A REMOTE DEFORMATION MONITORING SYSTEM FOR A CABLE-STAYED BRIDGE USING WIRELESS INTERNET-BASED GPS TECHNOLOGY

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Abstract: This paper describes a remote deformation monitoring system for a cable-stayed bridge using wireless Internet-based GPS technology. The system consists of two major sub-systems. The local data acquisition sub-system work as the base of the system, which using GPS sensors with high sample rates (20Hz) to measure the long term deformation information of the bridge. In order to reducing the high costs associated with installing extensive lengths of coaxial wires in the system, the data form the GPS sensors is wireless transmitted via Wireless Local Area Network (WLAN) to the remote operating sub-system, which is located 9 kilometers away from the bridge. The remote operation system is mainly composed of a database server and a web-server, which receives and propagates the data to the end-users around the world via Internet. The system was successfully implemented on the Shandong Binzhou Yellow River Highway Bridge of China, the end-users could remotely configure the equipments and monitoring the bridge status in real-time through the developed web site. To validate the feasibility and the effectiveness of the system, the dynamic characteristics of the bridge are studied using finite-element analysis and GPS measurements. Comparison between these two results shows the proposed monitoring method and the developed system can provide remotely, useful deformation information for the in-service health monitoring of large cable-stayed bridge wirelessly.

1. Instruction

Cable-stayed bridges with modern distinctive styles are increasing in number in China. Theses bridges require a substantial investment of money. To assess the state of in-service structural integrity is demanded to reduce maintenance costs and to extend the service life of the structure. Dynamic deformation monitoring is considered one of the most effective characteristics for investigating the behavior of bridges. Continuous monitoring of bridges leads to the early detection of any unpredicted deformations response to traffic load, temperature and wind load. Current deformation monitoring systems employ conventional cables to allow sensors to communicate their measurements to a central processing unit. Each cable may have contained multiple wires for both power and sensor data. When working with the number of sensors in large structures, this will be a daunting task to wire and cost-expensive [1]. Moreover, the remote operational environment of large bridges makes the deformation monitoring for damage detection difficult in the event of traffic load and environmental loads.

In recent years, some advance technologies for infrastructure health monitoring have been caused much more attentions, in which the wireless communication and Real-time differential GPS technology are received special interests. Global Position system is a precise new-generation positioning system prompted. Many researchers have applied continuous GPS to monitoring deformation of bridges for its advantages of all-global, all-weather and high accuracy [2, 3, 4]. In an attempt to lower the high capital costs associated with wire-based systems, replacement of system wires with wireless technologies was first introduced in 1996 by Straser [5]. Especially, with wireless communication technology evolved over the last two decades, wireless local area networks (WLANs) based on the IEEE 802.11 family of standards have become the most popular technology to provide wireless network connectivity. In the project, GPS sensors data were transmitted using WLANs and allows an operator the means to remotely access the processed data from anywhere in the world using a web browser over the Internet without requiring any additional software to be installed.

The aim of this paper is to propose a remote deformation monitoring and warning system for he Shandong Binzhou Yellow River Highway Bridge of China, based on wireless internet-based GPS technology. In the first section of the paper, the architecture of the system is presented and developed. The next section describes the design and installation of the monitoring system. It includes the organization of hardware and software of the system, and how the system work. Finally, the dynamic characteristics of the bridge are studied using finite-element analysis and GPS measurements. The processing data results have demonstrated the feasibility of the proposed system using field data collected from GPS sensors to evaluate different aspects of bridge performance.

2. Background

The entire system has been developed and instrumented on Shandong Binzhou Yellow River Highway Bridge in cooperation with the Shandong Department of Transportation, and Industry Partners. The Shandong Binzhou Yellow River Highway Bridge shown in Figure 1 was completed in 2004.

