INTELLIGENT BRIDGE INSPECTION USING REMOTE CONTROLLED ROBOT AND IMAGE PROCESSING TECHNIQUE

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ABSTRACT: In this paper, we discuss an intelligent bridge inspection system by using a Robot and IT technology which enables acquiring images of the bridge condition for managing the safety of its structure. The purpose of this study is composed of two parts: 1) the image acquisition of a bridge structure with the application of a vision-based robot, the name of the robot system is U-BIROS(Ubiquitous Bridge Inspection Robot System) which is remote controlled. 2) Development of digital image processing software for assessing condition of the bridge, and measuring the size of any crack captured in the images. The robot arm is designed to operate on the underside of superstructure during inspections, and equipped with vision devices (digital camera, lens, and lights). The domain of a superstructure has been divided into appropriate segments to facilitate the image acquiring task by making its total domain irrelevant to the procedure. The system's software detects, measures the width and length of a crack semi-automatically, and also composes a drawing map of the whole area of the bridge from the crack's data for a user's convenience in determining the status of bridge. Through field experiments, the application of this inspection system with specialty software has proven to be much faster, safer, and reliable than the inspections carried out by the naked eyes in managing safety of the bridges.

Keywords: *Bridge Inspection, U-BIROS, Remote Controlled Robot, Digital Image Processing, Crack Detection*

1. INTRODUCTION

In general, the current inspection of bridge structure is performed manually. However, 1) it is almost impossible to inspect inaccessible sections (e.g. bridges passing through river, high-rise pier or urban districts) for the reasons to be addressed below, 2) large-scaled inspection vehicles may interfere with traffic flows and a number of personnel are required to inspect a wide area in a short time, 3) poor working conditions for visual inspection can threaten the safety of inspectors, 4) frequent replacement of persons in charge and subjectivity in inspection reduce the reliability of data collection and management, and 5) maintenance expenses may be wasted since it is hard to determine precisely the point of time at which repair and reinforcement shall be executed.[1][2]

So, we have developed a new bridge inspection system in order to solve above problems, and to allow efficient and accurate inspection. The name of the system is U-BIROS. In this paper, we describes the construction of this system and the function of each part in this system.[3]

2. INTELLIGENT BRIDGE INSPECTION SYSTEMS

2.1 Composition of System and Inspection Sequence

The bridge safety management task using the bridge inspection robot consists of 'remote-controlled inspection' and 'digital image processing'. The remote-controlled inspection can be done by the remote-controlled robot equipped with digital camera, illuminator and ultrasonic rangefinder, and by using this robot the inspector can acquire images of desired regions on the deck of bridge. The robot is mounted on the transportation system made with the boom which facilitates inspection of lower parts of bridge and movement. The control room in the vehicle contains the control system which maneuvers the remote controlled robot and the boom transporting the robot, and acquired images can be stored and reviewed in this room. Those images are transferred to image-processing PC by users so that tasks such as crack detection and measurement can be operated. The sequence of system is as shown in Figure 1. First, the entire inspection range shall be determined by using the drawings of the bridge and the GPS installed in the vehicle. The range determined needs to be divided into multiples sections suitable for the robot's operation, the bridge inspection robot moves to each divided section. Then the images of deck in the bridge shall be acquired by using the hydraulic boom and the remote-controlled robot equipped with camera. Acquired images are transferred to the image-processing PC for integration, and the user operates the task of crack and damage detection by using the image-processing program. The final result is converted to the crack network diagram, so that the user can review and evaluate the current damage status of the bridge

