Demo: An Imote2 Compatible High Fidelity Sensing Module for SHM Sensor Networks

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***Abstract*—Existing Imote2 sensors (and the previous series such as Mica-2, Mica-Z) are developed for general purpose applications by the computer science community. During the past years, we have seen a sharp improvement in CPU speed, memory space and communication strength in these motes. However, when working on specific applications, e.g., the structural health monitoring that we are working on, we find that the Imote2 sensing capabilities are lagging far behind. Therefore, we redevelop a high quality sensing module for Imote2. This sensing module is capable of 1-1000 configurable amplification, 16-bit Analog to Digital Conversion (ADC) and up to 512-tap FIR programmable filtering, which practically meet sensing requirements of very weak signals from real world structures.**

In this demo, we will first show our sensing module and present its technical design principles. We will then show how it works with real data traces collected from Guangzhou New TV Tower. Finally, we will release a video including a complete testing procedure of this sensing module and its configuration details in real world field experiments.

I. Introduction

Wireless sensor networks have some unique advantages, such as readily and easily deployable, cheap, robust, etc. They are expected to be widely used not only in emerging new applications but also in some current applications to replace the conventional wired sensor networks. One example is the structural health monitoring (SHM) systems. There is a clear need for a transition of some stages of the SHM systems from the wired sensor networks to wireless sensor networks. For the SHM system we are currently working for the Guangzhou New TV Tower (GNTVT), China [1], wireless systems are partially adopted.

During the past decade, there are huge efforts in research and development of wireless sensor networks (i.e., the mote-like sensors). From architecture perspective, we see designs in data aggregation, routing, localization, synchronization, etc. From hardware perspective, we see Mica-2, MicaZ series and the nowadays Imote2 sensors. Nevertheless, the sensor networks are still yet to be used in real applications.

We consider this is mainly because that the development of the wireless sensor networks is still by the computer science community. The targeted applications are usually non-computer science, however. Focusing on application demands is thus a key for a wider and real usage of the sensor networks in the future. From the software perspective, in our recent effort (to be presented in INFOCOM'10) [3], we show our experience of a cross-discipline design for SHM systems that consider both SHM sensor placement quality and computer science system efficiency.

From the hardware perspective, as a state-of-the-art wireless platform, Imote2 has strong PXA271 XScale processor (13-416 MHz), large onboard storage (256KB SRAM, 32MB FLASH, 32MB SDRAM), and excellent wireless communication capability (250Kbps). Though Imote2 has superb processing/communication capability, our experience shows that applying Imote2 to SHM systems suffers from its weak sensing module, the ITS400 board. ITS400 does provide integrated onboard sensors and ADC channel. They are too simple for practical usage, and the ADC suffers significantly from its inaccuracy. In previous works, there have been one efficient UIUC SHM-A sensor board reported in [2], which is a significant reference for the adoption of *QF4A512* chip in our filtering board design. However, our sensing module is also notably different from UIUC SHM-A, as our sensing module features a unique amplification board and open sensor interface in the ADC board. Table I summarizes comparisons among ITS400, UIUC SHM-A, and our sensing module.

In this demo, we show an SHM-oriented high fidelity sensing module and share our experience in using it in SHM systems. More specifically, we will show 1) our design of a high fidelity sensing module; 2) how the module works jointly with Imote2; 3) performance evaluation using real data traces. We will also discuss the current development and results of the wireless monitoring system of the GNTVT.

II. Design of the Sensing Module

Due to the limitations of the Imote2 sensing module, we propose a new design, with advanced features of modularity, open-architecture, high-precision, configurable-amplification, online-programmable-filtering, and low-power-cost.

Modular architecture To be fully compatible to, but not limited to, the Imote2 platform, our signal sensing module follows a modular design. Our module contains two boards: one 1-1000 configurable amplifier board and one 4-channel high precision 16-bit ADC/programmable filtering board. The connection of these two boards is the general-purpose connector, making it easy to connect Imote2 boards.

Open sensor interface Unlike ITS400, which integrates various sensors onto a sensor board, our redeveloped sensing board has no onboard sensors. Our philosophy is: 1) With no

TABLE I
COMPARISON BETWEEN TYPICAL SHM REQUIREMENTS, THE SENSING CAPABILITIES OF IMOTE2 ITS400 AND OUR SENSING MODULE

Functionality	Typical SHM requirements	Imote2 ITS400 sensors	UIUC SHM-A sensor board	Our sensing module
Acceleration voltage resolution	mili-Volt	Volt	Volt	mili-Volt
Strain voltage resolution	mili-Volt	Volt	Volt	mili-Volt
ADC resolution	16-bit or above	12-bit	16-bit	16-bit
Amplification	required	NA	1-8	1-1000
Noise filtering	1-order RC filtering or above	NA	up to 512-tap FIR filter	up to 512-tap FIR filter

