CHALLENGES AND OPPORTUNITIES FOR STRUCTURAL IDENTIFICATION AND MONITORING USING SMART SENSORS

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1. Background

Structural health monitoring (SHM) provides the means for capturing structural response and assessing structural condition for a variety of purposes. For example, the information from an SHM system can be used to fine-tune idealized structural models, thereby allowing more accurate prediction of the response due to extreme loading conditions, such as earthquakes and typhoons. SHM also can be used to characterize loads in situ, which can allow the detection of unusual loading conditions as well as validate the structure's design. In addition, real-time monitoring systems can measure the response of a structure before, during and after a natural or man-made disaster, and may be used in damage detection algorithms to assess the post-event condition of a structure.

Given the size and complexity of many civil structures, a large network of sensors is usually required to adequately assess the structural condition. Traditional structural monitoring systems have been moving in the direction of dense deployment in recent years; however, the cost of installation can be thousands of dollars per sensor channel, and the amount of data generated by such a system can render the problem intractable. Networks of wireless smart sensors have the potential to improve SHM dramatically by allowing for dense networks of sensors employing distributed computing to be installed on a structure. As defined herein, a smart sensor is a battery-powered sensing node with a micro-processor, memory, and a radio transmitter.

While smart sensor technology has been commercially available for nearly a decade, full-scale implementation has been lacking with the exception of a few short-term demonstration projects [1,2]. This slow progress is due primarily to (i) the lack of an adequate sensing platform and (ii) the fact that programming smart sensors is extremely complex, putting the use of these devices for all but the simplest tasks out of the reach of most engineers. Moreover, critical issues inherent in wireless smart sensor networks (WSSNs), such as synchronized sensing and data loss, must be addressed. In addition, the numerical algorithms required for system identification and damage detection must be implemented on sensor nodes which have limited resources. The result is that SHM applications require complex programming, ranging from network functionality to algorithm implementation. Applications software development is made even more difficult by the fact that many smart sensor platforms employ special-purpose operating systems without support for common programming environments. The extensive expertise required to develop SHM applications has severely limited the use of smart sensing technology.

This paper presents an open-source hardware and software framework for structural health monitoring using WSSN. This framework provides the infrastructure necessary to obtain high-quality response data and to transport it reliably across the sensor network, as well as a broad array of SHM algorithms (see http://shm.cs.uiuc.edu/software.html).

2. Wireless smart sensor platform

The wireless smart sensor platform used in this research is the Imote2 (see Fig. 1), which is uniquely-suited to the demands of SHM applications. It has a low-power X-scale processor (PXA27x) with variable processing speed to optimize power consumption. It incorporates a ChipCon 2420 802.15.4 radio with an onboard antenna (Antenova Mica SMD). The onboard memory of the Imote2 is one of the features that sets it apart from other wireless sensor platforms and allows its use for the high-frequency sampling required for dynamic structural monitoring. It has 256 KB of integrated RAM, 32 MB of external SDRAM, and 32 MB of flash memory.

A new, versatile sensor board to interface with the Imote2 has been designed that is tailored to the requirements of SHM applications (see Fig. 1). This SHM Accelerometer board (SHM-A) allows 3 axes of acceleration measurement with user programmable anti-aliasing filters. This sensor board has excellent sampling rate accuracy and flexibility. Current versions of the board have incorporated temperature, light and humidity sensors to provide information that is critical in establishing a comprehensive assessment of the structural condition.

3. Service-oriented software framework

With the exponential growth in available computing power over the last 50 years, the complexity of computer software has likewise increased dramatically. Advances in the fields of programming language design and software engineering allow application developers to deal with this complexity by dividing the software system into smaller, manageable parts. Following this approach, enabling services and service-based applications specifically designed for the address the challenges of using smart sensors for structural health monitoring have been developed and made available at the Illinois SHM Project website ([2]; also see http://shm.cs.uiuc.edu).

3. Jindo bridge deployment

To demonstrate the efficacy of the proposed framework, results are presented for a WSSN deployment on the new Jindo Bridge, a cable-stayed bridge in South Korea with a 344m main span (see Fig. 2). This tri-lateral collaboration between University of Illinois, KAIST, and the University of Tokyo constitutes world's largest deployment of wireless smart sensors (70 nodes with 420 sensors) to date for civil infrastructure monitoring. This project signifies a new paradigm for structural health monitoring that is leading to dramatic improvements over existing capabilities.

Figure 1. Twin spans of Jindo Bridge with the newer span on the left.

4. Conclusions

Leveraging this hardware/software framework allows engineers to focus attention on advancement of SHM approaches and the development SHM systems without having to concern themselves with low-level networking, communication, and numerical sub-routines.

5. References

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