Wireless Data Acquisition System

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An Application to Crossbow's Smart Dust Challenge Contest

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1 Project Description

The project is the first phase of a rapidly deployable Wireless Data Acquisition system for surveillance of long-term structural health of critical infrastructure components such as bridges, tunnels, buildings, pipelines, etc. The system described herein uses Crossbow Mica2 motes to implement a wireless, autonomous, graphical Internet display of data collected from sensors at an arbitrary number of locations within a structure. There are two critical components of long-term structural health monitoring: acquiring sensor response and communicating these data in a timely fashion. Both of these components consume power, and thus power consumption becomes a critical aspect of any wireless system designed for long-term use. Careful selection of sensors and optimization of communication schemes will allow sustained operation of the Wireless Data Acquisition system for a year or more.

2 Origin of Idea

The Wireless Data Acquisition system is an extension of ongoing projects in Internet-enabled remote monitoring of critical infrastructure at the Infrastructure Technology Institute and the Department of Civil and Environmental Engineering at Northwestern University. The overall objective of Internet-enabled remote monitoring is to provide timely information to parties interested in the structural health of critical infrastructure components such as the crack in the bridge in Figure 1. Sensors on a structure are polled regularly so that responses may be compared graphically with past readings to identify trends and automatically alert authorities of impending problems. The main drawback of such a system of sensors is the extreme cost in labor and materials for installation, wiring, and maintenance of such a system. The natural extension of these wired systems is a wireless system that drastically reduces the cost of installation and eliminates the impact of the sensor network on the day to day use of a structure.

3 Objective

The objective of the project is to develop a system that will:

- Eliminate hard-wired connections to each sensor
- Operate for at least a month without human intervention
- Records data at a given sample rate, including
    - Sensor output voltage
    - Temperature
    - Humidity
    - Mote battery voltage
- Reduce cost, installation effort, and intrusion associated with a wired system.

4 Project Function

4.1 Description of Data to Be Acquired

This system is designed to record the response of any infrastructure component (such as the fracture-critical bridge as shown in Figure 1) where the rate of data is slower than 15 minutes. However, the proof of this system was established by measuring the response of cosmetic racks in a house subjected to blasting at a nearby quarry. As shown in Figure 2, sensors are attached across cracks to monitor long-term changes in crack width with environmental conditions and blasting activity. The same approach could be employed to monitor cracks in fracture critical bridges.

