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Bridge Health Mornitoring using Wireless Sensor Networks

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Summary

Wireless sensor networks bring new challenges to Bridge monitoring. To monitor a bridge, behavior, including vibration and displacement, must be measured to analyze the health of the structure based on measured and collected data. The collected data can be used to compute modal properties of the bridge.
A bridge is moved by external forces, including wind, seismic activity, and traffic. So it is very hard reliance of safety through a preexistence method which uses Data Logger. Dynamic behavior of a bridge is difficult to measure because of costs and installation methods. In this paper, a new method, using a U-Smart Sensor and Sensor Networking to measure the dynamic behavior of the bridge, is suggested. A new wireless MEMS accelerometer sensor (U-Smart Sensor) board is designed to meet the specific hardware and software requirements of structural engineering applications.

Introduction

A new generation of small, inexpensive, and efficient devices has emerged, thanks to advances in Micro Electro Mechanical Systems (MEMS), which can sense a physical response, process it locally, and communicate it wirelessly [1].

Software and hardware advances in networking, data management and wireless communication make it possible to create networks of hundreds or even thousands of these devices. Wireless Sensor Networks (WSN) can be used for monitoring applications, such as Structure Health Monitoring (SHM). Such a network consists of a high concentration of sensors throughout the critical points of the structure, which measure physical response of the system when and where needed, perform some local processing, and present necessary information for a human or an automated operator about the state of the structure. Such a network can be used after a structural event, such as an earthquake, to provide safety information for the users or in a continuous monitoring scheme to detect possible deterioration and damage, to update models of the structure, and to aid the engineers and owners in decision-making. These applications require a spatially dense network with the capacity to collect and process a high volume of data and reliable channels to communicate data and information.

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In this paper, hardware and software specifications for structural engineering applications are established by the need to measure ambient vibrations, as well as an earthquake's strong motions, in order to identify local and global damage in structural systems. A new MEMS sensor board is described, and software components are defined, for a software framework to create a sensor network suitable for SHM applications.

Hardware Architecture

The accelerometer board has sensors and signal processors (low-pass filter, analog to digital converter). A mote stores data from the accelerometer boards and later sends the data through an antenna. Mote, accelerometer, antenna, and power issues will be discussed.

First about a mote, a sensor unit consists of a sensor board and a control/communication device to drive the board and to store and communicate data. TIP710CM motes, which are used in this project, are equipped with a Micro-Controller (TI MSP430F1611), which has 48 KB of program memory, 10 KB of RAM. The mote is also equipped with a RF tunable radio chip (Chipcon CC2420). CC2420 supports a IEEE802.15.4/ZigBee, 2400∼2483.5 MHz RF band, O-QPSK modulation method, and 250 Kbps Data Rate. Table 1 shows characteristics of part of TIP710CM, which is shown in Figure 1.

Table 1: Characteristics of TIP710CM

TIP710CM		
MCU	Model	TI MSP430F1611
	Type	16Bit RISC
	Program memory	48Kbytes
	RAM	10Kbytes
External	Flash	1Mbytes(8Mbit)
	EEPROM	3wire serial : 128Bytes(1Kbits)
Radio	Model	CC2420(2.4Ghz)
	Data Rate(kbps)	250Kbps

Second, two sources of vibration (earthquake and ambient) are monitored, using a single board. The major sensors on the board are accelerometers of type ADXL203. Table 2 shows characteristics of ADXL203. Each board has a total of two channels, one in the vertical direction and one in the horizontal direction. Their range is ±1.7 g.

Third, the sensors were calibrated at Seohae Grand Bridge. The longest hop is 137.09 m. A patch antenna, which is reasonably small in size and increases the range (max 250 m) orthogonal to the patch, was used.

The last, it is not always possible to have wired power at the deployment site.

