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DEVELOPMENT OF ROBOTIC INSPECTION SYSTEM OVER BRIDGE SUPERSTRUCTURE

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Abstract

The increase of traffic over bridges has emerged as one of the most severe problems in terms of bridge maintenance. This is largely due to the load effect caused by vehicle passage over bridges which has created long-term damage to bridge structures. In addition, it is nearly impossible to maintain operational serviceability of bridges to a level that would be deemed satisfactory by user's without any concern to bridge maintenance during the phase of completion. Moreover, bridge maintenance operation should be performed by regular inspection of the bridge to prevent structural malfunction or unexpected accidents from occurring by the monitoring of cracks or deformations during service. Therefore, technical breakthroughs related to this little known field of bridge maintenance are creating a turning point with the public. This study aims to develop an automated inspection system to lower the surface of bridge superstructures and to replace the conventional system of bridge inspection with the naked eye, where the monitoring staff is directly on board to refractive or other types of maintenance vehicles. These are expected to solve some of the problems that are caused by the subjective manner of the monitoring staff. Essentially, the results of such inspections will be varied and will change in terms of quantitative data and objectivity. By using an effective method using data captured by cameras, the objectivity will be secured and an objective estimation of the cost will also be available. In addition, such a system will also increase stability in safety during the inspection, and make a contribution to the construct data base by providing objective and quantitative data and materials through image processing. By this system it is also expected that objective estimation over the right time of maintenance and reinforcement work will lead to an enormous decrease in maintenance cost.

INTRODUCTION

The load effect that occurs due to the weight of vehicles running on the road and the increase in traffic volume quickly develops damage on bridges and is considered an important issue in terms of maintenance and management. If we do not pay attention to the maintenance and management of structures from the stage of completion, we would not be able to maintain satisfying results throughout the use of the structures. In order to discover structural damage, such as cracks and large deformations early enough to prevent functional impairment or disastrous accidents, it is important to implement regular inspections. For an economic and efficient implementation of maintenance and management, it is important to provide scientific and systemized measures, and it is inevitable that the introduction and operation of a reasonable maintenance/management system that can integrate the developing computer systems, measuring devices, structural stability assessment techniques, and repair/reinforcement techniques in a single process.

This study was conducted to replace the current system, in which bridge diagnostics specialists ride on inspection vehicles to perform visual inspections, with a robotic system equipped with a small camera. The new system would greatly reduce the effort required, enhance the safety of inspectors and provide more accurate and efficient data that are objective and quantitative. As the robotic system would be small in size, maintenance would not require traffic restriction.

CONFIGURATION AND CHARACTERISTICS OF ROBOT SYSTEM

System Configuration

The robot system's configuration is shown in Figures 1 and 2. The system would consist of the following two parts in large.

Investigative Camera System: An encoder or potentiometer is installed on the focus or zoom lens of the investigative camera to control the camera's zoom and focus to record cracks up close. The electric signals from the sensors on the focus and zoom lens are processed through micro-processing technology to calculate the severity and width of cracks on structures.

Bridge Appearance Investigation Mechanism: A rail or steel cable is installed along the bridge to hold the Linear Motion Control System in place. The controlled camera system is installed on the mechanism to transmit video images through wired or wireless communication for inspectors to read them on their computers.

Operation Principles

A camera with pan/tilt drive that moves up and down and left to right is installed on a dual-axis scalar robot to transmit the images from the bottom of bridges through wired or wireless communication and the transmitted visual images are processed through the machine vision program to perform an inspection on the surface of bridges. The dual-axis scalar robot basically uses a single-axis motor for linear conveying and another motor for rotating. Inspectors may choose wired or wireless communication to operate the remote controls and move the camera to the desired locations quickly and conveniently.

The camera's zoom system adapts a super zoom lens and uses a pan drive and tilt drive to rotate 360° horizontally and 90° vertically. Thus, inspection can be done in every direction. The camera system has an image transmission circuit and transmits visual images to the monitoring computer via wired or wireless transmission. Transmitted images are processed using the vision program in the computer to calculate the width and length of cracks and can be saved for future references and comparisons.

In order to calculate the width and length of cracks, it is necessary to determine the physical size of each pixel on the image data. Sensors such as encoders or potentiometers are installed on the direct motor that operates the camera's zoom and/or focus lens, and deliver output electric signals from the two sensors to the controller to automatically determine the physical size of a pixel using manipulated data, which can then be used to calculate the width and length of cracks.

