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Wireless inclination acquisition system for swing monitoring of large engineering structures

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ABSTRACT: In this paper, a wireless inclination acquisition system is designed for swing monitoring of large engineering structures. Firstly, a kind of wireless inclination acquisition system is given; Secondly, the sensing unit MEME chip's principles and design are discussed in detail, the development of wireless communication module and power unit are introduced, and a wireless inclination sensor is integrated; Thirdly, the data acquisition system software, which can finish the functions such as data collection, data FFT, is developed based on Labview; Finally, the developed wireless inclination sensor data acquisition experiment is finished. The experimental result indicates that the wireless inclination sensor has good precision, the sensor node can perform wireless swing monitoring that do not affect normal working of the large engineering structures, and thus it has great application foreground.

1 INTRODUCTION

SHM has been an important research hotspot for evaluating and designing reliability of engineering structures (Ou J., Guan X.,1999; Straser E.G, et.al,2003; Spencer 2003a). To investigate both local and global damage, a dense array of sensors is anticipated to be required for large engineering structures. The type of the sensors is chosen according to the objective of the specific SHM system, and these sensors are then mounted in the structure to measure the static or dynamic response. Usually, in a SHM system the shear number of accompanying wires, fiber optic cables, or other physical transmission medium may be prohibitive, particularly for the structures such as large engineering heavy derrick lay barges or long-span structures. Fortunately, with recent advances in the technologies in sensing, wireless communication, and micro electro mechanical systems (MEMS), wireless sensor network technique has been developed rapidly and used gradually in the SHM for engineering structures(Mitchell, et.al 1999; Liu R.C., et.al 2001; Maser, et.al 2003; Ou, Li, 2003; Yu , Li et.al, 2004; Yu, Ou,2006).

The inclination is a good parameter presenting global change of a structure for a SHM system, but there has been little research on wireless inclination acquisition system for swing monitoring of large engineering hook structures. In the present research, a wireless inclination acquisition system for swing monitoring of large engineering structures is designed. The hardware is integrated using commercially available components. The experimental results are reported about the wireless inclination sensor and its acquisition system.

2 WIRELESS INCLINATION ACQUISITION SYSTEM STRUCTURE

According to recent development of existing MEMS and wireless communication, wireless inclination acquisition system, in which the inclination data is transmitted wirelessly, is designed. The data transmission structure is shown in Figure 1：the inclination data, sensed by inclination MEMS chip, is processed and transformed into serial data. By the wireless communication module, the serial data is transmitted into CC1020 wireless base station connected with a computer. The status of a structure can be estimated by the method of diagnosis arithmetic based on the collected data.

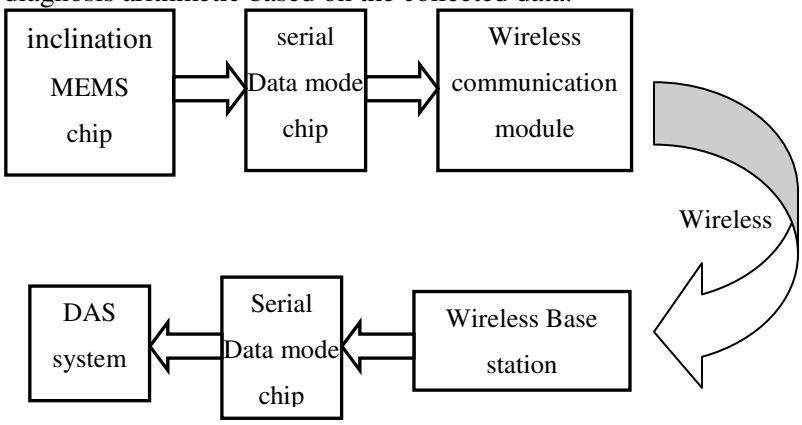


Figure 1. Wireless inclination acquisition system.

3 HARDWARE INTEGRATION

In this system, wireless inclination sensor is integrated using sensing disposal unit, wireless communication unit and power unit.

3.1 Sensing disposal unit

Sensing disposal unit, consisting of an inclination chip and micro-processing unit circuits, could measure the swing and transform these data into serial one for farther transmission.

SCA100T chip, which is low-cost, low-power, 2-axis inclinometer, is selected in this design for swing monitoring. The chip is a kind of single integrated circuit inclination measurement system based on MEMS technique. It is a surface micromachined polysilicon structure built on top of a silicon wafer. SCA100T is made up of silicon sensing differential capacitor and an ASIC circuit, and the ASIC integrates EEPROM memory, amplifier, analog/digital converter, temperature meter and Serial peripheral interface (SPI) interface. The SCA100T has the following features: single +5V supply, ratio metric voltage output; internal temperature sensor accessible via SPI to calibrate the inclinometer; sensing element controlled frequency response. The MEMS SCTA100T is virtually a kind of static acceleration sensor. While acceleration is static, this means that the sensing axis of the chip is vertical with gravitational vector, the sensing axis is affected by only gravity. The inclination is an angle between gravity and the sensor. For example, the relation of the X-axis output of acceleration and gravity is given in the equation 1,

$$a_x = g * \sin\alpha \tag{1}$$

Where, a_x is X-axis output of acceleration, g is gravity, α is inclination angle. Equation 1 is changed into equation 2 by anti-sine rule to get the inclination value. And the temperature compensation using internal temperature sensor makes inclination measure more precisely.

