Efficient Algorithms for Automatic Detection of Cracks on a Concrete Bridge

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Abstract: In the bridge inspection, the information of cracks is important to maintain a bridge. Therefore, automatic crack detection is highly desirable for efficiency and objectivity of crack assessment. However, in general, it is very difficult to detect cracks automatically from noisy concrete surfaces. In this paper, we propose a machine vision system for automatic inspection of bridges. The proposed machine vision system can detect cracks in real time, and it has some utility functions for supervised manipulation. The performance of the proposed system has been evaluated with 100 noisy images. In terms of accuracy in detecting cracks, experimental results show that the proposed method is superior to the conventional methods for detecting cracks.

1. Introduction

The crack information can be used to decide how to maintain the damaged bridge. Since most existing bridge inspection systems require many operators to inspect the defects of bridges by human eyes, the inspectors must stand on the platform of a bridge inspection vehicle or on a temporarily erected scaffolding to examine the structure underside of the bridge. Besides, the safety of inspectors is not ensured from dangerous circumstances in the workplace and the results of inspection in terms of accuracy, effectiveness, and practicality can be degraded[1]. For these reasons, automatic crack detection is highly desirable for efficiency and objectivity of crack assessment[2].

Automatic crack detection from a concrete surface image is very effective for nondestructive testing. In practice, cracks on concrete surfaces are traced manually for diagnosis. In manual trace, cracks are evaluated by a human operator. Thus, the assessment of cracks, defects or failures, for diagnosis of concrete structures, is significantly affected by operator's experience, skill level and picture quality. Hence, it is difficult to assess the deterioration objectively. Some systems with automatic inspection can be applied only in some specific circumstances and have some limitations in inspecting various defect types. Therefore, it is necessary to develop an automatic robot inspection system integrating hardware and software technologies for worker's safety, effectiveness, accuracy as well as cost reduction.

In this paper, we propose a bridge inspection system using machine vision techniques. The goal of this system is to inspect the defects of bridges automatically and to provide various kind of useful information for maintaining bridges.

This paper is organized as follows: In section 2, we introduce the overview of the bridge inspection system. The methods for crack detection and tracing are explained in section 3. The post-processings of results are described in section 4. In section 5, experimental results are shown. Finally, we draw conclusions and discuss future work in section 6.

2. System Overview

The purpose of the bridge inspection system is to detect cracks of bridge surface automatically from image inputs. The crack information can be used to maintain the bridge and to decide an appropriate rehabilitation method to fix the bridge with cracks. This information is very important for managing the bridge.

The overall system consists of a special designed car, a guide rail and an inspection robot as shown in Figure 1. The machine vision system is located at the inspection robot [3].

This vision system is composed of a Charged Couple Device (CCD) camera, a Digital Video Recorder (DVR) board and a computer[4, 5]. In order to determine the specifications for the vision system, the weight, electric power, communication scheme and cable width should be considered. The environment under a real bridge is not constant, for example, the wind can cause the swing motion of guide rail. In this case, the rail is shaken and bent by the external environmental disturbances. In order to deal with these kinds of unknown disturbances, we attached to the driving motor and gyro sensor to maintain the horizontality. The CCD camera is remote controlled by RS-485. Therefore, the inspector uses the function of pan, tilt, zoom, and focus via PC. The inspector can control the pan and tilt to a desired angle, and change the magnification of camera zoom. When the magnification of camera zoom is changed, the camera is focused automatically. Related algorithms for processing the images captured from cameras have been designed and implemented.