Figure 1: A bridge with a crack

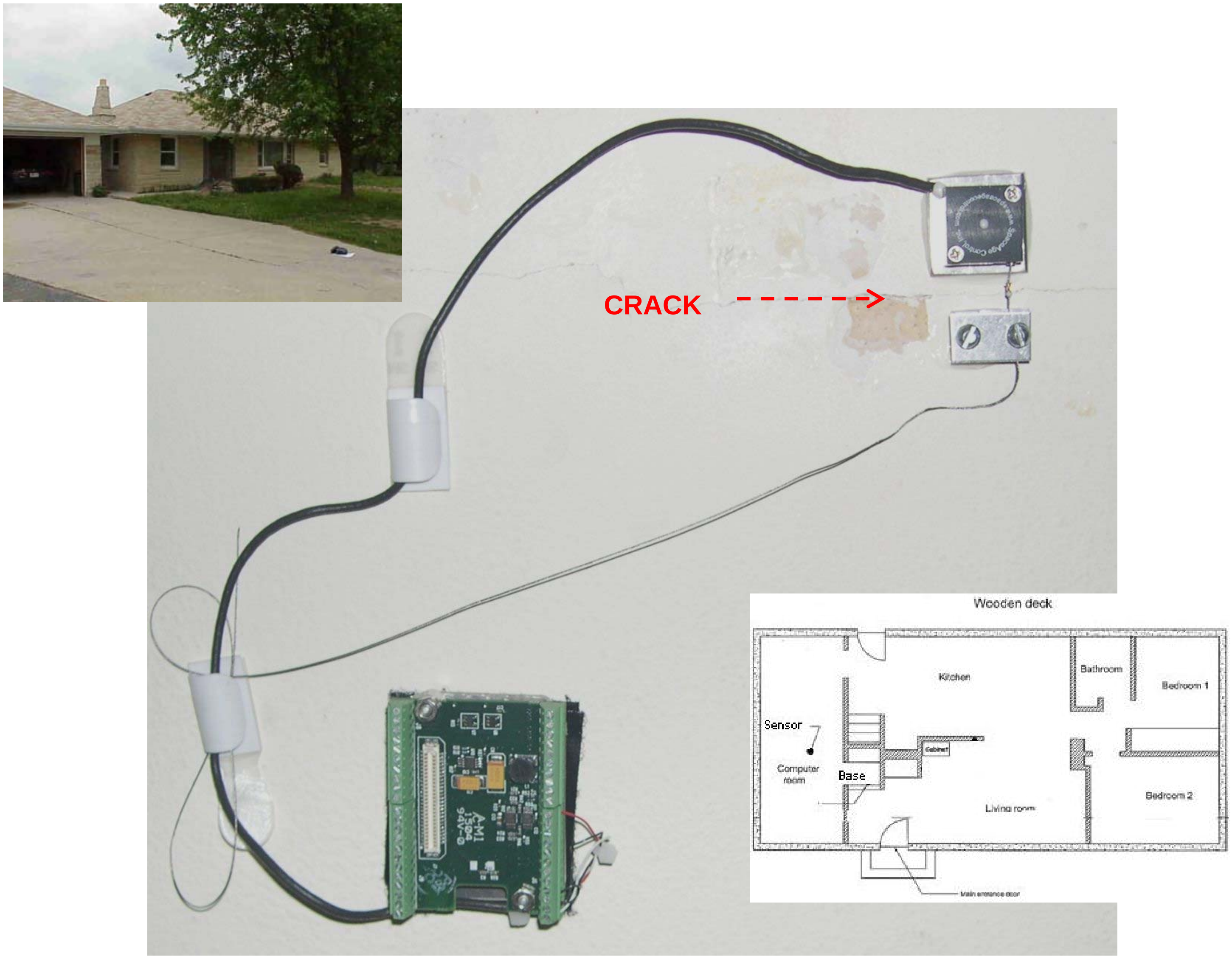

Figure 2: MDA300 and Potentiometer mounted over crack with plan view and picture of house

4.2 Description of Installed System

The Wireless Data Acquisition system consists of a network that is comprised of one "base node" and any number of "sensor nodes." Each sensor node consists of one Mica2 mote running MDA300Logger, one MDA300 sensor board, and one ratiometric string displacement potentiometer which is connected to the screw terminals of the MDA300 and installed across the crack. As shown in Figure 2, the mote with its attached sensor board is then mounted a few inches away from the crack. Though only one "sensor node" is pictured, any number of "sensor nodes" maybe attached within radio range of the "base node." At the time of the demonstration installation, only a single MDA300 board was available for testing. The system was later successfully tested in the lab with two “sensor nodes.” Self-assembling capability, though supported by the motes, is not necessary in this application since locations of sensors are determined before deployment.

The “base node” consists of a mote running TOSBase mounted on an MIB510 interface board. The interface board is connected via a serial cable to a MOXA NPort device which allows remote access to the system. This “base node” obviously requires AC power, and it is hidden in a closet as shown in Figure 3. This “base node” can be placed anywhere with in radio range of the “sensor nodes” as long as it has power and either a phone line or some variety of Internet connection, including cable modem, DSL, standard dial-up modem, or a cellular modem.

