DESIGN OF LOW COST WIRELESS SENSOR NETWORK FOR HEALTH MONITORING OF LARGER STRUCTURES.

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ABSTRACT:

To monitor the structural health of civil and mega mechanical structures, a wired sensor system is been used traditionally. From an economical and a maintenance point of view, the traditional wired SHM systems have limitations when used in offshore wind turbine, wave energy devices and other civil structures. Wireless sensor is getting importance because of its low price and suitability for mentioned applications. Commercially the available wireless sensor systems for SHM are expensive; hence there is a need of cheap wireless sensor network. A low cost wireless sensor network (WSN) for a Health Monitoring of these structures is proposed in this work. This work is divided into two tasks one, design of wireless sensor units (WSU). To measure the response of the system a WSU is designed by using available standard electronic components. This WSU consists of one acceleration senor, micro-controller, a radio frequency (RF) transceiver, and a battery power supply. The second part of the work consists of acceleration measurements for a four starry shear frame which is excited by shaker. Then the Autoregressive (AR) model coefficients are determined remotely for measured data at each starry of the shear frame. These coefficients are transferred to the master WSU which is connected to the computer using USB port for comparison with stored data base to recognize the pattern. In the extension to this work a Damage Index calculations could be performed at remote WSU.

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1 INTRODUCTION

Structural health monitoring (SHM) has become very important because of modern civil, mechanical structures because of its size and cost involved in it. These mega structures, brides, sky scappers, off shore wind turbines and wave energy devices are subjected to the external aerodynamic excitations, earth quakes. It has become important to monitor the response of such structure in such loading situations which leads to the defects in these structures and at some point it causes a catastrophic failure of the structure. Traditionally wire sensor channels are used to monitor the response, the cost of one such sensing channel may reach up to $5000 dollars, Lynch (2006). In last decade many researchers are involved in the development of the SHM techniques, a review of damage detection methods and wireless sensor network for SHM is documented by Lynch (2006) & Ciang (2008) respectively. A Wireless sensor network has got lot of importance because of its low cost and reliable data acquisition and its capacity to perform data interrogation within the sensor unit. Straser & Kiremidjian (1998) proposed the first design of low cost wireless modular monitoring system (WiMMS) for civil structures. Wireless sensor network solves the purpose of data acquisition and local data interrogation using engineering algorithms. Most of the commercially available wireless sensor platforms (Crossbow MICA2 Mote, Intel iMote) are having only data acquisition capabilities, in which huge amount of data is transmitted wirelessly to the central computer system for processing, Lynch (2006). To avoid the battery power loss in data transmission the engineering algorithms are performed remotely.

The engineering algorithms used in SHM technique are, calculation of Fast Fourier Transform (FFT) of measured data to identify the modal frequency changes in the structure, Lynch (2003a). Another widely used method proposed by Sohn (2001) is based on the pattern reorganization framework, in this method an Autoregressive (AR) time series model is fit to the measured data, and then the AR model coefficients are compared with the undamaged structure to identify any damages in the structure. For this the academic wireless sensor prototypes are developed and tested on site these are summarized in Lynch (2006). Such platforms are designed with two architectures one is assigned with data acquisition task and another is assigned for execution of embedded engineering analysis, Lynch (2004). The data is collected from the system and AR coefficients are calculated based on measured data, then these coefficients are transferred to the central server which is the central computer. The comparison of AR model coefficients with close AR model coefficients stored in the central computer is performed and Autoregressive exogenous (ARX) model coefficients are determined at central computer then they are transferred to the remote WSU. This method gives the rough estimate of damage index in the structure. The system proposed by Lynch (2004) is making use of central computer for comparison with stored data and also to design such a system one need core knowledge of electronic hardware and circuitry. Because of these necessities its use is limited in the academics or in research work, so there is a need of WSU which is modular and simple in construction, and ready to use with less efforts in hardware design.

Hence in this paper an easily available microcontroller development board, radio frequency transceivers (RF), and a Microelectromechanical systems (MEMS) based sensor are utilized to design a low cost wireless sensor unit for the SHM system. All of the hardware's chosen are based on the open source software. The local wireless sensor units are designed using an Arduino development platform (Arduino). A four starry building structure (shear frame) is used to test the performance of the designed wireless sensor unit. These wireless units are mounted on the each starry of the shear frame to collect the acceleration data of each floor with help of accelerometer also refer Chougule (2010). In the second part of this work the engineering algorithm of an AR model coefficient determination is performed locally. Then theses coefficients are transferred and are compared with an ARX model coefficients which are calculated based on the stored AR model coefficients in the external RAM of the master WSU by burg algorithm. The damage index of the structure could be find out using AR and ARX model coefficients which is the rough estimate of the presence of a damage in the structure.

