AN INSPECTION SYSTEM FOR DETECTION OF CRACKS ON THE CONCRETE STRUCTURES USING A MOBILE ROBOT

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Abstract: To assess safety, cracks in concrete structure are measured by inspectors, who observe cracks with their naked eyes and record them. But manual inspection is slow, and measured crack data is subjective. Therefore, this study proposes inspection system for measuring cracks in concrete structure and providing objective crack data to be used in safety assessment. The system consists of the mobile robot system and crack detecting system. The mobile robot system is controlled to keep a constant distance from the wall to acquire image data with a CCD camera on scanning along the wall. The crack detecting system extracts crack information from the acquired image using image processing. To improve accuracy of crack recognition, the geometric properties and patterns of cracks in a structure were applied to image processing. The proposed system was verified with experiments in both laboratory environment and field.

Keywords: crack, inspection, image processing, mobile robot

1 INTRODUCTION

Over the last several decades, many concrete structures have been constructed on a variety of the fields. Concerns have been directed towards the safety of concrete structure. To determine safety in this structure, periodic inspections have been conducted using non-destructive testing technologies and techniques. Non-destructive tests, however, cannot replace the human visual inspections because they entail their slow and complicated procedures. For this reason, Non-destructive tests have been limited to precision inspections [1]. In the first stage of inspection, cracks in the 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 developments of automatic crack inspections using image processing have been made in areas including roads, bridges, fatigues, and sewer-pipes[2]-[5].

The Komatsu Engineering Company 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. Roadware Group Inc., Canada commercialized a system that acquires an image of the road with a CCD camera, an ultrasonic sensor, and a gyro-sensor with a speed of 80km/h and a resolution of 3~4cm [7]. Those systems are useful to collect data of cracks, leakage, scale, and spall but only by using the image acquisition, and not through automatic defect detection. The algorithm for crack detection and measurement is required for fully automatic inspection system. It is necessary, therefore, to develop the automatic crack detection and measurement algorithm to obtain both fast inspection and objective crack data.

Cameras and lasers are widely used to image the surface for inspections of the surface of structures. Although it is sufficiently efficient to be applied in a wide variety of 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 an illumination problem. It is common sense in engineering that cost is one of the most important considerations. Study of the image data acquisition of the surface acquired by cameras is therefore necessary to ensure a high level of safety in the concrete structure.

Therefore, this study proposes an inspection system for cracks on the surfaces of concrete structures that inspects faster and more objectively than the manual inspection. The inspection system is consisted of a mobile system and crack detecting system. The mobile robot system is controlled to keep a constant distance from the wall to acquire image data with a line CCD camera on scanning along the wall without inspectors. To obtain fine images, a high power illuminator, shock absorber devices and a sensor for measuring velocity for control the line CCD camera are used. The maximum inspection speed of the system is 5km/h when the resolution is set to

0.3mm/pixel. The crack detecting system is software that extracts crack information through image processing from the acquired images. Measured crack information is composed of crack thickness, crack length, crack orientation. They are important factors for the fundamental inspection. To test the proposed system, experiments were performed inside the buildings and road tunnels

2. THE DESCRIPTION OF THE INSPECTION SYSTEM

2.1 The subject of inspection

An itemized list of contents of the inspection of concrete structure contains cracks, leakage and spall etc. In an itemized list, the survey on cracks is very important factor to be determined safety in evaluating the concrete state [8].

Cracks in the concrete structure are the combined results from deficiency in the repairing period, the contraction due to a plunge in temperature, fluctuation between contraction and expansion caused by the temperature change, extra loads from the partial ground expansion.

The cracks are categorized as vertical, horizontal, shearing and complex crack. The proportions of the categories are 40% vertical, 11%horizontal and 30% shearing [9]. Therefore, the proposed system is targeted to inspect vertical, horizontal, and shearing cracks.

2.2 The system configuration

The crack inspection system consists of mobile robot system and crack detecting system as shown in Figure. 1. The mobile robot system is composed of optical, mechanical, and data storage devices that obtain the image of the inner face of the concrete structure to maximize to contrast distribution of crack and non-crack and minimize the noise while it moves parallel to the structure.

