SEI 02 Towards a multi-tier sensor array for instrumenting large buildings

SEI 02.1 People

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SEI 02.2 Overview

Structural Health Monitoring (SHM) has important applications in fields such as civil engineering and earthquake study. The emergence of the wireless sensor network (WSN) provides a promising means to such applications. However, because most WSNs are still in the experimentation stage, very few take realistic application requirements into consideration. To collect comprehensive data for SHM domain experts, high-resolution vibration sensors and sufficient sampling rate should be adopted, giving rise to challenges for current WSN technology in the following aspects: processing capabilities, storage limit, and communication bandwidth. The wireless sensor network has to meet expectations set by wired sensor devices prevalent in the structural health monitoring community. In this project, we are building an application-realistic portable wireless sensor network called **ShakeNet** for instrumentation of large civil structures, especially for buildings or bridges after earthquakes. ShakeNet should be easily deployable by 2-3 people within hours after an earthquake in order to measure the structural responses of the building or bridge using the aftershocks. ShakeNet involves development of a state-of-the-art sensing platform (ShakeBox) running the Tenet software suite for networking, data collection, and monitoring.

SEI 02.3 Approach

In collaboration with Refraction Technologies, Inc. of Plano, TX, we are adopting a modular design paradigm for the ShakeBox (Figure 1) which consists of four independent modules: CPU, Power, Analog to Digital (A/D) and Sensor, connected via standard SPI protocol. Figure 2 shows the CPU, Power and A/D modules. These modules are then housed in a custom made weatherproof casing as shown in Figure 1. Below is a short description of the different modules of ShakeBox and the associated characteristics. The wireless, strong-motion network is specifically designed to be deployed in structures with no existing power or communications infrastructure. It conforms to U.S. Geological Survey Advanced National Seismic Systems Class A strong-motion design specifications, the most accurate and advanced class of structural measurement systems. The network will be tested under controlled laboratory conditions, and later in pre-existing structures for more realistic settings of the hardware and software performance.

SEI 02.4 System(s) Description and/or Experiments

**Design of Shakebox : CPU module**

The CPU module controls all system operations and contains the system processor, a Crossbow iMote2 mote, and the RT617 board. The iMote2 mote controls the communication to the other three modules via two SPI interfaces. The RT617 board consists of an FPGA, precision oscillator, battery backed RTC, SD memory

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Figure 2: ShakeBox modules. a) CPU module with iMote2, b) Power Module, and c) A/D module
card slot, GPS interface and a board ID EEPROMs. It also provides the timing for the Power and A/D modules. The iMote2 is an advanced sensor network platform, and consists of a PXA271A 32-bit microcontroller and CC2420 radio. It has multiple communication interfaces; prominent among those are the SPI, I2C, USB host and USB slave, JTAG and AC97 audio codec. The CC2420 is an 802.15.4 compliant 2.4 GHz radio which can give up to 256 Kbps bit rate. Dynamic scaling of core frequency of the PAX271 microcontroller from 13MHz to 208MHz provides a varied range of options for balancing processing power with energy usage.

Power module

The Power module provides the power requirements of the different components and consists of an RT618 FPGA board and RT620 power board. The RT618 provides communication with the CPU module, a clock, control of the voltage monitor A/D converter, control of analog power supplies and board ID EEPROMs. The RT620 provides an input power controller, switching supplies at different voltage levels, a 16-bit A/D monitor for supply voltages and input currents, and a board ID EEPROMs.

Analog to Digital Module

The A/D module takes the analog sensor inputs and provides a time-stamped, 24-bit digital output; it consists of an RT618 FPGA board and RT614 analog board. The RT618 provides communication with CPU module, a clock for time stamping sampling data, control of A/D chips, test signal generator for debugging, relay control, a board ID EEPROMs and sensor ID interface. RT614 provides the scaling of sensor signal voltages, three 24-bit A/D converters, replays to connect test signals to internal analog inputs, a board ID EEPROMs and voltage regulators.

Sensing module

The Sensor module consists of three Colibrys SiFlex 1500 accelerometers, which are interfaced to the RT614 board in the A/D module. The SiFlex 1500 operates from a bipolar power supply voltage that can range from ± 6 V to ± 15 V with a typical current consumption of 12 mA at ± 6 V. The full linear acceleration range is ± 3 g with a corresponding sensitivity of 1.2 V/g.

