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LOW FREQUENCY VIBRATION MONITORING SYSTEM USING WIRELESS SENSOR NETWORK

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Abstract – This paper presents a wireless sensor network technology for low frequency vibration monitoring system. Sensor node collects the data from accelerometer and transmits the data back to base station through wireless communication. The data has been computed and converted into acceleration information that is stored in database. Then users can monitor using a web application. The experiments were carried out by collecting the acceleration data from three-axis accelerometer. The data from each axis was measured and verified by vertically aligning with a Very Low Frequency Primary Calibration System. The experimental parameters are the vibration frequency between 0.4Hz and 10Hz and the amplitude between 0.0981m/s^2 and 17.6580m/s^2. The calibration results of the low frequency vibration monitoring system using wireless sensor network are conformed with the wire vibration monitoring system.

Keywords: Vibration Monitoring System, Wireless Sensor Network, Acceleration, Low Frequency

1. INTRODUCTION

Vibration monitoring system is widely used to monitor health of many structures such as building, bridge, machinery and dam. As soon as the vibration can be detected, the alarm system must report to administrator immediately. A real-time system such as wireless sensor network is considered to be applied.

Wireless Sensor network is an interesting technology that has been applied to various monitoring applications such as disaster warning systems. This system consists of a small device that collects vibration measurements from sensors. By using wireless, this can reduce cost of wiring and increase more location flexibility [1].

The proposed vibration monitoring system is designed for building. The system is tested frequency response in range of mostly frequency of ground shaking during earthquake [2] and tested linearity of the system in range that a shaker can be done at each frequency.

This paper is organized as follows. Section 2 describes the designed system. Section 3 describes the system calibration that the system is tested frequency response and linearity of the system and then shows the results in section 4. Conclusion of this paper is in section 5.

2. DESIGNED SYSTEM

The block diagram of designed system in this research is illustrated in Fig. 1. The designed system composed of 5 subsystems, sensor node, base station, computer server, database, and web application, which can be described as follows.

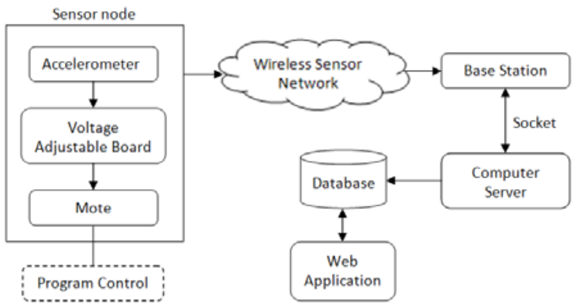

Fig. 1. The block diagram of designed system

2.1 Sensor node

Sensor node is used to capture the vibration signal from the physical environments and transmitted to base station via wireless communication. The sensor node consists of 3 hardware components and works properly under program control, which can described as follows.

2.1.1 Accelerometer: K-Beam accelero-meter type 8393B2 [2] is used to measure vibration. It is designed as a low frequency vibration sensor. It can measure acceleration from range -19.62m/s^2 to 19.62m/s^2 with 1000mV per 9.81m/s^2 of sensitivity for 3 perpendicular axes between 0 and 250 Hz with maximum vibration effectiveness.

2.1.2 Mote: Mote was developed on MSP430F1611 microcontroller and cooperated with wireless transceiver model CC2420 which supported to IEEE 802.15.4 at 2.4 GHz. The advantage of this mote is an ultra low power wireless and supports 8 channels of 12-bit analog to digital converter (ADC). This platform is called Unode which is developed from Tmote Sky [3].

2.1.3 Voltage Adjustable Board: The voltage adjustable board provide availability connection between vibration sensor and mote. It is used to convert voltage level of signal from vibration sensor to ADC compatible voltage vibration signal.

2.1.4 Program Control: Program control which is installed on sensor node is used to get the acceleration raw data from 3 channels of 12 bits ADC module. Then it makes the packet and sends to base station via wireless communication every 3 milliseconds. The program control procedure is shown in Fig. 2.

