Telecommunication technologies in real-time centralized structural health monitoring

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ABSTRACT: With the increase in structural health monitoring (SHM) activities in civil engineering, telecommunication technologies have become significantly involved and participate as an essential component of a SHM system. This paper describes two techniques currently applied in the SHM system by ISIS Canada, the TCP/IP based data socket communication tool for real-time sensing data transfer and the pcAnywhere remote control software for SHM system supervision. An event triggered e-mail system and web camera image recording scheme are explained. The implementation of these techniques will be illustrated through the case study of a centralized real-time SHM system. This centralized real-time SHM system monitors three bridges and one statue. In the conclusion of this paper, future activities and research needs related to the reliability and security of the SHM system will also be discussed.

1 MOTIVATION OF REAL-TIME CENTRALIZED SHM SYSTEM

Structural health monitoring in field applications started in the 1990s with the requirement to determine and predict a structure's health condition and service life. Different sensor technologies are applied based on the different type and design of structures. The most commonly used sensors are resistance-based strain gauges, fiber optic sensors, accelerometers, inclinometers, wind meters and thermocouples. By using these sensors, researchers can derive the internal stress, vibration and inclination of the structure to examine its response to loading. This examination of response can be used to assess the condition of the structure or structural components to identify damage or to verify its current level of safety.

A complete structural health monitoring system involves many integrated components and degrees of sophistication in data analysis and damage detection (Mufti, 2001). Common to all projects, however, is the need to efficiently and effectively have the sensor data collected and transferred from the site to the engineer. From 2002 to 2004, ISIS Canada successfully integrated Internet technology into a structural health monitoring program and developed a system for real-time centralized monitoring of many projects from a single location in terms of hardware but with simultaneous multiple user access from anywhere (Han et al. 2004).

2 TCP/IP BASED DATA SOCKET COMMUNICATION

In the implementation of this centralized real-time SHM system, to collect the sensing signals from different sensors, different signal conditioning modules from National Instrument (NI) are employed and integrated together as a SCXI data acquisition system. Different selections of the signal conditioning modules with a universal SCXI chassis make the SCXI DAQ the most extendable and versatile option. The high resolution PC plug-in A\D card can control the channel scanning and collect data on a PC (Fig. 1).

In order to transfer data in real time to the central data server, ISIS Canada is using a cable modem as a communication tool that has a communication bandwidth of 100 Megabytes and a total upload and download capacity of 12 Gigabytes (GB) per month. The data transferring protocol is a TCP/IP data socket (DSTP). DSTP is a reliable and secure form of a

TCP/IP based communication socket. Systems participating in a DSTP data exchange consist of three components: a Data Socket server, a publisher, and subscribers. A publisher acquires data from a local or remote data acquisition system and sends it to the server. The server is usually located on the same machine as the DAQ. Subscribers who have an interest in the published data can subscribe to receive the data from the server. The publisher, server and subscriber all need an IP address. The benefit of the DSTP is automatic data socket connection recovery. A user can specify the duration to allow the subscribers to keep trying to reconnect to the publisher. The data transferred via the DSTP is compressed by the publisher and decompressed automatically by the subscribers, which substantially reduces the Internet communication bandwidth requirement.

