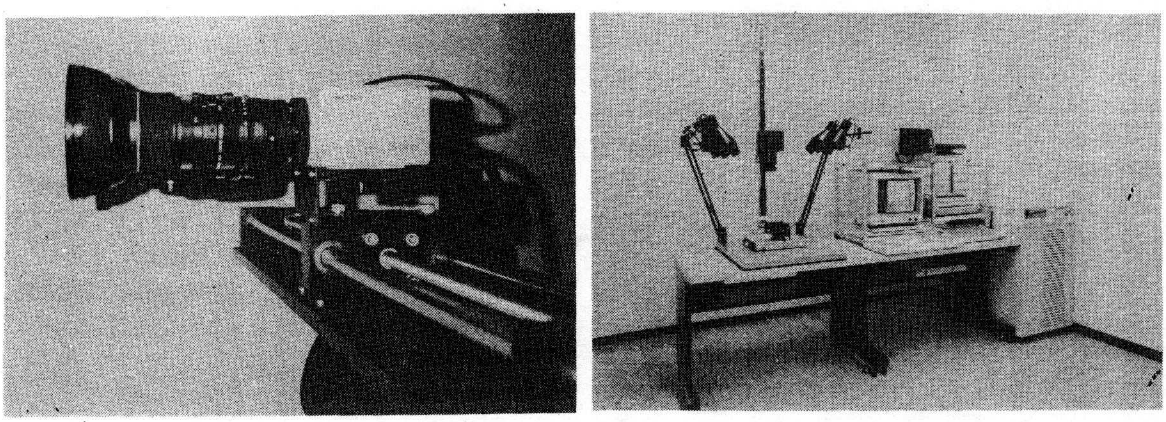


Photo 1 Charge-Coupled Image Sensor and
Crack Measuring Apparatus with Image Scanner

III. Development Concepts

1. Problems with Image Data

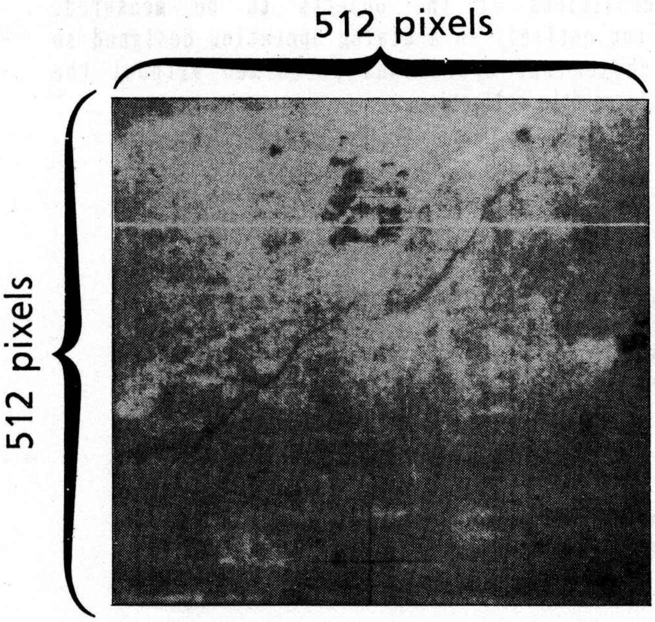
The problems in measuring cracks using image data processing can be summarized by the following two statements:

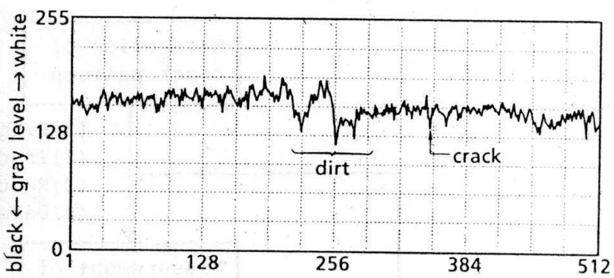
(i) The resolution of image gathering and image processing equipment is limited, and if the measurement area observed is too large, the measurement of fine cracks is impossible.

(ii) If the concrete surface is soiled, it is difficult to distinguish even a relatively wide crack from the dirt.

To explain (i) in detail, the resolution of both image gathering equipment and image processing equipment, except highly specialized items such as those for remote sensing, is generally about 500 pixels x 500 pixels = 250,000 pixels, as shown in the left side of Fig. 3. When the area of the input image is 50 cm x 50 cm, for example, the size of one picture element, the smallest unit, is 1 mm x 1 mm and cannot be decreased further.