Figure 3: MOXA NPort (left) and MIB510 with mote running TOSBase (right)

4.3 What Is Measured?

The system excites and records the voltage output of the ratiometric string potentiometer, shown in Figure 2, which measures micrometer changes in crack width. The potentiometer is optimal because of its high sensitivity, low power draw, and instantaneous response time. Such low-power devices are essential to the success of any wireless sensor system. As the width of the crack changes, so will the resistance of the potentiometer. The change in crack width is then a linear function of the output voltage of the potentiometer given a known input voltage.

4.4 Operation of the System

At each sampling time (every hour in this test case), the Mica2 activates the MDA300's 2.5 Volt excitation voltage to power the ratiometric string potentiometer. The voltage output of the potentiometer along with temperature, humidity, and battery voltage are stored locally on the "sensor node" mote's onboard non-volatile memory. It is necessary to utilize the precision input channels on the MDA300, which have 12-bit resolution over the 0.5mm full scale travel length of the string potentiometer to achieve a resolution of 0.12 micrometers.

Whenever data retrieval is required (every day at 11:00 PM in this test case) the central PC autonomously communicates with the remote Wireless Data Acquisition system from a remote location via the Internet via a modified version of BcastInject to broadcast a "read_log" command and a mote address across the mote network. The mote in question will then transmit all of its data back to the off-site PC where it is recorded to the hard disk. This process is repeated for each address in the network. Once all motes have sent their data, a "start_sensing" command is issued which tells all motes in the network to clear their memory and resume scheduled sampling. This process is easily automated.

The interface from the off-site central PC to the Wireless Data Acquisition system is provided through the command-line java application BcastInject. Since MDA300Logger is based on SenseLightToLog, BcastInject requires only slight modification to interact properly with MDA300Logger.

4.5 Presentation of Data on the **Civil Data Systems** *Web Site*

After data is retrieved and stored on the off-site, central PC, access to the data is granted to Civil Data Systems, a firm that specializes in the presentation over the Internet of dynamic remote-monitoring data. Each time new data is retrieved from the remote Wireless Data Acquisition system, the web site is updated to graphically present data in near real time as shown in Figure 4. Since all of the computation and graphing of the data is accomplished by Civil Data Systems, a user with any web browser on any computer can quickly and easily view the data collected by the system. Figure 4 displays screen shots of the website which can be visited at http://www.civildata.com/motes to observe live operation of the system.

