Fundamental Test of Seismic Information and Building Damage Data Gathering System using OSHW with Wireless Sensor Network

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ABSTRACT

To cope with a large disaster such as that caused by a large earthquake, it is necessary to gather seismic information and building damage data. This paper describes open source hardware (OSHW) with various sensors and a wireless communication system used as a new device to measure the strength of an earthquake and the extent of building damage. The OSHW assessed in this study is inexpensive and readily accessible. Therefore, the spread of wireless sensor network with the OSHW is expected. For this study, an acceleration sensor is used to conduct the following examinations. First, a component of OSHW with the wireless sensor network is explained, as are its specifications. Secondly, simple and extensive applications for the system for gathering seismic information and building damage data are proposed. Thirdly, future subjects of these applications are defined. Several fundamental test results are presented. Finally, the effectiveness of this seismic information gathering system is discussed.

INTRODUCTION

The 2011 Great East Japan Earthquake and its consequent tsunami caused vast destruction throughout maritime areas of Tohoku, Japan. For large earthquakes and to cope with the aftermath of any large disaster, it is necessary to gather seismic information and building damage data. Nevertheless, that task often becomes impossible because of power outages, communication cable disconnections, and other disruptions. Monitoring the structural performance of buildings during their life cycle is becoming increasingly important, especially after experiencing extreme motions caused by earthquakes.

Sensor network systems using strain gages and/or acceleration sensors have been studied experimentally and have become used in practical buildings recently. Numerous communication technologies such as RFID and wireless networks have also been introduced into monitoring systems by Tani et al. (2007, 2010), Murakami et al. (2007), and Liang et al. (2011, 2012). In these studies, the method of measuring relative story displacements accurately is discussed as an important seismic index of structural performance. However, as described herein, a seismic information gathering system using an OSHW with sensors and wireless communication system is proposed for gathering seismic information and building damage data urgently and extensively.

Examinations of the wireless communication system's communication performance are then explained. Based on results of testing, the seismic information gathering system effectiveness is verified and discussed.

SEISMIC INFORMATION AND BUILDING DAMAGE DATA GATHERING SYSTEM

OSHW. In this study, Arduino is used as open source hardware. Table 1 shows Arduino Uno R2 specifications. The Arduino is readily programmable with the Arduino development environment using Arduino programming language and Processing programming language. The OSHW, which has analog and digital input ports, can be connected to various sensors.

Table 1. Specifications of Arduino Uno R2.

CPU	Atmega328 (8 bit-AVR, Clock 16 MHz)
Flash Memory	32 Kbyte
SRAM	2 Kbyte
EEPROM	1 Kbyte
Analog Input	10 bit, 6 ports
Digital Input	14 ports

ACCELERATION SENSOR. A MEMS type acceleration sensor is used for this study. Table 2 presents specifications of the acceleration sensor used for this study.

Table 2. Specifications of acceleration sensor.

Range of detection	±2 *g*
Sensitivity	1000 mV/*g*
Margins of Error	±0.1%
Input Voltage	5 V

WIRELESS COMMUNICATION SYSTEM. XBEE is used in this study as a wireless communication system. It is readily connectable to Arduino. XBEE embedded RF modules provide cost-effective wireless connectivity to devices in ZigBee mesh networks. Therefore, it is extremely convenient and function-rich. Table 3 presents specifications of XBEE. Of the several types of XBEE that exist, XBEE series 2 is used in this study.

Table 3. Specifications of XBEE.

RF Data Rate	250 kbps
Indoor/Urban Range	40 m
Outdoor/RF Line-of-Sight Range	120 m
Transmit Power	2 mW
Receiver Sensitivity (1% PER)	-96 dBm in boost mode
Frequency Band	2.4 GHz
Serial Data Rate	1200 bps − 1 Mbps

Operating Temperature	-40º C to +85º C 0-95% humidity non-condensing
Supply Voltage	2.1 − 3.6 VDC
Transmit Current	35 mA / 45 mA boost mode @ 3.3 VDC
Receive Current	38 mA / 40 mA boost mode @ 3.3 VDC

