The 3rd International Conference on Structural Health Monitoring of Intelligent Infrastructure
Vancouver, British Columbia, Canada
November 13-16, 2007

ROBOTIC SYSTEMS FOR AUTOMATED BRIDGE INSPECTION

Jong Seh Lee
Hanyang University at Ansan, Korea

Inho Hwang
Hanyang University at Ansan, Korea

Jun Hyung Park
Hanyang University at Ansan, Korea

Jong Han Lee
Hanyang University at Ansan, Korea

Abstract

Conventional bridge inspection involves the physical positioning of an inspector by the hydraulic telescoping boom of a “snooper truck” thereby providing visual access to otherwise inaccessable bridge components. The process is time consuming, hazardous, and may be affected by environmental conditions. Therefore, it is of great interest that an automated or teleoperated inspection robot be developed to replace the manual inspection procedure. This paper describes the advanced bridge inspection robot system under development and other related activities currently undergoing at the Bridge Inspection Robot Development Interface (BIRDI). The BIRDI is a research consortium with its home in the Department of Civil and Environmental System Engineering at Hanyang University at Ansan in Korea. Its primary goal is to develop advanced robotic systems for bridge inspection and monitoring for immediate field application and commercialization. The research program includes research areas such as advanced inspection robots and motion control systems, sensing technologies for monitoring and assessment, and integrated systems for bridge maintenance. This research project will contribute to the advancement of infrastructure maintenance technology, enhancement of construction industry competition, and promotion of the national capacity for technological innovation.

INTRODUCTION

After the collapse of the Seongsoo Bridge in 1994, the Korean government established the "Special Law for Safety Maintenance of Infrastructures." This law mandates that all important civil infrastructures, such as bridges, tunnels, etc., must be inspected periodically. Conventional inspection methods involve the physical positioning of an inspector by the hydraulic telescoping boom of a “snooper truck” thereby providing visual access to otherwise unaccessible bridge components. The process is time consuming, hazardous, and may be affected by various environmental conditions. Therefore, it is of great interest that an automated or teleoperated inspection robot be developed to replace the manual inspection procedure. In some cases, the inspection robot system could provide the only feasible means to access the place where structural engineers can not access.

There have been previous efforts using robots for infrastructure maintenance and monitoring. The Robotic Inspector (ROBIN) was developed at the Intelligent Robotics Lab at Vanderbilt University to inspect man-made structures [1]. The Robotic Bridge Management System (RBMS) was developed by the Construction Automation and Robotics Laboratory (CARL) at North Carolina State University. The system consists of a 4-degree-of-freedom robot mounted on the end of a truck-mounted peepercrane. Primary goals of the RBMS include paint removal and painting of steel bridge beams and trusses [2]. Huston et al. [3] showed that a robot can be used to power and interrogate remotely placed addressable sensor modules (ASM's) for structural inspection. Some early attempts up to the 1980's have been reviewed by Skibniewski [4].

The Bridge Inspection Robot Development Interface (BIRDI) is a research outfit with its home in the Department of Civil and Environmental System Engineering at Hanyang University at Ansan in Korea. The BIRDI is funded by the Ministry of Construction and Transportation through a new R&D initiative on the Cutting-Edge Technology Fusion for Construction which started in 2005. Its primary goal is to develop advanced robot systems for bridge inspection and monitoring for immediate field application and commercialization as shown in Fig. 1. The research program consists of three major subject areas: 1) Integrated systems for maintenance of bridges, 2) Sensing technologies for monitoring and assessment, and 3) Advanced inspection robots and motion control systems. The center embraces 12 institutions, which consists of 7 universities, 2 research institutes, and 3 private enterprises. Research projects are cross-disciplinary and include experts from structural engineering, mechanical engineering, electronic and control engineering. This research endeavour should contribute to the advancement of infrastructure maintenance technology, enhancement of construction industry competitiveness, and the promotion of national capacity for technological innovation through collaborative research.

This paper describes the bridge inspection robot systems under development and other related activities that are currently undergoing at the BIRDI.

