Development of an Inspection System for Cracks on the Lining of Concrete Tunnels

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ABSTRACT: Over the last several decades, many concrete tunnels have been constructed on roads, highways, and railways. For safety in concrete tunnels, periodic inspections have been conducted using nondestructive testing technologies and techniques. However, non-destructive test cannot replace the visual inspection due to their slow and complicated procedures. For this reason, they have been limited to precision inspections. The visual means also need time and there may be subjective in the measured crack data. Here, this study proposes inspection system for fast measuring cracks in tunnel lining and providing objective crack data for safety assessment. The system consists of both image data acquisition system and analysis system. The acquisition system takes images with CCD line-scan cameras. The analysis system extracts crack information from the acquired images using image processing. Measured crack information is crack thickness, length, and orientation. To improve the accuracy of crack recognition, the geometric properties and patterns of cracks in concrete structure should be applied to image processing. This proposed system was verified through a series of experiments in both laboratory and field environment - subway tunnel.

KEYWORDS: Crack, Inspection System, Tunnel Lining, Tunnel Safety.

1. INTRODUCTION

A considerable amount of tunneling activity has been going on in the last few decades. Concerns have been directed towards the safety of tunnels. For safety in concrete tunnels, periodic inspections have been conducted using nondestructive testing technologies and techniques. However, non-destructive test cannot replace the visual inspection due to their slow and complicated procedures. For this reason, they have been limited to precision inspections [1]. In the first stage of inspection, cracks in concrete structure are usually measured by inspectors who observe cracks with their naked eyes and record them while walking along the structure. As such, the main disadvantage of visual inspection is the impossibility of making a fast and sure survey. Therefore, varied studies and developments of automatic crack inspections using image processing have been made in areas including roads, bridges, fatigues, and sewer-pipes [2]-[5].
The Japanese corporation Komatsu Engineering has developed and commercialized an image acquisition system that can acquire the images of road and tunnel lining by using a laser-scanning device [6]. The Railway Technical Research Institute in Japan developed an image acquisition system of railway tunnel lining by using line CCD cameras. This system consists of five sets of line sensor camera heads, image record devices, light fittings, expansion-packing device, and tachometer-generator to acquire image of the whole inner wall of the railway tunnel [7]. Those systems are useful to collect data of crack, leakage, efflor, scale, and spall but only by using the image acquisition, and not the automatic defect detection. The algorithm for crack detection and measurement is going to be studied for fully automatic inspection system. Hence it is necessary to develop the automatic crack detection and measurement algorithm for the fast inspection and the objective crack data.
To inspect the surface of structure, it is widely used to image the surface by using camera or laser. Contrary to the efficiency enough to be used in widely varied fields, the laser-scanning device is too costly and it has a heat problem in maintaining the system. The camera-scanning device is more cost-effective than the laser device but it still has a illumination problem. From the common sense in engineering, cost is one of the most important criteria so it is required to study the image data acquisition of the surface acquired

by cameras to ensure a high level of safety of the concrete structure. Therefore the system proposed in this paper acquires images of the concrete tunnel lining with line CCD camera, Then detects cracks and picks out of the necessary items - crack length, width, and orientation. To verify the proposed system, we performed experiments inside the building, road tunnel, and subway tunnel.

2. THE SUBJECT OF INSPECTION

An itemized list of contents of the inspection for tunnel inner-wall surface contains cracks, leakage, efflor, scale, and spall etc. Especially, the survey on cracks is crucial for its role that evaluates the tunnel status and that determines the contents, methods, and procedures of the precision inspection [8].
The cracks are categorized into vertical, horizontal, shearing and complex crack. The Vertical crack is linear and parallel to the central line of tunnel arch. The horizontal crack is also linear, but orthogonal to the central line. The shearing crack is diagonal to the central line, and the complex crack is the combination of all the other cracks.
The proposition is 54% vertical and 27% horizontal [9]. Therefore, the proposed system is targeted to inspect vertical, horizontal, and shearing crack.

3. SYSTEM CONFIGURATION

The crack inspection system consists of image acquisition and analysis system as Figure 1.