As an example of (ii) above, the gray level of a line across a particular concrete surface is shown in the right side of Fig. 3. This is the gray level distribution at the white line in the image on the left. We can clearly recognize the crack with the naked eye in the original image, but it is impossible to identify a crack numerically only by the fact that a crack shows up as "black," that is, its gray level is low.





Gray level at the white line on the left

Fig. 3 Concrete Surface Image and Gray Level Data

2. Definition of Crack Data and Processing Goals

To solve the problems stated above, various kinds of existing image processing algorithms were effectively combined, with data peculiarities taken into account. It is required to establish a logical process in which the conditions for recognizing cracks as cracks, that is, an artificial intelligence algorithm, is incorporated. However, the construction of the necessary knowledge base cannot be achieved in a short period of time, as this requires accumulated know-how and much data.

Thus, the concept which governs our study is that first, image data which represent cracks are defined and then, on the basis of the definition, a measuring system (reviewed below) is constructed as required, as data are accumulated.

Crack data have been defined as follows:

(i) A crack appears relatively blacker than other areas. However, the idea "blacker" here indicates the color of a crack relative to a limited adjacent area. As for the level of blackness, "blackness" is not defined by an absolute difference in gray level (for instance, 10 units lower), but means blacker than nearby image noise.

(ii) Unlike a crater which is dark but definitely closed, a crack is continuous and of elongated shape.

(iii) Cracks are rather of natural occurrence and do not form straight lines.

IV. Data Processing

1. Processing Procedure and Items to Be Processed

The basic procedure for measuring cracks is shown in Fig. 4.

Broadly categorized, items for processing are the extraction of the crack pattern and the measurement of crack length, direction and width. First of all, a crack pattern is extracted from image data obtained from a concrete surface, and then the length, direction and width of the pattern are measured. The original image and all the results obtained by processing are stored on disk.

As shown in Fig. 4, there are two to four choices for each of the items to be processed in this system. Detailed explanations of these are provided below. Choices for other than automatic processing have been prepared for the occasions where changes in processing patterns are required in accordance with the conditions of the objects to be measured. Even on such occasions, the system is still run entirely in a dialog operation designed so that the optimum processing method may be chosen and operations performed without the operators attending to the details of processing and image data collection.

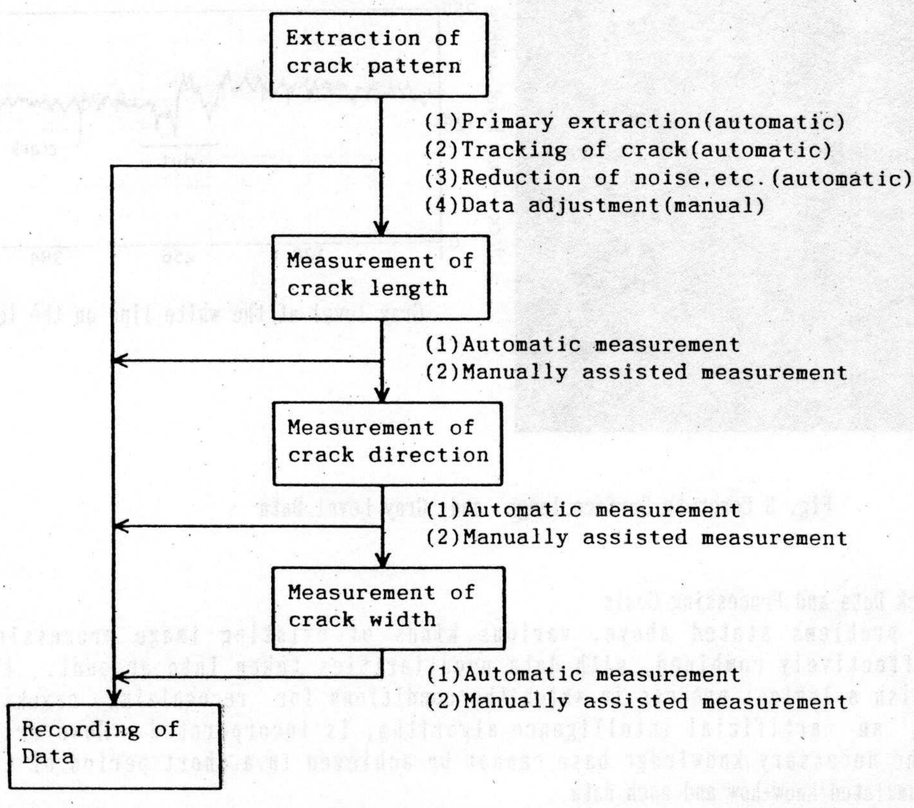


Fig. 4 Generalized Processing Flow Chart

2. Extracting Crack Patterns

The extraction of crack patterns is a precondition for the measurement of crack length, direction and width, and is the most important process in this system. As shown in Fig. 5, there are four operations involved in this process.

