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DEVELOPMENT OF WIRELESS SENSORS FOR RAPID DEPLOYMENT IN CIVIL INFRASTRUCTURES

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Abstract

Buildings and civil infrastructures are frequently subjected to natural hazards such as earthquakes, typhoons, hurricanes and fires. Therefore, developing an efficient and robust monitoring system has become a most significant research area. Wireless Sensor Network (WSN) is a novel and attractive technology and has been an energetic research area in recent years. Furthermore, wireless sensor networks have developed several applications mainly to monitor hazardous environments. The bolt is ubiquitous in our life environment, such as buildings, bridges, railways and pipelines. Therefore, the new inspiration for developing a wireless sensor device, which is named “smart bolt”, is proposed in this paper, which is to develop a wireless sensor device for rapid deploying. The prototype device is capable of wireless sensing via embedding the wireless sensor into a bolt, consisting of sensing and wireless communication modules. This paper introduces wireless technology and applications; moreover, it presents the prototype device design that includes hardware design and sensor integration. Experimental study was designed to investigate the benefit and efficiency of the proposed prototype and is finally shown in the paper to confirm the feasibility of a wireless sensor network in buildings and civil infrastructure.

INTRODUCTION

To continuously monitor and control the responses of buildings and civil infrastructure in real time has been increasingly more important because of natural hazards, such as earthquakes. Therefore, developing a low cost, high stability and more advanced monitoring system is important now. Compared with traditional monitoring systems, a wireless sensor monitoring system has significantly higher level of advantages [1-3]. Wireless sensors are smaller in size and mostly powered by a battery only. Furthermore, a wireless sensor has the advantages of low power, lower manufacturing costs, self-organization and wireless communication. Due to specific characteristic features, these wireless sensors become an appropriate choice for developing an intelligent civil infrastructure monitoring system. At the same time, a lot of research has been devoted to applying wireless sensor networks in civil infrastructure monitoring. For example, Lynch et al. designed an active wireless sensing unit[4] that could input excitations into a structural system and proposed a computational framework for analyzing piezoelectric based active sensor signals for indications of structural damage. A multi-hop wireless data acquisition, called Wisden[5] was designed for structural health monitoring. The Wisden can measure tri-axial structural vibration data reliably across multiple hops with low latencies for sampling rates up to 200Hz. Straser et al. [6]developed a structural wireless monitoring system that includes data acquisition devices and a central data collection device. The system was designed for monitoring large civil structure during structural natural hazard or other extreme events. For monitoring of buildings and civil infrastructure, deploying of sensors is another issue. How to deploy wireless sensor nodes efficiently, correctly and rapidly is also imperative. Therefore, the prototype device of integrating wireless platforms and sensors into a bolt is presented in this paper. The experimental study is conducted to investigate the proposed prototype.

THE HARDWARE OF SMART BOLT

Smart bolt plays a role of wireless sensing and contains two functional modules: (1) sensing and data acquisition module; (2) microprocessor with wireless communication module. MTS510 is chosen as the sensing and data acquisition module; MICA2DOT is chosen as microprocessor with wireless communication module. The MTS510 is a sensor board including accelerometer, light, and microphone/acoustic sensors, and is designed to mate with the MICA2DOT. The MTS510 has a dual-axis ± 2g MEMS accelerometer for seismic, tilt, and shock/event detection applications. The MTS510 also has digitally acoustic and photocell light sensors. The analog outputs of all three sensors connect to an onboard ADC on MICA2DOT. MICA2DOT has 6 input channels, each with its own 10-bit analog to digital converter (ADC). The expansion pin on MICA2DOT is used for connecting 6 analog inputs, digital I/O, and a serial communication or UART interface. These interfaces make it easy to connect to a wide variety of external sensors and devices. For wireless communication, the data transmission between the MICA2DOTs is linked by a RF radio (CC1000, Chipcon AS, Oslo, Norway) via FSK. The RF chip (Chipcon CC1000) FSK-modulated radio has three models according to the frequency of the RF transceiver: the MPR500 (915 MHz), MPR510 (433 MHz), and MPR520 (315 MHz). In this system, the MPR510 is selected as the transmitting frequency. Figure 1 reveals the all the electrical components of proposed smart bolt.