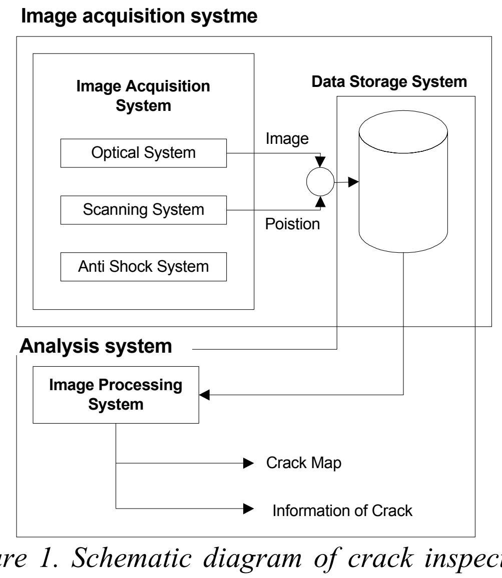


Figure 1. Schematic diagram of crack inspection system.

The image acquisition system is composed of optical, mechanical, and data storage device that obtain the image of the inner face of tunnel wall to maximize the contrast distribution of crack and non-crack minimize the noise while it moves parallel to the tunnel lining. The analysis system is software that extracts, visualizes cracks, and figures out the numerical information of cracks from the image data. The information including length, width, and orientation of the crack gives a clue to judge and determine the next stage of precision inspection for tunnel safety.

4. IMAGE ACQUISITION SYSTEM

The image acquisition system is formed by the CCD camera unit, frame grabber, controlling apparatus for the field of view of camera, anti-vibration device, illuminator, encoder to measure moving velocity, and the computer for controlling the system. Figure 2. shows the image acquisition system.

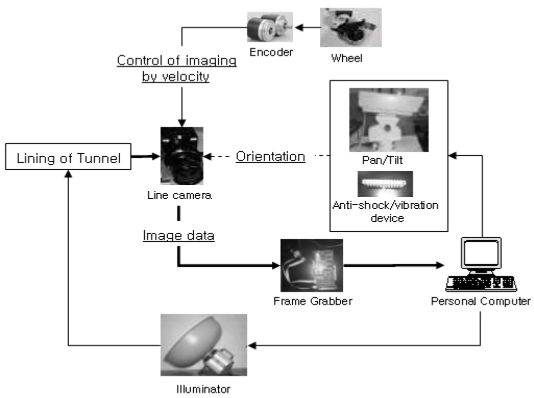


Figure 2. Image acquisition system.

CCD cameras are divided into line-scan and matrix cameras, based on their array of light sensitive device. The main advantage of matrix camera is that the camera takes images of an area only by one exposure so it is familiar with human eyes and that the interface of the camera is standardized. But, it is difficult to get the images over a large area due to the low density of sensitive device. It is hard to take a photograph with a line-scan camera because the array of light sensitive device is only one column that means for the photograph, object or camera have to move one direction but it has advantage to image the large area because of the high density of sensitive device. Therefore, the proposed system imports line-scan camera for the image acquisition sensor.

If the camera doesn't move with constant velocity while it takes images from the surface of an object, the size of scanned-images changes in correspond to the different velocity. This change induces the dimension error when the crack information from the image data is extracted. Hence the image has to acquire a fixed rate of distance even though the velocity of the moving cart is changed. The control of line-rate on line-scan camera could be done by a feedback of measured velocity. A tachometer is used for velocity of movement. However, the line-rate of camera can be controlled by TTL level pulse with encoder.

The line-scan camera usually needs high power illuminator unlike matrix camera due to its low sensitivity. One more property that illuminator must have is the time-independent stability of irradiation. Therefore, maximum 1000W halogen light is selected for the inspection system. In addition, a reflection mirror and a scattering lens are designed for the efficiency of irradiation and equal spread of light over a large area.

Image acquisition is performed by field trials, not in a purely flat floor. The vibration caused by ununiform floor makes it difficult to extract the crack from the image data due to the out of focus of camera. Accordingly, anti-vibration caster and wire-rope are used to the system in order to reduce the vibration.

5. IMAGE DATA ANALYSIS ALGORITHM

Manual recognition of the crack requires the amount of reflected light. The crack is a portion of unsealed surface area and it reflects light less than the other area of surface. The crack and surface can be distinguished by the contrast of the light reflection. The analysis system is composed of crack detection and measurement algorithm that utilize the images derived from this pattern of reflection. Figure 3. shows the flowchart of the algorithm.