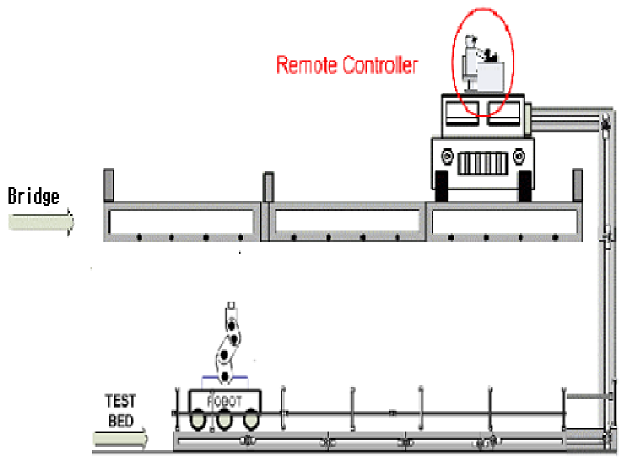


Figure 1. Overview of the Sytem for Bridge Inspection.

Figure 2. Result of Crack Detection.

3. Crack Detection and Tracing

Existing systems for crack detection simply display the detected cracks. However, for more effective bridge inspection, we also need some information about the crack assessment such as length or width of the cracks. In the crack detection, there are many problems such as irregularities in crack shape and size, various soiling and painted surfaces, and irregularly illuminated conditions. These may cause serious problems in automatic crack detection. In order to solve these problems, we propose the following method for automatic crack detection.

3. 1 Crack detection

Our method consists of two steps: crack detection and crack tracing. For the crack detection, we perform three steps of pre-processing and extract the candidate cracks.

Firstly, we subtract the smoothed image from the original image. The smoothed image is obtained by using a median filter [6]. The purpose of this process is to maintain a uniform brightness throughout the image and to effectively detect cracks in the shadows.

Secondly, we remove noises on the bridge surfaces using a filter for removing isolated points. Through this process, we can reduce the candidate cracks and the unnecessary search time.

Thirdly, we apply morphological operations such as dilation and thinning to guarantee the connection between crack segments, where the number of iterations is determined by the distribution of candidate cracks. After this process, we obtain the connected cracks from the original image. Figure 2 shows the result of crack detection.

3. 2 Crack tracing

For the crack tracing, we divide the image with detected cracks into several regions and select a seed point in each region. Each seed point which has the maximum probability of being a crack in the region is selected. From a seed point as a starting point, the cracks are traced bidirectionally. For each seed point, we examine the intensities of 8-neighbor pixels to determine the direction of next pixel with the minimum intensity.

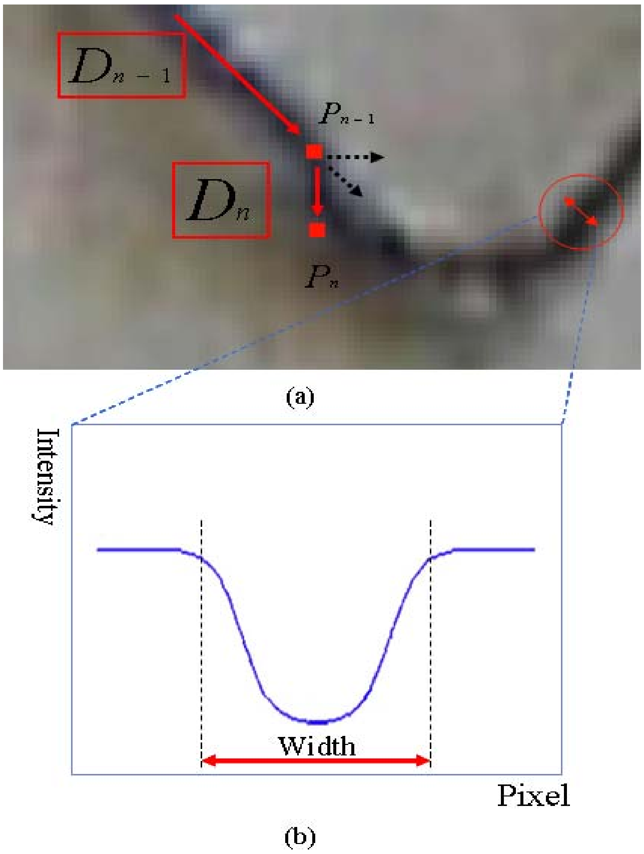


Figure 3. The Procedure of Crack Tracing.