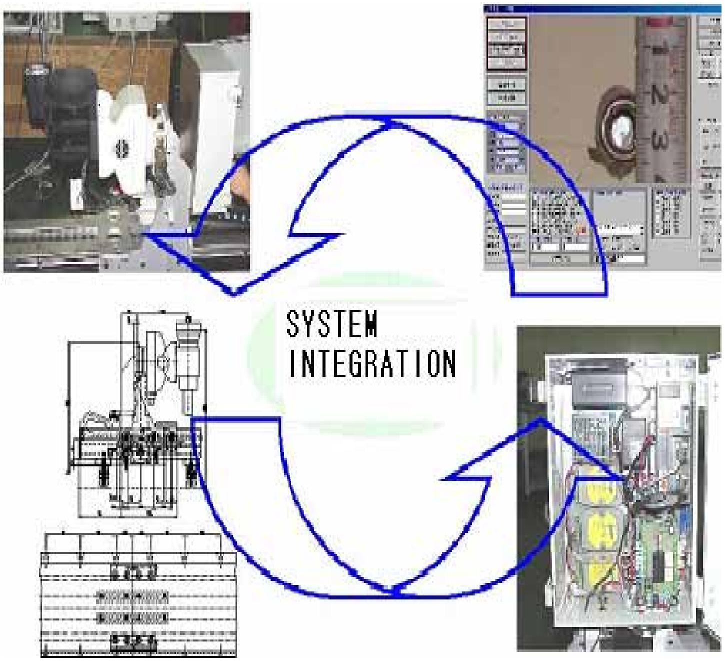

Figure 1. A Schematic Diagram of an Automated Inspection System.

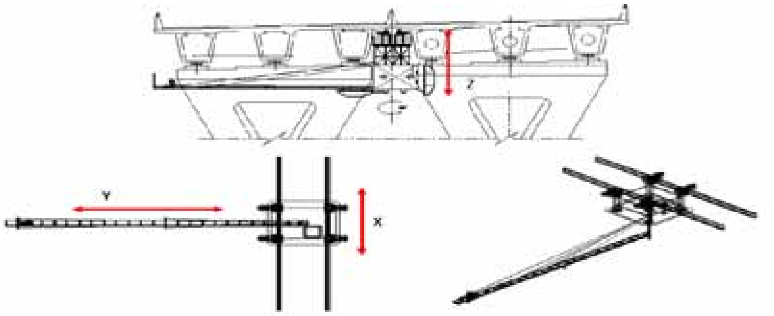

Figure 2. A Design Example of Bridge Appearance Inspection Mechanism

System Characteristics

The developed Machine Vision System is the key part of the automated bridge inspection system and has the following characteristics.

- It can determine the objective width and length of cracks.
  (0.1mm width cracks can be measured at a distance of 2-5m).
- Maximum approach is possible as the system is remote controlled.
- The information of defects is saved in image files and stored as an objective datum.
- Inspectors operate the system at a safe place for safety.
- Minimum number of inspectors are needed for labor-efficiency.

DEVELOPMENT DETAILS

Machine Vision System

The Machine Vision System consists of pan/tilt drives, zoom lens, CCD camera, controller, and crack width/length measuring program as shown in Fig. 3. In this study, two more cameras are added to improve performance and enhance efficiency when measuring width and length of cracks.

Linear Motion Control System

As shown in Fig. 4, the Linear Motion Control System holds the Machine Vision System and moves perpendicular to the longitudinal axis of the bridge for inspection. This study considered field application on a concrete bridge supporting a two-lane road and was set to operate automatically according to the user's setting criteria.

PLC Control of a Mechanism

The Programmable Logic Controller, shown in Fig. 5, was developed to move the Machine Vision System along or perpendicular to the bridge axis. Operators can set coordinates for the range of scanning, and enter increments to each direction (Dx, Dy), to operate the Machine Vision System automatically and to capture and save images of bridge bottom.