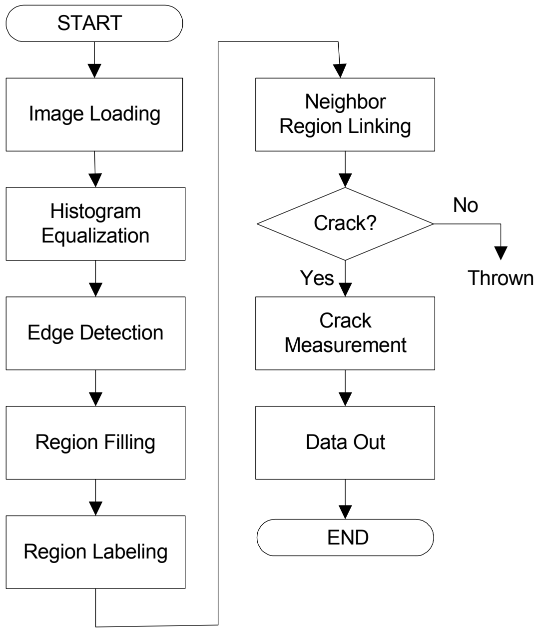


Figure 3. Flowchart of crack detection and measurement algorithm.

The current use of automation by image processing is limited, for the complete realization of automation is hard to achieve in the unpredictable environment. Although this study sets a goal at the complete crack detection, it is not easily obtained in effect. For example, some cracks could be wrong detected or undetected. In this case, the user intervention is needed to detect the missing crack and to delete the wrong detected crack. Therefore, the semi-automatic algorithm is realized by using a graph search method based on the two points on the crack offered by users.

5.1 Automatic crack detection

Crack detection is to distinguish cracks from the background image and is called image segmentation. If the images contain high contrast between cracks with background, the crack detection can be performed efficiently even though the illuminator is not so stable. The histogram equalization one of the most well-known a method to enhance the contrast of an image.

To extract crack information, the edge of the crack has to be extracted and the Sobel and the Laplacian operators are applied. The Sobel operator has the property of first order derivative. And the Laplasian operator has the property of second order derivative.

The Sobel operator is applied to obtain the orientation of the edge. To find the zero-crossing point from the second derivative is easier and more efficient than to find the maximum point from the first derivative as seen in Figure 4.

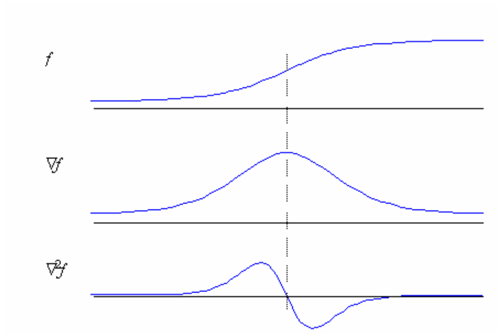
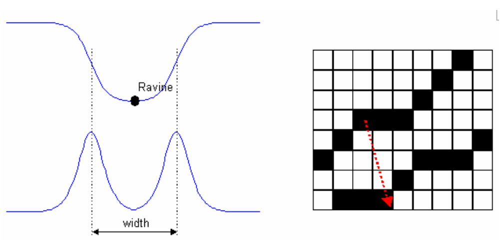


Figure 4. 1-D edge profile of the zero-crossing

Also The Laplacian operator has rotation invariant property and the acquired edges are closed curve line that is an advantage of this study targeting an region composition from the crack edge. To get the stiff second derivative Gaussian filter is applied because the Laplacian is sensitive to noise.
The detected edge constructs a ravine, which is defined as a local minimum point between two edges as displayed in Figure 5(a). The 2-D image is scanned in the direction of edge as seen in (b) and the 1-D profile is acquired as in (a).



(a) (b)

Figure 5. (a)1-D profile of ravine (b)2-D profile of ravine

The scanning from one edge to the other is stopped when it satisfied with following condition.