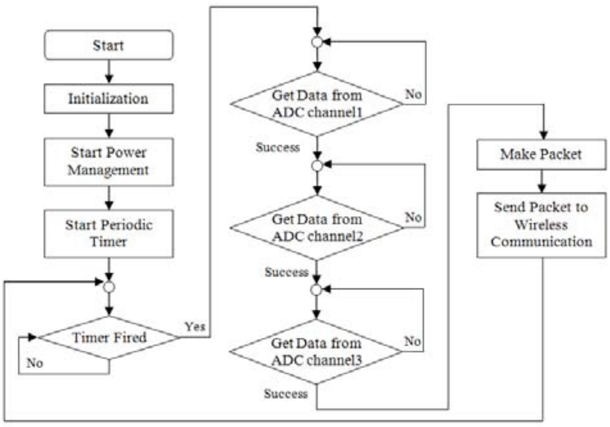

Fig. 2. Flow chart of the program control procedure

The packets which are sent to base station have a format as shown in Table 1.

Table 1. Sensor Node Packet Format

nodeID	seq	dataX	dataY	dataZ

Sensor node packet format has 5 fields. "nodeID" is 16 bits ID number of mote that generates this packet. "seq" is 16 bits packet number that is increased by 1 every packet. "dataX", "dataY" and "dataZ" are 16 bits acceleration raw data at X-axis, Y-axis and Z-axis respectively.

The program control is developed by using NesC [4] (Network Embedded System C) language and TinyOS [5].

2.2 Base Station

Base station is used to collect data from sensor node, one or more sensor nodes, via wireless communication. It does connect the computer server via R232 serial communication. Base station used the same mote platform as sensor node.

2.3 Computer Server

Computer server is used to access and load the packet from base station when computer server connects to base station via socket service. The acceleration raw data is converted into acceleration information by using ADC converting formula of MSP4301611 microcontroller [6], but the vibration signal was adjusted voltage by voltage adjustable board. Therefore the ADC converting formula of MSP4301611 microcontroller has been accommodated to (1).

$$A = ((0.00061 \times N_{ADC}) - V_{cal}) \times \frac{4.905}{S} \quad (1)$$

when

A	Acceleration information
N_{ADC}	Acceleration raw data
V_{cal}	The voltage of vibration sensor when it does not motion.
S	Sensitivity of vibration sensor (Volts/g)

2.4 Database

Database is used to keep the results from computer server and other data of the packet.

2.5 Web Application

The users can monitor acceleration using a web application as shown in Fig. 3. A web application shows the acceleration raw data of 3 axes with graph. Users can change a time to update graph.

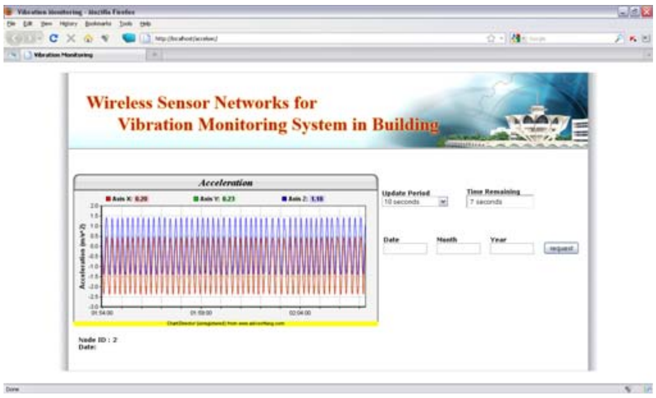

Fig. 3. Acceleration web interface

3. SYSTEM CALIBRATION

3.1 Equipments

The calibration setup as shown in Fig. 4 is consisting of computer server (1.66GHz Intel® Atom™ Processor N280 with 1GB of RAM), base station, sensor node, test accelerometer (Kistler K-Beam® accelerometer type 8393B2), a personal computer (3.2GHz Pentium with 512MB of RAM) running SPEKTRA CS18 program which is used to configure sine wave generator about frequency and acceleration, PCB Peizotronics® 301A10 ICP reference accelerometer with frequency range 0.3Hz-14kHz [7], a Very Low Frequency Primary Calibration System that consists of sine wave generator, power amplifier, shaker (ELECTRO-SEIS® APS113-AB [8] very low frequency and long stroke electro dynamic shaker with air bearings).