(1) Primary extraction

Among common image processing algorithms, "edge detection" is considered to be most similar to the task at hand and these algorithms are plentiful.

All of them are methods which extract places where the gray level changes. These methods enable cracks to be extracted with some clarity, but all have the disadvantage of extracting significant amounts of noise along with the crack pattern.

In contrast to them, the extraction method we have worked out isolates a crack using the differences in gray levels in an image which is formed after passing the raw data through two different low-pass filters. In terms of theory, crack patterns are isolated by capitalizing on the fact that gray levels vary more between cracks and surrounding areas and cracks appear blacker than the adjacent areas.

This method is capable of extracting fine cracks, and a crack of 0.5 pixels in width was extracted in an experiment using this method. An example of original data is shown in Fig.5-(a), and the result of this processing method is shown in Fig. 5-(b).

The crack is reproduced better and with less noise in comparison with other methods , though there are some places where the crack image becomes discontinuous.

(2) Crack tracking

This is the operation which joins the discontinuous parts which result from the primary extraction operation.

The logic of automatic crack tracking is that the data provided by the primary extraction operation are assumed to represent a crack, and on the basis of this assumption nearby areas where the gray level is low are sought and connected. The conditions for making these connections are that each of the locations must be the lowest in gray level among the adjacent picture elements and that the levels must be lower than the dispersion (in terms of standard deviation) in the gray level of adjacent areas, excluding that of the crack itself.

An example of the result of this operation is shown in Fig. 5-(c).

(3) Noise reduction

In the above two operations, some linear or circular data other than that of cracks are also extracted. Therefore, operations are performed to isolate crack data from other data containing a mass of undifferentiated data on the basis of size and shape, and to extract only the crack data.

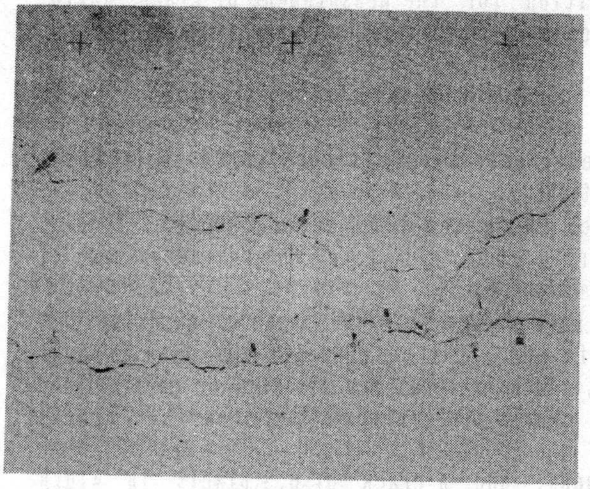
In Fig. 5-(d), an image which has passed through noise reduction treatment is shown. Comparing it with Fig. 5-(c), we can see that small enclosed area data and non-crack linear data have been eliminated.

(4) Data adjustment

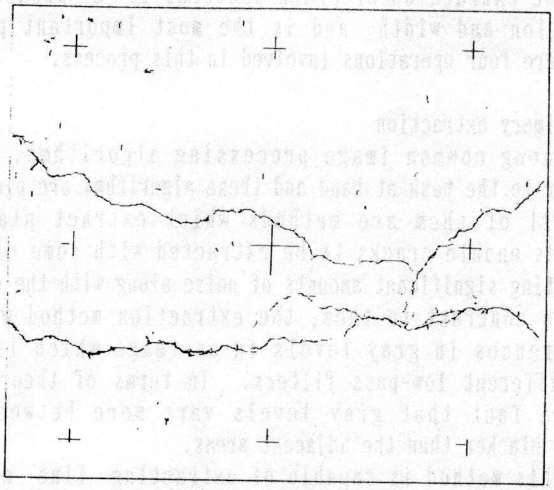
There are cases in which all image noise cannot be eliminated and the entirety of a real crack cannot be extracted.

Anticipating such cases, the system is equipped with the capability of eliminating noise data and correcting data by means of manual operations.