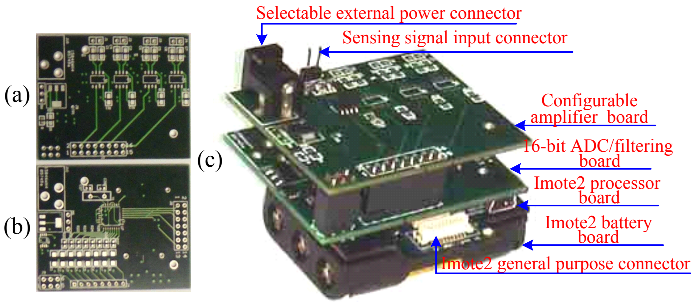

Fig. 1. The high fidelity sensing module: (a) Configurable amplifier board; (b) 16-bit ADC/filtering board; (c) Assembled stack of the sensing module and the Imote2 processor package.

fixed sensors but 4 open ADC channels, our sensing module is open to accept various external sensors; this also substantially reduces the price of this sensing module (35 USD each as opposed to 286 USD of ITS400); 2) With friendly SPI and I^2C buses, our module is possible to output digitized ADC results directly into Imote2; 3) For SHM applications, strain sensors should be attached to the structure body (e.g., the surface of a wall). The sensors integrated on a sensor board cannot be used. Thus, our module with open ADC channels instead of onboard sensors is more practical.

High precision Practical SHM systems requires 16-bit ADC precision or above for weak signal collection. Our module adopts *QF4A512*, which supports 4 channel 16-bit ADC.

Configurable amplification ITS400 open ADC channel only accepts 0-3 V voltage input, with no amplification. This is impractical. For example, in our ongoing project SHM for GNTVT, acceleration output of the high-precision accelerometer *AS-2000(C)* is around 0.05 gal (1g=1000gal), i.e., the output voltage is only around 0.0625mV. In our new module, an amplification board is specifically designed using *AD623* and provides 12 configurable gains ranging from 1-1000.

Programmable filtering Besides very low signal amplitudes, signals from real structures usually have a strong background noise, making filtering necessary at the sensing end. In our module, the adopted *QF4A512* has an integrated programmable 512-tap FIR filter. With this filter, online filter can be flexibly customized according to specific applications.

Power efficient In our module, key chips *AD623* and *QF4A512* both accept power supply under 5V. The overall operating current is around 20mA with 1K sampling rate and 1.8V power supply, making our module power efficient.

III. DEMO DESCRIPTION

We will provide three level of demo: 1) our sensing module (as in Fig. 1); 2) an on-stage demo using real structure data traces showing the difference between our sensing module and ITS400; 3) a video showing performance of our module.

In the first level, we will present our sensing module. As can be seen from Fig. 1, we have a configurable amplifier board (Fig. 1 (a)), a 16-bit ADC/filtering board (Fig. 1 (b)), and the assembled stack with Imote2 (Fig. 1 (c)).

As it is not easy to directly demo the usage of our module on structure. In the second level, we will use real data trace from GNTVT. The data trace will be input into the Imote2 with our sensing module and the normal Imote2 pack. One key feature we would like to demonstrate is the reliable accuracy of our module, which should be understood in twofold: (1) the 16-bit ADC of our sensing module can theoretically guarantee a better data quality than that of the 12-bit ADC on ITS400. (2) In practice, accompanied by the 1-1000 configurable amplification gains, our sensing module can accept very weak signals as small as mili-volt (e.g., the output of AS2000(C) as stated above) and amplify them 1,000 times into volt-level, which can much better give play to the 16-bit ADC. In contrast, however, without amplification, mili-volt signal will be even unsensible to ITS400.

Apart from the advantage on accuracy, we will also show the anti-noise feature of our sensing module. Since structural signals sensed from real structures are usually accompanied by strong background noise, noise must be filtered from structural data. Our experiences show that Resistor Capacitor (RC) based 4-order Bessel filter works properly in real SHM systems. In this demo, we will use real data traces collected from GNTVT to show, with the programmable 512-tap FIR filter, our sensing module can not only effectively filter noise, but also be much easier realized in a harsh yet time-compact filed test. In the demo, we will also show how to customize and program the filter (e.g., bandwidth of the filter, cut-off frequency etc.) according to specific demands.

In the third level, we will release a video to show the real usage of our sensing module. The released video will comprise an episode of field measurement, which records testing and practical working procedure of our sensing module. With this video, potential users can very easily get familiar with the performance of this module, as well as its configuration details.

REFERENCES

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