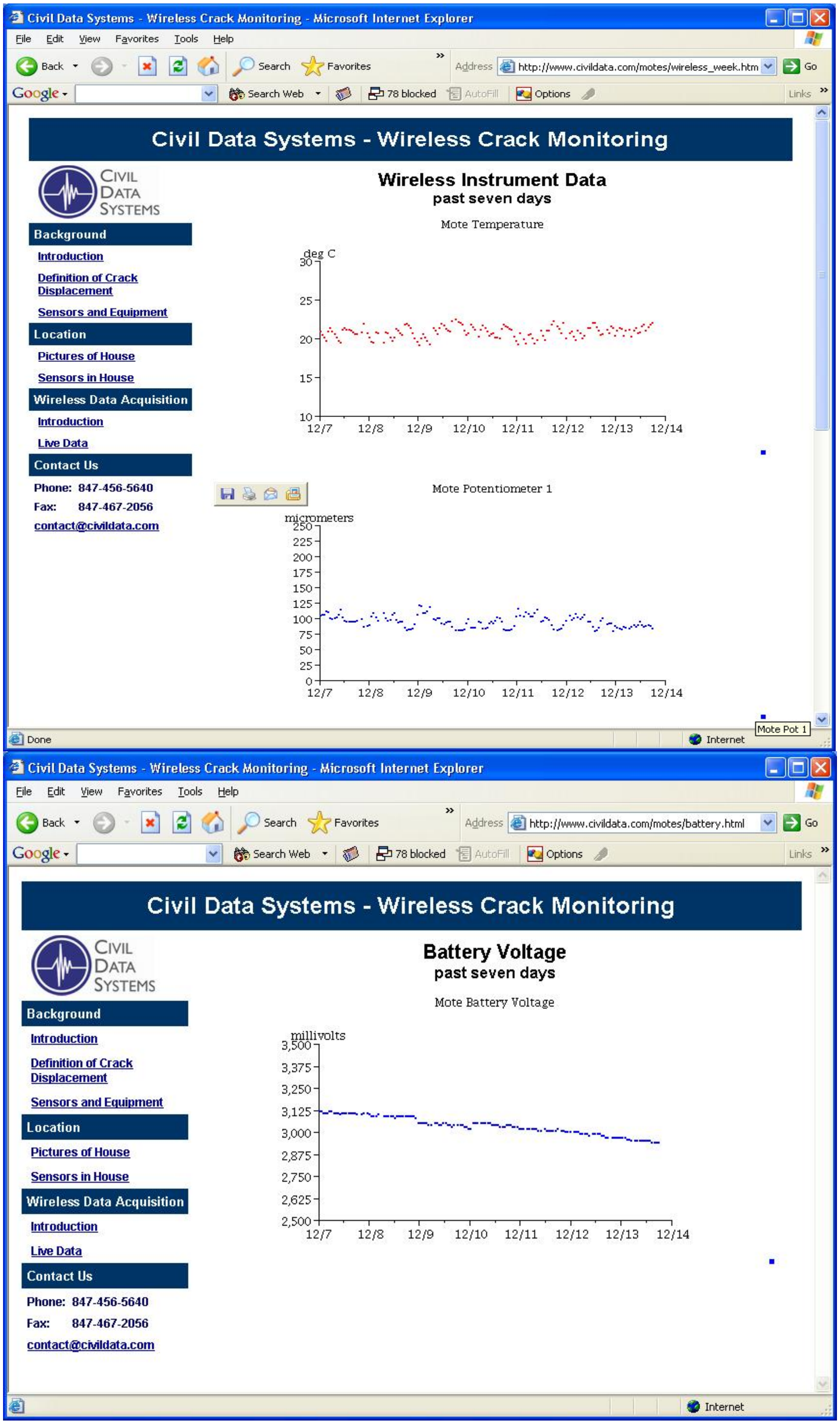

Figure 4: Civil Data Systems web site: http://www.civildata.com/motes

5 Outcome of Demonstration

5.1 Installation of the System and Difficulties Overcome

Installation is rapid. The MDA300 board is attached with small standoffs to a thin sheet of Velcro-backed aluminum. The other half of the Velcro is then affixed to the wall where the mote is to be mounted. As shown in the close up photo in Figure 5, the potentiometer base and termination unit is glued to the ceiling with quick-set epoxy. Zeroing the potentiometer required the use of Crossbow's XSensorMDA300 application which had been modified to read at 10 Hz.