SEISMIC INFORMATION AND BUILDING DAMAGE DATA GATHERING System. Figure 1 shows the used gathering system of seismic information. The left panel shows a sensor node composed of Arduino, XBEE, and triaxial acceleration sensor. This device measures triaxial accelerations and transmit the data via an XBEE device. The right panel shows the data receiving equipment, which is the XBEE connected to a PC. The PC receives the observation data and processes the data. In this study, a sensor node is assumed to be installed at a house. The sensor node has several sensors to observe seismic information and building damage data: an acceleration sensor, a gyro sensor, a range sensor, and so on, as shown in Figure 2. The earthquake strength is detected and quantified by the acceleration sensor and instrumental seismic intensity as defined by the Japan Meteorological Agency is calculated. Furthermore, residual deformation of the house is assumed to be observed by a gyro sensor and/or range sensor. The sensor node can observe seismic information and building damage data using the method described previously. However, a discussion of how many sensors can be installed to the sensor node must be undertaken because an installation of highly functional and many sensors might be expensive and might disturb the spread of sensor nodes.

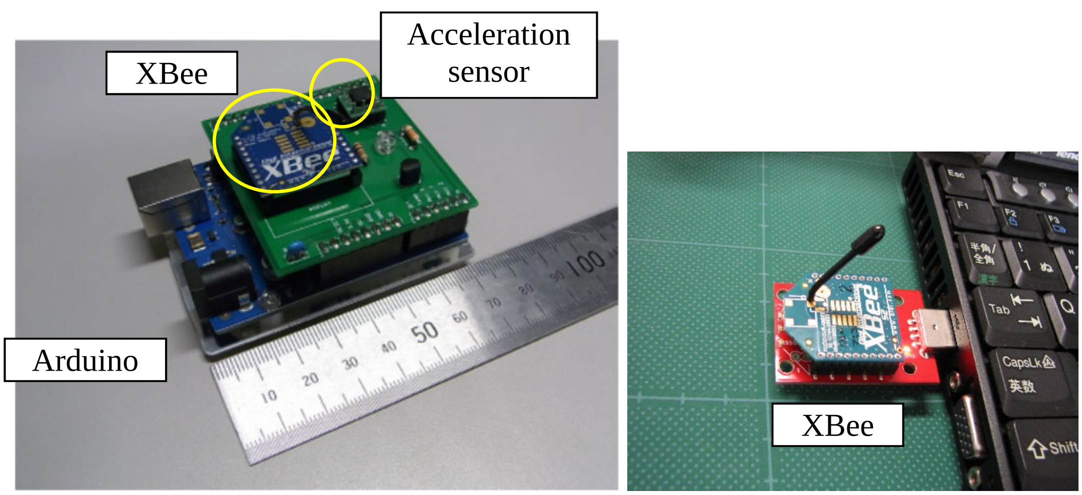

Figure 1. Information gathering system.

Simple Application. Figure 3 presents a simple application for the system. The PC receives seismic information and building damage data from the sensor node and sends the information to homeowner via email. A homeowner who is absent from home can receive information and rapidly take some appropriate actions in response to the earthquake.

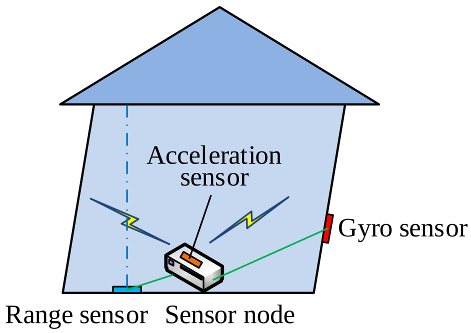

Figure 2. Sensor node and sensors.

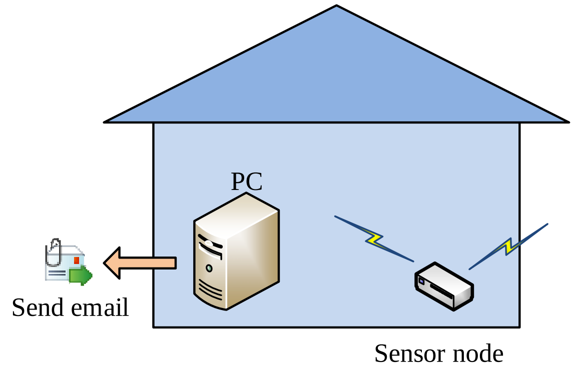

Figure 3. Simple application.