2 SYSTEM HARDWARE CONFIGURATION

A standard WSU consists of subsystems, the sensing interface, computational core, and a RF transceiver and, for some cases an actuation interfaces. Figure 1 shows the fundamental subsystems of WSU.

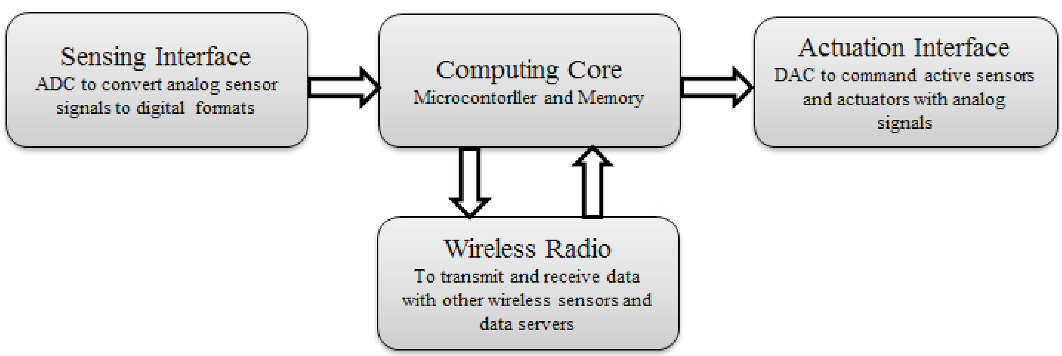

Figure 1. Wireless sensor subsystems.

In this work by making use of commercially available electronic components a remote WSU and a master WSU is designed. The Sensing interface consists of a sensor capable of converting analog signal to digital signal, in this work a three axis 1.5g micro machined accelerometer (MMA 7361L) is used to measure the acceleration of a four starry shear frame. The accelerometer has a bandwidth response of 300 Hz in z-direction. Figure (2) shows the assembly of a remote WSU which is mounted at the each starry of the shear frame.

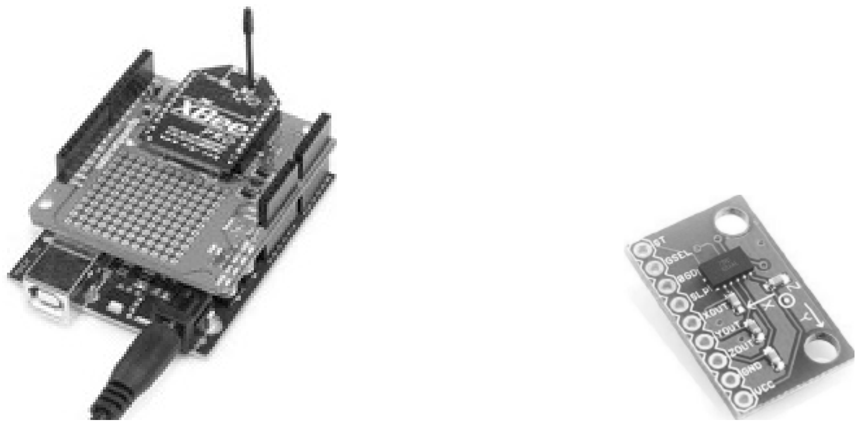

Figure 2. Arduino Duemilanove board with RF wireless module and MMA 7361L Accelerometer