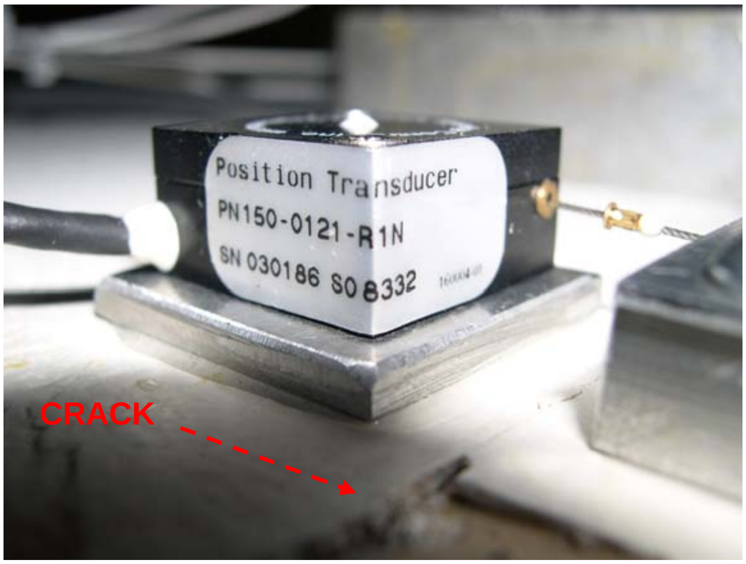

Figure 5: Close-up view of the potentiometer across the crack

Installation was accomplished much more quickly than it would have been for a wired system. The "base node" was installed in 30 minutes while a "sensor node" required 1.5 hours to install. At least half of those 1.5 hours was devoted to zeroing the potentiometer. A re-design of the termination unit would reduce the installation time of each "sensor node" by at least 30%. The equivalent wired benchmark system took a team of three engineers over a day to install.

5.2 Analysis of the Results

The data obtained from the Wireless Data Acquisition System were validated by comparison with a wired benchmark system that had been used in the same test house for about three years. The benchmark system uses two types of position sensors to measure micrometer changes in crack width – an LVDT displacement gauge and an Eddy-Current displacement gauge. As shown in Figure 6, the measurements taken using the Wireless Data Acquisition system clearly follow the same trends as the measurements taken by the two types of wired sensors.