Extensive Application. Figure 4 presents a proposal of an extensive application for the system. Sensor nodes placed each house can build wireless ad-hoc network using XBEE functions. Therefore, if there is a blackout and/or communication cable disconnection. Then the sensor nodes can mutually communicate and pass seismic information and building damage data to a Server PC. The disaster prevention center can gain perspective information related to damage in a jurisdictional area and cooperate with emergency and fire department offices. Accordingly, the disaster prevention center can organize rescue operations expeditiously and appropriately.

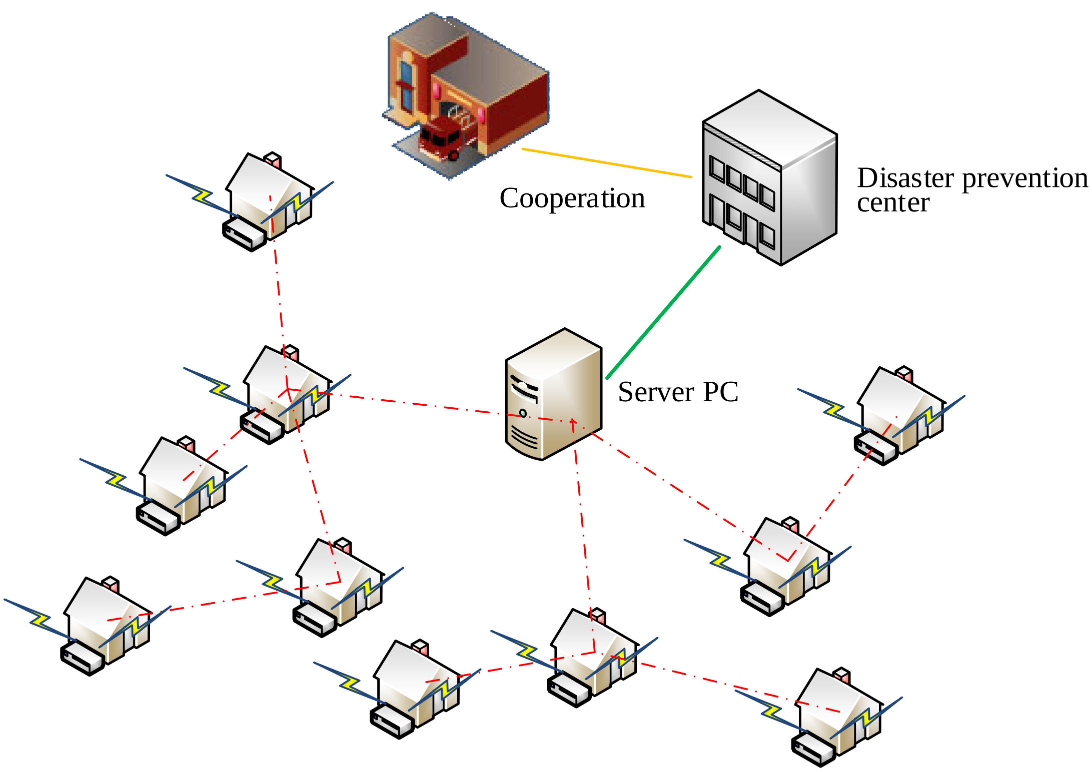

Figure 4. Proposal of extensive application.

Subject. Future subjects of these applications are described below.
1) Measurement accuracy of sensors connected to sensor node.
2) Where is the sensor node placed in a house?
3) How is power supplied to a sensor node?
4) Sensor node maintenance and durability.
5) Reliability of communication between sensor nodes and the server PC.
6) Information security.
7) How many sensor nodes can communicate simultaneously?

FUNDAMENTAL TEST

To verify the effectiveness of the proposed applications and approach the subjects described above, several experimental studies were conducted by the authors. Some examinations and results are explained below.

