Field measurements of a cable-stayed bridge by using wireless sensors

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ABSTRACT: In order to understand the dynamic characteristics of a cable-stayed bridge, field measurements of the traffic loadings and wind-induced response of the bridge using wireless technology have been carried out. Conventional field measurement systems employ cables for measurement transfer, and collect data at a single server for centralized processing. A major drawback of these systems is their installation time and costs can be very high. To solve the key problem of theses systems, a highly cost-effective wireless sensor network system for structural data acquisition is proposed in this paper. The system integrated with wireless sensing communication, computation, data management and data remote access via wireless local area network (WLAN). The performance of the system is validated in the field using a newly constructed Sifangtai cable-stayed bridge over the Song Hua Jiang River, Harbin, China. Both time domain data and Fourier transformed frequency domain analysis techniques were used to examine the structural response. The proposed system is shown to be effective for measuring the structure dynamic properties.

1. INTRODUCTION

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. Conventional field measurement systems employ cables for measurement transfer, and collect data at a single server for centralized processing. A major drawback of these systems is their installation time and costs can be very high. And the equipments needed in the system are rather cumbersome.

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 [1]. With recent advances in digital circuitry, wireless communications, and Mciro-Electro-Mechanical Systems (MEMS) technology have led to the emergence of Wireless Sensor Networks (WSN) as a novel class of networked embedded systems[2,3]. A wireless network solution can support mobility and flexibility of sensor nodes in a network[4]. Sensor nodes are low-cost, low power devices with limited sensing, computation, and wireless communication capabilities. Many projects and diverse applications for these systems are currently being explored. The Wireless Integrated Network Sensors (WINS) [5] at UCLA has been developed since 1993 for defense applications in battlefield, vehicle condition based maintenance, and applications in industrial automation and healthcare; the “Smart Dust”[6] project started in 1999 at Berkeley explores the limits on size and power consumption in autonomous sensor nodes; the Wireless Modular Monitoring Systems (WiMMS)[7] was proposed in 2002 for civil structures, a sensing unit to be used in the system has been designed and fabricated from commercially available components. Besides lowering installation time and costs, the sensor network makes micro sensors ideal for deployment otherwise inaccessible environments where maintenance would be inconvenient or impossible [8].

The objectives of this paper are to study the feasibility of wireless sensor network for the traffic loadings and wind-induced response measurements and to demonstrate its efficiency in measuring the dynamic characteristics of a full-scale bridge. A wireless field measurement system is proposed and developed. The characteristics of the hardware and software modules of sensor network are discussed. The measured dynamic characteristics are then compared to the wired-based system results and to the theoretical computations. Advantages of this system over conventional systems include continuous unattended monitoring, reduced costs associated with field data collection, instant access to data files and graphs by project team members.

2. WIRELESS MEASUREMENT SYSTEM

To solve the key problem of the conversional measurement systems, a wireless measurement system of Wireless Sensor Local Area Network (WSLAN) for large infrastructure dynamic response is proposed and developed. The system consists of two subsystems, one is a local wireless measuring system of wireless nodes and base station and another is a remote operating system of personal computers. By employing WLAN technology, the subsystems are linked via two wireless modules, as shown in Figure 1.

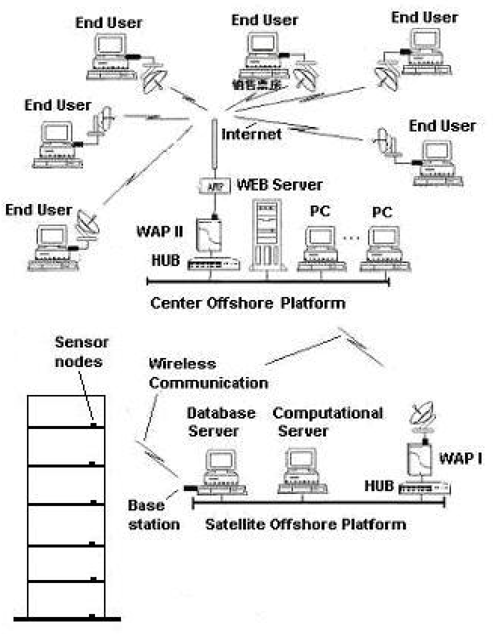


Figure 2 Architecture of wireless measurement system

2.1 Local wireless measuring system

The system will be distributed on the bridge. The main task of local measuring system is to measure 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. Various sensors (e.g. wired and wireless sensors) deployed on the building are used to measure the dynamic responses of the building and a computer to record the sensed data. The sensed data is constantly monitored and recorded. This data is periodically acquired by the computer which using a wireless 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.

2.2 Remote operating system

The remote operation system can be deployed in the university. The mainly components of the system are a database server and a web server. It retrieve data from local measuring system via Internet, 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. In view of the safety of the system, only the developers or administrators can configure or access key components of the system.