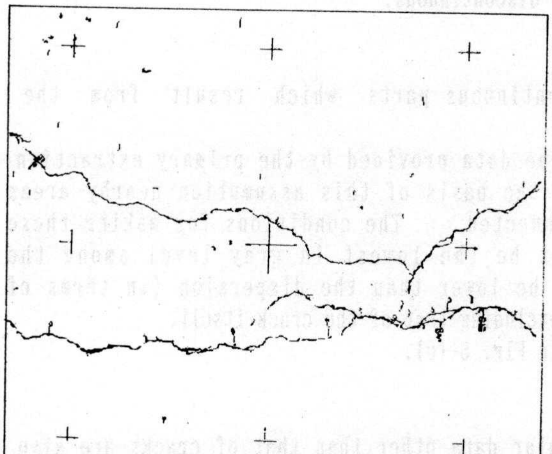
This operation is very simple. An operator employs a digitizer to enclose an area which is deemed to consist of noise and to erase the inside of the resulting figure, and, likewise, to connect crack segments.



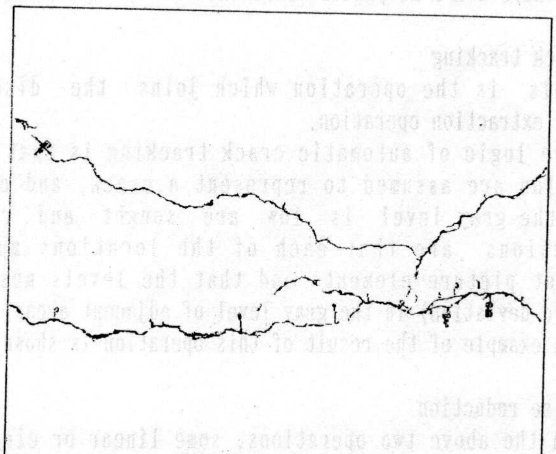
(a) Original Data



(b) Primary Extraction



(c) Crack Tracking



(d) Noise Reduction

Fig. 5 Results of Extracting Crack Patterns

2. Measuring Crack Length

(1) Automatic measurement

An image produced by the processing described above shows the crack in black (gray level: 0) and the surrounding area in white (gray level: 255).

The crack data form a long line of varying width, and if picture elements are continuously arranged along the crack line with the center of the line passing through each of the elements, the crack length can be calculated from the number of these picture elements.

In the measuring process, crack data are examined both vertically and horizontally, then the center of the crack line is fixed, and finally the length of the crack is computed from the number of the picture elements obtained.

An example of automatic measurement processing is shown in Fig. 6. In Fig. 6 (a), an image in which the crack is represented in black and the surrounding area in white is shown. Fig. 6 (b) shows an example of vertical scanning and Fig. 6 (c) illustrates horizontal scanning. The combined result of vertical and horizontal scanning is shown in Fig. 6 (d) and the center points obtained, whether by horizontal or vertical scanning, are each counted as one point on the center line.

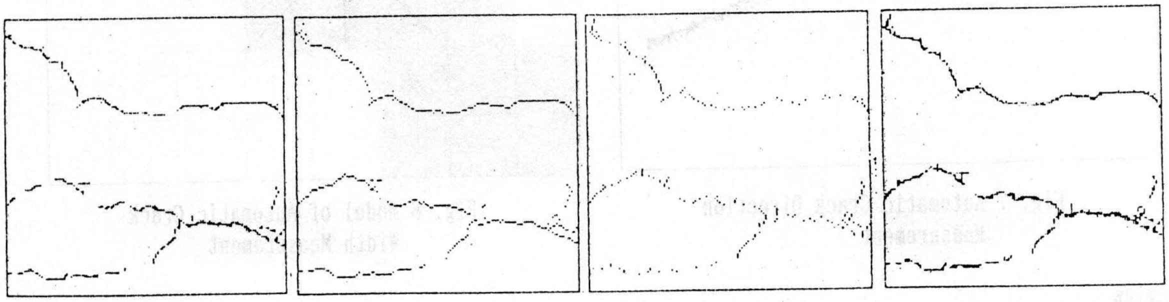
The precision of measurements thus obtained varies with the shape of the crack, and the length of a crack computed by this process is usually greater than what would be obtained by a person with a scale. This seems to occur because this process measures length by tracing the shape with micro-analytic fidelity using picture elements, while a person measures a crack rather linearly with a scale.

(2) Manually assisted measurement

As described above, there are cases in which the automatic extraction of crack data is impossible. This is particularly true of heavily soiled surfaces.

In such cases, the length of a crack can be measured with the aid of operator input.

The procedure is very simple. First, a few points are plotted along the crack with a digitizer, and then the overall length is calculated.