Wireless Communication Performance Test. To ascertain the distance at which sensor nodes with XBEE devices can communicate with the server PC, several communication experiments have been performed in different environments. Figure 5 presents an experimental method in an outdoor environment. Figure 6 shows the result. The sensor node is set at a point. An experimenter moves away from the sensor node in steps of 10 m. In Figure 6, the horizontal axis shows the distance between the sensor node and the experimenter. The vertical axis shows the accuracy of transmitted and received data. Color codes of lines show the transmission intervals of data. The data accuracy clearly differs according to transmission intervals from the graph. Especially, a great difference exists between 35 ms and 36 ms. Furthermore, the amount of change according to the distance is small. The maximal communication distance is regarded as 100 m.

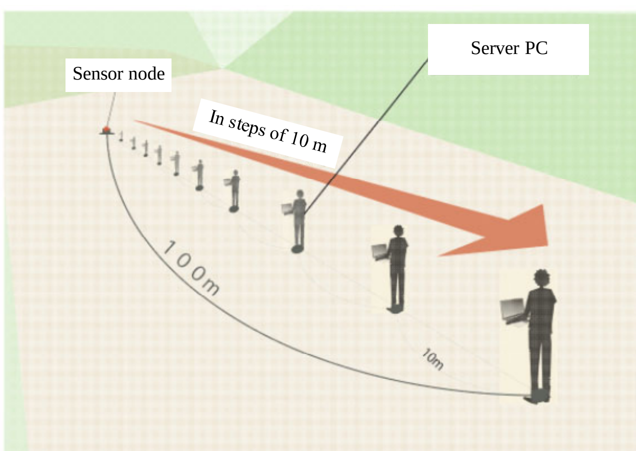

Figure 5. Experimental method of outdoor environment test.

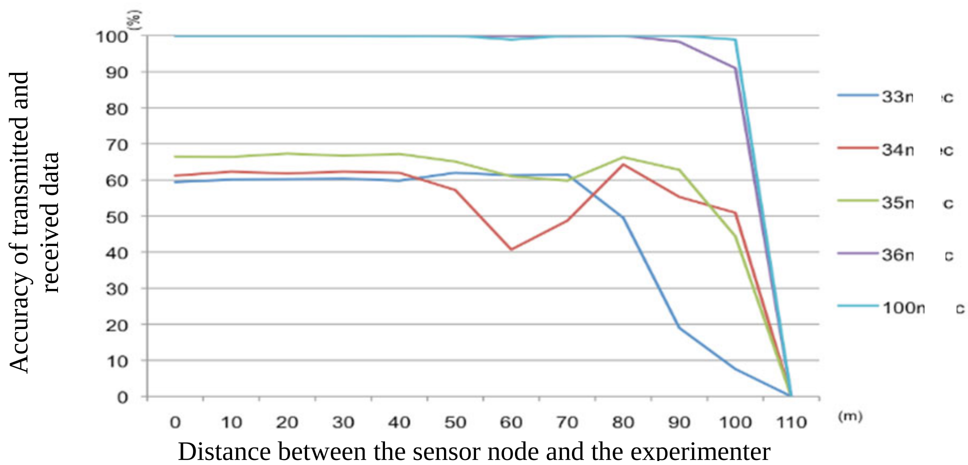

Figure 6. Result of outdoor environment test.

Figure 7 portrays experimentally obtained results of tests conducted in an indoor environment. In the floor map, the blue circle is the sensor node location. The red area shows a place where communication data can be received and the red shading shows accuracy of communication. Additionally, the white areas show places where the data cannot be received. The gray areas are beyond the bounds of the experiment. Results show that wireless communication using XBEE tends to go straight.