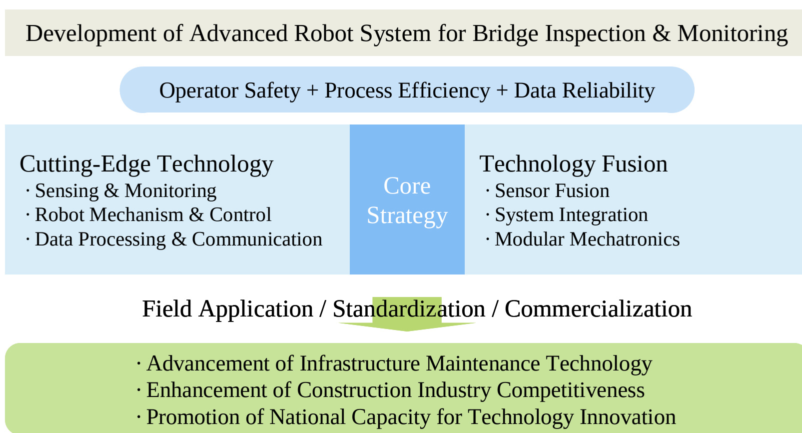

Figure 1. BIRDI's Mission.

BRIDGE INSPECTION ROBOT SYSTEM

Research efforts in bridge inspection at the BIRDI focus on the development of products that will allow remote inspection of bridges, while reducing human risks and improving efficiency and reliability. The inspection robot system consists of three major units: the robot and platform system, machine vision system, and the data management system. Fig. 2 shows the process of the bridge inspection robot system.

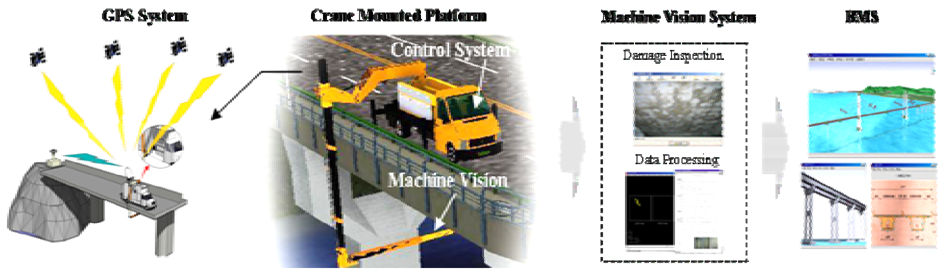

Figure 2. Bridge Inspection Robot System.

Crane Truck

The crane truck looks similar to the conventional bucket crane, but is much smaller in size and is light in weight. The modified peeper crane truck with a four-boom crane is being built as shown in Fig. 2. At the end of the telescoping boom which is 12m long, a robot platform is mounted which allows the operator to scan the bridge structure under the deck through the camera.

Robot Platform and Control

This robot system consists of three parts: the base transport, vertical movement part, and the horizontal position control part (Fig. 3). Each part which has a motor driver and a motor is modularized for easy maintenance and repair. For added maneuverability, the robot is controlled by a PHANTOM omni haptic device to give “force reflector.” This device has three translational and three rotational degrees of freedom. The user interface employs haptic window and open GL window for 3D control. The haptic device sends signal through Win32 process using the shared memory to RTX process which in turn communicates with the robot by UDP and writes received feedback signal at the shared memory. The feedback signal can be used for force reflection of the haptic device and 3D realization of the OpenGL. Communication between the devices can be accomplished using DSP 2812 and UDP protocol.