3. SYSTEM SETUP

3.1 Background

The objective of field validation is to quantify the performance of the proposed system. A Wireless Sensor Network and a conventional cable-based data acquisition system were deployed on the deck of Sifangtai Bridge. Sifangtai Bridge is newly constructed over the Song Huang Jiang River, Harbin, China. It is a cable-stayed bridge, approximately 1269m long, consisting of a main span of approximately 336m, two side spans of 136m each. The two door-shaped towers are of reinforced concrete. The height of two towers are approximately 120m Both of towers are 106.10m above the bridge deck. The roadway accommodates four lanes of traffic. A bridge photograph is shown in Figure 2.

Figure 3 Bridge photograph

3.2 *Instruments*

The data out of the cable-based accelerometers were used to compare with the data measured by the wireless sensor nodes.

Besides to further validate the system performance on existing structure, also investigates the use of wireless sensors as a means of assigning the behavior and condition of the bridge. The wireless system includes a base station and 26 wireless sensor nodes. The base station was plugged in a laptop to record and receive the data from the sensor nodes, and the wireless nodes were deployed on the deck of bridge to measure the acceleration response of the structure. Each node in this network consists of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit. The features of the wireless measurement system are shown in Table 1.

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, as shown in Figure 3.

Table 1 Features of the wireless measurement system

Sample rates	50 Hz, 60 Hz, 250 Hz, 500 Hz
Memory	32 MBytes
A/D converter	16 bit
Measurement range	0.01g~5000 g
Frequency range	0.01~500 Hz
Power supply	DC6.5～7.5 V
Temperature range	-40 ~ +70 ℃
Radio Range	2 km

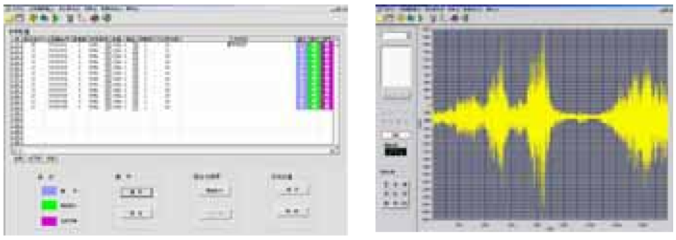


Figure 4 GUI of software.

3.3 *Instrumentation process*

The natural frequency and modal shapes are important dynamic characteristics of the tall buildings for health monitoring and evaluation. Sensors should be installed at a number of locations, so the important modes of bridge will be recorded and specific instrumentation objectives can be achieved.

The wireless accelerometers were installed at the surface of the bridge in the vertical and transverse directions. Measurement points were chosen on both sides of the bridge at a location near the joint of the suspenders and deck. As a result, a total of 26 locations (13 points per side) were selected and measurements made there in both directions. Measurement point arrangement on the bridge deck is shown in Figure 4. Figure 5 shows the wireless accelerometers mounted on the bridge deck in the vertical directions.

The cable-based monitoring system is installed in parallel with the wireless measurement system, as shown in Figure 6. All the sensors include wireless and cable-based accelerometers for collection of data were made at a sampling rate of 50 Hz for duration of 30 minutes each time. To compare the efficiency of radio communication, the wireless sensor nodes were configured at a sample rate of 250Hz in the repeat measurement.

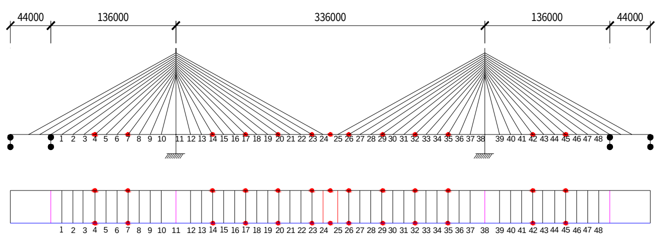


Figure 5 Measurement point arrangements.

Figure 6Vertical wireless accelerometers mounted on deck.

Figure 7 Wireless and cable-based accelerometers mounted on deck.

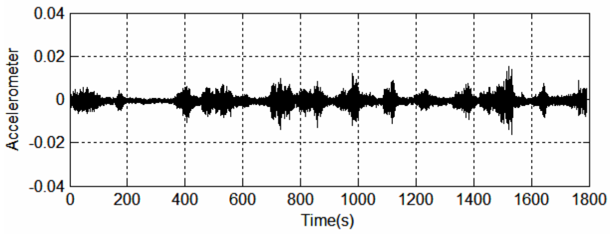
4. RESULTS AND DISCUSSION

To compare the dynamic response of the structure measured by two systems, a time-history and spectral analysis was performed.