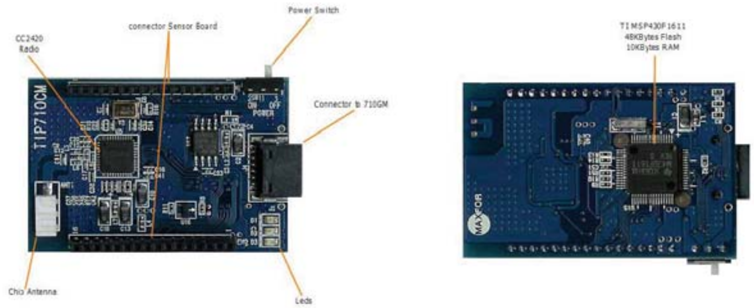


Figure 1: TIP710CM

Table 2: ADXL203 Accelerometers

ADXL203	
Type	MEMS
Number of axis	2
Range of system	-1.7g to 1.7g
System noise floor	$110(\mu\text{G}/\sqrt{Hz})$

Even if possible, the cost exceeds the benefit. In a bridge environment, this is a problem. Our system, instead, relies on a battery as a power source. We analyzed whether the design meets our desired length of deployment and how much it would cost for the system to operate for as long of a duration as we desire.

Software Architecture

TinyOS, provides the software infrastructure for the sensor network. It is an operating system developed at UC Berkeley, which has become the de facto standard operating system in WSN. In this section we describe the components added to TinyOS for SHM applications.

First, data acquisition has been developed to address the following important issues for SHM applications:

- High-frequency sampling and low jitter, which is variation in sampling intervals.
- Time synchronization to enable sampling to start simultaneously at all nodes.
- Large-scale multi-hop network: Monitoring systems span long distances, which makes it impossible to cover the entire network with single hop communication.
- Reliable command dissemination and data collection: commands/triggers need to be disseminated, and data should flow throughout the network reliably. In SHM applications, loss of data due to transmission issues cannot be tolerated.

Second, structure monitoring requires sampling at a high frequency with uniform intervals, and jitter becomes a critical problem as sampling rate increases. Figure 2 shows the interaction of sampling and other jobs, such as writing data from RAM to flash in CPU. The timer event for sampling occurs regularly with a uniform interval. However, to be serviced by the CPU, the CPU should finish servicing, pending atomic section. Only then can the CPU handle timed events and sampling. The worst jitter is determined by the longest atomic section, which can be running when the timer event occurs. This implies that no chance should be given to unnecessary components' atomic section to run on the CPU. Therefore, every component is turned off except EEPROM during sampling. Figure 3 is the histogram of jitter values. A peak occurs at 625 ns, which is the wakeup time.

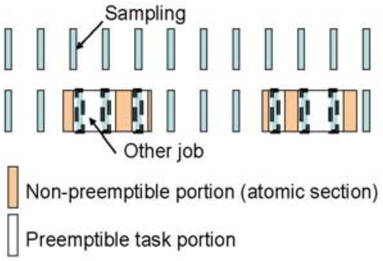


Figure 2: Occurrence of Jitter

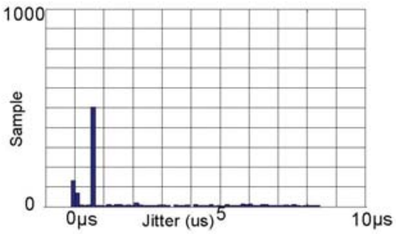


Figure 3: Occurrence of Jitter

LARGE-SCALE DATA TRANSFER

Significant loading events on a structure, such as an earthquake, happen rarely and within a relatively short period of time, which makes it unacceptable for the WSN to lose data due to transmission. The goal is to achieve reliable data transmission with minimal expense for channel capacity and bandwidth. It is also necessary to design a protocol for data collection that scales over a multi-hop network. In applications like SHM, sampling cycle is determined by data collection time; since sampling is fast, data collection takes most of the time. Resource usage should be minimized because wireless sensor nodes are limited in computational power, memory space, and energy.