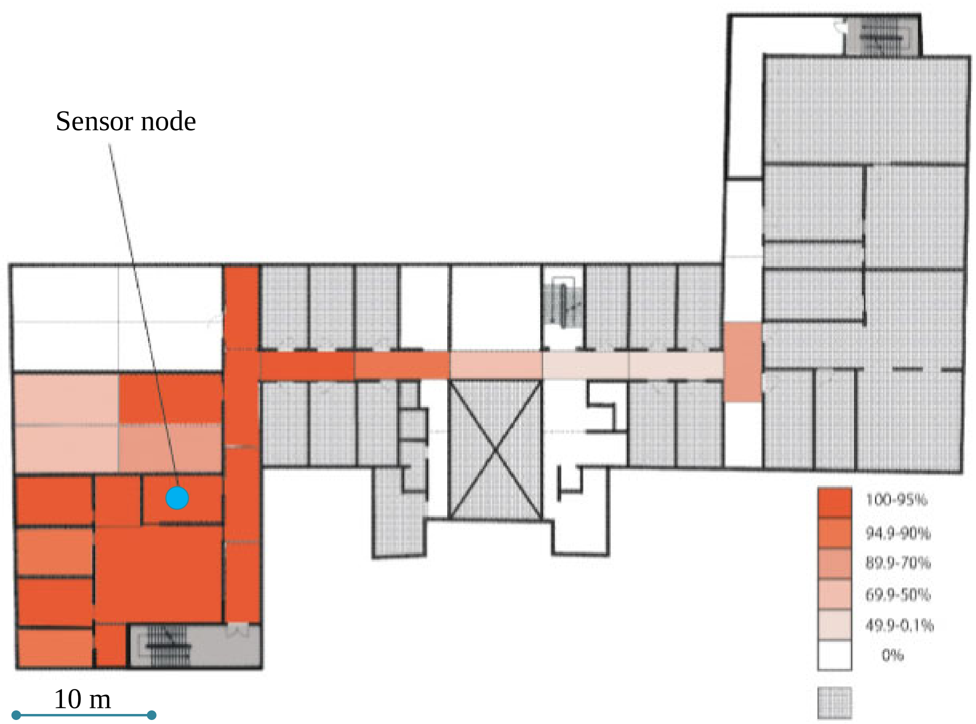

Figure 7. Results of indoor environment test.

Acceleration Sensor Accuracy. To confirm the acceleration sensor accuracy, shaking table tests were performed. The sensor nodes with acceleration sensors and other high-performance acceleration sensors are placed on the shaking table. Earthquake wave models of several types are used. For example, Figure 8 presents a comparison of time historical response acceleration for the Taft EW (1952) wave. Results show that response accelerations by sensor node almost coincide with those by a high-performance acceleration sensor with phases and amplitudes. However, a degree of differences in amplitudes is observed in comparison with the result.

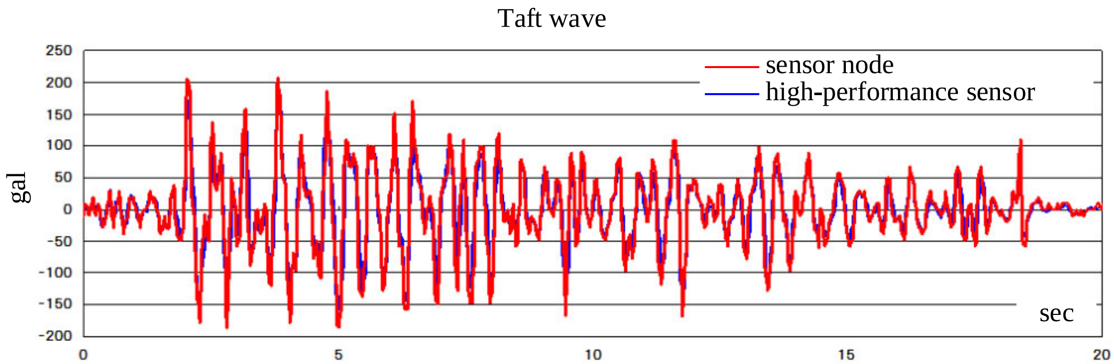

Figure 8. Comparison of acceleration sensors (Taft EW wave).

CONCLUSION

As described in this paper, first, the component of OSHW with wireless sensor network and the respective specifications were explained. Secondly, simple and extensive applications for the system for gathering seismic information and building damage data were proposed. Finally, the future subjects of these applications were defined. Several fundamental test results are introduced.

As described above, several subjects remain. However, the proposed system is assumed to be inexpensive and accessible. Therefore, the spread of the OSHW with a wireless sensor network is expected. It becomes a useful tool for gathering seismic information rapidly and extensively.

ACKNOWLEDGEMENTS

A part of this research was financially supported by a Grant-in-Aid for Scientific Research, No. 23510201 and No. 25420581 by Japan Society for the Promotion of Science (JSPS).

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