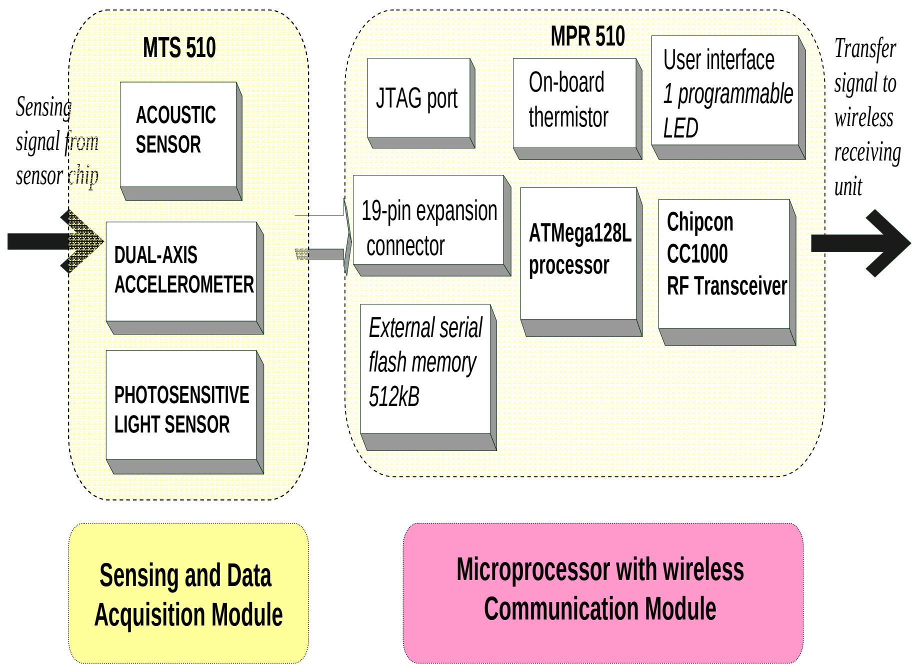

Figure 1. Architecture of smart bolt comprising two functional modules: sensing with data acquisition and microprocessor with wireless communication module.

WIRELESS SENSOR SYSTEM BASE ON SMART BOLT

Herein, Figure 2 demonstrates a wireless sensor system based on smart bolt. This system integrates smart bolt and a wireless receiving unit. Within this architecture, the smart bolt can embed in any proper location of civil infrastructure. The wireless receiving unit consists of two functional modules, microprocessor with wireless communication module and a gateway. The MICA2DOT is also chosen as microprocessor with wireless communication module and the MIB510 is chosen as a gateway.

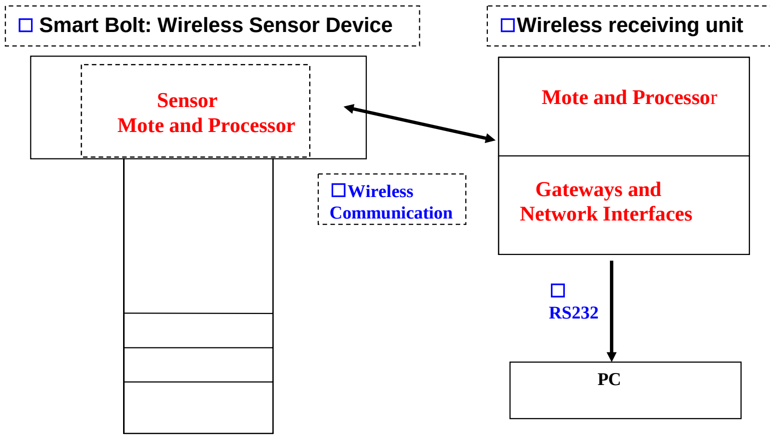

Figure 2. Architecture of wireless sensor system based on smart bolt

Sensors on MTS510 are connected to MICA2DOT directly for linking external sensing signals to the MICA2DOT. Once the sensors acquire the signals from the environment, the analog signals are converted to output voltage via ADC. After that, the microprocessor and wireless communication module send the signal to the wireless receiving unit. Upon sensing, the signal is transmitted to the host PC via RS232 serial port directly. Figure 3 shows all components in this system.