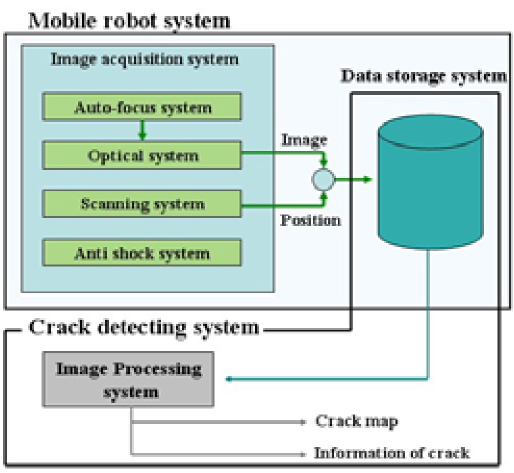


Figure 1. Schematic Diagram of Inspection System

The crack detecting system is software that extracts and computes the numerical information of cracks from the image data.

The information, including length, width, and orientation of the cracks gives a clue to judge and determine the next stage of precision inspection of concrete structuer safety.

The mobile robot system consists of a CCD camera, frame grabber, controlling apparatus for an autofocus device, isolated vibration device, illuminator, encoders to measure moving velocity and to compute the distance from the structure for an autofocus, and a computer for controlling the system. Figure 2 shows the image acquisition system.

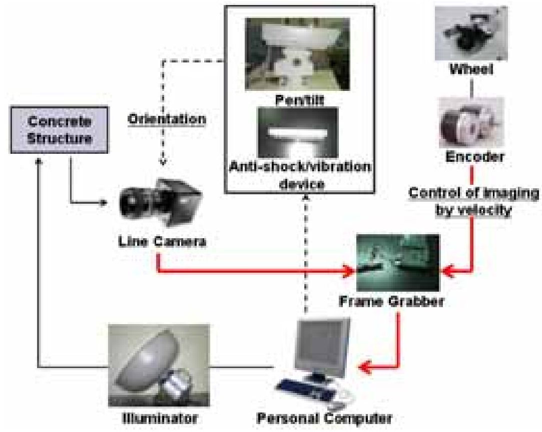


Figure 2. Mobile Robot System

CCD cameras are either line-scan or matrix cameras, based on their array of light sensitive devices. The main advantages of the matrix camera are that the camera takes images of an area with one exposure so it is similar to the human eye and the interface of the camera is standardized. However, it is difficult to obtain images over a large area due to the low density of sensitive devices. It is hard to take a photograph with a line-scan camera because there is only one column in the array of a light sensitive device. This means that, for the photograph, the object or camera must move one direction, but it has the advantage of being able to image a large area because of the high density of the sensitive device. The proposed system, therefore, imports a line-scan camera for the image acquisition sensor.

If the camera does not move with constant velocity while it takes images from the surface of an object, the size of scanned-images changes in correspondence to the different velocity.

For this reason, the control of line-rate on the line-scan camera could be accomplished through feedback of measured velocity. So, the line-rate of the camera can be controlled by TTL level pulse with an encoder.

The line-scan camera usually requires a high power illuminator. A maximum 1000W halogen light is selected for the mobile robot system.

To obtain fine images from the camera, the mobile robot have to keep a constant distance from the structure that is not straight path but changed path continuously. The mobile robot system, therefore, has a laser sensor that obtain the distance and the angle between mobile robot and concrete structure and has an autofocus device for depth of the field using the obtained distance.

The system is 0.3mm/pixel when the distance between the surface and the camera is 1.5m.

3. SYSTEM CHARACTERIZATION

3.1 Mobile robot system

The wheels of the mobile robot have the subject of formation made by the speed difference of two wheels controlled by two auto actuators. The diagram to realize the kinematical model is set as the following Figure 3.