Figure 3 (a) shows the procedure for crack tracing. We decide the next pixel that has the lowest intensity of 8-neighbor pixels by equation (1).

$$P_n = \min(\text{intensity of } P_i), \quad i = 1,2,\cdots,8 \qquad (1)$$

In this process, the progress direction is replaced by D_n that is from P_{n-1} to P_n. To avoid local minima, the range of direction is restricted.

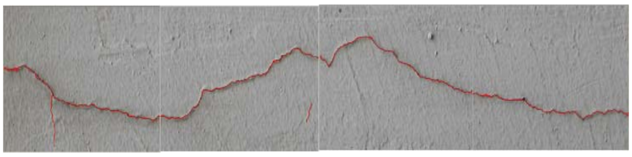
While tracing the crack, we measure the width and the length of the crack at the same time. Figure 3(b) shows the gray-level profile of an orthogonal line of the progress direction. Because the crack has lower intensity than the background, we can define the distance between two inflection points of second-order derivative as the width of the crack.

Since the width of the crack is calculated in pixels, the final measurement is represented by the multiplication of the number of pixels and the pixel resolution. In order to improve the measurement accuracy, the width of the crack is calculated considering the gradient between the crack and the background.

After the bidirectional tracing is finished, both of the cracks are merged.

4. Post-processing of the results

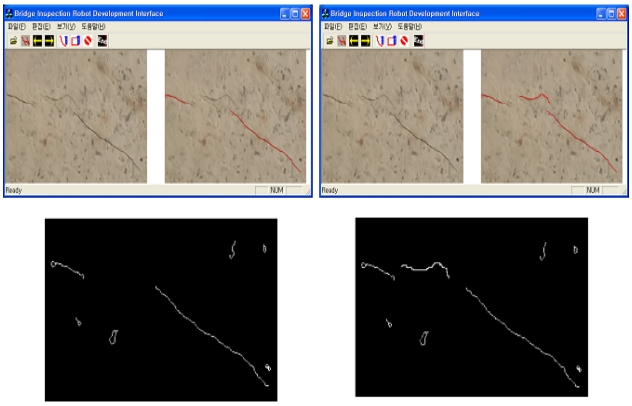
4. 1 Making the results into database



(a)

(b)

Figure 4. Result of Stitching Images and dxf File.



(a) (b)

Figure 5. Result of user's manipulation

The results of crack detection are stored into database, in order to keep all the information necessary to maintain the bridge. The results of inspection are converted into an interchangeable file so that the results can be used in the Bridge Management System (BMS). The interchangeable file is stored in dxf format that is compatible with CAD files. The structure of the dxf file format is carefully investigated to parse the syntax of each component, in order to write the information of detected cracks into a dxf file. Figure 4(b) shows the result of created dxf file.

Moreover, we should also be able to display the whole image of the results so that the defects in a wide area beneath the bridge can be examined at a glance. The detected cracks and the result of image stitching are shown in Figure 4(a).

4. 2 Supervised manipulation

For the crack tracin It is very difficult to detect cracks automatically from noisy images of concrete surface. Therefore, some utility functions to support user's manipulation are necessary for the accuracy of inspection. The proposed machine vision system can detect cracks in real time, and it also has some utility functions for supervised manipulation.

These functions include the capability for adding lines and polygons. If an inspector wants to add some missed defects such as cracks, water leakages and scars in the result, he can draw the shape of defects using polylines and polygons.

5. Experiments

We evaluate the proposed system with noisy image from concrete structures. In terms of the performance, we compare the proposed method with three approaches: Sobel, Canny and Fujita's method [6].