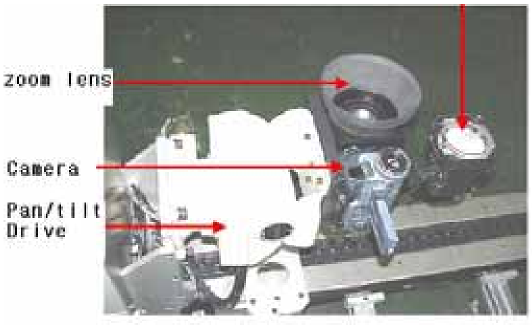

Figure 3. Controlled Machine Vision System.

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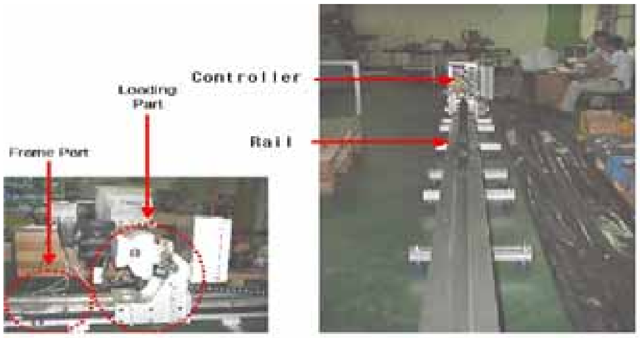


Figure 4. Linear Motion Controlled System.

Figure 5. Programmable Logic Controller.

Bridge Investigation Network Program and Its Interaction with BMS

As shown in Fig. 6 or Fig. 7, the visual image data is connected to the existing Bridge Management System (BMS) and combined into a single unit of data for higher efficiency. Then, users can scroll down to enter information on cracks or convert it to a CAD file to open on the existing BMS. As the existing BMS has variable configurations and input/output formats, the new program improves compatibility with BMS by allowing it to save image files in Auto-CAD format as shown in Fig. 8.

Various Mechanism Design for Field Application

To enhance field application of the crack investigation vision system, various mechanisms and application methods were developed for each type of bridge. These mechanisms and application methods were produced in drawings for various applications. This study chose the following applications according to the types and environments of selected bridges, and produced drawings for these applications for future reference.

- When using rails;
- When using a small robot that moves on cables;
- When using a refractive vehicle with four links;
- When using to inspect the appearance of steel bridges.

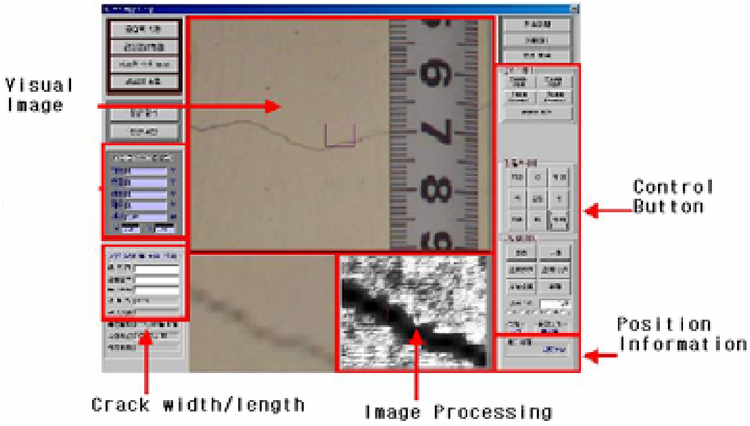


Figure 6. Digital Image Processing for Crack width.

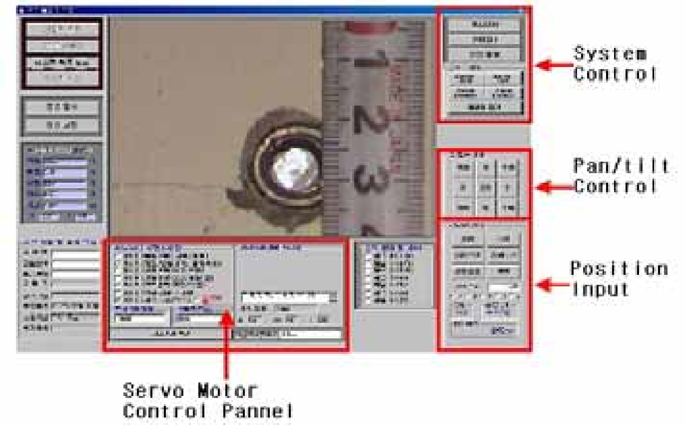


Figure 7. Position Control and Its Interaction with BMS.

