Poster Abstract: Wireless Sensor Networks for Structural Health Monitoring[*]

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Categories and Subject Descriptors

C.3 [**Special-Purpose and Application-Based Systems**]: Real-time and Embedded Systems

General Terms

Experimentation, Reliability, Design

Keywords

Wireless Sensor Networks, Structural Health Monitoring, Deployment, Large-Scale

1 Introduction

Structural Health Monitoring (SHM) is estimating the state of structural health, or detecting the changes in structure that effect its performance. Two major factors are the time-scale of change and the severity of change. Time-scale is how quickly the change occurs, and severity is the degree of change. Two major categories of SHM are disaster response [5] (earthquake, explosion, etc.) and continuous health monitoring (ambient vibrations, wind, etc.). This work is focused on continuous health monitoring. There are two SHM approaches: direct damage detection (visual inspection, x-ray, etc.) and indirect damage detection (change in structural properties/behavior). We use indirect detection, especially through vibration.

SHM itself is not a new concept [2]. The conventional method uses PCs wired to piezoelectric accelerometers. Compared to the conventional method, Wireless Sensor Networks (WSN) provides the same functionality at a much lower price which permits much denser monitoring. In WSN, wiring is not needed, so installation and maintenance are easy and inexpensive. Moreover, WSN affect the operation of the structure less. However, some requirements of structural health monitoring become challenges in WSN: (1) high fidelity data, (2) high frequency sampling with low jitter, (3) time synchronized sampling, (4) large-scale multi-hop network, (5) reliable command dissemination, and (6) reliable data collection. In this work, (3), (4), and (5) are solved by existing works: FTSP, MintRoute, and Drip respectively. And this work proposed solutions to (1), (2), and (6). However, they will not be covered in this poster in detail.

Figure 1. Accelerometer Board

Table 1. Two Accelerometers

	ADXL 202E	Silicon Designs 1221L
Type	MEMS	MEMS
Range of System	-2G to 2G	-0.1G to 0.1G
System noise floor	$200(\mu G/\sqrt{Hz})$	$30(\mu G/\sqrt{Hz})$
Price	$10	$150

2 Accelerometer Board

A new accelerometer board is designed for structural health monitoring. It has very accurate accelerometers and a thermometer to calibrate them. It is shown in Figure 1. Even though this work focuses on the ambient vibration, the board itself is designed to monitor two quite different sources of vibrations (earthquake and ambient). Therefore the accelerometer board has two kinds of accelerometers: ADXL 202E to capture big movements like an earthquake and Silicon Designs 1221L to sample subtle signals like an ambient vibration. Table 1 shows characteristics of each accelerometer part (range and system noise floor shows the performance in combination with the entire system). Both accelerometers capture two orthogonal axis of acceleration. 16 bit analog to digital converters (ADC) are used for each channel, and the vertical channel of the Silicon Designs 1221L has a 1G offset to compensate for the gravity. And the accelerometer board has low-pass filters at 25Hz. A MicaZ mote stores data from the accelerometer board, and later sends the data.

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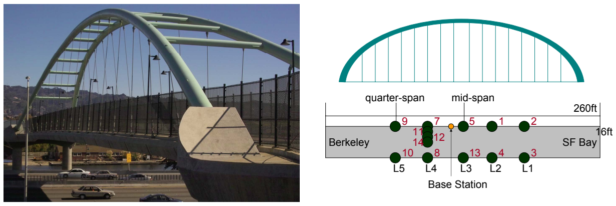


(a) Footbridge Over I-80 (b) Location of Nodes

Figure 2. Deployment at a Footbridge

3 Software Architecture

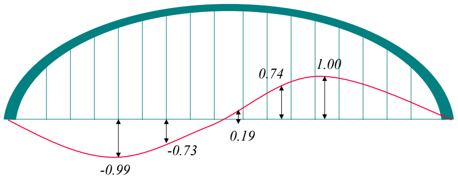
As an underlying software infrastructure, TinyOS is used. On top of the best-effort one-hop communication, Broadcast is used for the command dissemination, and MintRoute [4] is used for the information reply. MintRoute provides a best-effort multi-hop convergence routing. Reliable data collection layer (Flush) lies above Broadcast and MintRoute. For time synchronization, FTSP [1] is used. BufferedLog is used to support high frequency sampling with a light-weight logging. To minimize sampling jitter, when sampling starts, only sampling components and logging components remain active; all other components like the radio are turned off. Structural hEalth moNiToRing toolkIt (Sentri) is an application layer program, which drives all components. To reduce the noise of the vibration measurements, the digital signal processing techniques of oversampling and averaging are used.

4 Deployment Experience

We deployed on the Berkeley pedestrian footbridge. On the bridge, we tested our radios and network in a real world physical environment. We measured the actual vibration of the bridge, and analyzed the collected data. The Footbridge is a 260ft long and 16ft wide suspension bridge hung by two steel arches as seen in Figure 2(a). Data is sampled at 1KHz for 4 minutes. Every 5 samples are averaged together into one measurement, making the effective logging rate 200Hz. Figure 2(b) shows the location of motes. 13 motes are deployed. 10 of them were used to measure the vibration of the bridge, 3 of them were used to see calibration accuracy and the variation of boards. The deployment was successful. The multi-hop network formed, commands are disseminated correctly, and the reliable data collection layer delivered high frequency sampling data as expected. All nodes sampled data synchronously. Figure 4 shows the first vertical mode of the vibration. The modal properties of the bridge estimated using an ARX model with our collected data is consistent with the structural properties [3] of an arch structure.

5 Status and Future Work

We are now deploying nodes on the Golden Gate Bridge. The bridge can be divided into a mid-span, two side-spans, and two towers (south, north). We already deployed 51 nodes covering one side of the mid-span, and 8 nodes covering both sides of south tower's 4 struts, as shown in Figure 4. We are collecting data, and analyzing the data.



First Vertical Mode of Vibration
Frequency: 1.41 Hz
Damping Ratio: 2%

Figure 3. First Vertical Mode

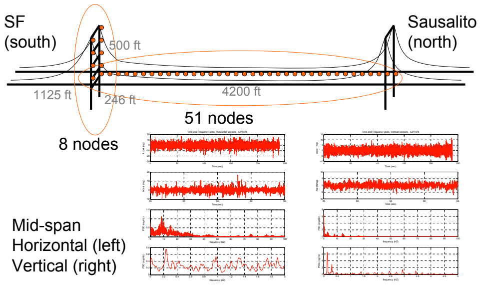


Figure 4. Deployment at the Golden Gate Bridge and Sample Data

6 References

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