In the experiment, we use 100 noisy images with irregular illuminations, various shading conditions and various blemishes on concrete surfaces. The resolution of digitized image is 640 × 480 pixels, and one pixel corresponds to 0.15mm. Our targets of cracks to be detected are over 0.2mm in width.

Figure 6 shows the results of crack detection. (a) and (b) in Figure 5 are the original image and the result of manual tracing. (c) is the result of the proposed method. (d), (e) and (f) are the results of Sobel, Canny and Fujita's method. From the results, it is shown that the cracks are successfully detected by the proposed method.

Table 1 shows the performance comparison in terms of the accuracy for four methods for detecting cracks. From the table, it is shown that the accuracy of the proposed method is improved by 2% - 7%, compared with other methods.

6. Conclusions

We have introduced a system for automatic inspection of bridges using machine vision technique. This system can detect cracks of bridges and obtain useful information of each crack automatically. Besides, this information can be stored in database in order to be utilized in the Bridge Management System.

The experimental results show that the result of our proposed method is better than other methods for crack detection.

The proposed inspection system will contribute to expand the span of bridge life and reduce the cost of inspection. The developed technologies can also be applied to various types of industries, and many commercial spin-offs can be expected.

Acknowledgement

This work was supported by BIRDI, MOCT (Ministry of Construction and Transportation) & KICTTEP, Rep. of Korea.

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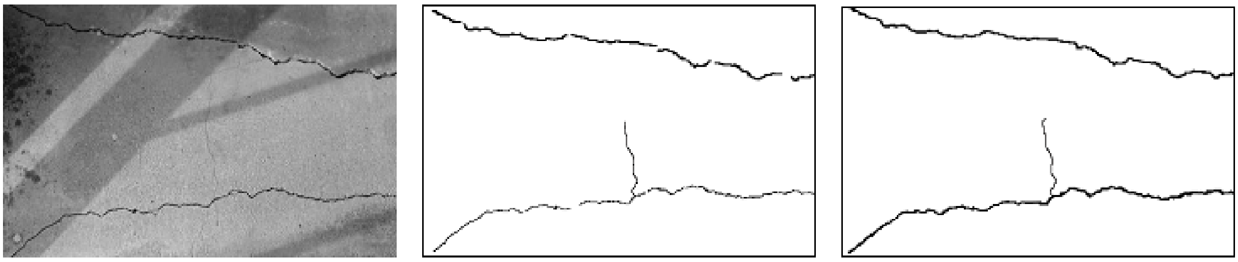
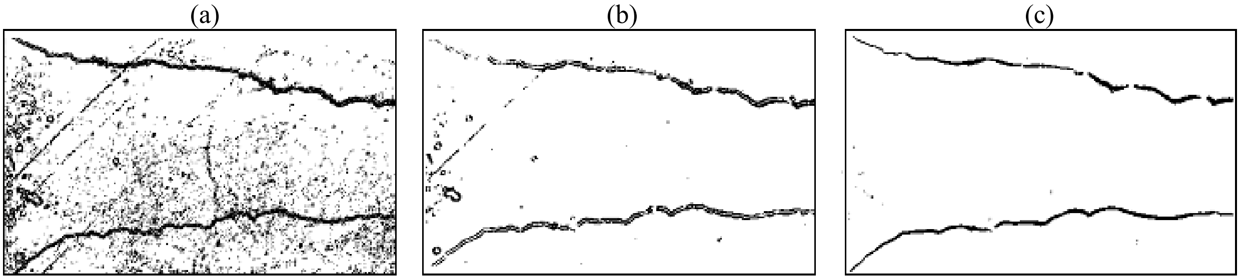


(a) (b) (c)



(d) (e) (f)

Figure 6. Results of crack detection
(a) original image (b) manual tracing (c) proposed method (d) Sobel (e) Canny (f) Fujita's method

Table 1. Performance comparison of four methods

Methods	Proposed method	Sobel	Canny	Fujita's method
Accuracy	94.1%	87.3%	89.3%	92.2%

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