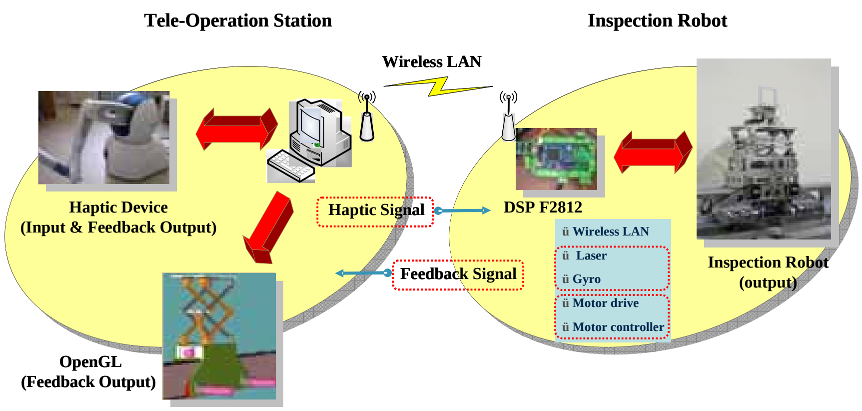

Figure 3. Robot Platform and Control System.

Machine Vision System

A machine vision hardware system and related image processing algorithms have been developed to replace the manual inspection of the underside of the bridge deck (Fig. 4). The vision system obtains images from a camera mounted on the telerobotic platform. The camera can be panned and tilted to see from any angle. It is equipped with a motorized, auto focusing zoom lens. Specification of the camera unit has been determined along with some image processing algorithms, such as image enhancement, crack detection and image mosaicing. For optimal performance of the vision system, many parameters such as weight, electric power supply, communication method, and cable thickness, etc. have also been determined.

Conforming to the system specifications, the hardware system for inspecting defects of bridges is designed. Associated algorithms for processing the images captured from the hardware system are designed and implemented. Current activities focus on building a prototype of a semi-automatic vision system. The main issues under investigation include the development of interfaces for controlling robot systems, implementation of hardwares and softwares for remote control, and the development of vision algorithms for semi-automatic system control for detection of cracks and other damages. The ultimate goal is to develop an intelligent vision system which is suitable for immediate field application for autonomous bridge inspection. To this end, an improved version of vision algorithms for more accurate inspection is to be developed. Various techniques with artificial intelligence for autonomous detection of defects are being investigated, and the performance of the integrated system is analyzed and evaluated.

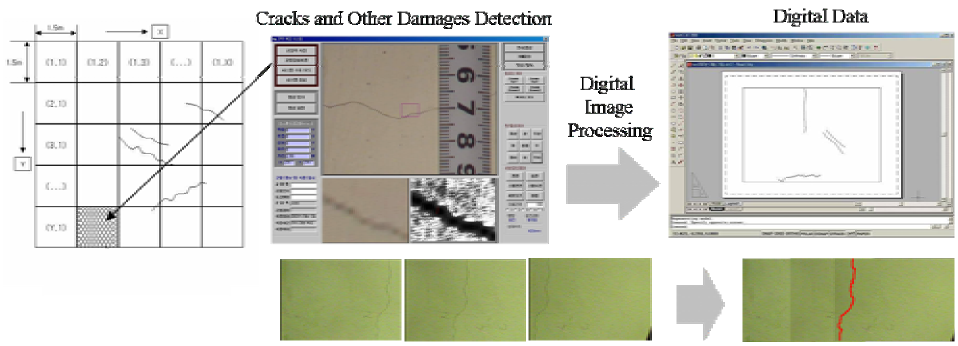

Figure 4. Machine Vision System (crack detection and digital image processing).

Web Based Monitoring System
Another system under development in parallel with the machine vision system is a wireless, web-based remote monitoring and control system which will allow users to collect, access, and easily view data from the robot 24-hours a day from any Internet-connected appliance via a secure, central web site. This web-based interface allows users to monitor, report, and configure with ease. Users will benefit from the system's timesaving functionality, relevant data reports and security features. Personnel can simultaneously configure multiple RTUs via the triple redundant, secure Web interface. For detailed analysis, users can view and export a variety of reports.

All hardware and interface software have been designed and developed to be used exclusively for the BIRDI so that the system can easily make updates as the technology grows. In addition, the BIRDI designed the web interface to provide users with a reliable and dynamic means to gather remote data, manage the generation, delivery, as well as to allow for easy equipment configuration and manipulation.