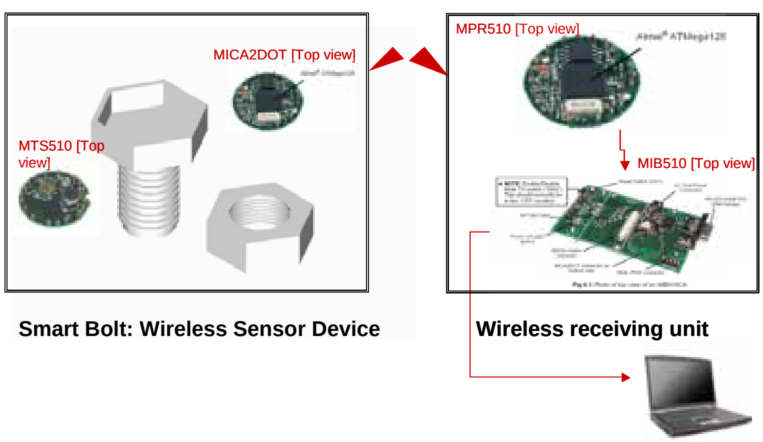

Figure 3. Components of wireless sensor system based on smart bolt

Within this architecture, the sensors are connected to the wireless sensing unit. The MTS510 is connected to MICA2DOT directly. Once the sensors acquire the signals from the environment, the analog signals were converted to output voltage via ADC. After that, the microprocessor and wireless communication module send the signal to the wireless receiving unit. Upon sensing, the signal is transmitted to the host PC via RS232 serial port directly.

EXPERIMENT AND RESULTS

Experimental study was conducted to investigate the proposed prototype system. MICA2DOT and MTS510 are embedded into a simple smart bolt model that is made of plastic. Figure 4(a) demonstrates the 3D model of smart bolt prototype. Figure 4(b) shows smart bolt prototype that is embedded MICA2DOT and MTS510. In order to estimate the performance of smart bolt, the prototype is tested through mounting with a small scale shaking table (Quenser, Shake Table II) by inputting Northridge earthquake excitation (see Figure 4(d)).

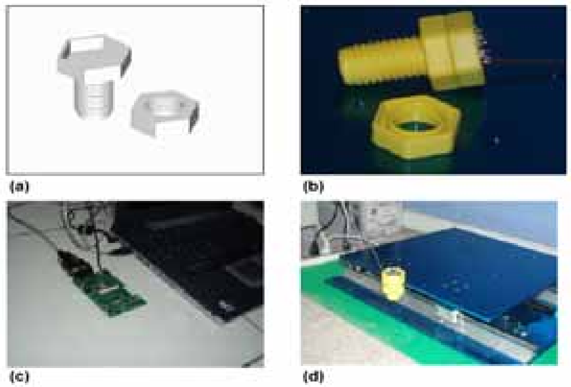

Figure 4. (a)3D model of smart bolt. (b) Smart bolt prototype which is embedded MICA2DOT and MTS510. (c) Wireless receiving unit. (d) Smart bolt mounts on shaking table.

Figure 5 shows the Northridge earthquake excitation data that was input into the shaking table. Figure 6 illustrates the data that was received by a laptop computer with a wireless receiving unit (see Figure 4(c)). According to the result of the shaker test, it could be considered that the MICA2DOT is not effective enough for detecting the structural acceleration in real civil infrastructure monitoring. The wireless receiving unit could only get a maximum of ten packets per seconds owing to the hardware restrictions of MICA2DOT. Moreover, for MTS510, the smallest data rate will be 200ms because of the waiting time when sampling acoustic data. Hence, using fewer sensors on a single node may improve the limitation of the sampling rate, because lots of sensors will take a little bit of time to read data from the sensors. A wireless communication quality test is also completed in this paper. Figure 7 shows that a high sampling rate gets high wireless communication quality.