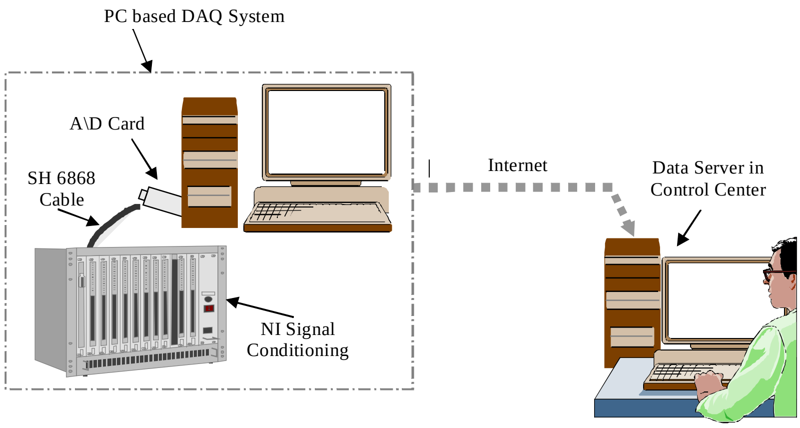

Figure 1. DAQ system and real-time data transferring via the Internet

By using the NI DAQ system and LABVIEW DSTP data transferring tool, four remote SHM systems are successfully connected together and managed under a centralized control system (Fig. 2). These four SHM systems are for the Taylor Bridge, Golden Boy Statue, Portage Creek Bridge (Mufti et al. 2003) and Esplanade Riel Pedestrian Bridge (Shehata 2004). These four structures are different in design and location. The Portage Creek Bridge is located in Victoria, BC; the Taylor Bridge is in Headingley, Manitoba; and the other two structures are in Winnipeg, Manitoba.

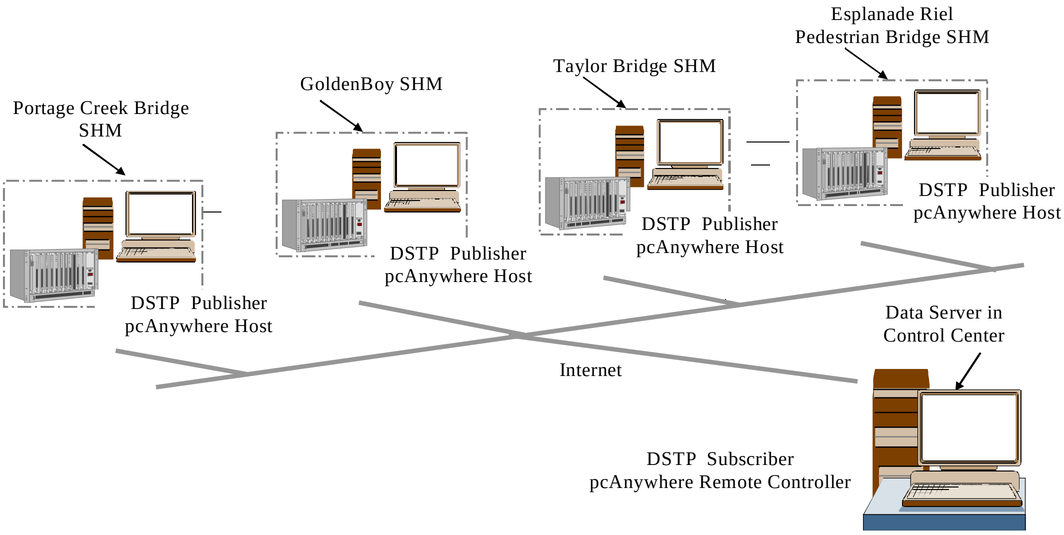

Figure 2. Diagram of centralized SHM supervision via DSTP and pcAnywhere

At the on-site DAQ, an application program is continuously running on the PC to collect the data at 32Hz and publish it to the data socket server every 5 seconds. The data socket server in these applications is located in the on-site PC and with the same IP address as the publisher. On the central control site, the data server is a Dell SC1400 Windows 2000 server. An application program is running continuously to subscribe the data from four remote sites. Every 5 seconds the new data is received and real-time signal processing is applied. The data server generates a data file every day for each monitored structure.

3 PCANYWHERE REMOTE CONTROL FOR SHM SYSTEM SUPERVISION

For the maintenance of this centralized SHM system and to avoid personal on-site visits, a remote supervision tool, pcAnywhere, is used. PcAnywhere is the most powerful remote control software. It can manage both Windows® and Linux® systems. Enhanced built-in AES 256-bit encryption helps make communications fast. PcAnywhere has three tools: a host, a remote control and file-transfer capability. A PC with pcAnywhere installed can be configured as a host, a remote control site or both simultaneously. A pcAnywhere host is usually set up to allow only authorized users to log in remotely. A host can be accessed via dial up phone line, network cable/DSL and direct connection. A pcAnywhere remote has management tools to allow direct access to vital operating system utilities on the host, such as File Manager, Command Prompt, Task Manager, and Services. In the application of the centralized SHM system, pcAnywhere is used as a supervision tool. The on-site SHM systems of Portage Creek Bridge, the Golden Boy Statue, Taylor Bridge, and Esplanade Riel Pedestrian Bridge are set up as hosts (Fig. 2). The Data Server is a remote controller, which allows to remote log in each SHM system to perform regular maintenance tasks such as disk cleaning, critical security updates, modifying the data collection application program, etc.