$$\alpha = \sin^{-1}(a_x / g) \tag{2}$$

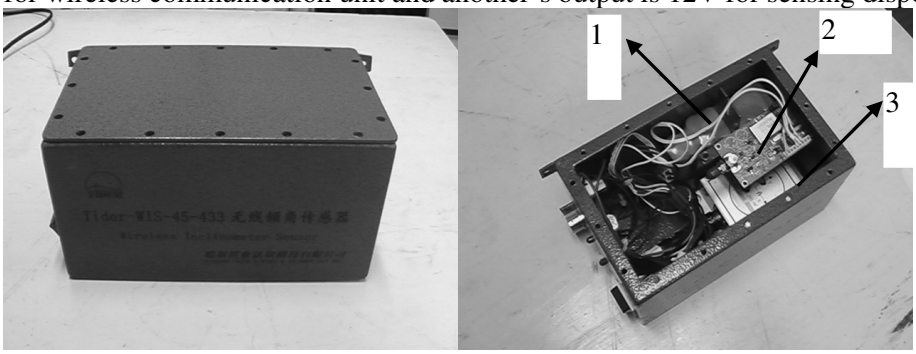
The micro-processing unit used in this research is Atmega8 chip, which integrates bigger storage memory and many hardware interface circuits. After Atmega8 corresponding interface is connected with SPI of SCTA100T, the micro-processing unit could read, pre-process the inclination data, and then transmit data to wireless transceiver by RS485 signal format.

3.2 Wireless communication unit

Wireless communication unit is used to transmit data collected by sensor to base station by wireless mode. In this research wireless transceiver is developed on the basis of CC1020 radio frequency chip, which is a true single-chip ultra high frequency and low power RF transceiver produced by Texas Instruments Corporation. The CC1020 circuit is mainly intended for the ISM(Industrial, Scientific and Medical) and Short Range Device frequency bands. Besides, CC1020 data rate is up to 153.6kBaud. The CC1020 wireless transceiver is steady and its transmission distance is up to 500 meters

3.3 Power unit

There exists a limit of power consumption for wireless sensor node working in some circumstances where there are no condition of supplying power continually, so energy optimization is a basic problem for wireless sensor networks(Erin and Harry,1999). For a wireless sensor, energy is usually provided by either solar power (Kohvakka Mikko, et. al 2003), structure vibration(Scott Meninger, et. al 2001), chemical batteries, or lithium batteries. In the present design, two groups of lithium batteries with charge circuits are used for power units taking into account their small volume and relatively long service time, one's output is 5V for wireless communication unit and another's output is 12V for sensing disposal unit.



1— power, 2—wireless module, 3—inclinometer

Figure 2. Wireless inclination sensor and its internal structure

The integrated wireless inclination sensor and its internal structure are shown in Figure 2. Sensing disposal unit and power unit are put under the designed box, wireless communication unit is deployed with a high-gain antenna outside the box to transmit data more far. The wireless sensor node's measuring range is ±90°, the resolving power is ±0.01°, and the frequency response is more than 20Hz.

4 SOFTWARE DESIGN

The data acquisition system software is designed in modularization using Laboratory Virtual Instrumentation Engineering Workbench(LabVIEW), which is a platform and development environment for a visual programming language from National Instruments. The programming language used in LabVIEW, referred to as graphical language, is a dataflow programming one. LabVIEW is commonly used for data acquisition, instrument control, and industrial

automation on a variety of platforms. The designed software based on LabVIEW can finish such the functions as data collection, data display, data transform, data memory. The software interface is shown in Figure 3. Besides, the remote users can visit the acquisition system by internet.