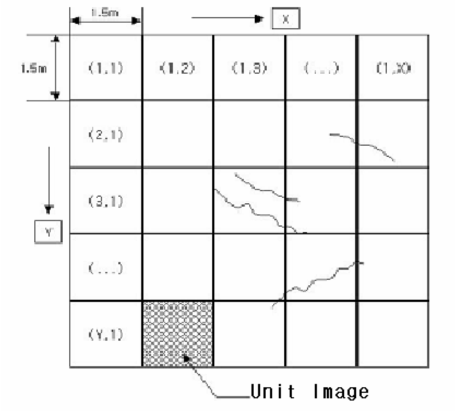


Figure 8. Unit Images and transforming to Auto-CAD formatted files.

EXPECTED EFFECTS

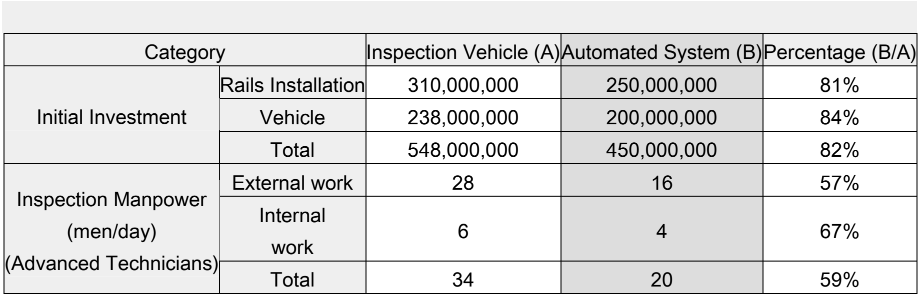
Most production facilities are adopting automation for advanced industrialization, but constructional products are too various in type and style and it is difficult to standardize production of materials and structures. Thus, automation of constructional devices is respected and delayed. However, automation technology has direct effects by allowing for higher productivity and social effects by creating a better work environment and protection from industrial hazards. The technical ripple effect of this study would be:

Bridge Management Database: This study uses Machine Vision System to save visual images of the defects of a bridge and builds a database of images to manage the performance history of bridges.
Revitalization of Automation Technology in Construction: This study is limited to automating appearance investigation of bridges, but its technology could be applied to construction robots and repair/reinforcement robots to minimize hazards and increase the use of automation technology at construction sites.

Broader Use of Know-how: This study uses Machine Vision System based on Digital Image Processing Technology. This technology could be applied to inspecting various other structures such as tunnels and LNG tanks.
Safety Culture at Construction Sites: By replacing the visual inspection technique with automated (robotics) technology, construction works would improve in efficiency and achieve various social effects, such as an improved work environment and protection from hazards. With the introduction of a safety system, a culture of safety would be established.

Economic gains : An estimated comparison of the existing inspection system and the new automated system in terms of manpower and initial investment required to perform inspection on a 500m range of a six-lane steel box bridge, is as shown below:

Table 1. Comparisons of expenses between the Existing Method and Automated System.



Category		Inspection Vehicle (A)	Automated System (B)	Percentage (B/A)
Initial Investment	Rails Installation	310,000,000	250,000,000	81%
	Vehicle	238,000,000	200,000,000	84%
	Total	548,000,000	450,000,000	82%
Inspection Manpower (men/day) (Advanced Technicians)	External work	28	16	57%
	Internal work	6	4	67%
	Total	34	20	59%

CONCLUSIONS

Bridge structures are generally massive and have many parts that are difficult and unsafe to access. These characteristics greatly restrict performances of visual inspectors and may cause them to produce inspection results that are erroneous or have ommissions. To solve these problems and to secure the safety of inspectors, it is necessary to adopt mechanical measures to perform inspections. The purpose of this study was to solve these problems. This study can be applied to most bridges and is especially expected to accomplish inspection under the following circumstances:

- Express railroad bridges, bridges connecting islands, and urban arterial bridges that have high volumes of traffic and cannot be blocked for inspection;
- Long and wide PS concrete bridges, bridges across rivers, and bridges across seas;
- Bridges difficult to access, bridges that pass mountains, express railroad bridges, and bridges across waters.

In addition, the technology developed in this study would also be applicable to inspect underground box structures, such as urban electricity/communication panels and box structures that are buried beneath highways.

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