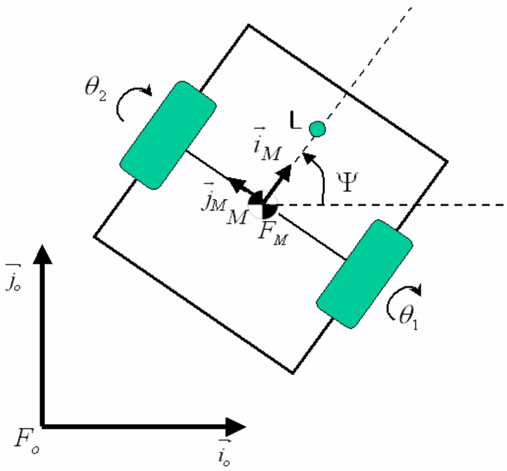


Figure 3. Schematic Diagram of Mobile robot

Figure 3 is the model of mobile robot that has two driving wheels. In the diagram, M is the standard point as the CG point of the robot. O is the origin point of the standard coordinate, and M is the origin point of the coordinate of the robot. In order to obtain the simple kinematical model, the wheels of the robot are presumed to satisfy the complete rolling requirement on the surface without the sliding on the side. Through this hypothesis, the following kinematical formula may be obtained.

$$\dot{x}_M = \frac{r}{2}\left(\dot{\theta}_1 + \dot{\theta}_2\right)\cos\Psi$$
$$\dot{y}_M = \frac{r}{2}\left(\dot{\theta}_1 + \dot{\theta}_2\right)\sin\Psi \qquad (1)$$
$$\dot{\Psi}_M = \frac{r}{2}\left(\dot{\theta}_1 - \dot{\theta}_2\right)$$

Eq. (1) is the kinematical function of the most generalized two-wheel driven robot. However, the first two formulas have the nonholonomic feature that cannot completely be integrated that it is difficult to control. First, the point that is connected in imagination is presumed to apart with the distance of d from the axis of the wheels. In the event that the control position, namely, d=0, is set in the middle of the robot, it is not collected accurately on 0. However, in the event that d is not 0, namely, the origin point is set in a place apart by d from the robot axis, it is collected on 0. Therefore, d has to be set near to the center of the robot and control.

3.2 Automatic crack detecting

The crack and the surface can be distinguished by the the contrasting light reflection. The analysis system is composed of a crack detection and measurement algorithm that utilizes the images derived from this pattern of reflection. The current use of automation by image processing is limited because the complete realization of automation is hard to achieve in an unpredictable environment. Although this study has the goal of complete crack detection, it is not easily accomplished. Therefore, the semi-automatic algo-rithm is realized.

If the images contain high contrast between cracks and the background, crack detection can be performed efficiently even though the illuminator is not completely stable. The histogram equalization defined by the following Eq. (2) is methods for enhancing the contrast of an image.

$$s_k = \sum_{j=0}^{k} \frac{n_j}{n} \qquad k = 0,1,2,\ldots,L-1 \qquad (2)$$

Where

s_k : Acquired normalized gray-level value

n : Number of pixel

n_j : Number of pixel that has j gray-level value

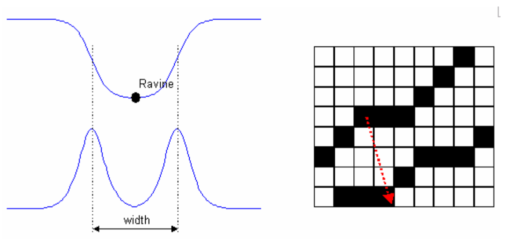
k : The input gray-level,

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 is applied to obtain the orientation of the edge as shown in Eq. (3) [10].

$$\phi = a\tan 2\left(\frac{\partial f}{\partial y}, \quad \frac{\partial f}{\partial y}\right) \qquad (3)$$

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. Also The Laplacian operator has rotation invariant property and the acquired edges are closed curve line that is an advantage of this study targeting a 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 4(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 4. (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 follow condition.

In the first place, when the scanning cross the other edge, the position of local minimum point is acquired and stored, and then the width of the crack from the minimum point to the edge is calculated. In the second place, when the current pixel gray-level is higher than that of edge. Finally, when the scanned length is longer than threshold, it gives the high efficiency of calculation and the effect of noise removal because the crack is lengthy but it has problem that can not detection thick cracks which is thicker than the threshold.

The area extracted from images should be grouped according to the pattern of connection. 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 [11].

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 segment end 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.

3.3 Crack extraction 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 [12].

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 ②.

This algorithm always finds an optimal value. How-ever, 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. Figure 5 shows the algorithm.