The bridge is constructed over the Yellow River, Shandong, China. It is a cable-stayed bridge, and the main bridge is approximately 768 m long, consisting of two main spans of approximately 300 m each, two side spans of 84 m each. There are three towers made up of reinforced concrete. The heights of central tower and side tower are approximately 123.25 m, 75.78 m, respectively. One-hundred cables were installed to hold the main bridge. The roadway accommodates four lanes of traffic. The bridge model is shown in Figure 2.

Figure 1: Shandong Binzhou Yellow River Highway Bridge

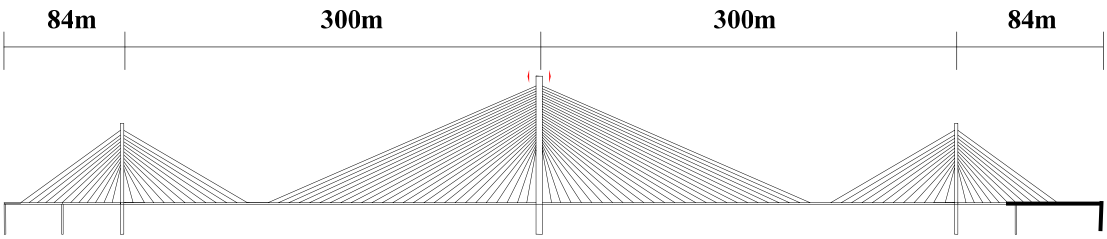

Figure 2: Bridge model

3. System Architecture

The proposed system is a real-time Internet based remote data acquisition and bridge deformation monitoring system. We will advance the usage of the Internet and of Internet technology for monitoring, management and control of the system. Deployed GPS sensors on the structures are interrogated on-site by remote monitoring units via wireless data transfer. The data recorded by the on-site instrumentation is continuously or periodically uploaded, via the Internet. Multiple users with a proper access authorization to the URL site may simultaneously acquire, display data and monitor real-time performance of the bridge remotely using a Web browser. The system integrates all monitoring, control, archiving, transfer and analysis functions and puts them on-line, performed using commercially available hardware and software systems, utilizing open client-server architecture and standard protocols. The primary feature of the system is to use the public telephone network and a Web browser to provide remote access to sensing data. The proposed system is mainly consisted of two subsystems (as shown in Figure 3), one is a local bridge deformation monitoring system and the other is a remote operating system of computers. By employing WLAN technology, the subsystems are linked via two wireless modules.