A low cost Arduino Duemilanove Board with ATmega328P-PU microcontroller is used for remote WSU. An Arduino Duemilanove Board has 14 input/output pins, 6 analog input pins, a 16 MHz crystal oscillator, a USB connection, a power jack, and an ICSP header and a reseat button. Atmega238P-PU microcontroller is the 8-bit core, 20MHz, 32 KB of flash memory and, 2KB of SRAM memory. For data transmission the XBee-Pro 802.15.4 (series 1) OEM Radio frequency (RF) module is used, for more technical details refer (XBee). The XBee-Pro 802.15.4 RF module operates within the ISM 2.4 GHz frequency band; they can transmit data within 1500 m range outdoor. They are easy to configure and can be used for point to point and point to multipoint and, peer to peer network technology. RF module is easy to assemble with Arduino board with help of RF shield. The WSU unit without acceleration sensor is shown in the Figure (2) has been used as a remote WSU to measure the acceleration of the cantilever beam and the fundamental frequencies are successfully calculated by implementing the FFT algorithm for measured time history data Chougule (2010). This WSU has only one 8-bit microcontroller; to store the ARX model coefficients for exogenous inputs it needs external RAM. Hence a dual core WSU is used for performing a data comparison and used as a master WSU in this paper.

A master WSU is designed with keeping in mind the determination of ARX coefficients to find out the state of structure and hence damage index. A master WSU is constructed by using a Micropendus3 which is an open hardware development board. It has Atmel's AVR microcontroller AT90USB1287 with USB port which is similar to the Arduino Duemilonave board. AT90USB1287 has 128 KB of Flash memory for program, 8 KB of SRAM, 4 KB of EEPROM and 112 KB of external RAM on Micropendus3. Additionally it has got micro SD connector slot expandable to increase the storage memory.

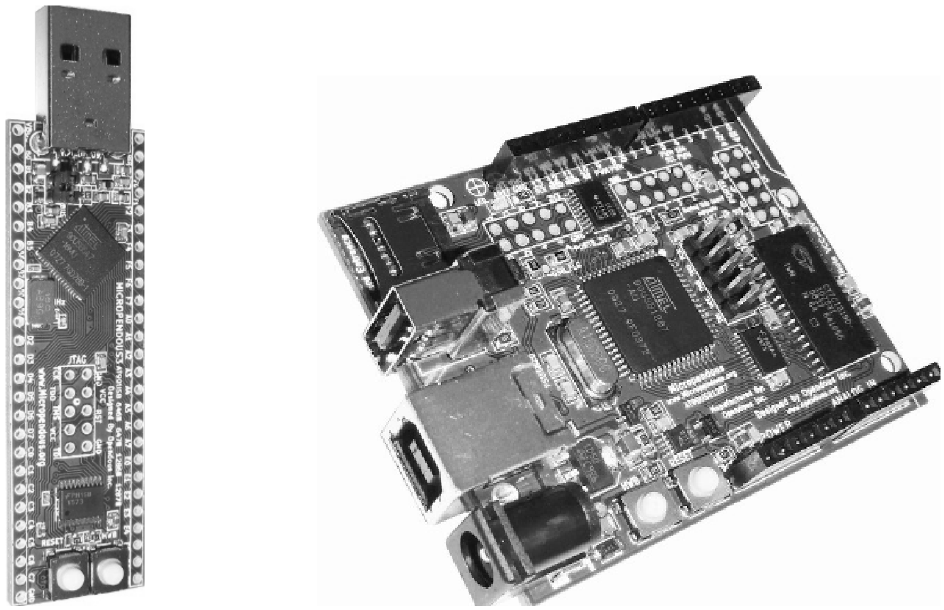

Figure 3. Micropendus3 development boards

3 EMBEDDED DAMAGE DETECTION ALGORITHM

In the area of SHM the vibration based damage detection techniques are widely used. Many researchers have proposed the use of modal frequencies as a primary damage indicator. This method is insufficient to find the frequency changes when the structures are sensitive to the environmental and operational variations. To overcome this, the damage detection methodology based on the pattern reorganization is proposed by Sohn (2001). In this method using the measured data, an Autoregressive (AR) time series model is fit to the data. The AR model coefficients are then used to fit a second Autoregressive with exogenous input (ARX) time series model. In this method damage is detected by decentralized system secondly it reduces the power consumption in data transmission. The AR coefficients for time series data measured are calculated in WSU by solving the Yule-Walkers equations with Burg’s method. These coefficients are transferred to the centralized computer system where the AR-ARX model coefficients for undamaged structure are stored Lynch (2004). In this paper the AR coefficients of the measured time series data are determined by solving the following equation with Burg’s method.

$$x_t = \sum_{i=1}^{N} a_i \, x_{t-i}$$

(1)

Where *ai* are the autoregressive coefficients, *xt* is the time series under investigation, *N* is the order of the polynomial, *xt-i* are the previous observations of the system response.