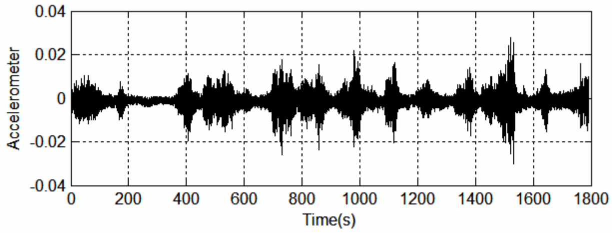
Figure 7 presents the time history response is acquired by the two systems using accelerometers mounted at the center of the span. Similar findings are found in the time-history records recorded at different sensor locations. Figure 8 depicts the time history response is acquired by wireless accelerometer at different sample rate.

The spectral densities of the deck accelerations were computed from the recorded data obtained by the two systems. A comparison between wireless measurements and cable-based measurement is given in Figure 9 for the first and second vertical mode. There is a good agreement exists, particularly in the shape and location of their peaks and valleys.

Table 2 gives the peak frequencies for the considered modes. The results indicate the performance of the wireless sensing unit is reliable and accurate when compared to a conventional cable-based monitoring system.

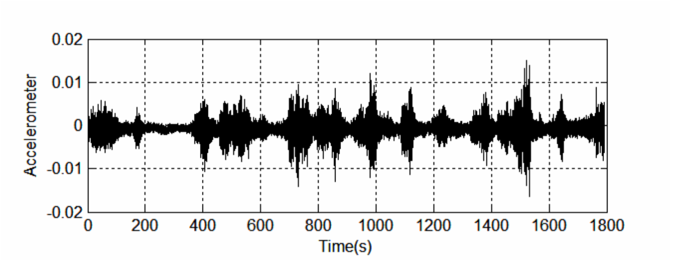


(a) Wireless accelerometer

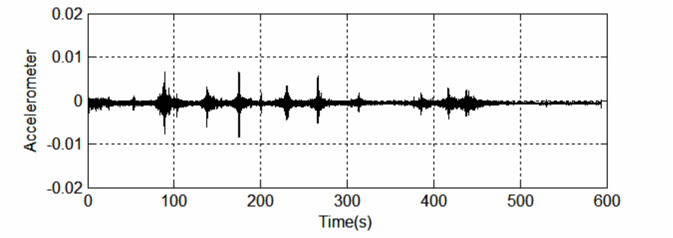


(b) cable-based accelerometer

Figure 8 Acceleration time history: (a) Wireless accelerometer. (b) cable-based accelerometer

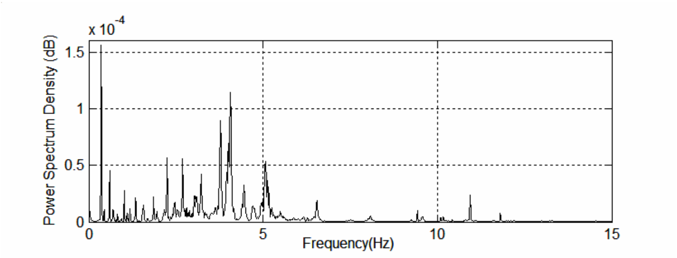


(a) Sample rate is 50Hz

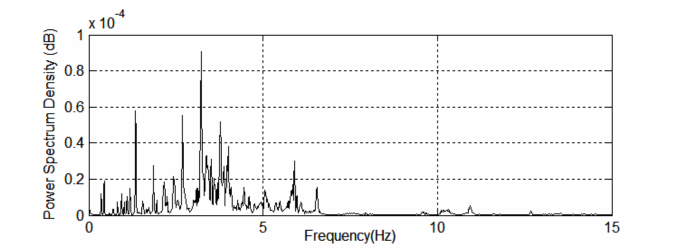


(b) Sample rate is 250 Hz

Figure 9 Time history of wireless accelerometers mounted at different sample rate: (a) 50Hz. (b) 250Hz



(a) PSD of wireless accelerometer response



(a) PSD of cable-based accelerometer response

Figure 10 PSD of Wireless and cable-based accelerometer response: (a) wireless .(b) Cable-based

Table 2 Frequencies obtained by wireless and cable-based measurement system

Modes	Wireless	Cable-based	Difference (%)
1^{st}	0.354	0.356	-0.56
2^{nd}	0.452	0.444	1.8

5. CONCLUSIONS

Field measurements were carried out using wireless sensor on a cable-stayed bridge located in Harbin, China. In this paper, a WSN based system for dynamic properties of structures is proposed and developed. The proposed system was installed on the Sifangtai Bridge to quantify the performance. To provide a baseline for the wireless measurement system, a cable-based monitoring system was installed on the bridge. The analysis of the acceleration response recorded by the two system indicates the feasibility and validity of the presented system. Advantages of this system over conventional systems include continuous unattended monitoring, reduced costs associated with field data collection, instant access to data files and graphs by project team members, and it is anticipated that WSN may enable new methods for field measurement of full-scale structures.

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