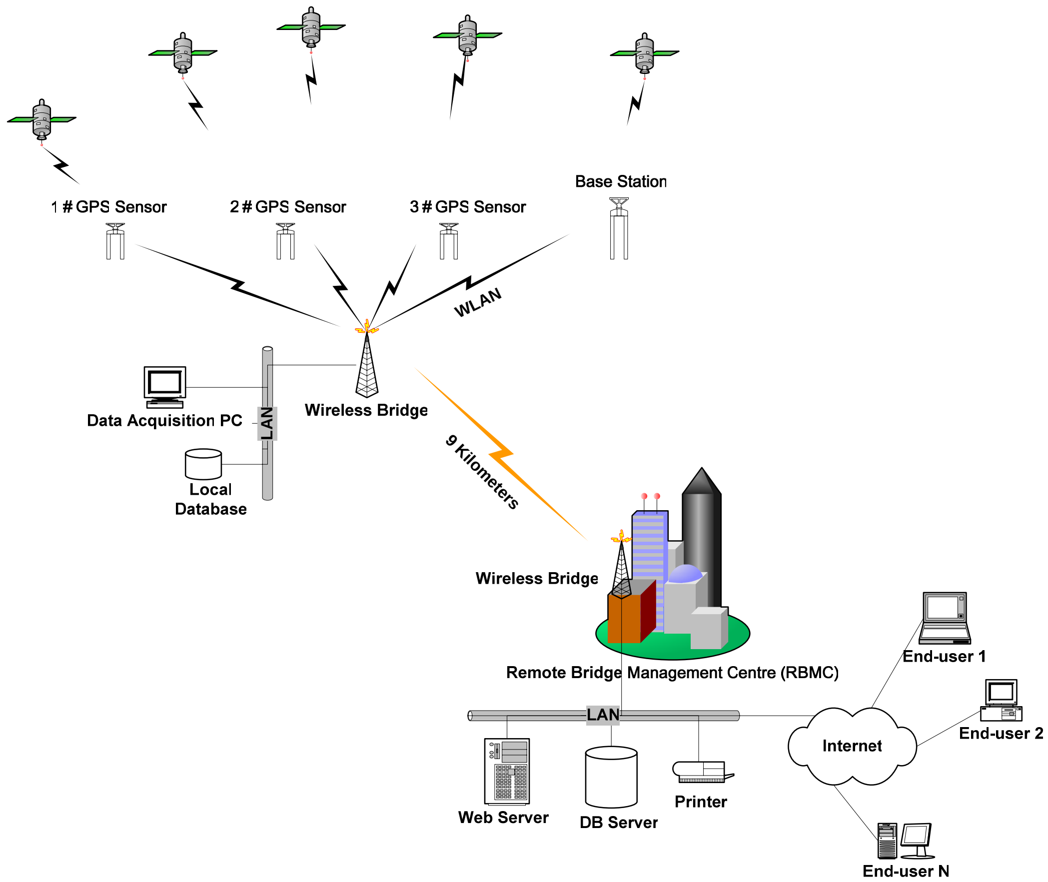

Figure 3: System architecture

4. System Instrumentations

4.1. Local Bridge Deformation Monitoring System

4.1.1. System Design

The local bridge deformation monitoring system has been installed in the bridge. The main task of the system is to measure displacement changes in dynamic response of the structure and transmit data to the local computer. The software running on the computer will save and analyze all the transmitted data. This will reduce communications overhead greatly. The sensed data is constantly monitored and recorded. This data is periodically acquired by the computer which using a wireless bridge connection to the remote operating system. The computer then processes the data and inserts it into a database which is one of the issue components of the remote operating system. For comparison, and with the objective being to assess the integrity of structures, a conventional cable-based monitoring system was installed for acceleration measurement and analysis of measurement data is presented.

4.1.2. GPS Sensors for Deformation Monitoring

The system is composed of one reference station, three monitoring points, and installed permanently. Four GPS receivers, JAVAD GB1000 were used, which are dual-frequency receiver module characterized by low power consumption and good sensitivity. The GB1000 has a nominal accuracy of 1 cm +1 ppm for horizontal displacements and 2 cm +2 ppm for

vertical displacements with a maxim sampling rate of 20 Hz. To obtain the high quality of the signals to carry out the kinematics solutions within the specified horizontal and vertical errors, GPS antennas must have excellent sky visibility to communicate with a minimum of four satellites and to mitigate the multi-path effects caused by the water surface and structures.
The GPS reference station is located on the river-bank, and this provides the reference GPS data for the differential carrier phase computation. A compatible dual frequency GPS receiver is used and the antenna position whose three-dimensional coordinates are determined using conventional static GPS carrier phase positioning, as shown in Figure 4 and Figure 5. The reference station also provided ideal accommodation for the communications equipment, and the necessary power and security. To monitoring the continuous deformation of the main span of the bridge, two of the GPS receivers were mounted on the bridge deck symmetrically, and the third unit was mounted at the top of the central tower, as shown in Figure 6 and Figure 7. GPS observation recording interval was set to at 0.05 sec, and the elevation angle of each receivers is 15。

Figure 4: Conventional static GPS measurement

Figure 5: Reference station

Figure 6: GPS sensor mounted on the bridge deck

Figure 7: GPS sensor mounted at the top

of the bridge tower

4.1.3. Conventional Cable-based Monitoring System

The cable-based monitoring system includes a set of accelerometers with corresponding amplifiers and filters; an A/D conversion board features 16 channels (eight differentials) of analog input, two channels of analog output, a 68-pin connector, and 8 lines of digital I/O. The A/D board was employed to take raw signals from accelerometers that were connected to a PC computer through amplifiers. Software has been developed to automate measures and save results.