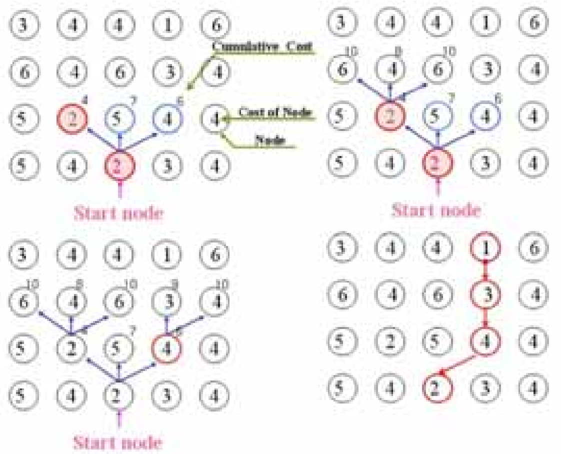


Figure 5. Example of Dijkstra method

3.4 Crack measurement

Not all prospect crack area is derived from cracks. The causal elements include construction layer, an artificial mark, noise, or blot. So, this erroneous area is removed when it is satisfied that a very small area resulted from noise and an area whose shape is not long and narrow is not a crack and very straight area resulted from the attachments such as construction layer or a cable.

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. The width of each area is calculated as Eq. (4).

$$w = \frac{1}{N}\sum_{i=1}^{N} \hat{w}_i, \quad \hat{w}_j = med\{w_{j-2}, L, w_{j+2}\} \qquad (4)$$

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

4. EXPERIMENT SETUP AND RESULT

4.1 Experiment setup

In an experiment at an indoor structure, the image of the surface wall was obtained by mobile robot that could keep a constant distance from the wall and an encoder on its wheel. Even if mobile robot can't keep a constant distance, using the laser sensor, the image of the surface wall was obtained by adjusting focus ring. 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 6 shows the experiment setup for indoor circumstance.

Figure 6.Experimental setup in a building.

Figure 7 displays the image processing software. The crack information is released from the right side of the software. Figure 8(a) is the menu offered for camera calibration, inputted through a conversion of the distance between each pixel into mm. The camera calibration used the plate which has the black dot on the surface with an interval of 5mm between each point. Figure 8(b) shows an over-layered image of both obtained image and extracted compensating points.

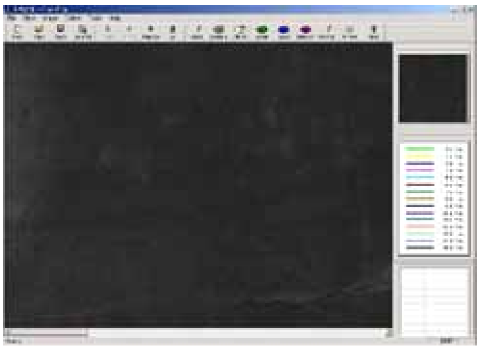
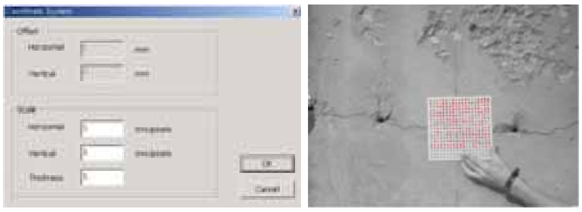


Figure 7. The software of crack detecting system



(a) (b)

Figure 8. (a) Window for mapping data
(b) Over-layed Image for clibration

4.1 Experiment resultt

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.

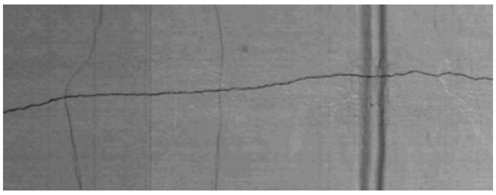


Figure 9. Image of indoor wall

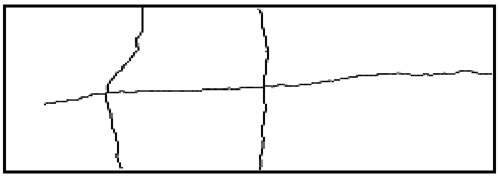


Figure 10. Extracted crack of indoor wall

Figure 11 and Figure 12 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.