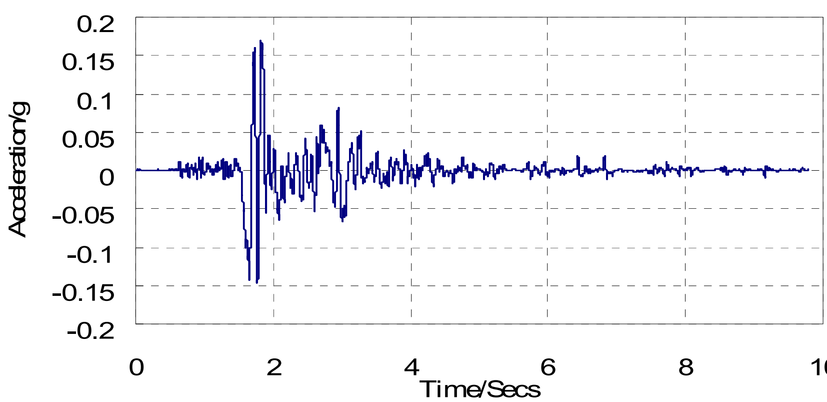

Figure 5. Data of Northridge earthquake excitation

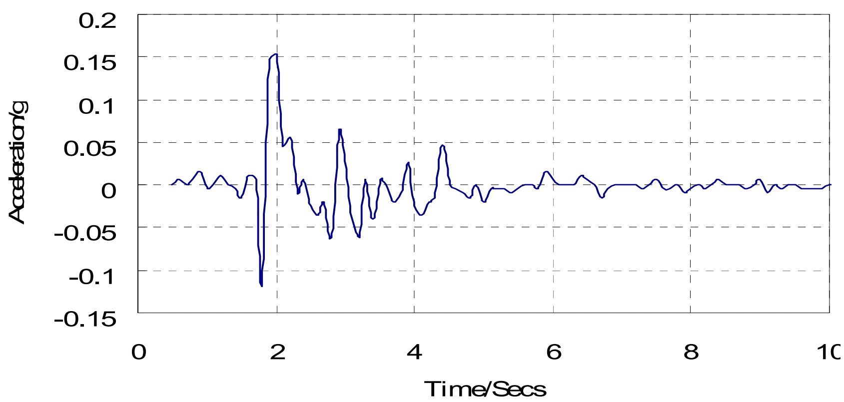

Figure 6. Data collected from smart bolt

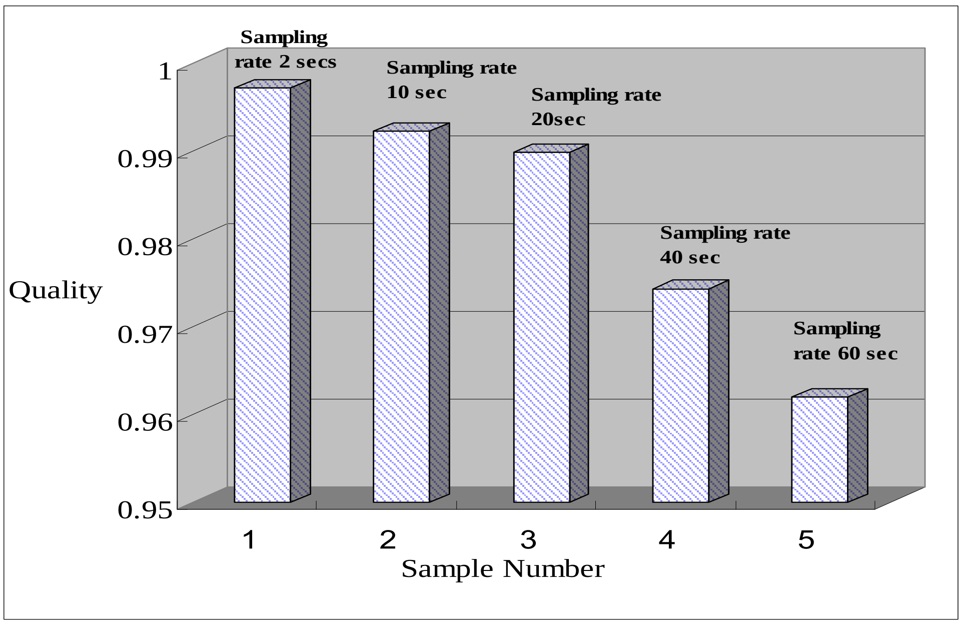

Figure 7. Wireless communication quality test through different sampling rates.

CONCLUSIONS

In this paper, the prototype device of integrating wireless platforms and sensors into a bolt (named smart bolt) is presented. Smart bolt contains two functional modules: (1) sensing and data acquisition module; (2) microprocessor with wireless communication module. MTS510 is chosen as the sensing and data acquisition module, MICA2DOT is chosen as the microprocessor with wireless communication module. According to the experimental results, the MICA2DOT is not effective enough for detecting structural acceleration in real civil infrastructure monitoring. However, the smart bolt is the first generation prototype for realizing the concept. Afterward, the next generation can improve the weakness and get more advanced. A wireless sensor system based on smart bolt can deploy wireless sensor nodes efficiently, correctly and rapidly. Any sensors can easily be adapted with this smart transmitting scheme. The proposed wireless sensor system is suitable for civil infrastructure monitoring. However, this work is a pilot study that only investigates the proposed prototype feasibility. Subsequently, a more complete study and investigation should be conducted.

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