At the top of the tower, a GPS antenna together with a triaxial accelerometer and an anemometer were installed, as shown in Figure 8. At the same location of each GPS antenna installed on the bridge deck, there is a vertical accelerometer to measure the dynamic response of the bridge, as shown in Figure 9. Bridge ambient acceleration responses were sampled at a rate of 200Hz resulting in a Nyquist frequency of 100Hz, which is much higher than the frequencies of interest (< 1Hz for this bridge).

Figure 8: Triaxial accelerometer at the top of the tower

Figure 9: Vertical accelerometer mounted on the bridge deck

4.2. Remote Operating System

The remote operation system was deployed in the Remote Bridge Management Centre (RBMC). The mainly components of the system are a database server and a web server. During the monitoring program, users working in RBMC retrieve data from local monitoring system via WLAN, the center unit of the remote system will asses the condition of the structure and display data in real-time. To provide data to remote end-users, the web server included in the remote system will propagate the data to the Internet and users can access and browse the processed data with Browser. Depending upon the needs of the user, the data can be viewed in several ways including bar graphs, trend charts and numerical data.

Optionally, the data can be downloaded into the customer's computer for further analysis. In addition to the sensed data, the customer can also collect operating data on any piece of equipment or parameter of interest. Beside that, all GPS stations can be configured from the central computer. In view of the safety of the system, only the developers or administrators can configure or access key components of the system. The software receiving and recording the GPS data run in the RBMC is shown in Figure 10.

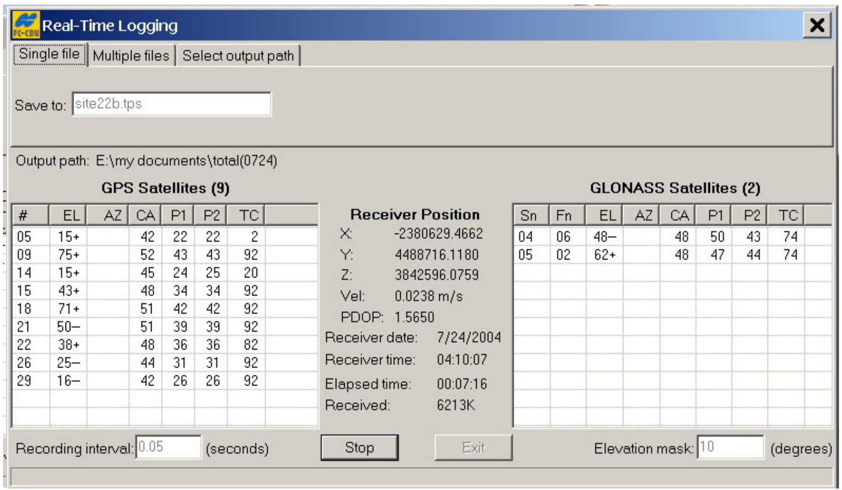

Figure 10: Window of receiving and recording software

4.3. Wireless Data Transmission System

In most instances, the performance of an RTK system relies on the availability of real-time data communication. To minimum installation consumption and establish stable broadband access connectivity. Two dual-mode WLAN (IEEE 802.11b and 802.11a using the 2.4 GHz and 5.8 GHz frequency bands, respectively) and wired LAN have been used for real-time data transmission. Wireless local area networks (WLANs) constitute one of the most dynamically developing fields of telecommunications. They play a very important role in the system as a provider of easy and unconstrained access to the wired infrastructure. In our system, at each of the GPS sites, a wireless access point (WAP) was used to transmit the data to the local data server in real-time. The maximum data rate of the WAP is 2 Mbps. Two wireless bridges were installed on the bridge tower and RBMC respectively, as shown in Figure 11 and Figure 12. Then the deformation data of bridge were transmitted to the RBMC 9 kilometers away in real-time. The maximum data rate of the wireless bridge is 7 Mbps.