Weatherproof casing

The weatherproof casing houses all the modules. Each module is electronically shielded to protect against electromagnetic disturbance. The lead acid battery used in the ShakeBox is placed in a separate sealed compartment to isolate it from the electronics in case of battery leakage. The box provides serial connectors, connector for GPS, LEDs for display and feedback and antenna connector for high gain external antenna used by iMote2’s radio. It has three screws and a spirit level for leveling. The prototype box in Figure 1 is made of resin plastic but the production pieces will be metallic aluminum.

Communication

Communication between modules in the ShakeBox is achieved via three buses: the SEL bus, the SPI command and control bus, and the A/D data bus. While the SEL bus is used by the iMote2 mote to select a specific component in a module, the SPI command and control bus (the SPI1 port on iMote2) is used to communicate with that component. The A/D data bus (the SPI2 port on iMote2) is used for the iMote2 mote to collect sampling data from the A/D module and auxiliary data from the Power module. During development we will need debugging facility and features to upload driver code and FPGA images on the boards. The board modules expose the JTAG port for FPGA programming, while iMote2 is programmed and debugged using the USB slave port.

SEI 02.5 Accomplishments

Work during the reporting period has primarily consisted of establishing basic communication procedures between iMote2 and other modules. We have been able to establish Serial and I2C communication. More specific task details are given below:

- Communicate with the battery backed real time clock (RTC) to set the system time which is used for keeping time when the ShakeBox is turned off when GPS is not used.
• Use the SEL bus to select a specific component on a module. Component involves the FPGA and device and sensor ID EEPROMs.

• Perform read and write on the EEPROMs on CPU, Power, and A/D modules.

• Perform read and write on the FPGA registers on the RT617 and RT618 boards on the CPU, and A/D modules.

• Write the temperature compensated voltage controlled oscillator (TCVCXO) digital to analog converter on the RT617 of the CPU module for time-keeping purposes.

• Set up the A/D module for ramp sampling data generation.

Tenet has already been demonstrated to run on the telosb and micaz platforms. We have been able to port Tenet on iMote2. Not all tasklets are working on iMote2 and we are in the process of fixing them. Dynamic memory allocation is not fully supported and the current port of Tenet has memory leaks; we are currently focused on addressing this.

SEI 02.6 Future Directions

Immediate Next Steps

Since we have been able to show the basic communication occurs successfully between the iMote2 and ShakeBox board modules, we want to finish and test the data collection code for iMote2 and for the ramp sampling data. Then we will use the test signal generator on the A/D module to test the accuracy of the A/D converter and the working flow of the whole system. Finally, we plan to use the standard input sensors (i.e. the Colibrys accelerometers) to do the calibration and data collection in the environment of a shake table. In all these tests, we will need a domain expert to verify the fidelity of our collected data. We have the communication interface definitions for iMote2 and board modules which will be used in writing the device drivers for the boards.

Interfacing the devices with the Tenet suite is the next step which will involve defining the interfaces used by Tenet for communication and parameter setting on the boards. Additional tasks such as programming the FPGA image on the air will involve new tasklet definition. We will be using the experience of interfacing MDA-400 boards with Tenet (used in the Vincent Thomas Bridge deployment) for this purpose.

Long-term Plans

After finishing the in-lab testing, we plan to deploy 25 ShakeBoxes in realistic environments such as the Factor building at UCLA, other buildings, bridges, and a dam. We will test the working flow of the whole system and the fidelity of the sampling data collected. Pending the outcome of a USGS proposal, we will collect ambient vibration from four USGS-instrumented structures that represent a range of structure types, ages, and degrees of retrofit. They include the Seven Oaks Dam in Redlands, CA, the Santa Ana River Bridge in Riverside, CA, 1100 Wilshire Blvd. in downtown Los Angeles, CA, and the Long Beach Veterans Administration Hospital in Long Beach, CA. The data would be used to carry out structural identification of the four structures to be compiled in a database of pre-event system identification.

SEI 02.7 External Research Partnerships

Refraction Technologies, Inc. of Plano, TX (current)