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Vibration Measurement of Wireless Sensor Nodes for Structural Health Monitoring

Surgwon Sohn, Seong-Rak Rim, In Jung Lee

Div. of Computer and Information Eng., Hoseo University,
Chungnam, Rep. of Korea
{sohn, srrim, leeij}@hoseo.edu

Abstract. Low-cost wireless sensor nodes have become more important in the area of modern structural health monitoring (SHM) because the power consumption and cost of the wireless sensor nodes play an important role in the development of modern SHM. This paper presents a low-cost wireless vibration measurement method using wireless sensor nodes. In order to demonstrate their feasibility to the SHM, experimental modal analysis for a cantilever beam has been carried out and compared with the conventional wired vibration measurement system. Experimental results show the feasibility of using low-resource wireless sensor networks for structural health monitoring.

Keywords: Wireless Sensor Nodes, Vibration Measurement, Experimental Modal Analysis

1 Introduction

Since wireless sensor nodes reduce the time and cost of installation and maintenance for the structural health monitoring (SHM), the use of wireless sensor networks (WSNs) has recently become an area of interest [1]. To better understand any structural dynamic problems, the resonant frequencies of a structure need to be identified and quantified. Today, experimental modal analysis has become a widespread means of finding the modes of vibration of a structure. Modal analysis is the field of measuring and analyzing the dynamic response of structures during excitation [2]. The frequency response function (FRF) describes the input-output relationship between two points on a structure as a function of frequency [3]. Experimental modal parameters, such as natural frequency, damping ratio, and mode shape, are also obtained from a set of FRF measurements.

Many researchers choose commercial off-the-shelf products as their wireless sensor nodes rather than building their own prototypes because of their performance and ease of implementation. For such a reason, we also choose a commercial low-cost wireless sensor node that is composed of a MEMS accelerometer, Arduino compatible processor board, and IEEE 802.15.4 communication module. In this paper, the selected wireless sensor node is briefly described in Section 2. In Section 3, experimental analysis for both the conventional wired sensor and proposed wireless sensor is presented.

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2 Wireless Sensor Nodes

Functional subsystems of WSN are sensing interface, computational core, and actuation interface as shown in the previous research [4]. By keeping in mind the low-resources, we have selected a commercial off-the-shelf product, Libelium Waspmote [5], that includes ATmega 1281 micro-controller. It has 8 kb SRAM, 4 kb EEPROM, 128 kb flash memory, and 2 gb SD memory. For saving the power consumption, there are 4 modes; On: 15mA, Sleep: 55 μA, Deep sleep: 55 μA, Hibernate: 0.7 μA. It automatically selects the appropriate power supply (USB or external power), eliminating the need for the power selection jumper. It also has 7 Analog (I), 8 Digital (I/O), 1 PWM, 2 UART, 2 I2C, 1 USB, and 1 SPI for I/O.

A low cost accelerometer sensor, LIS331DLH, is built on the Waspmote that is used to measure the accelerations of the cantilever beam. It has three scales (±2g, ±4g, ±8g) and seven work modes which is important in case of battery operated products. In normal mode, the output data rate can be 50 Hz / 100 Hz / 400 Hz / 1000 Hz. But in low power mode, it can be 0.5 Hz / 1 Hz / 2 Hz / 5 Hz / 10 Hz.

A ZigBee-802.15.4-Pro 802.15.4 rf module is used for a wireless data transmission to satisfy the low resources. It operates -100 dB sensitivity within the ISM 2.4 GHz frequency band. It has 100 mW EIRP power output (up to 7000 m outdoor range), RPSMA connector. To interface this rf module on the Waspmote, it needs a Waspmote gateway. It communicates with the host PC via IEEE 802.15.4/ZigBee protocol. Fig. 1 shows the Waspmote with the ZigBee module and Waspmote gateway.

Fig. 1. Waspmote with ZigBee and the host gateway

3 Experimental Modal Analysis

To investigate a suitability of low-resource wireless sensor node in a SHM, an experimental modal analysis for a cantilevered steel beam is carried out. The frequency response function was performed at the host PC using Smart Office Analyzer software with the 1,024 sample of data.

3.1 Experimental Setup

To study the accuracy of the dynamic acceleration measurement obtained with a wireless accelerometer such as LIS331DLH on the Waspmote, we used a conventional wired IEPE accelerometer to measure the transient response of a cantilever beam simultaneously. The experimental modal analysis of a simple cantilever beam was performed to demonstrate the use of wireless sensor nodes.

A cantilevered steel beam was used for the experiment with approximate dimensions of 900 x 60 x 3 mm. An IEPE or ICP type impact hammer, model 086C03 of PCB Piezotronics, was used as the excitation source at any point input and response data was acquired at the point of the beam. A cable with the hammer is connected to the NI-9234 as data acquisition hardware. A wired accelerometer, 603C01 of PCB Piezotronics, was used for the reference. A MEMS accelerometer, LIS331DLH built on the Waspmote, is located at the end of the cantilever beam and the excitation was imparted on the point as shown in Fig. 2.