To prevent ripple effect, the test accelerometer must be attached to reference accelerometer as the same object. For this calibration, the test accelerometer setting is shown in Fig. 5.

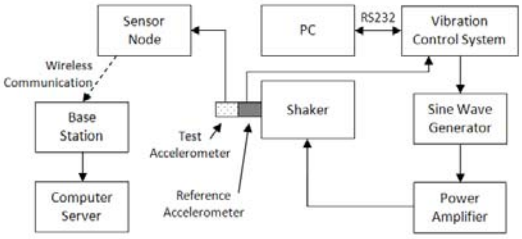

Fig. 4. Calibration Setup Block Diagram

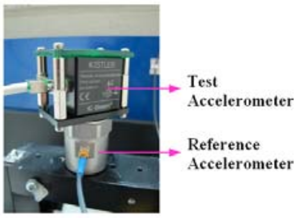

Fig. 5. The accelerometer setting,

3.2 Calibration procedure

The calibrations are performed on APS113-AB shaker with the 301A10 reference accelerometer to determine the performance of the system, frequency response and linearity of the system. The system is calibrated at frequency between 0.4Hz to 10Hz and the acceleration between 0.0981m/s^2 to 17.6580m/s^2. At each case, it is iterated 5 times. The test accelerometer and the reference accelerometer are verified by vertically aligning with a Very Low Frequency Primary Calibration System.

The calibration procedure as shown in Fig. 6 is summarized as the following steps; SPEKTRA CS18 program running on PC assigns frequency and acceleration for sine wave generator. Sine wave generator generates the signal and sends it to the power amplifier for amplifying signal. Shaker receives signal from the power amplifier and then shake test accelerometer and reference accelerometer. Finally, the acceleration raw data from test accelerometer is kept into database and SPEKTRA CS18 program shows frequency and root mean square (rms) acceleration that measure from reference accelerometer.

3.3 Data Analysis

Data analysis compares the acceleration information from test accelerometer with the acceleration information from reference accelerometer in term of frequency and rms acceleration. The acceleration information from reference accelerometer is average frequency and rms acceleration which are computed by SPEKTRA CS18 program, but on the other hand the acceleration information from test accelerometer is the data series of acceleration in time domain. So it must be analyzed frequency and rms amplitude of acceleration before comparing. Data analysis program is programmed using MATLAB.

The data analysis procedure for each time of each case of calibration, as shown in Fig. 7, is summarized as the following steps. First, the data from database is calculated real sampling rate because some packets are lost from high sampling rate and wireless communication characteristic when packets are transmited to base station. Even though some packets are lost but it does not affect the waveforms. The approximately sampling rate is used as the important parameter to compute the frequency and amplitude of waveform.

Second, smooth the data signal for improving estimated results from the fast Fourier transform of the data. Next, transform the data in time domain to frequency domain for calculating frequency using fast Fourier transform. Then, calculate DC amplitude and substract it from the data signal. The DC signal is effect of voltage adjustable board. Next, improve a frequency estimate using autocorrelation and then calculate the main frequency and rms acceleration.

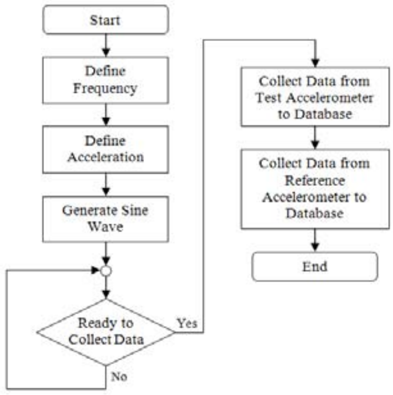

Fig. 6. Flow chart of calibration procedure

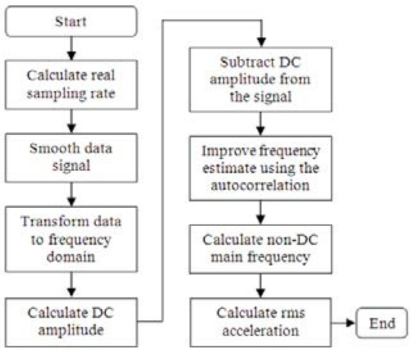

Fig. 7. Flow chart of data analysis procedure

4. RESULTS

As a system calibration, the frequency response for each acceleration(A) at X, Y, Z axis are shown in Fig. 8 – Fig. 10 and linearity for each frequency(f) at X, Y, Z axis are shown in Fig. 11 – Fig. 13.