(a) target image (b) vertical scanning (c) horizontal scanning (d) results of scanning

Fig. 6 Automatic Crack Length Measurement

3. Measuring Crack Direction

(1) Automatic measurement

In automatic direction measurement, correlation analysis is performed to obtain a regression line for each group of data which are connected with each other in a crack image, and direction is computed from the inclination of the regression line. Fig. 7 shows an example.

(2) Manually assisted measurement

Manually assisted direction measurement is performed simultaneously with manually assisted length measurement (see 2-(2)). The direction of the line segment which was indicated by manual input at the time of length measurement is calculated to determine the direction of the crack.

4. Measuring Crack Width

(1) Automatic measurement

The principle of automatic width measurement can be described with reference to the model image shown in Fig. 8. When measuring crack width from point A, the number of picture elements arranged continuously along each of four directions, (vertical, horizontal, and two diagonal) is counted. In general, the smallest of the four totals is used to determine the width. In Fig. 8, the vertical count is adopted for calculating crack width.

(2) Manually assisted measurement

This method is applied to cracks which are difficult to extract because of soiled surfaces and to those which require exceptionally accurate measurement, such as for the investigation of aged concrete.

In this method, enlarged images of the areas at which width measurement is desired are usually used. Upon designation of the location to be measured, by a digitizer, a threshold value is automatically set on the basis of the noise level to effect automatic polarization within the limits of the area. The average width of the area blackened by this treatment is taken as the crack width.

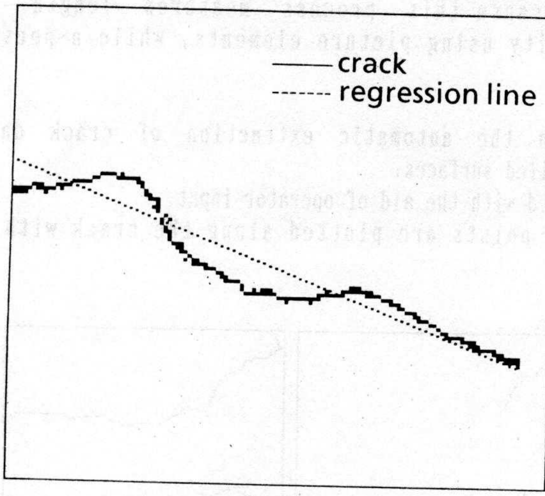


Fig. 7 Automatic Crack Direction Measurement

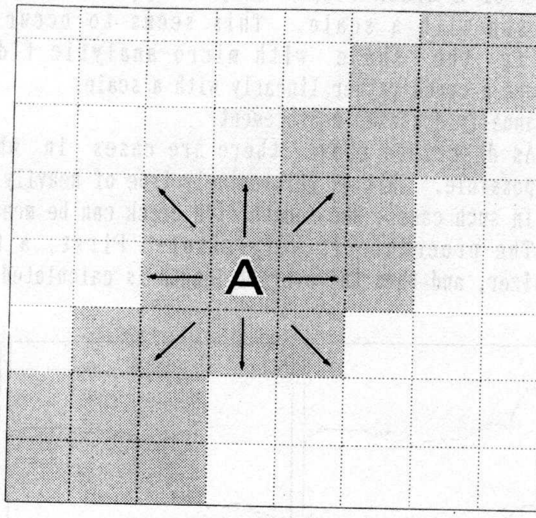


Fig. 8 Model of Automatic Crack Width Measurement

5. Review

If these automatic processes are combined, crack measurement can be performed automatically because the computer automatically determines the required parameters for processing on the basis of image data conditions.

In experiments, the automatic measurement of features on clean surfaces was achieved. As for cracks in soiled concrete surfaces, the extraction of their patterns, which is essential for automatic measurement, was done manually because of its difficulty, while automatic measurements of length, direction and width were successfully accomplished. The techniques of obtaining crack data from concrete surfaces, unlike conventional image processing jobs involving objects arranged in predictable patterns, involve extracting information from undifferentiated data, and thus much time will be required to complete a "perfectly automatic" system. Therefore, for the time being, a hybrid system which can be operated both automatically and manually, seems to be the best option.

V. Conclusion

This system features a crack extraction processing ability brought about by the combination of conventional image processing techniques and artificial intelligence theory. It automatically determines the relevant parameters in accordance with the conditions of an image. The system also realizes the automatic measurement of crack length, direction and width. The development of this measurement system for general use has been made possible by combining automatic and manual operations. Data required for diagnosing concrete structures can be provided by this system.

However, before the completion of a totally automatic crack measurement system, which is the goal, quite a few problems must be solved. There still remain some steps in data processing as well as in photographing which require manual operation, and there are problems in the automatic extraction of crack data from heavily soiled surfaces.