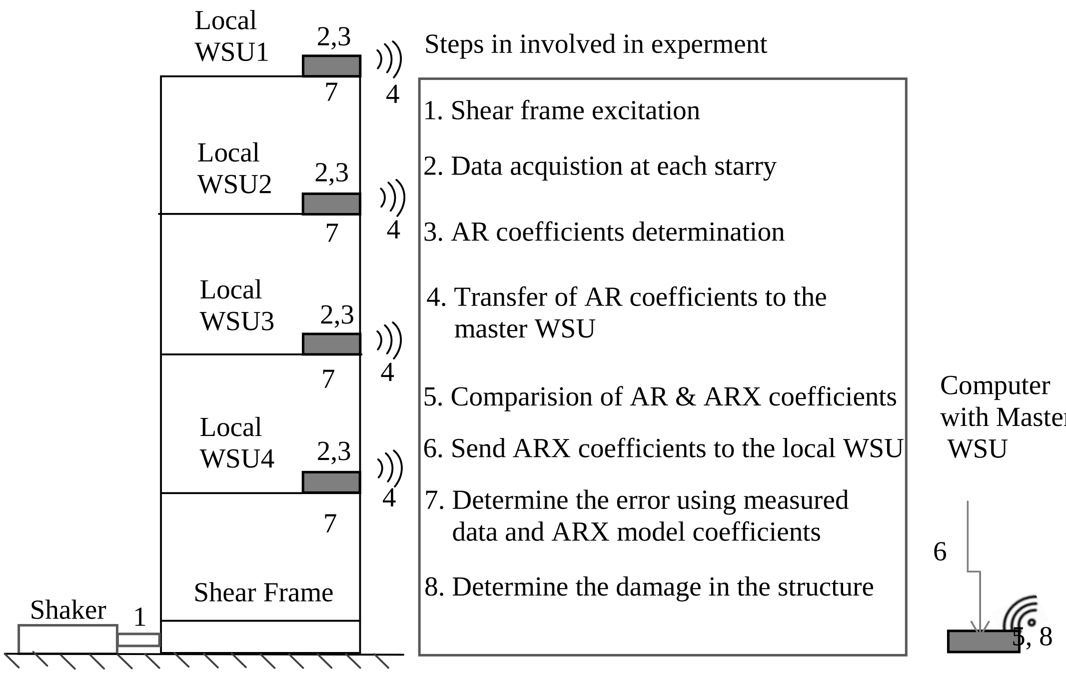

Figure 4. Autonomous damage detection procedure

Figure 4 indicates the experimental setup and the steps involved in the SHM of the shear frame. Shaker is fixed to the bottom of the shear frame and it allows the shear frame to move in horizontal direction with sinusoidal waves. A four starry shear frame is considered and at each starry one WSU is mounted, which is based on Arduino development board as shown in Figure 2. The remote WSU are meant for starry acceleration data and they are configured by peer to peer communication with master WSU which is connected to the computer. The designed remote WSU is tested for the data normalization, determination of statistical mean, variance, and fundamental frequency determination by FFT algorithm. In this work it is important to determine the AR coefficients based on the recorded *i* samples of time series data. The computational method proposed by Burg is used in this work. The AR model order is decided based on the number of experiments performed for shear frame under undamaged condition. The AR model coefficient patterns prepared and stored in the master WSU. The comparison of AR coefficients are carried out at master WSU and a rough estimate of a state of the structure is planned to found out at step number 5 as shown in Figure 4. If the damage is present in the structure, the AR model coefficients for the measured data will not match with the stored AR model coefficients for undamaged structure. The step number 6 and 7 gives the more precise estimate of a state of the structure by comparing the AR-ARX model coefficients, and a standard deviation of the ARX model residuals with residuals of measured data.

4 CONCLUSION

The low cost wireless sensor unit designed for SHM of structures is tested for data interrogation such as measured data normalization, determination of statistical means variance, and fundamental frequency calculation. An experimental setup of shear frame is used with external exciter to measure the acceleration time series with designed WSU's. They are reliable in measurement and transmission of data wirelessly. These WSU's are suitable for engineering analysis at remote locations, hence the AR model algorithm is planned to perform suing these remote and master WSU. The AR algorithm is tested in Matlab for measured data, once the system is ready for full-fledged testing, it is expected that designed WSU will give same AR model coefficients.

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