MONITORING CIVIL STRUCTURES BASED ON IEEE 802.15.4 WSN

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ABSTRACT

The civil structures are often exposed to severe loadings during their lifetime, especially at extreme events like earthquake and typhoon, which causes serious concerns on the integrity of the structures that, is closely related to the public safety. Tragic disasters on the civil structures, like collapses of bridges or buildings, often accompany a large number of casualties as well as social and economic problems, thus most of the industrialized countries are on the verge of increasing their budget for structural health monitoring (SHM) of their major civil infrastructures. Ubiquitous monitoring using a network of wireless sensors is one of the most promising emerging technologies for this purpose. Structural health monitoring aim to find out the natural vibration frequencies of a structure under naturally induced or forced vibrations, and use this information to detect any structural damage or wear the system might have. The stress and strain on various beams in the structure is also useful for monitoring the health of a structure. We have designed and implement an efficient monitoring system in order to realize progressive accumulation of damages due to seismic events, unforeseen foundation settlement, material aging, design error, etc., using the combination of MEMS sensors and embedded network terminals.

Keywords: Structural Health Monitoring (SHM), Micro-electromechanical systems MEMS Sensor (ADIS16223), Accelerometer ADXL335, Wireless Sensor Network (WSN) IEEE 802.15.4

I. INTRODUCTION

The interest in sensing technology for various uses has been growing, and new kinds of sensors have been developed by micro-electro mechanical systems (MEMS) technology. Environmental information such as brightness, temperature, sound, vibration, and a picture of a certain place in a building, is evaluated by the network to which a huge number of microcomputer chips with sensors were connected.

Periodic monitoring needed to guarantee an adequate level of safety and serviceability. The installation of a permanently installed sensing system in buildings has to be economically viable.

The SHM system often offers an opportunity to reduce the cost for the maintenance, repair, and retrofit throughout the life-cycle of the structure. In the conventional SHM system, the expensive cost for purchase and installation of the SHM system components, such as sensors, data loggers, computers, and connecting cables, is a big obstruction. To guarantee that measurement data are reliably collected, SHM systems generally employ coaxial wires for communication between sensors and the repository. However, the installation of coaxial wires in structures is generally very expensive and labor intensive. For example, it was reported that a SHM system installed in a tall buildings generally cost in excess of $US5000 per sensing channel.

As SHM systems grow in size (as defined by the total number of sensors), to assess the current status of the structure accurately, the cost of the monitoring system can grow much faster than at a linear rate. For example, the cost of installing about 350 sensing channels on Tsing Ma Suspension Bridge in Hong Kong was estimated to have exceeded $8 million. If the maintenance cost of the SHM system, which will be increased as the system gets older, is also considered, the total cost may be increased exponentially.

This limitation on economical realization of SHM system may prevent installation of large number of sensors enough to assess the accurate status of a large civil structure, if the big budget for the SHM system is not secured. Recently, smart wireless sensor has been considered as an alternative tool for economical and accurate realization of structural health monitoring system. Smart wireless sensor is an emerging sensor with the following essential features: on-board micro-processor, sensing capability, wireless communication, battery powered, and low cost. When many sensors are implemented on a SHM system for a sizable civil structure, wireless communication between sensors and data repository seems to be attractive in the aspects of the cost.

Dense arrays of low-cost smart wireless sensors have the potential to improve the quality of the SHM dramatically using their onboard computational and wireless communication capabilities. These wireless sensors provide rich information which SHM algorithms can utilize to detect, locate, and assess structural damage caused by severe loading events and by progressive environmental deterioration as well as economical realization of SHM system. Information from densely instrumented structures is expected to result in the deeper insight into the physical state of the structural system. A risk monitoring of buildings for natural and man-made hazards mitigation is discussed in this paper. The following section defines about micro-electromechanical MEMS sensor and accelerometer required for SHM.

1.1 Mems Sensor

Recent advancements in micro-electromechanical sensor made it feasible to deploy low-cost, self-configuring wireless sensor networks for monitoring an area of interest with fine granularity. The ADIS16223 Sensor is a tri-axial, digital vibration sensor system that combines industry-leading MEMS sensing technology with signal processing, data capture, and a convenient serial peripheral interface (SPI). The SPI and data buffer structure provide convenient access to wide bandwidth sensor data.

The ADIS16223 also offers a digital temperature sensor, digital power supply measurements, and peak output capture. The ADIS16223 is available in a 15 mm × 15 mm × 15 mm module with a threaded hole for stud mounting with a 10-32 UNF screw.

1.2 Accelerometer

The main trigger for the recording of an acceleration measurement is the detection of the start of an earthquake. Accelerometer and strain gauges are the two sensors that are most useful for structural monitoring applications. The three-axis accelerometer (ADXL335) provided with the mote platform measures acceleration with a minimum full-scale range of ±3 g. It is a small, thin, low power, complete 3-axis accelerometer with signal conditioned voltage outputs. It can measure the static acceleration of gravity in tilt-sensing applications, as well as dynamic acceleration resulting from motion, shock, or vibration.