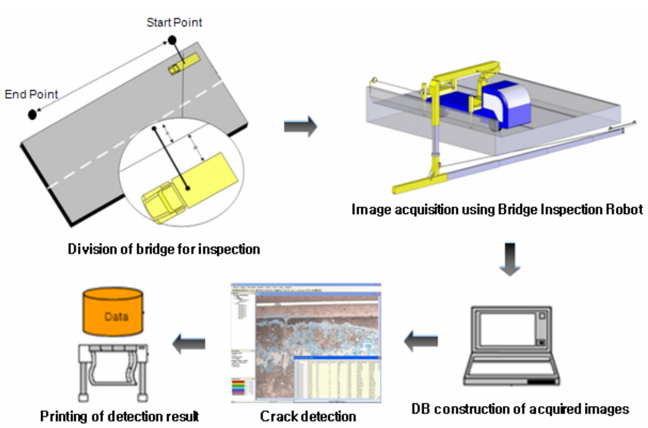

Fig. 1 Sequence of intelligent bridge inspection system

2.2 Outline of Intelligent Bridge Inspection System

The Intelligent bridge inspection system consists of robot transporting vehicle, hydraulic transportation boom and remote-controlled robot. The robot transporting vehicle is equipped with the transportation boom and the remote-controlled robot, and it can be fixed on the ground by using the caterpillar. The transportation has three axes of tilt, rotate and move, and is driven by the hydraulic valve control. It can move the remote-controlled robot to any desired location on the lower part of bridge. The remote-controlled robot is equipped with digital camera, illuminator and ultrasonic rangefinder so it can acquire images of deck in the bridge.

A user operates the transportation boom and the remote-controlled robot through the main PC mounted in the control room of vehicle. One main PC and ten embedded PCs in the remote-controlled robot are connected to each other through wireless LAN, so that acquired images can be saved and analyzed in real time.

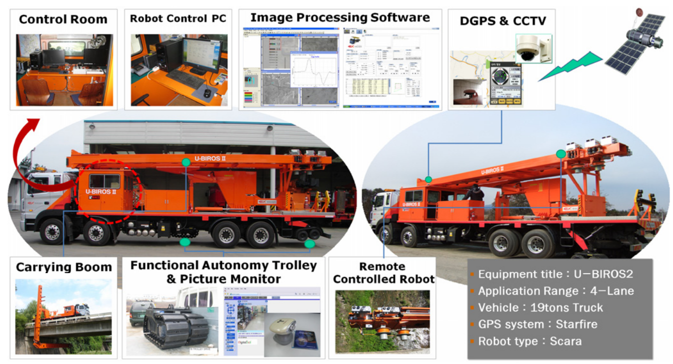

Fig. 2 Outline of intelligent bridge inspection system

1) Specification and Operation Scope

This bridge inspection robot was designed as a small scale to minimize the traffic interference considered as a problem of current inspection vehicles, and the length of hydraulic boom was determined so that the inspection can be performed safely without the vehicle being overturned even if the hydraulic boom is fully extended. The length of hydraulic boom is 22m. It can measure a bridge with 5 or less lanes in each way. The accuracy of robot is ±0.02m which allows the high resolution of position recognition from images acquired.

2) Control System Structure

The control of entire system can be done with the main PC in the control room of vehicle. The motion controller used for scanning the bridge drives 4 axes of hydraulic boom and robot as instructed from the main PC (3 axes of hydraulic boom for rotation, movement and deformation compensation, and 1 axis of remote-controlled robot for maintaining the levelness of image).

Images of bottom surface of bridge deck are transferred to the robot controller after being superimposed with the distance information measured between the ultrasonic rangefinder and the deck, and a user acquires and save images to the computer in the optimized condition after analyzing all information.

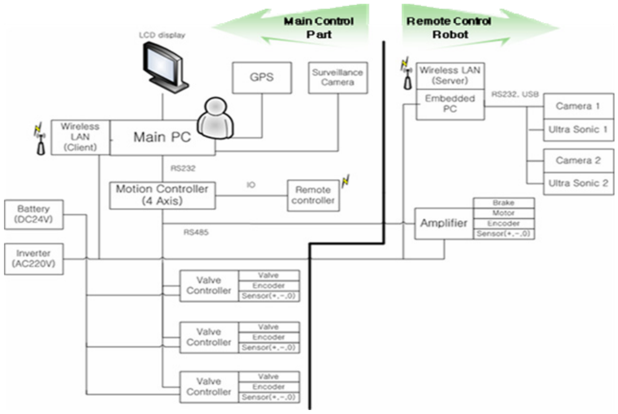

Fig. 3 Control system diagram

The power for control system is supplied from the generator of vehicle, and the module with sufficient safety is used to prevent the hydraulic system and the robot system from malfunctioning due to vibration and dust from the vehicle as well as humidity and temperature in the field.

3. REMOTE CONTROLLED ROBOT

3.1 System Structure

The remote-controlled robot mounted at the end of hydraulic boom cannot be controlled through wired connection, because it is distant from the main PC in the control room and there is the possibility of interference while manipulating boom.