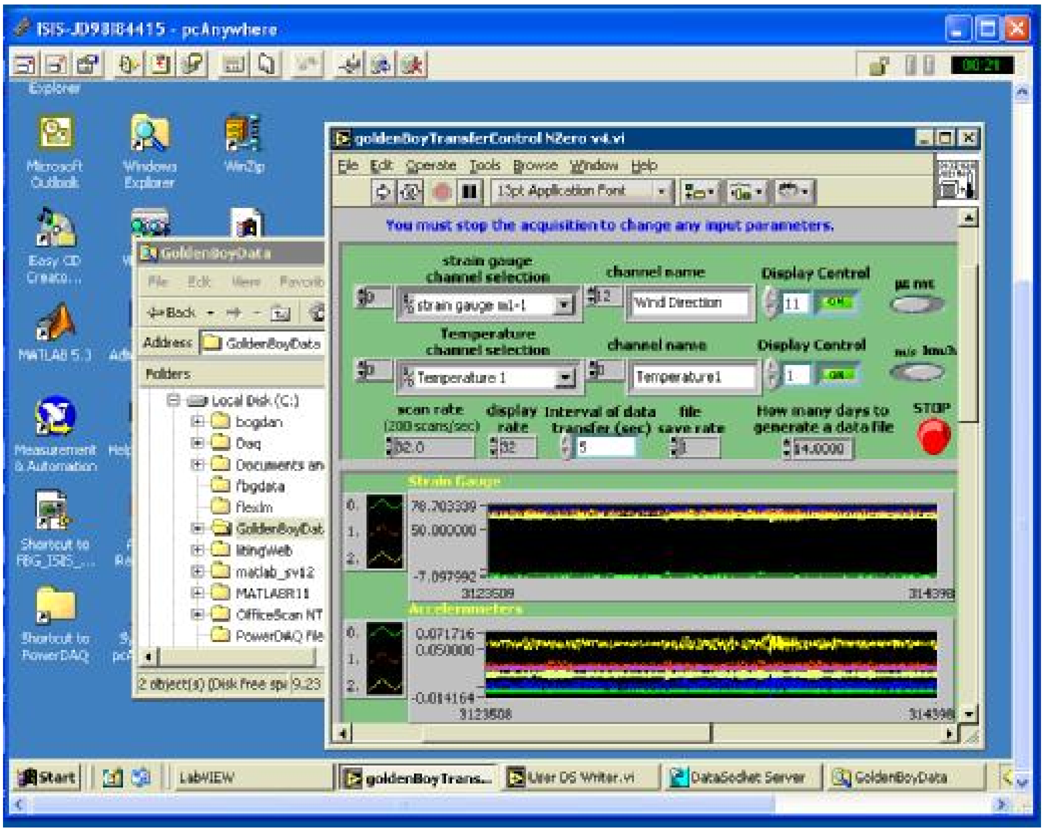

Figure 3. The pcAnywhere remote access window

Figure 3 shows the pcAnywhere remote access pop up window on the data server when the data server logs in the Golden Boy SHM system to set up the data collection program. From that window, the data sever has power over everything running on the Golden Boy SHM system. The hosts are in the waiting status when there is no remote controller log in. PcAnywhere was first employed as a SHM remote supervision tool in 1997 for the Taylor Bridge SHM system. With new features continuously developed, the pcAnywhere becomes more stable and secure which makes it to be a feasible remote supervision tool in the application of centralized SHM systems.

4 EVENT TRIGGERED E-MAIL SYSTEM

From a practical point of view, how to effectively utilize the real-time data from the SHM system is dependent upon the efficient detection of an abnormal event and the delivery of an event message concurrently to the supervisors. Besides using a professional intelligent algorithm to extract the event-related data, the following shows a very simple method, which is based on the readings from a set of pre-determined sensors located at key points in the monitored structure. Whenever a reading from any of those sensors exceeds a pre-defined threshold, an event message will be sent out in real-time. Figure 4 illustrates the structural health monitoring program implemented for the Esplanade Riel Pedestrian Bridge project. In this program, the user can select which channels should be the e-mail trigger and set the threshold of each trigger. When the program begins, a recipient list window will pop up to allow the user to input the e-mail addresses to which the event alerts will be delivered. This ‘Email Function’ can be integrated into either the data collection program of the on–site DAQ or the data management program on the central data server. In the latter case, there will be a delay of a few seconds due to the data transferring from the on-site DAQ to the central data server. Some algorithms, such as the logical combination of the triggers, can also be implemented to generate the event alerts.