Straw (Scalable Thin and Rapid Amassment Without loss) is a reliable data collection method for providing these properties. The sender sends all data once, and the receiver asks for retransmission of missing data.

Deployment Plan

Six motes were used in the test-bed experiment. One is a sink mote, and the others are sensor motes. The motes were placed on both sides of the main span at 5 different locations. The network collected data for 1 minute, with a sampling frequency of 100 Hz, resulting in 6,000 samples per channel. Vertical acceleration at L1-L5 is shown in Figure 4.

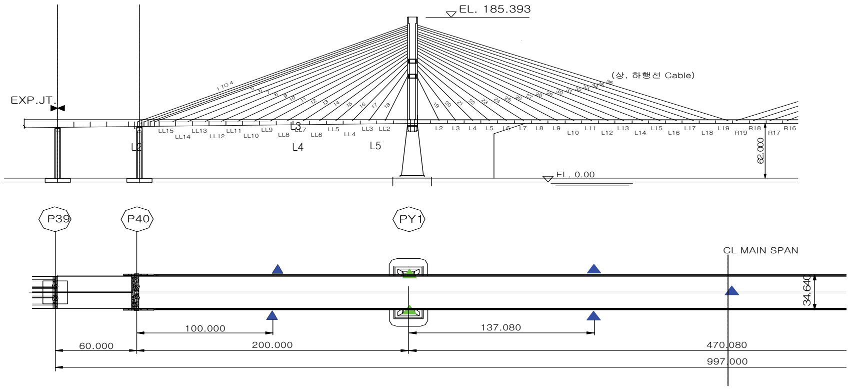
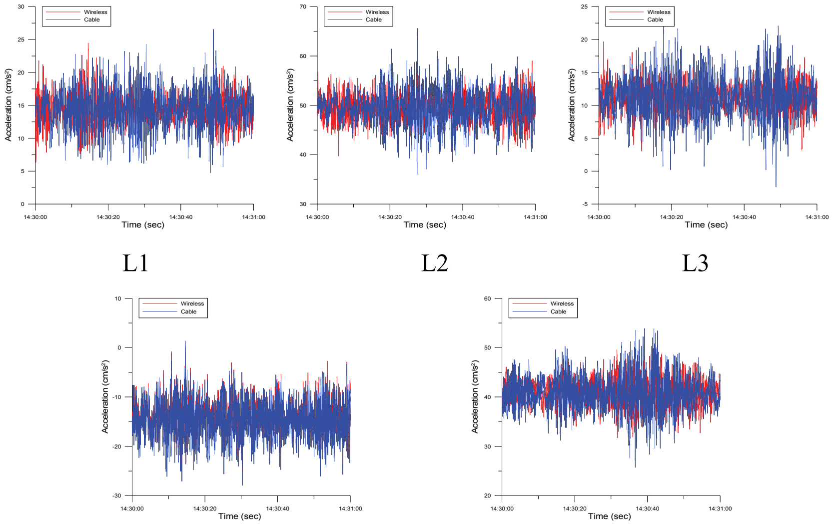


Figure 4: Deployment plan



L1 L2 L3

L4 L5

Figure 5: 3 Time plot, Vertical Acceleration at L1-L5

Conclusion

A new accelerometer sensor board is developed that meets the requirements of SHM applications. The board is equipped with inexpensive accelerometers to sense earthquake strong motion and ambient vibrations. Software components provide capability of high frequency sampling, time synchronization, multi-hop networking and reliable transformation of data and commands throughout the network.

A network of 6 boards was used on Seohae Grand Bridge overpass as a preliminary testbed structure. Ambient vibrations of the bridge were recorded and vertical modal properties of the bridge were estimated. In this test the data of smart wireless accelerometers and cable sensor show similar value. So the appliance of this smart wireless accelerometer to bridge is acceptable.

References

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2. ADXL203 Datasheet, Analog Devices Inc. 2004.