Fig.4 Remote-controlled robots

Thus this system is built with the embedded PC, which is installed on the inspection robot and is controlled remotely in the control room through wireless LAN communication. Ten remote-controlled robots use commercial digital cameras (Canon Powershot G10) to acquire images of slab and girder in the bridge.

These cameras are favorable because they are cheaper than existing industrial CCD cameras, suppresses noises better and can compensate vibration. On both sides of the camera, the ultrasonic rangefinder and laser distance meter are installed to measure the distance between the camera and the bridge deck with the accuracy of ±1mm (sensing range 3M). The robot can perform the task with a constant distance maintained by using the measured distance. It can also automatically stop when facing with an unexpected obstacle, for increased safety.

3.2 Resolution and FOV

The image resolution is critical in detecting cracks. This study aims at detecting 0.1mm crack at finest, and thus the method of quarter-pixel interpolation was applied to the image acquired in the resolution of 0.1~0.4mm per pixel. Since the camera used has 15-megapixels (4,416 x 3,312 pixel), the FOV of acquired image is 2.2m x 1.65m. About 10% of overlapping is applied to images because it is difficult to divide images of bridge into each section precisely. The actual FOV of image with overlapping considered is 2.0m x 1.5 m.

4. IMAGE PROCESSING SYSTEM

Fig. 5 shows the inspection machine vision robot for acquisition of bridge deck images. Each Embedded PC of robot can acquire images by controls the camera's zoom magnification by the measured distance and image acquisition resolution that worker has set up. Because the measuring distance would not be fixed, a commercial digital camera, which can provide auto focusing function and zoom magnification, was used instead of the industrial CCD camera, which requires changing lenses and manual focusing function according to the numerical formula (1) whenever user captures images.

$$\text{Focal Length} = \left(\frac{\text{Sensor Size} \times \text{Working Distance}}{\text{Resolution} \times \text{pixel number}}\right) \quad (1)$$

- Focal length : Focal length of lens
- Sensor size : CCD sensor sizes(mm)
- Working Distance : Distance between camera and target

Fig. 5 Inspection machine vision robot

4.1 Crack Detection

The crack can be defined by the sets of pixels lower than its surroundings. Chen, LC using the characteristics of these cracks definition, proposed an algorithm which can automatically trace dark points and detect the thickness of the crack.[4]

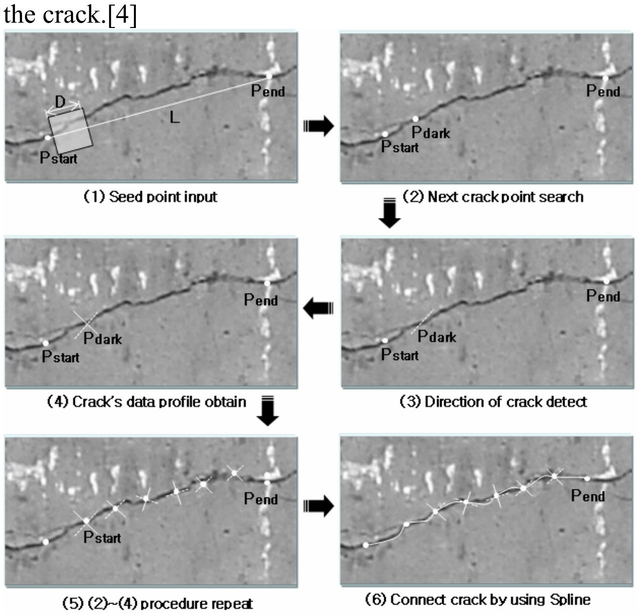

Fig. 6 Procedure of the crack detection algorithm

In this study, based on previous techniques, we have proposed a method which can detect cracks more accurate and robust to noise by applying the algorithm for crack-direction search. Additionally, the final described crack images will be shown on the screen almost the same as the real one by using the B-spline interpolation. The procedure of the crack detection algorithm is shown Fig. 6

1) Seed Point Input & Next Crack Point Search

Area setting, the 1st step of crack detection, is carried out with entering starting point and end point. After this setting input is finished, the darkest pixel to the direction of normal will be detected moving along with the established base line that connects with these two points. After the detection is finished, this pixel will be established as a starting point again where next crack detection will be performed. At this time, detection range will be made to be about ±1mm depending on the crack evaluation criteria. For example, detection range will be ±5pixel in case of image acquisition by pixel resolution degree of 0.2mm.