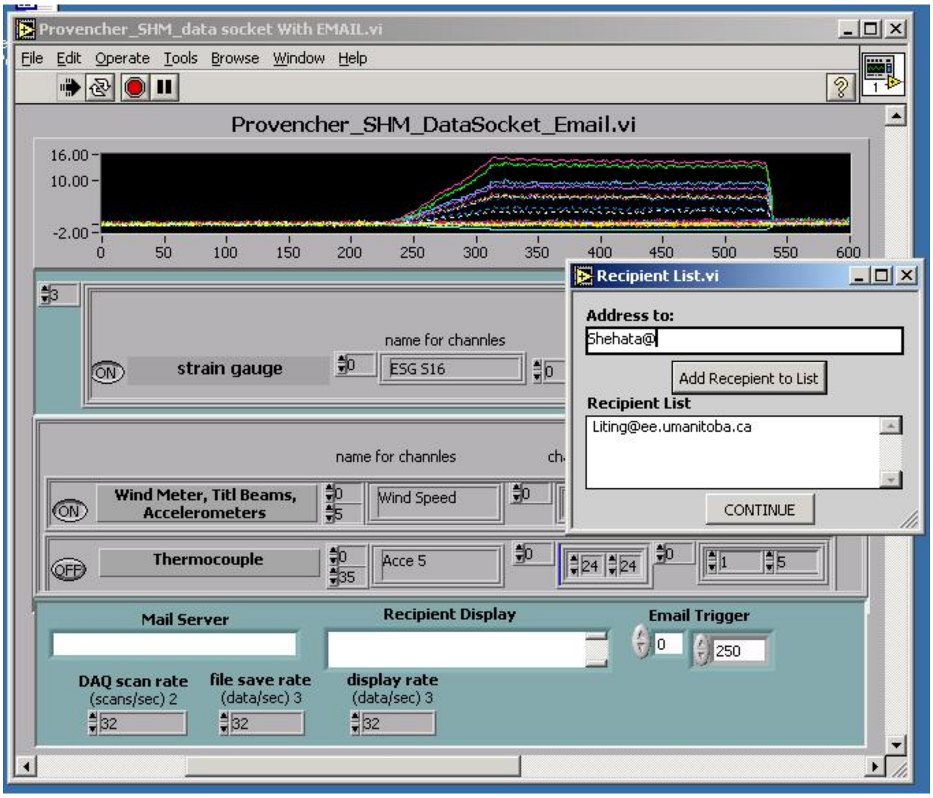

Figure 4. Event triggered Email Function in Esplanade Riel Pedestrian Bridge SHM system

5 EVENT TRIGGERED WEB CAMERA IMAGE RECORDING

ISIS Canada is currently hosting four real-time SHM systems. An example of this is for the Portage Creek Bridge (Fig. 5) located near Victoria, British Columbia. Due to seismic loading concerns, fibre reinforced polymer wraps are used to strengthen the short columns of the Pier No. 2. The bridge is instrumented with 8 Fibre optic long gauge sensors developed by Fox-Tek Inc., Toronto, Canada, 16 electric strain gauge rosettes, 2 M-Series Cross Bow 3-D accelerometers (Fig. 6). A strain gauge rosette is an arrangement of two or more closely positioned gauge grids, separately oriented to measure normal strains along different directions. The FFT analysis is also applied to the accelerometer readings to view the frequency responses.