① Cross the other edge
② Current pixel gray-level is higher than that of edge
③ The scanned length is longer than threshold

When the scanning is stopped by condition ①, the poison of local minimum point is acquired and stored, and then the width of the crack from the minimum point to the edge is calculated. The condition③ gives the high efficiency of calculation and the effect of noise removal because the crack is lengthy but it has problem that can not detect thick cracks which is thicker than the threshold.
The area extracted from images should be grouped according to the pattern of connection. In other words, a distinct identity between connected and disconnected sets should be endowed. A specific crack implies the set of pixel, and in this paper, the depth first search method was implemented in order to label each region.
The discontinuous image may decrease the connectivity within pixels. This further makes influence on the calculation of features by labeling differently even in the same region. To solve this problem, slopes of each end of segments are computed with certain number of pixels being modeled into a straight line, and the segments are merged if the gradient change is miniscule between the segments.

5.2 Crack extract via graph search

With a given start point and an end point, a graph is constructed by images and the boundary of the image is estimated through finding the least cost function. The pixels of an image are interpreted as nodes and 8-neighborhood of a pixel are connected via links in the graph, using Dijkstra method for finding shortest path [10].

① Input all nodes from the expansion of the start node into the queue. The previous node pointer is defined as nA . Calculate the cost of expanded nodes.
② It is failure if the queue is empty. Output the least cost note ni from the queue and remove it. If $ni = nb$, back-track the previous pointer saved in each node and terminate.
③ If the condition to terminate in the process ② is not satisfied, expand the node ni and input all other following nodes into the queue. Define the previous node pointer as ni and calculate each cost of node. Go back to the process □.

This algorithm always finds an optimal value. However, the number of enlarged nodes is numerous. To correct the inefficiency, a method that does not require the expansion of a node if the cost per unit length is above a certain value is used.

5.3 Crack measurement

Not all prospect crack area is derived from cracks. The causal elements include construction layer, an artificial mark, noise, or blot. This erroneous area is removed when it is assessed as non-crack through the following standards of distinguishing crack and non-crack.

① A highly small area resulted from noise.
② The area whose shape is not longish is caused by blots from water leakage.
③ A highly straight area resulted from the attachments such as construction layer or a cable.

So far crack is defined as a set of pixel. However, this definition is improper to the higher level of assessment such as safety inspection, such that an adequate use of physical quantum is required. This paper uses the quantum for the crack length, width, and the direction. The width of points comprising each area is already calculated when the region is formed from the edge. To remove the outlier among these, the width was derived as a mean value using 5 lengths of median filter.
Length depends on the number of pixel. After calculating the length of diagonal as $\sqrt{2}$, and the vertical and horizontal line as 1, the real length was measured by the camera calibration. The direction of crack is determined by estimating the straight line through the principle plane.

6. EXPRIMENT SETUP AND RESULT

The experiment for evaluating the developing system was conducted in a hallway of indoor structure, a road tunnel, and a subway tunnel.

6.1 Experiment setup

In an experiment at an indoor structure, the image of the surface wall was obtained by an aluminum profile structure attached a camera pan/tilt system and an encoder on its wheel. To prevent the vibration transmitted to the camera by a disproportionate state of the floor, the flat board upholding the camera was stabilized by a wire rope. Figure 7. shows the experimental setup for indoor circumstance.

Figure 7.Experimental setup for indoor inspection

Figure 8. Experimental setup for subway inner wall

In a road tunnel, image acquisition was conducted with the indoor apparatus loaded on the truck, with the encoder attached to the tire. In the case of subway tunnel, aluminum profile structure was used in order to make the railway driving available as shown in Figure 8.

6.1 Experiment result

The image acquisition from the indoor structure was seen in Figure 9. And the crack detection was extracted as shown in Figure 10. The two vertical lines on the right of circle is groove embedded in the structure. Therefore, the highly straight line was removed, following the recognition.