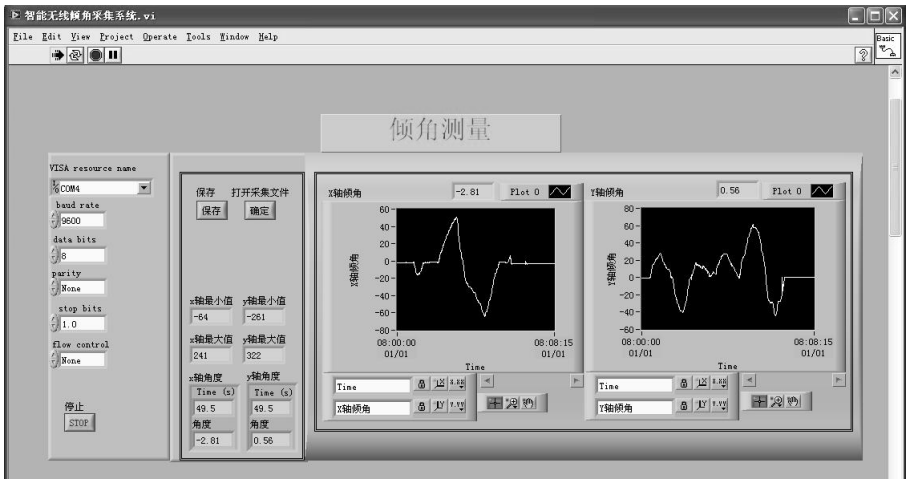


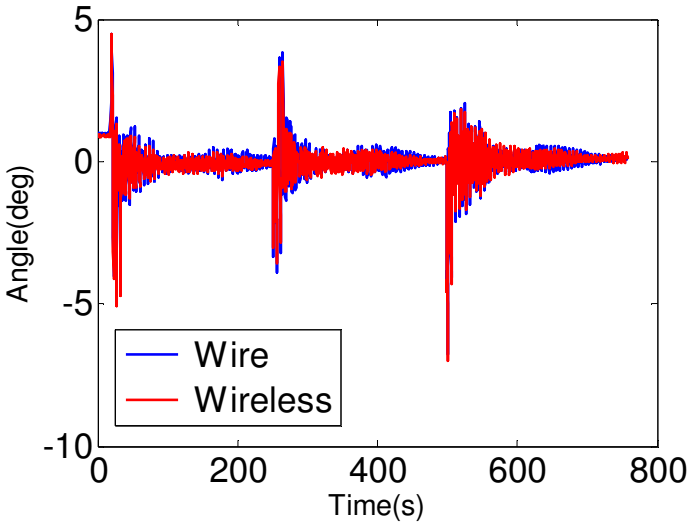
Figure 3. Data acquisition system software

5 EXPERIMENT AND DISCUSSIONS

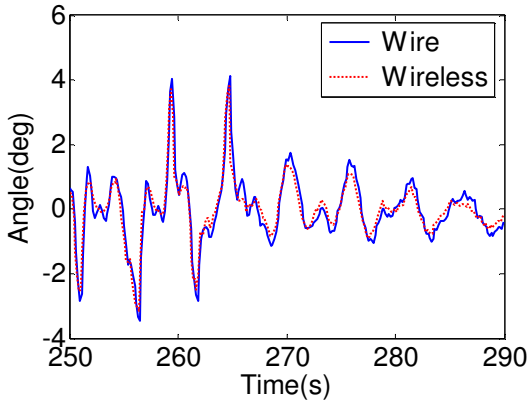
The inclination of the designed wireless sensor was tested using a bridge crane with lifting capacity of 10 tons constructed into the large engineering structural model shown in Fig.4. The bridge crane can swing while its initial swing angle value is not equal to 0 degree. We used the wireless inclination sensors to gather inclination data for monitoring the swing of the model, and the reference inclination can be gotten by the use of a wired sensor. In this experiment, the model begins to swing at initial swing angle value in every experimental case. Each experimental case begins after the swing angle is reduced close to 0.

Figure 4. Experimental setup

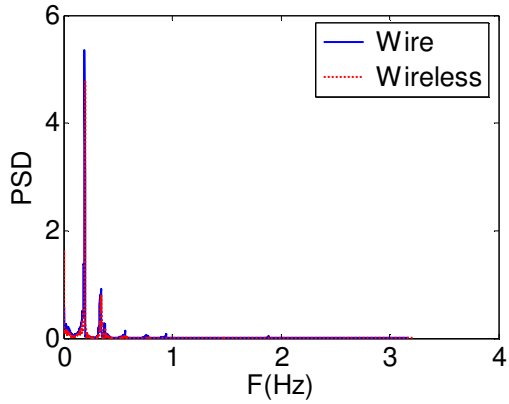
Inclination data from continuous tests of three cases is shown in Fig.5: in the same case, the time histories of the wireless and wired inclination waves are depicted in Fig.5-a and Fig.5-b. Although minor differences are presented, they agree well. Fig.5-c shows the power spectral density $A(\omega)$ of the two inclination processes, respectively. The peak frequency of the measured inclination is 0.197Hz, while that of the reference inclination is 0.193Hz. The small difference meets the requirement for the SHM in civil engineering.



(a) Global time histories of inclination waves



(b) Local time histories of inclination waves



(c) Power spectra of inclination processes

Figure 5. Experimental results

6 CONCLUSIONS

A wireless inclination acquisition system is developed for swing monitoring of large engineering structure. Performances of the sensor node are presented in Table 1.

Table 1 Parameters of Wireless inclination sensor and its data acquisition system

Distance Transmitted	500m	measuring range	±90°
frequency response	20Hz	Sensitivity	±0.01°
Maximal error	1%	Voltage	5V-12V(DC)

The following conclusions about wireless inclination acquisition system can be drawn: the sensing MEMS SCA100T chip with internal temperature meter can compensate inclination measurement for more accurate value; the designed sensor is put in a airproof box, this make it more reliable, and that high-gain antenna is used make the sensing data transmitted farther; The wireless inclination sensors with a maximum error of 1% can place monitored structures without the need for electrical control lines.

In general, the wireless inclination acquisition system with good precision can perform wireless swing monitoring that do not affect normal working of the large engineering structures, and it has great application foreground.

7 ACKNOWLEDGEMENTS

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