II. PROBLEM DEFINITION

1. To design and implement an smart sensing system to realize early detection of progressive accumulation of collapse to a multistory age building
2. To guarantee an adequate level of safety and serviceability economically using a combination of the local acceleration data and strain data from multiple sensors and voice activation system (wireless sensor nodes)across the building

3. The strain sensors are mounted at the base of the building to measure the settlement and plastic hinge activation of the building.
4. The accelerometers are mounted at every floor of the building to measure the seismic response of the building.

III. WIRELESS SENSOR NETWORK

Due to its commercial potential, monitoring of large public buildings is a significant emerging application area for wireless sensor networks. Wireless sensor networks can be deployed for monitoring the response of structures to strain and ambient vibration (e.g, wind, earthquakes), monitoring and controlling of indoor environment (e.g., lighting, heating, air quality), and helping in extreme event response (e.g., detecting congested exits, finding safe routes during an evacuation).

A wireless sensor network spatially distributed autonomous sensors to monitor physical or environmental conditions, such as temperature, sound, pressure, etc. and to cooperatively pass their data through the network to a main location. Table 1 shows various kinds of hazards, and possible applications/combination of sensors. The more modern networks are bi-directional, also enabling control of sensor activity. WSN is one of the fastest growing technologies in ubiquitous networking today. Standardization efforts, such as IEEE 802.15.4 are geared to reduce costs, provide device customizability for diverse applications and create standards for interoperability. The risk to buildings includes aging of structural performance, fatigue, damage, gas leak, invasion, fires, etc. According to the results of risk monitoring, appropriate risk control measures such as structural control, maintenance, evacuation guidance, warning, alarm, fire fighting, rescue, security measures, can be applied (Fig. 1).

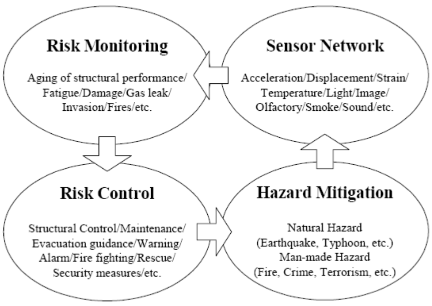


Fig.1 Building Risk Monitoring and Hazard Mitigation

Table 1. Sensor Applications.

HAZARD	APPLICATION	SENSOR
Earthquake /Wind	Observation	Acceleration
	Experiment	Acceleration, strain
	Structural control	Acceleration
	Health monitoring	Acceleration, strain
	Damage detection	Acceleration,
Fire	Fire detection	Temperature, smoke, acoustic,
	Gas leak detection	Olfactory
	Alarm, warning	Sounder
	Evacuation	Temperature, smoke, acoustic,
Crime	Surveillance	Acceleration,
	Security alert	Sounder

A wireless sensor network plays a vital role in such strategies and can be connected to the internet so that this information can be used for monitoring future risks. Wireless sensors are easy to install, remove, and replace at any location, and are expected to become increasingly smaller (i.e., "smart dust") by using MEMS technology. They provides a ubiquitous environment in buildings. For example, acceleration and strain of each beam and column, temperature and light in each room, images and sounds in desired locations can be obtained by the "smart dust" sensors, as illustrated in Figure 2.

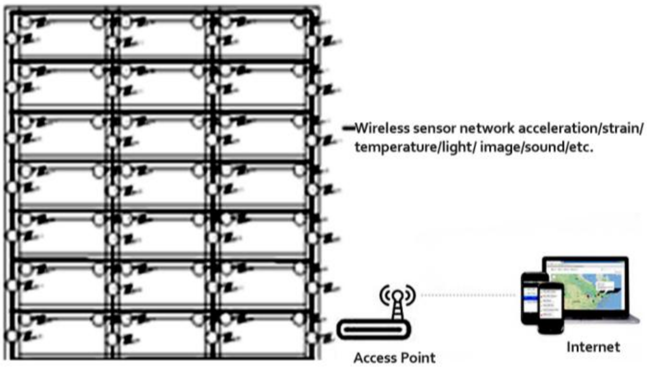


Fig. 2 Example Of Risk Monitoring System

IV. PRINCIPLE OF OPERATION

The monitoring nodes (fig.3) are selected based on their location and amount of environmental noise. Ground level node may be suitable. The monitoring node senses the data and passes it to the nearby base station via router. The base station compares the received data with the preset threshold value, if the received value exceeds the threshold value it will send a wakeup signal to both monitoring nodes as well as non –monitoring nodes.