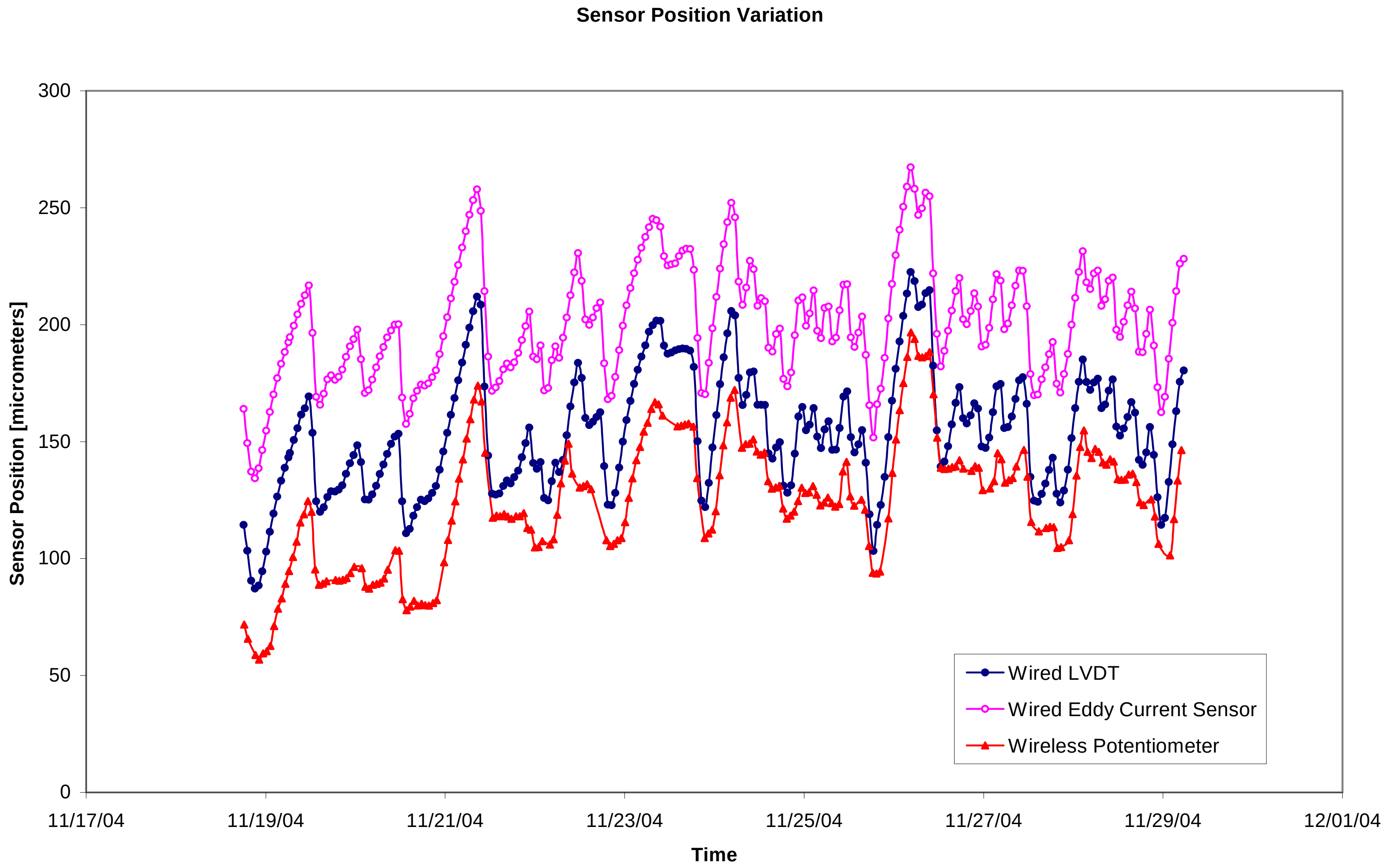

Figure 6: Comparison of Results from wired and wireless data acquisition systems

6 Project Benefit

As described in section 5.3, a wireless system saves time and money. Additionally, it significantly reduces the risk associated with running cables through a structure that is in use. In addition to reducing the labor and cost of installation, the Wireless Data Acquisition system also reduces intrusion when employed in occupied structures.

As shown in Figure 7, wires are an attractive nuisance. This photo was taken after the tenant of the test house decided to “hide” the wires and transducers. The plastic ivy across the transducers rendered them completely inoperable and the system had to be moved out of the living room.

Figure 7: Plastic Ivy used to hide wires and sensor

Long term power requirements for the Wireless Data Acquisition system were overcome by taking advantage of the Crossbow hardware's low-power sleep mode. The screen shot of the CDS web site in Figure 4 shows battery voltage declining during November 2004. The system, with radio communication allowed for 15 minutes per hour, operated for about 27 days. If data is retrieved from the "sensor nodes" only once per day, battery life is projected to be many months and possibly up to a year with a higher-density power cell.

Power limitations also complicate the issue of high-frequency sampling triggered by outside phenomenon, since the motes must be sleeping most of the time in order to conserve power. Future Wireless Data Acquisition systems could rely on solar cells for energy scavenging or device such as a geophone that produces a voltage pulse to wake up the mote.

The wired system against which the Wireless Data Acquisition system is compared measures displacement with two different types of sensors. The first is an eddy current displacement gauge made by Kaman Measuring Systems. The second is a Linear Variable Differential Transformer (LVDT) displacement sensor made by Macrosensors. Operation of the wired system is similar to that of the Wireless Data Acquisition system in terms of data acquisition. The wired system collects data once an hour. Once a day, this data is retrieved autonomously by a central computer located in a remote laboratory. This system also operates over the Internet, standard land line modem, or cellular modem.

7 Project Innovation

Currently, there is no company that sells a system that delivers wireless micrometer sensing with this small a footprint. There exist wired data logging computers that can supply the resolution and sampling frequency needed. The SoMat 2100 Turbo and the SoMat EDaq data loggers have been staples of the benchmark systems for years. However, they require a large amount of power, and of course, wiring.

The nearest wireless analog to the Wireless Data Acquisition system is that sold by Microstrain. They sell wireless nodes that include arbitrary excitation output and voltage input; however, they have no products in their catalog that rival the size, low power consumption, and adaptability of the Crossbow motes with the sensors and software demonstrated by the Wireless Data Acquisition system.

Using the potentiometer or low-power pulsed strain gauges, the Wireless Data Acquisition system can be used to monitor fracture-critical bridges or other structures in which it would be prohibitively expensive or dangerous to run wires. An ideal location for such a system is shown in Figure 1.