The data which the web-based monitoring system supports can be classified into the real time data such as vibrations and positions of the inspection robot, the image data obtained by the camera unit and the basic information data of the bridge. The information about vibration and position of the inspection robot is received by local area receivers through a wireless data transmitting system which acquires signals by GPS, the accelerator sensor, angle meter, etc. The data is obtained through a TCP/IP network by the data disposal processor which uses web protocols and saves the data in a web database. The image data enables mapping the GPS location information with the existing database information to closely investigate and identify the damages and defects.

Inspection Database Management
The inspection data obtained by the inspection robot system will be stored in a database as shown in Fig. 5. The database includes processing and preserving the inspection data and also includes assessing the condition of the bridge based on the inspected data whether or not it needs repairs. This database will be incorporated into existing bridge management systems such as the KBMS.

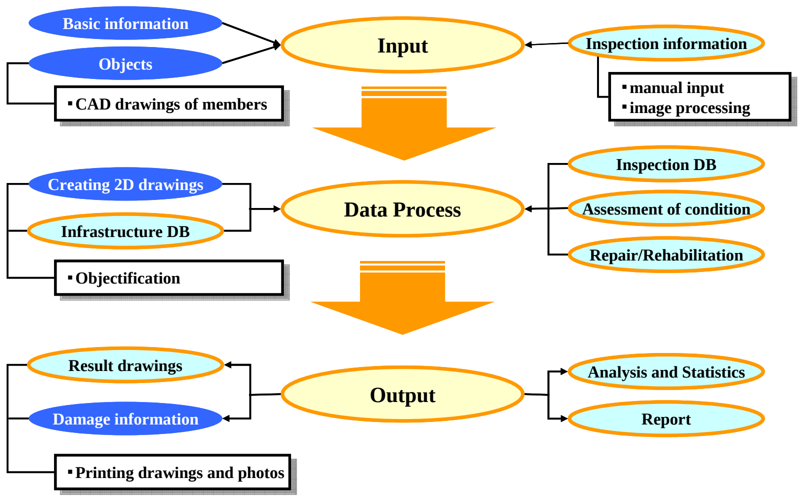

Figure 5. Schematics of Database System.

OTHER PLATFORMS UNDER DEVELOPMENT

Other robot platforms under development at the BIRDI include light-weight rail-driven platforms, aerial platforms, and wall-climbing platforms. These platforms should provide easier or more economical means of access to different types of bridges for which the crane type platform may not be a viable mode of automated inspection.

Rail Driven Platform

Another robot platform under development is a light-weight rail-driven automated inspection system as shown in Fig. 6. A guide rail is installed to the under side of bridge superstructure. Attached to the rail is a boom on which a camera unit is mounted. The camera unit can move along the boom scanning the underside of the bridge deck in the transverse direction while the boom travels along the rail in the longitudinal direction. Once the half of the bridge deck underside is inspected, the boom can swing around to repeat the scanning for the other half of the bridge deck.

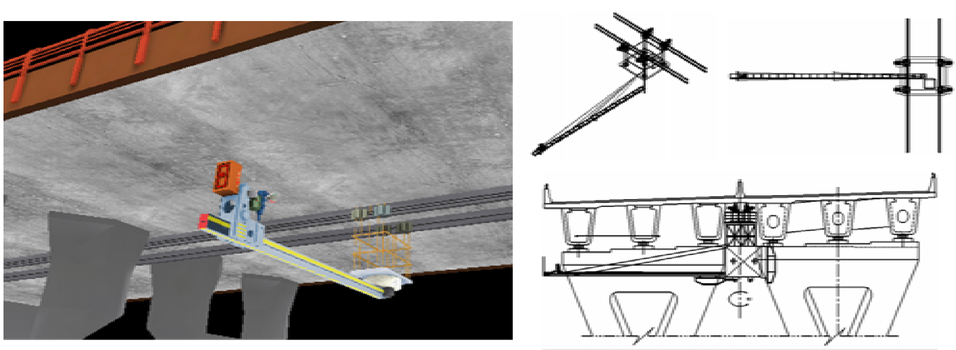

Figure 6. Schematics of Rail-Driven Platform.