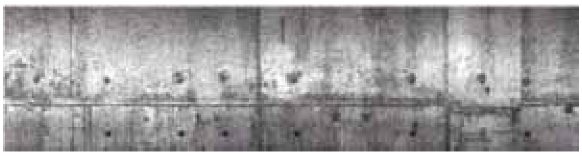


Figure 11. Image of subway inner wall

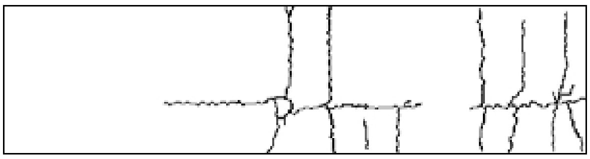


Figure 12. Extracted crack of subway inner wall

Above process result was shown as a picture in order to discriminate by human eyes. 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 75~85% and the measuring error of recognized crack is 10% or less.

5. CONCLUSION

This paper proposed an inspection system using an image process, which can be a solution to the problems of crack detection in concrete structuer, 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 in to an expert system, there needs to be further study of the characteristics of cracks and the algorithm must move towards complete automation. It is hoped that this paper will encourage futuer research.

REFERENCES

[1] Christian Huber, Habibollah Abiri, Stoyan I. Ganchev, and Reza Zoughi, *Analysis of the Crack Characteristic Signal Using a Generalized Scattering Matrix Representation*, IEEE Transactions on Microwave Theory and Techniques, Vol. 45, NO. 4, 1997.

[2] J. Pynn, A. Wright, and R. Lodge, *Automatic Identification of Cracks in Road Surfaces,* Image Processing and its Applications, Conference Publi-cation No. 465, IEE , 1999.

[3] D. H. Ryu, T. W. Choi, Y. I. Kim, S. H. Nahm, *Measurement of the Fatique-Crack using Image Processing Techniques*, Fourth International Conference on Knowledge-Based Intelligent Engi-neering System, Brighton, UK, IEEE, 2000.

[4] Paul W. Fieguth and Sunil K. Sinha, *Automated Analysis and Detection of Cracks in Underground Scanned Pipes*, IEEE. , 1999.

[5] Pi-Cheng Tung, Yean-Ren Hwang, Ming-Chang Wu, *The development of a mobile manipulator imaging system for bridge crack inspection*, Automation in Construction , 2002.

[6] T. Tomikawa, *A Study of Road Crack Detection by the Meta-Genetic Algorithm*, AFRICON, IEEE, 1999.

[7] Roadware Group incl.,Http://www.roadware.ca

[8] *Developments of the Safety Assessment System and Crack Investigation Equipment for Tunnels (Ⅰ),* Report of The Korea Institute of Construction Technology, 1998.

[9] *Evaluation and Control of Cracks in Reingorced Concrete Structures*, Report of The Ministry of Construction & Transpotation, Korea, 1996.

[10] A. K. Jain, *Fundamentals of digital image processing,* Prentice Hall Press, USA, 1989.

[11] R. E. Tarjan, *Depth-First Search and Linear Graph Algorithms*, SIAM J. Compution, Vol. 1, 1972.

[12] Jayadev Misra, *A walk over the shortest path: Dijkstra's Algorithm viewed as fixed-point computation*, Information Processing Letters 77, 2001

[13] R. C. Gonzales and R. E. Woods, *Digital image processing,* Prentice Hall Press, USA, 2002.

[14] J.H. Jang and C.S Han, *The State Sensitivity Analysis of the Front Wheel Steering Vehicle: In the Time Domain,* KSME International Journal, Vol. 11, No. 6, 1997

[15] X. Yun and Nilanjan Sarkar, *Dynamic Feedback Control of Vehicle with Two Steerable Wheels,*IEEE Inter. Con. on Robotics and Auto.,pp. 3105-3110, April 1996.

[16] Luis E. Aguilar, T. Hamel and P. Soueres, September 7-11, *Robust Path Following Control for Wheeled Robots via Sliding Mode*, Proc. IROS 97, pp. 1389-1395, 1997.

[17] T.J. Park, J.W. Ahn, C.S. Han, *"A Path Generation Algorithm of an Automatic Guided Vehicle Using Sensor Scanning Method*, KSME International Journal, Vol. 16, No. 2, KSME, pp. 137～146, 2002