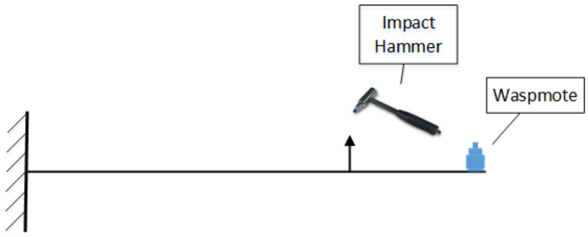

Fig. 2. Test setup and the data acquisition point

The measurement for experimental modal analysis is to acquire frequency response function data from a test structure. As the cantilever beam setup was excited with the hammer manually the response of the structure was measured in the form of acceleration. Both the excitation and response signal were sent to the data acquisition hardware with a signal processing software. Fig. 3 shows the Waspmote, which is composed of accelerometer, processor, and communication device, on a cantilever beam for experimental modal test. The Waspmote communicates with the host PC using a gateway device via the IEEE 802.15.4 protocol.

Fig. 3. A wireless accelerometer on a cantilever beam

Sampling rate of the wired ICP accelerometer was 256 Hz, and the vibration signal was collected for 4 seconds, so a total of 1,024 samples were recorded for postprocessing. In case of wireless accelerometer, the sampling rate of the LIS331DLH was 400 Hz, and the vibration data was recorded at a rate of 256 Hz for 4 seconds.

3.2 Test Results

The signal processing software, Smart Office Analyzer, was used to capture and analyze the signal acquired from the both ICP accelerometer and LIS331DLH on the Waspmote. The modal frequencies were estimated as the frequencies where we received maximum gain in the frequency response function plots in Smart Office Analyzer. Fig. 4 and Fig. 5 represent frequency response function of the wired and wireless accelerometer respectively. The modal frequencies as compared are in the Table 1.

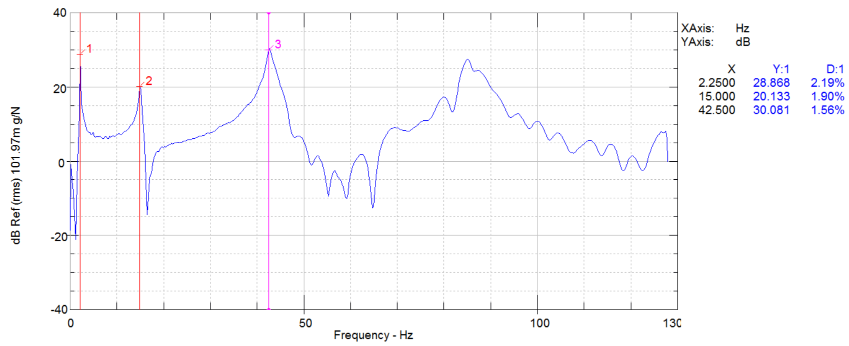

Fig. 4. Frequency response function using wired IEPE accelerometer

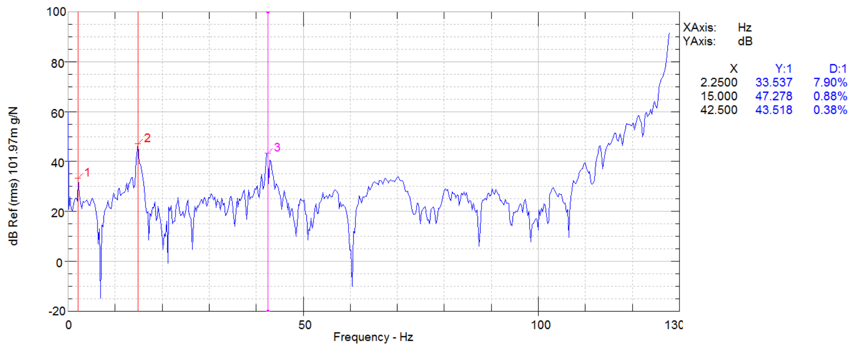

Fig. 5. Frequency response function using wireless MEMS accelerometer

Table 1. Modal frequencies and damping ratio

Mode	Accelerometer type	Natural Frequency (Hz)	Damping Ratio (%)
1st	wired	2.25	2.19
1st	wireless	2.25	7.90
2nd	wired	15.60	1.90
2nd	wireless	15.00	0.88
3rd	wired	42.50	1.56
3rd	wireless	42.50	0.38

4 Conclusion & Future Works

In this paper, the feasibility of using wireless sensor nodes on a vibration measurement was investigated. To this end, both the wired and wireless sensor-based measurements were carefully examined. In order to justify the performance of wireless accelerometers, an experimental modal analysis for the cantilever beam was carried out. To verify its feasibility, the natural frequency and damping ratio of the cantilever beam was calculated with Smart Office Analyzer software.

A further step of the research is to design wireless sensor networks of the SHM applications. Expecting issues would be data transmission bandwidth and time synchronization.

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