Figure 11 Wireless bridge at the top of the bridge tower

Figure 12 Wireless Bridge installed in RBMC

5. Data Processing and Results

In order to evaluate and compare the measurements with the design characteristics of the bridge, a finite element (FE) model (as shown in Figure 13) of the Shandong Binzhou Yellow River Highway Bridge was developed based on commercial software (ANSYS 8.1) and model parameters of the bridge were obtained as Table 1 shown.

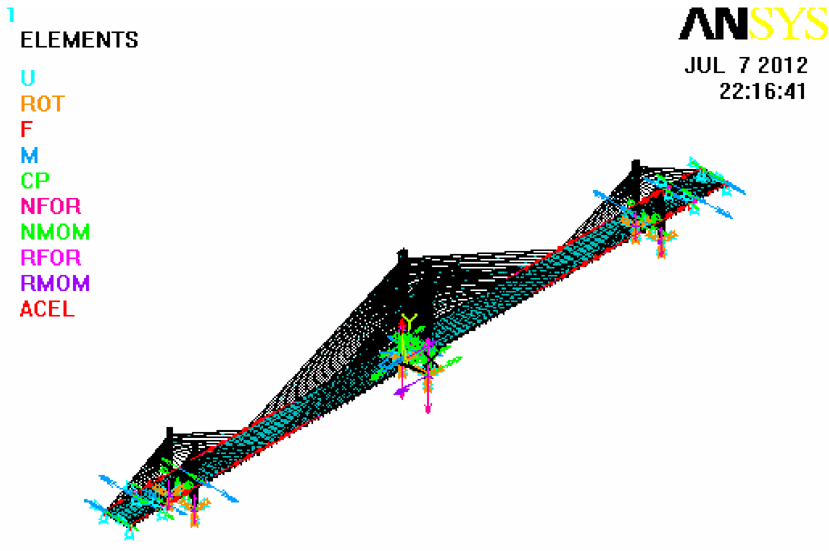

Figure 13: FE model of the bridge

To compare the dynamic response of the structure measured by two systems, a time-history and spectral analysis was performed. The Fast Fourier Transformation (FFT) is a widely used computationally efficient algorithm for implementing the Discrete Fourier Transform (DFT) which is used to transform discrete data from the domain of time or space to the frequency domain. Through the selection of suitable parameters such as fast Fourier transform (FFT) length, window, amount of overlap, and sampling data rate, spectrum analysis is used for isolating and detecting the dominant structural vibration frequencies from GPS and accelerometer data. Figure 14 presents the time-history of 3-D responses of the main-span of the bridge measured by GPS. In Figure 15 the response spectrum of the bridge calculated using the GPS measurements is presented, and comparison between calculation and measurement is presented in Table 2. It can be seen that the comparison between the accelerometer and GPS system shows a good agreement for the dynamic response of the structure.

Table 1 Natural frequencies of Shandong Binzhou Yellow River Highway Bridge

Bridge tower		Main span	
Horizontal	Longitudinal	Horizontal	Vertical
0.2150Hz	0.2333Hz	0.8668Hz	0.2330Hz