Figure 5. Portage Creek Bridge in Victoria, British Columbia

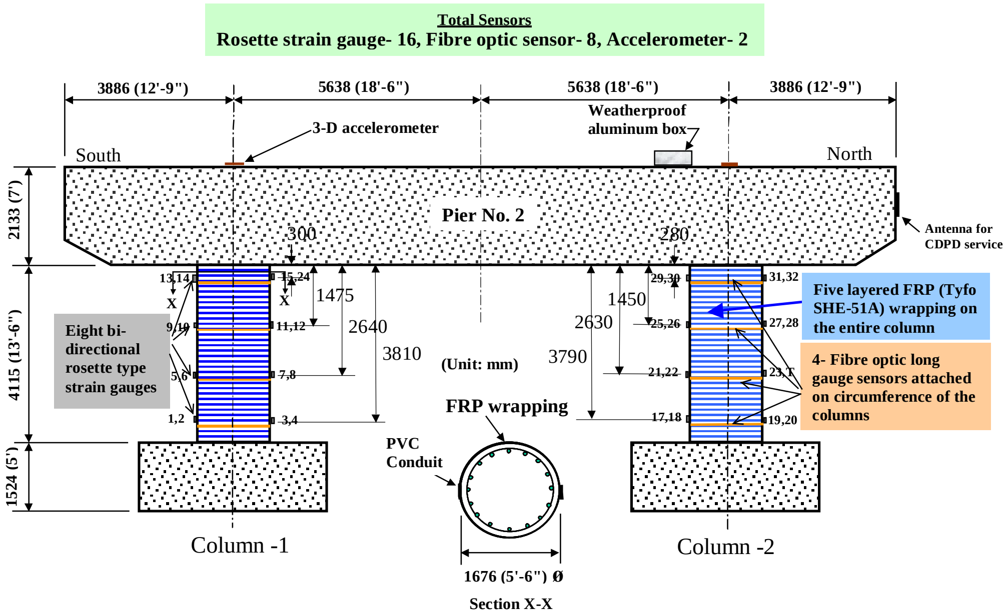

Figure 6. Elevation of Pier No. 2 with sensor locations

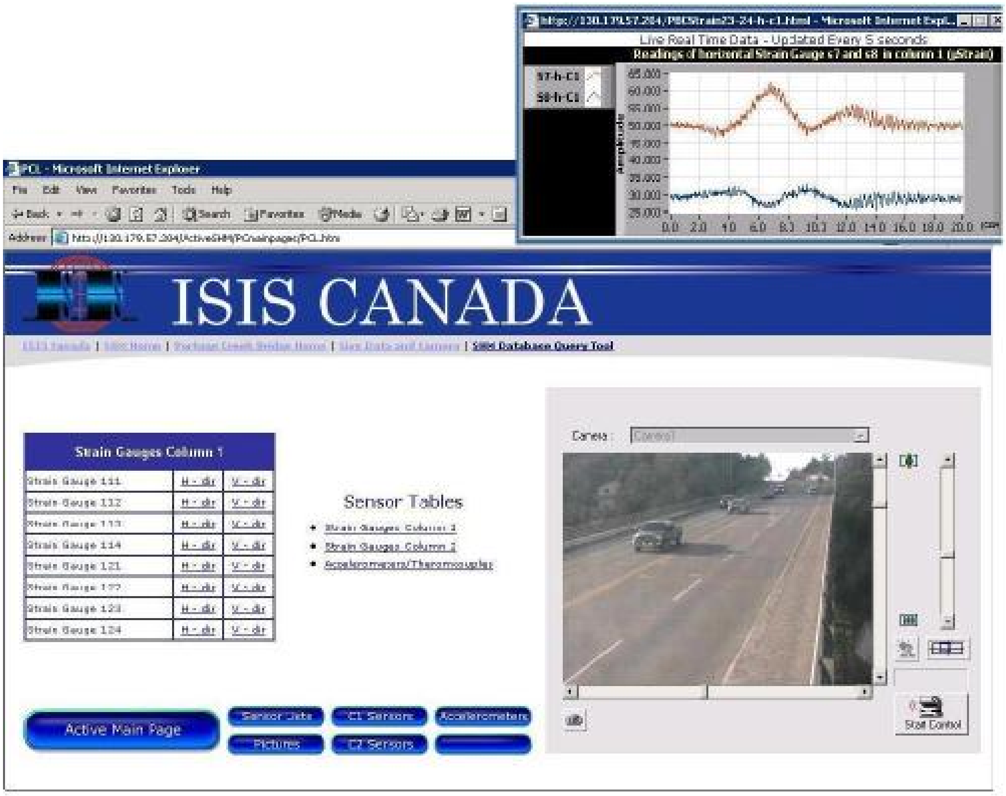

Figure 7. Portage Creek Bridge SHM web page integrating sensing data and web camera