The base station receives all the cumulative data from the building module and checks once again to conform that the response has occurred. Immediately the base station will pass the information that the building is going to collapse and people have to vacate the building.

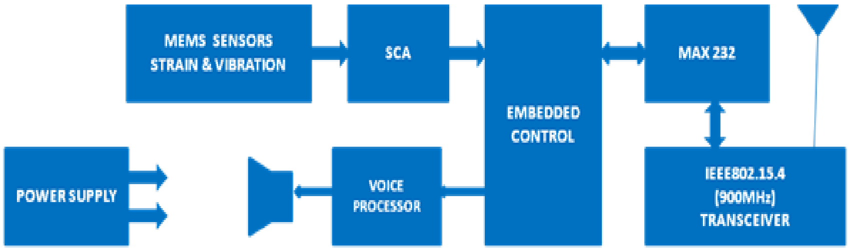
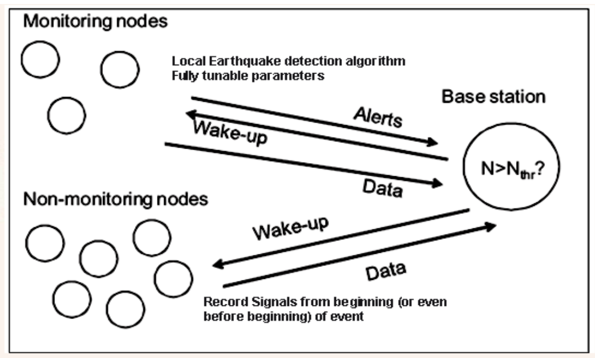


Fig.3 Block Diagram Of Monitoring Node



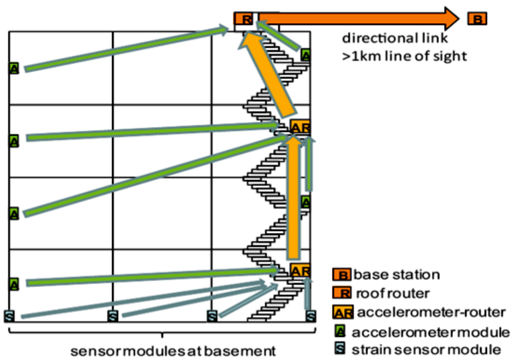


Fig.4 Working Principle of Monitoring System

Fig.5 Architecture of the Structural Monitoring System

V. PERFORMANCE TEST

To investigate the performance of the wireless acceleration sensor, free vibration tests were conducted using Visual Basic Software. An oscilloscope software application included in the Tiny OS version 0.6 is used. Fig. 6 shows building shakes alert monitoring node in normal case. Fig.7 shows Seismic event occurred indicating emergency symbol in the Monitoring Node.

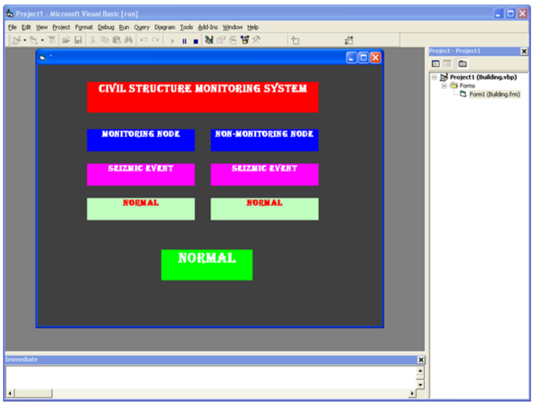


Fig. 6 Building Shakes Alert Monitoring Node In Normal Case

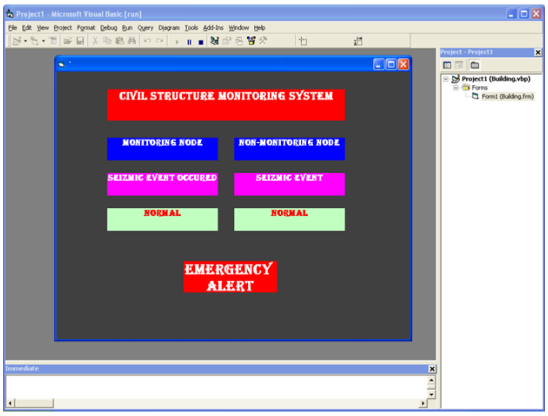


Fig.7 Seismic Event Occurred In The Monitoring Node

VI. CONCLUSION

The sensor observations are tested and found working satisfactorily. The integration of hardware using MAC protocol has to be completed. We hope our system will improve the survival rate of the human lives from natural disasters and seismic events. The presented wireless system for building monitoring takes advantages of the unique features of custom-developed MEMS sensors to realize a solution which offers long battery lifetime and potentially low cost in manufacturing, installation and maintenance, while providing high-quality sensor data at right time.

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