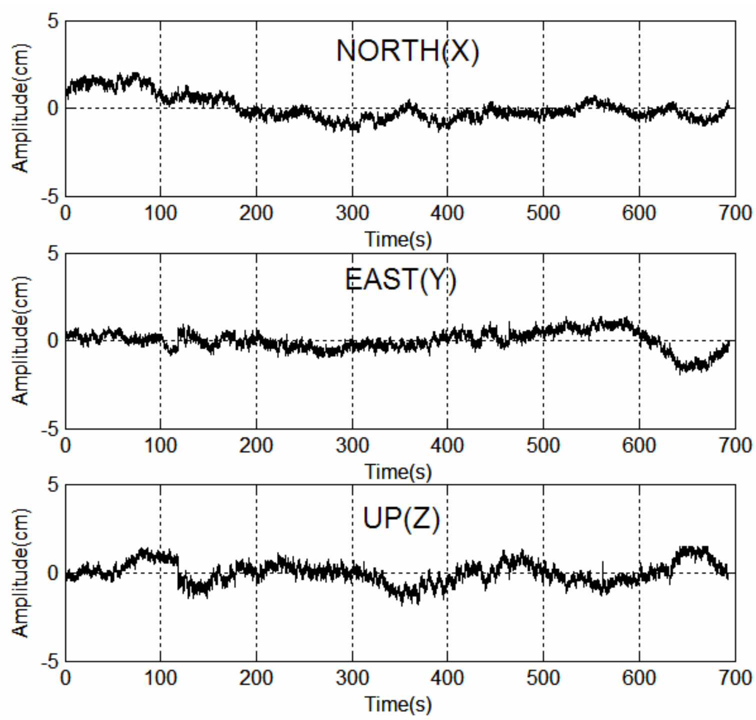

Figure 14: time-history of 3-D responses of the main-span of the bridge

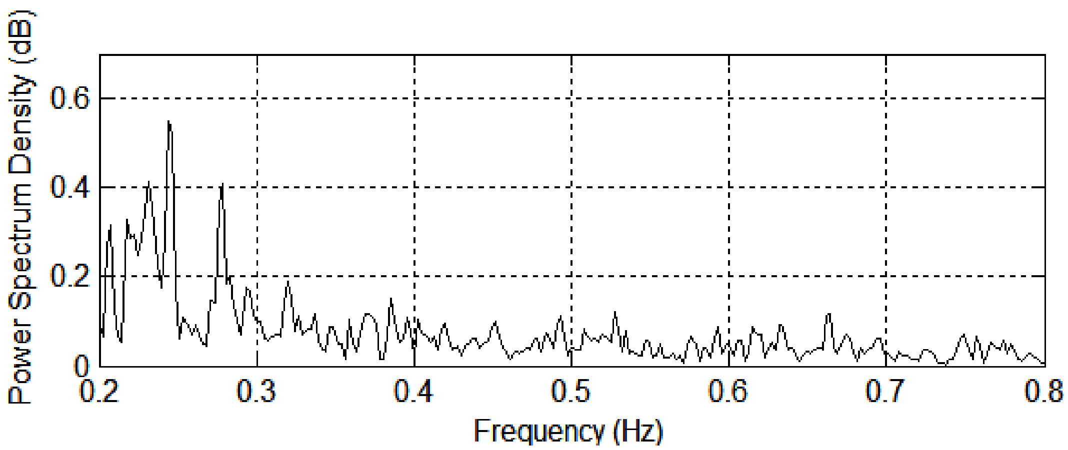

Figure 15: PSD of bridge main-span calculated using GPS measurements

Table 2: Natural frequency obtained by GPS measurement and FE calculation

Main span (Vertical)		
GPS measurement	FE calculation	Difference (%)
0.2442	0.2330Hz	4.59

6. Conclusions

Structural health monitoring is one of the important components in the maintenance technology for civil infrastructures. In this paper, a remote deformation monitoring system for a cable-stayed bridge using wireless Internet-based GPS technology is proposed and developed. The system was installed on Shandong Binzhou Yellow River Highway Bridge of China. Global Positioning System (GPS) technology not only overcome the limitation of climate, but also measures the structure displacement in three-dimensional directions. Mm-level accuracy is obtained by using a differential GPS carrier-phase approach. To provide a baseline for the system, a cable-based monitoring system was installed on building. The analysis of the acceleration response recorded by the two systems indicates the feasibility and validity of the presented system. Advantages of this system over conventional deformation monitoring systems include continuous unattended monitoring, reduced costs associated with field data collection, instant access to data files and graphs by remote users via Internet.

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