The general framework for website construction integrating sensing data and a web camera has been implemented and is shown in Figure 7. A Pan, tilt, zoom web camera has been installed on-site and integrated onto the web page to allow researchers a real-time view of the condition of the structure and the sensing data simultaneously. But to record and store web camera images continuously 24 hours a day is still not practical due to the storage space of the data server. With a medium resolution, one image data file is about 60 Kilobytes. Saving one image per second creates 5.2 Gigabytes every day. For a data server with 120 Gigabytes of data space, it can only host six days of data when monitoring four SHM systems. To process and manage huge volumes of image data is also very time consuming when actually 80% of the images are not significant or event related. To solve this problem, a trial is being conducted for the Esplanade Riel Pedestrian Bridge SHM system. The camera on site is being configured to continuously FTP one image per second to the central data server. The central data server keeps only images of the most recent 5 minutes by the first in and first out rule. These images are temporarily saved in cache memory. When the sensors generate an event trigger, the central data server will time tag the recorded images in cache memory and move them to the hard drive for archiving. It has been proven that transferring 60 Kilobytes of image data every second from the on-site camera to the central data server is still possible, and the event triggered web camera image recording method makes the maintenance of the data server easier and the image data storing and processing more effective and valuable.

6 FUTURE WORK: RELIABILITY AND SECURITY OF SHM SYSTEM

For long-term continuous monitoring, the most desirable SHM system should be reliable and highly secure, especially when the SHM system is located at a remote site and cannot be accessed effortlessly. A SHM system can crash due to a power failure, disk overflow, memory leakage or frozen programs, etc. A computer-based SHM system is also vulnerable to viruses, especially as it is running continuously. Improving the reliability and security of a SHM system is still being researched and more investigation is required.

6.1 *Reliability*

Engineers within ISIS Canada are currently conducting research into different methods to improve the reliability of the SHM system. Through the studies of four established SHM systems, it has been determined that using an uninterrupted power supply (UPS) is an efficient and cost-effective method for preventing the DAQ from crashing due to a power failure. In addition, almost all UPS systems have surge protection, which is also beneficial to the DAQ system. Future research will be focused on how to automatically detect and stop the memory leakage problems and kill the frozen programs. A temporary solution that is currently used is to automatically and routinely restart the DAQ system. At implementation, a schedule is established on the data server to take this action every two weeks. The data server sends a command to signal the Ethernet card on the remote DAQ to trigger a restart. The data logger program, which is running as a service, will automatically be launched once the DAQ is restarted. It has been confirmed that, since this method was applied, maintenance of the four SHM systems has been greatly reduced and the chance of a system crash reduced to zero.

6.2 *Security*

The security level of a SHM system is closely related to the operating system on which it is built. The four SHM systems operated by ISIS Canada are Windows-based, which is user friendly but relatively easy to attack. To make the SHM system more secure, critical updates and service packs are automatically installed. Keeping the DAQs and data server running under a general user account rather than as an administrator is also very helpful. It has been found that using a router to isolate these devices from the public interface greatly reduces the security vulnerability.

7 CONCLUSIONS

This paper addressed the general outline and motivation for real-time structural health monitoring and the strategy for incorporating Internet technology. Two techniques, the TCP/IP based data socket communication tool for real-time sensing data transfer and the pcAnywhere remote control software for SHM system supervision, were described. An event triggered e-mail system and web camera image recording scheme have been explained. Some techniques to improve the reliability and security of a SHM system have been proposed, but they are still not the final solution and more research and investigation is required. It has become apparent that, due to the diversity of expertise and the technologies required to construct structural health monitoring systems, structural engineers will be faced with many challenges outside the realm of traditional structural analysis and design. To effectively construct and utilize real-time structural health monitoring systems, engineers will need to become knowledgeable in many ancillary technologies including instrumentation, signal processing, communication and information technology. Therefore, future engineers must become highly conversant with civionics and its related disciplines.

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