Design of a Wireless Sensor Network for Structural Health Monitoring of Bridges

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Abstract. As the installation costs of conventional sensors are expensive and time intensive to deploy, wireless sensor networks are promise to provide an expedient alternative. New wireless sensor platforms and distributed processing algorithms, going hand in hand with new or enhanced monitoring methods, promise an early damage detection and damage estimation. The design of a wireless sensor network for the Structural Health Monitoring of bridges is presented. The network is based on using commercially available wireless sensors to measure and extract the vibration characteristics of a bridge. Due to the distances associated with large systems trade-offs are necessary in the standard network design. One key feature of the present system proposed is the need of multi-hop of partially processed data to the base station. The functionality of the network is verified in a laboratory experiment.

1 Introduction

Many existing bridges are quite old and may be either near or exceed their 75 to 100-ear design life. Moreover, modern live load traffic/train demands have increased since these older structures were originally designed and constructed many decades ago. At the time of design, in the first half of the 20th century, little was known of fatigue and fracture mechanics – requirements that are included in present new designs, but ignored in much of the past. Furthermore, little was known about corrosion in the early 20th century. At that time, steel was a relatively new modern material; little was known of its long term performance.

Motivated by the fact that older existing bridge structures have numerous deficiencies, it is essential to have automated monitoring and sensing techniques that can measure and diagnose by inference potential structural problems – desirably incipient failure. Bridges tend to be large spatially distributed structural systems that
often exist in remote locations. Thus structural health monitoring (SHM) presents its own set of unique problems and challenges. Wireless Sensor Networks (WSNs) are a relatively new and promising technology that can be developed in a flexible fashion for the structural health monitoring of bridges. However, there are several practical difficulties that require resolution prior to widespread deployment. Amongst other things there is a need to (i) provide time synchronization between motes; (ii) specify data packaging and transmitting; (iii) accommodate multi-hopping routing between motes to a distant base station/computer; and (iv) consider the energy consumption [11].

Following a brief description of previous work, this chapter addresses these needs by developing of a wireless sensor network to extract the basic behavioral features, specifically eigenfrequencies and acceleration mode shapes from a structure in a general way. The wireless sensor network design considers time synchronization, modularity, multi-hop routing and flexibility in post-installation usage. The functionality of the wireless sensor network is validated in a laboratory experiment.

2 Previous Work

In Europe a large project called sustainable bridges [2] with over 30 partners develops tools, measurement sensors and monitoring characteristics for monitoring different types of railroad bridges. Haridas [6] and Mishra [13] developed a hard- and software solution for wireless railroad bridge monitoring. The hardware of this wireless sensor network consists of motes made for specific tasks, hence, lacking of flexibility. Xu et al. [17] and Paek et al. [14] developed a wireless sensor network which is designed to be a vibration measurement tool for civil engineers for fast installation and short time measurements. It is a standardized tool for vibration measurements and uses a high precision data acquisition card and an external accelerometer to achieve a high sensitivity. However, this wireless sensor network is a measurement tool set for data collection for structural analysis and not a structural health monitoring tool to use over a long period of time.

There is a need for a wireless sensor network for structural health monitoring that provides high flexibility and the possibility of in-work configuration after installation. Of particular importance is the role model, allowing grouping of motes with similar duties and the flexible number of measurement channels. The ambient vibrations induced by trains or winds have to be high enough to excite a bridge with measurable and usable accelerations. Furthermore a wireless sensor network has to provide several data preprocessing programs, allowing one to combine several modules to working applications.

3 Vibration-Based Structural Health Monitoring

Many vibration based or global SHM methods use mode shapes as initial raw input for further processing and extract the shapes from measured vibrations with acceleration sensors or strain gages and use this data to extract significant