Flying Robot Platform

A robotic aerial bridge inspection platform is under development that will make bridge inspection safer, faster, more efficient, and less expensive. This project introduces a flying robot system which is combined with an UAV (Unmanned Aerial Vehicle) and a mobile robot platform on which inspection instrumentation can be mounted. The UAV has two coaxial rotors to fly and four thrusters to be attached under bridges, and the mobile robot platform has four omni-directional wheels to navigate the lower surface of the bridges (Fig. 7). The developed robot is attached to the lower surface of a bridge using the UAV, navigates the surface autonomously using the mobile robot platform under the localization environment using ultrasonic satellite, and sends images of the surface using a CCD camera through wireless communication.

Figure 7. Flying Robot System.

Areas under development include the omni-directional movable algorithm, flying robot system and flight control algorithm for bridge inspection, 3 DOF controllable camera gimbals, and ground control system and its operation technology. Attention is being directed also to the establishment of the fittest design basis according to design variables such as payload and flying time and the development and stabilization of small-sized light- weight embedded controllers.

Wall Climbing Platform
A wall climbing robot platform is under development as it is desirable for autonomously inspecting vast areas of an industrial structure including bridge decks and piers. Wheel type movements and vacuum pad adhesion methods have been chosen after reviewing many alternatives. Motor-impeller type adhesion mechanisms have been designed and prototyped as shown in Fig. 8.

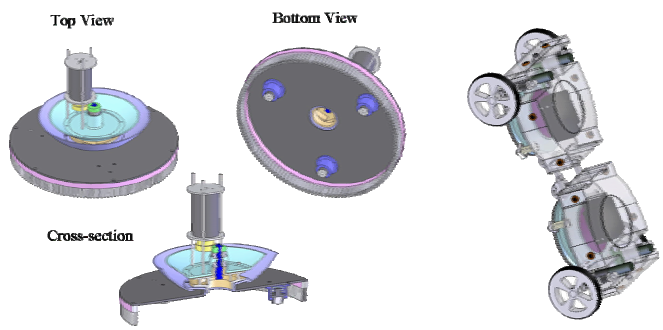

Figure 8. Wall Climbing Platform.

REPAIR ROBOT PLATFORM

A repair robot platform and corresponding control technologies have been developed to repair cracks using epoxy injection on the bottom of a concrete slab. Fig. 9 shows the prototype repair mechanism. One of the difficulties encountered in developing this mechanism is the vibration of the robot platform and the lack of the reactive force. Vacuum technology is adopted at the four legs of the robot frame using multiple pads in order to obtain sufficient reactive force for repair load. The vacuum level is controlled according to the air leaks into the rough concrete surface.

Various control technologies have been developed and tested to perform the injection procedure including the force control. A CCD camera is used to aid the remote control of the robot. The auxiliary indexing laser beam is adopted to guide the robot to the surface and compensates the rectangular coordinates for the robot workspace. Synchronous serial data communication of SynqNet and the CAN are used for the communication and power supply for precise control of servo motors between the robot and the controller.

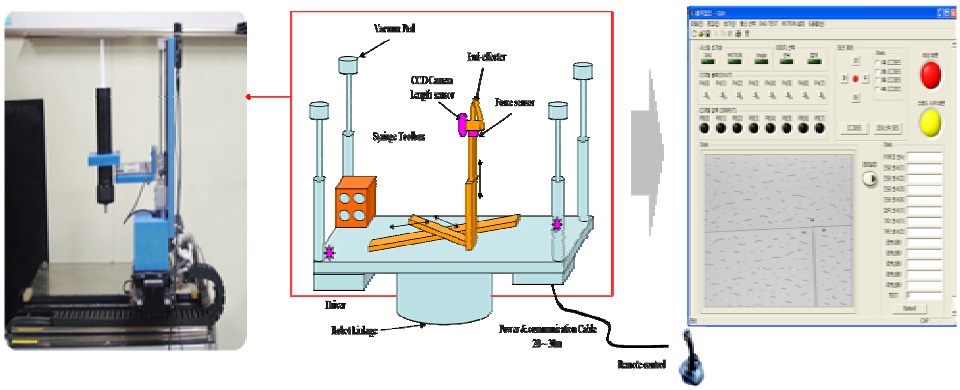

Figure 9. Repair Robot Platform System.