2) Direction of Crack Detect

Crack thickness can be measured in the vertical direction of crack progressing direction for ensuring precise thickness measurement. As the crack thickness has been measured only in the vertical direction of the line connecting starting point and end point by the existing tracing algorithm, it was difficult to measure the crack direction accurately. In this study, by carrying out detection work for crack progressing direction based on pixel where crack detection is achieved, such short-comings could be overcome.

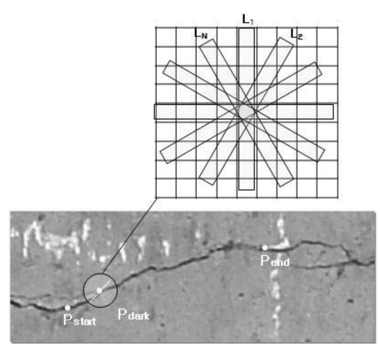

Fig. 7 Detection of the crack direction

3) Crack data acquisition

Data for the vertical direction of crack progressing direction was obtained with sub-pixel accuracy by using B-spine interpolation (2). B-spline function is robust to against gaussian noise being distributed around crack [5].

$$f(x) = \begin{cases} \frac{1}{2}|x|^3 - |x|^2 + \frac{2}{3} & (0 \le |x| \le 1) \\ -\frac{1}{6}|x|^3 - |x|^2 - 2|x| + \frac{4}{3} & (1 \le |x| \le 2) \\ 0 & (2 \le |x|) \end{cases} \quad (2)$$

4) Crack thickness measure

Crack thickness can be calculated by applying a general linear differential equation to vertical direction data obtained. Crack thickness is the range between the maximum value of gray-level variation and the smallest one[2].

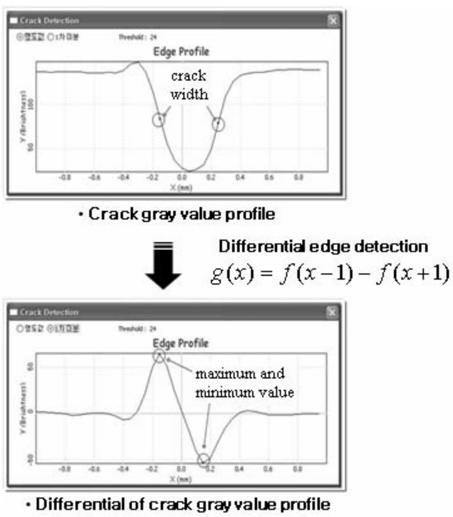

Fig. 8 Width determination by using differential edge detection

5) Representation of crack

As the degree of safety of bridge is evaluated by crack average thickness and length, total length and average thickness are measured with connecting tracing-finished individual crack joints into one.

Connection of each tracing points could be expressed in soft curve in similar form with actual cracks by using Bezier-curve instead of straight line connection. Total length was calculated with total distance value between each detected measured points[6]. Accurate average thickness was made to be calculated as a final crack thickness by applying Median filter to each detected crack thickness value with eliminating the values for any specifically too thin or thick areas.

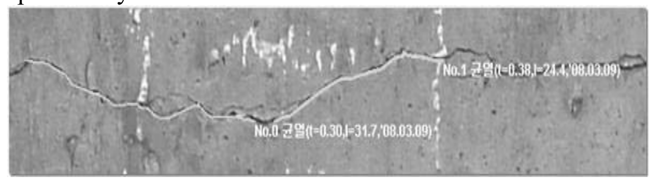

Fig. 9 Representation of detected crack

4.2 Database System of Digital Image

1) Database Structure

As shown in Figure 10, the results for the inspection can be implemented in a tree structure. One unit of a bridge is equivalent to one unit of a project and one project is divided into sections, columns and rows, depending on the location of the box and the location of the robot.