8 Product Specification Form

I. Additional Power Sources

A. The “base node” requires AC power for the MIB510 and the NPort.

B. Each “sensor node” requires two AA lithium-ion batteries. Batteries life depends on configuration. As a reference, one 15-minute radio transmission interval per hour gives a battery life of 25-28 days. One 15-minute radio transmission interval per day would extend battery life to about 90-100 days.

C. Detailed power consumption of the “sensor node” is shown in Figure 8.

1. Taking Sample (0.3 seconds per hour): ~22mA
2. Radio-accessible period (15 minutes per hour) ~14mA
3. Low-power sleeping mode (45 minutes per hour) ~1.47mA
4. Retrieving data (10 seconds per day) ~19mA

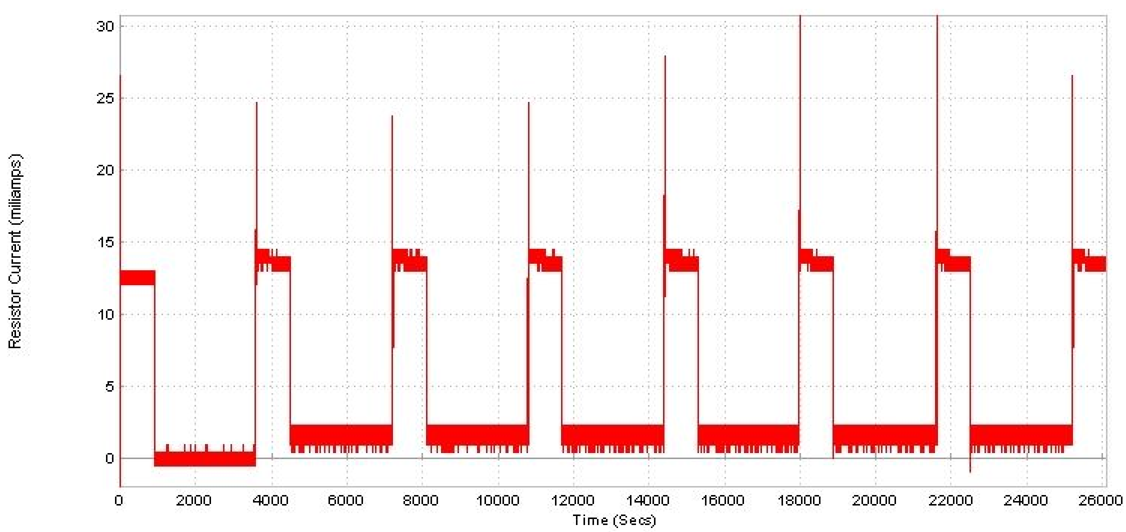

Figure 8: Power consumption profile for “sensor node”

II. Installation

A. Installation of the “sensor node” requires a thin Velcro-backed aluminum sheet that is attached with standoffs to an MDA300. The MDA300 is then affixed to the area of interest with the Velcro.

B. Installation of other sensors varies with the sensor type

C. Installation requires someone familiar with running the calibration application, XSensorMDA300

III. Maintenance

A. Batteries must be changed based on I(B).

B. Mote memory can hold approximately 30,000 data points, so data must be taken off the motes accordingly

9 Required Documentation Supplements

I. Software Disclosure (attached to the end of this document)

II. Crossbow Hardware Disclosure

A. 3 Mica2 Motes (MMA410CA)

B. 1 MIB510 RS-232 Programming Board (MIB510CA)

C. 2 MDA300 sensor board (MDA300CA)

III. Non-Crossbow Hardware Disclosure

A. SpaceAge Controls String Potentiometer Position Transducer (PN 150-0121-R1N)

B. MOXA NPort 5410

IV. Modification to Crossbow Hardware: NONE

V. Packaging Materials

A. Velcro-backed aluminum sheet

B. 2 standoffs to mount MDA300 to aluminum sheet

C. quick-set epoxy

10 Software Disclosure