The proposed system has excellent frequency response and excellent linearity except for 10Hz frequency at Y axis and Z axis, the system has linearity at acceleration between 0.0981m/s^2 to 9.8100 m/s^2. The results at Y axis have some error acceleration. It is greater than input that is set in SPEKTRA CS18 program. It is a result of physical characteristics of tri-axial accelerometer that is composed of three accelerometers which sensitivity of each is not equal, although there are the same models. Another factor is binding equipment, between test accelerometer and reference accelerometer, which structure, format and size of equipment affects the linearity of system. This problem can be solved by programming.

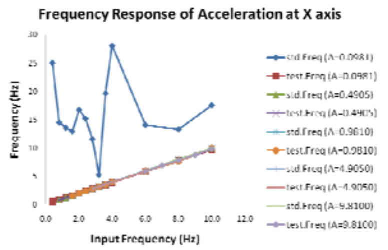

Fig. 8. Frequency response of acceleration at X axis

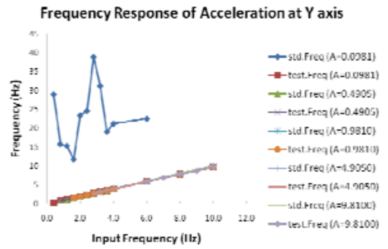

Fig. 9. Frequency response of acceleration at Y axis

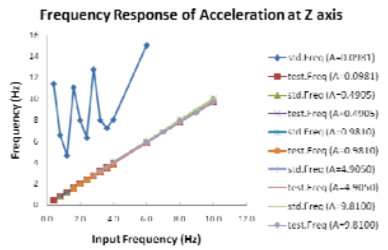

Fig. 10. Frequency response of acceleration at Z axis

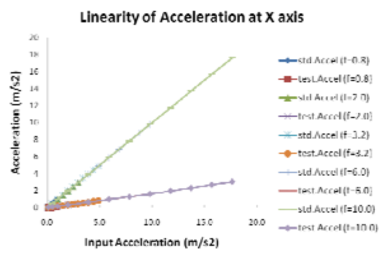

Fig. 11. Linearity of acceleration at X axis

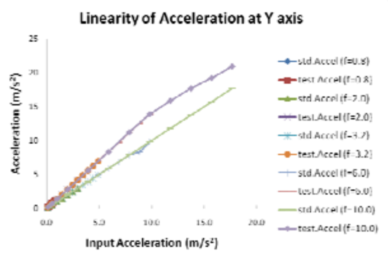

Fig. 12. Linearity of acceleration at Y axis

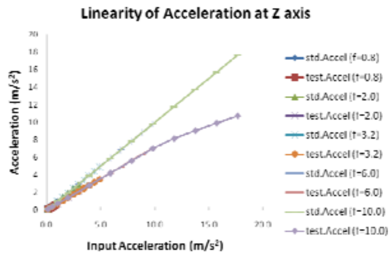

Fig. 13. Linearity of acceleration at Z axis

On the other hand, the reference system has an excellent linearity and excellent frequency response except for 0.0981 m/s^2 acceleration. The results of calibration show that our system is suitable for low frequency more than reference system.

5. CONCLUSIONS

In this paper, we presented the design of low frequency vibration monitoring system using wireless sensor network technology. Some packets are lost but it does not affect the waveforms. Frequency response and linearity are excellent results except for 10Hz frequency that the system has linearity at acceleration between 0.0981m/s^2 to 9.8100 m/s^2. The results of calibration show that our system is suitable for low frequency and low acceleration.

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