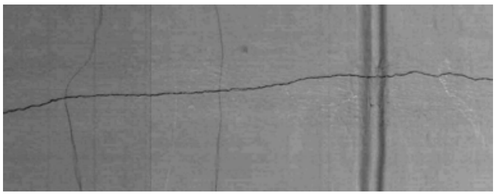


Figure 9. Image of indoor wall

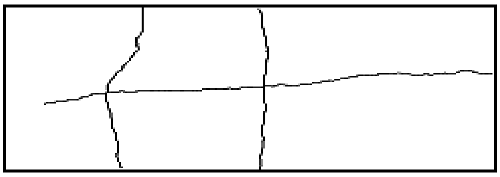


Figure 10. Extracted crack of indoor wall

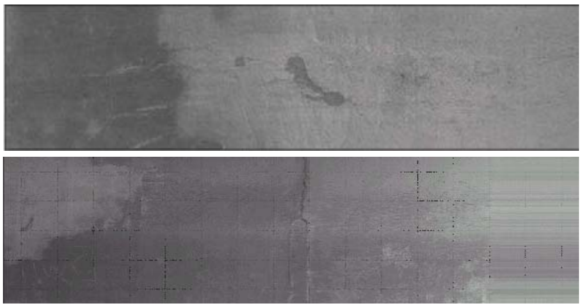


Figure 11. Image of Namsan tunnel

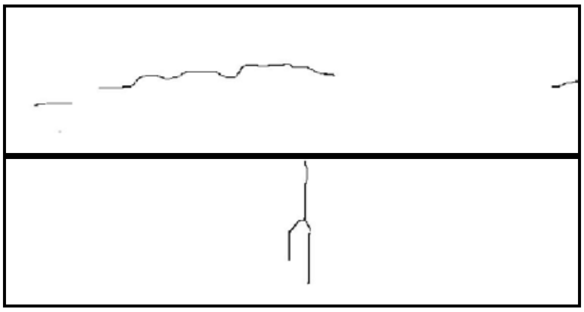


Figure 12. Extracted crack of Namsan tunnel

Figure 11. and Figure 12. are the results of image acquisition and crack detection from Namsan tunnel(road). The edge widely distributed by pollution is remained un-extracted.

Figure 13. and Figure 14. exhibit the process and the result of acquired image. Since the finishing line of iron bar was not longish and formed a certain area instead, it was not recognized as crack.

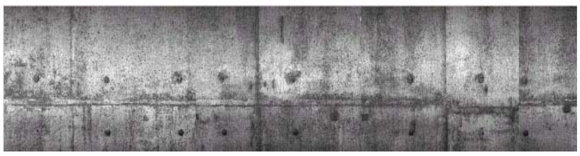


Figure 13. Image of subway inner wall

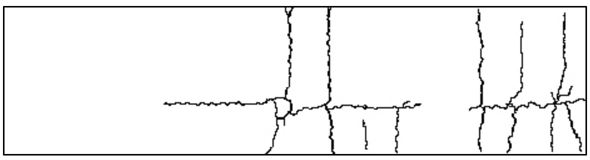


Figure 14. Extracted crack of subway inner wall

Above process result was shown as a picture in order to discriminate by human eyes. The actual data was shown as numerical value in Table 1.

Table 1. Example of list of data

ID	class	length	width	start X posion	start Y posion	end X poision	end Y posion
1	Diag	66.7	0.3	6361	2769.4	6397.1	2754.3
2	Horz	134.2	0.3	6257	2956.9	6388.7	2953.1
3	Horz	132.7	0.3	6432.5	2960.8	6564.1	2953.1
4	Vert	190.1	0.4	7214.6	2859	7197.5	3044.7
5	Vert	247.9	0.3	7128.2	2643.4	7227.2	2866.7

The crack orientation displays vertical, horizontal, and diagonal crack, using length, width, the start point and the end point.

The crack inspection system proposed in this paper, although the state of surrounding environment is not negligible, has overall error rates of 70~80% and the measuring error of recognized crack is 10% or less.

7. CONCLUSIONS

This paper proposed an inspection system using an image process, which can be a solution to the problems of crack detection in tunnel lining – inaccuracy, slow rate, subjectivity, and the inefficiency in managing data. Also, the system ensures the validity and possibility based on the experiment in the indoor structure, road tunnel, and subway tunnel. However, an erroneous recognition of a crack as non-crack and vice versa prevails. Therefore, the system is semi-automated to get rid of wrong recognition of non-crack as crack, and to identify crack by a graph search method using the user-based input of the start-point and end-point of crack.

In order for a crack inspection system to develop into an expert system, a study on the characteristics of crack has to be proceed for complete automation. This paper would be help for further study by many researchers.

8. REFERENCES

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