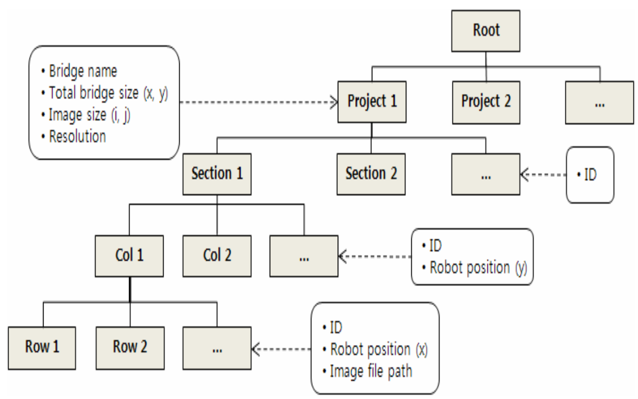

Fig. 10 Database structure

All it data relating to the bridge name, size and measurement accuracy is stored in the project. The lower section, column and row have their own unique IDs and the location of the robot at the time when the image is obtained. The file directories for the saved image file are also stored in them. The project size varies depending on the entire size of the bridge and the measurement accuracy, and the measured data can be edited arbitrarily by the user. For example, a bridge measuring 15M X 50M takes up about 0.8GB of database storage capacity. However, if the use deletes everything except the problematic portion (where cracks or damages occur), the project unit will be lighter, and the storage load will be decreased significantly. As for the results, the user can manage the bridge more efficiently. Figure 11 shows that the data-based crack pictures.

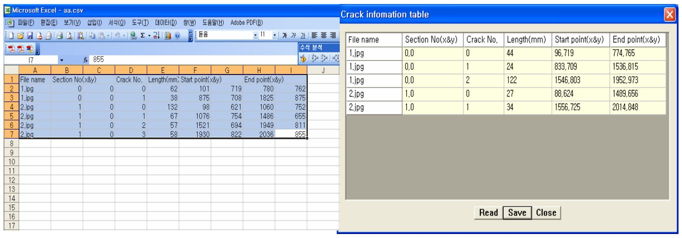

Fig. 11 Crack detection results and database

2) Inspection Drawing and Bridge Management

By using the crack network diagram and the crack tabulation, the current status of a bridge can be identified and managed. The crack network diagram can be moved, scaled up/down and printed for easy analysis of the crack status for each section of the bridge, and the crack tabulation can be exported as a document file for recording and managing the crack status of bridge. Figure 12 and Figure 13 show that detected overall crack map in one span of bridge and composite image.

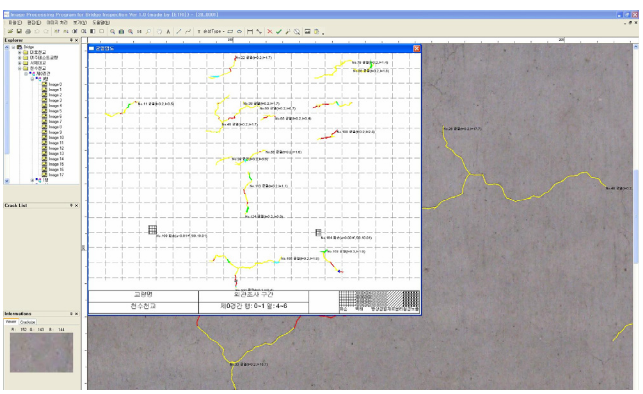

Fig.12 Crack Detection Map

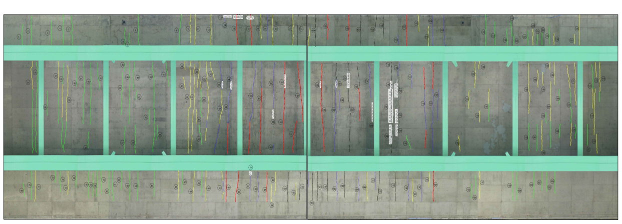

Fig.13 Composite Image and Damage Drawing

5. CONCLUSION

This study proposed the bridge safety management system by using the bridge inspection robot. As results, the followings have been developed: 1) image processing program to acquire and process images, detect positions and manage data, and 2) remote-controlled robot system for image acquisition and automatic control, as well as integral system to transport and operate this inspection robot. Also the program manuals for system operation and the structural techniques using the image process were defined. This system solved the problems in current visual inspection of bridges, and systemized the inspection tasks scientifically. However, in order to apply this system to the practice, it is still required to prepare damage photos, damage grades and DB for efficient image processing, up to a certain level. In addition, it is necessary to develop a new system for inspecting bridges with 4 or more lanes in each way, since the current system was developed for 2-lane (each way) bridges, so the entire range of highway can be inspected. Finally, it is desired to prepare institutional plans or guides by which the inspection can be performed with the developed system through the coordination with pertinent authorities.

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