NON-DESTRUCTIVE METHODS

Non-Destructive Tests (NDT) are increasingly popular not only for assessing the physical properties of materials in bridges, but also for interrogating physical conditions and the extent of damages or anomalies of structural members and systems. Conventional NDT techniques are manually performed to get useful information from the target structures. However, these techniques have been gradually transformed to automated modes spurred by the rapid development of information technologies. At the BIRDI, we have noted the promising potential of the infrared thermography as a viable means for inspection of concrete bridges for damages or defects under surface to complement the visual inspection of the surface.

Infrared thermography has its advantages over other non-destructive techniques. Infrared thermographic devices are much safer as it does not emit any radiation. It only records the infrared radiation emitted from the surface of a material under assessment. Moreover, infrared thermography is an area investigating technique, whereas most of the other nondestructive methods are designed for point-wise investigation. In addition, infrared thermographic testing may be performed during both day- and night-time hours depending upon the environmental conditions. The main limitation of the infrared thermographic technique is the inability to determine the exact dimensions (depth and thickness) of the delaminations.

The infrared thermography technique is applied to the NDT of concrete structures. Any damage or defect identified from the thermographic information may be investigated in detail using other non-destructive evaluation techniques such as radars, ultrasonic devices, etc. The schematic representation of the procedure is given in Fig. 10. Some preliminary studies have been performed to demonstrate its potential for field application. The research effort will focus on the development of a prototype probing module which will be mounted on the robot platform developed at the BIRDI.

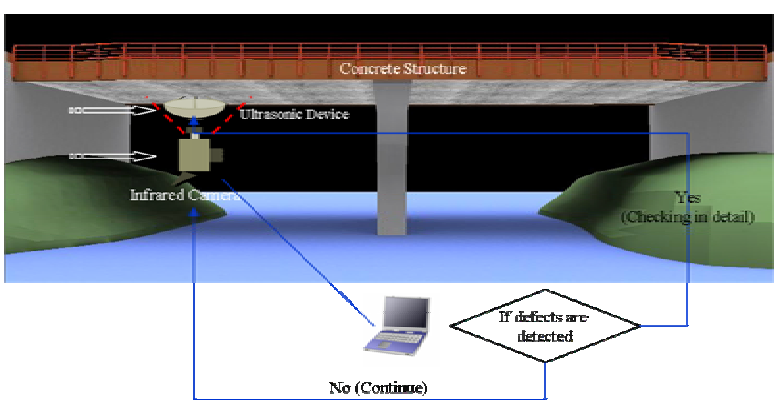

Figure 10. Infrared Thermography.

CONCLUSIONS

This paper has described advanced bridge inspection robots under development and other related research activities at The Bridge Inspection Robot Development Interface (BIRDI) at Hanyang University. The developed robot system allows remote inspection of bridges while reducing human risks and improving efficiency and data reliability. In addition, the automated inspection system is expected to expand the life span of bridges because more rational and objective inspection data obtained, in conjunction with the BMS, will help to determine the appropriate time and method for repair. The robotic systems developed in this project, with minor modifications, can easily be expanded for application to other types of infrastructures such as dams and tunnels.

REFERENCES

1. Pack, R.T., Iskarous, M.Z., and Kawamura, K., ‘Climber Robot’, US Patent No. 5551525(1996).
2. Lorenc, S.J., Handlon, B.E., and Bernold, L.E., “Development of a Robotic Bridge Maintenance System”, Automation in Construction, (9)(2000) 251-258.
3. Huston, D.R., Pelczarski, N., Esser, B., Gaid, A G., Arms, S., and Townsend, C., “Wireless Inspection of Structures Aided by Robots”, SPIE Symposium on Smart for Bridges, Structures, and Highways, Newport Beach, CA, (4330-09)(2001).
4. Skibniewski, M.J., Robotics in Civil Engineering, Computational Mechanics Publications, Ashurst Lodge(1988).