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Machine Monitoring With Wireless Sensor Networks

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ABSTRACT

Wireless sensor networks offer a versatile system for instrumenting mining equipment, allowing freedom in the number and placement of sensor units. The work we describe in this paper aims toward developing a fatigue monitor using wireless computation modules known as motes and a custom sensor board configured for strain sensing. Each sensing node runs an application to sample and process the strain data, and to transmit a statistical summary of this data to a base node for logging in a database and reporting to the machine operator. The main purposes of the system are to:

1. *provide regular feedback, to the operator, of fatigue damage during normal operation; and*
2. *log this information for analysis and further post-processing.*

To filter the raw data a rainflow cycle analysis is performed in real-time as the data is collected. Radio linkage of sensor nodes to the base node provides communication, as required, of the stress-strain cycles. Aggregation of these cycles provides a performance metric for fatigue damage. This paper reports on the development of the sensor units, including both the software applications and construction of the sensor board. Preparations for field trials on an electric rope shovel are reported.

INTRODUCTION

Duty monitors for mining equipment provide information on the accumulation of fatigue damage. The method for obtaining such information is typically strain gauge instrumentation. In terms of computing fatigue damage information, the more strain gauges the better. Taking the dragline boom as an example, it may be desirable to have 50 or more sensors simultaneously reporting strain history.

Wireless sensor networks are a practical development platform for highly instrumented structures. They remove the issue of laying cables, and are particularly suited to installations involving moving parts. If each sensor node also has some computational ability, eg the capacity to count stress cycles, then the sensor network may be considered a distributed duty meter. Each sensor node would therefore provide duty monitoring functionality, and connectivity over an ad hoc wireless network. While the sensor network is local to the machine, it is feasible to have local networks deployed across a mine site, with local networks implemented as identifiable groups.

This paper reports on the development of a sensor unit as a building block for a distributed duty meter. The following functions have been targeted:

- mounting of units in arbitrary locations, with each unit given a unique identification,
- read and buffer strain (and acceleration) data at regular time intervals,
- provide a statistical summary of strain data, specifically load cycle information, and
- offload data with a time stamp and unit location identification.

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SYSTEM OVERVIEW

The sensor units comprise three main components: a wireless unit, strain gauge sensor board, and a solar rechargeable power supply. Figure 1 shows a schematic of the sensor unit components.

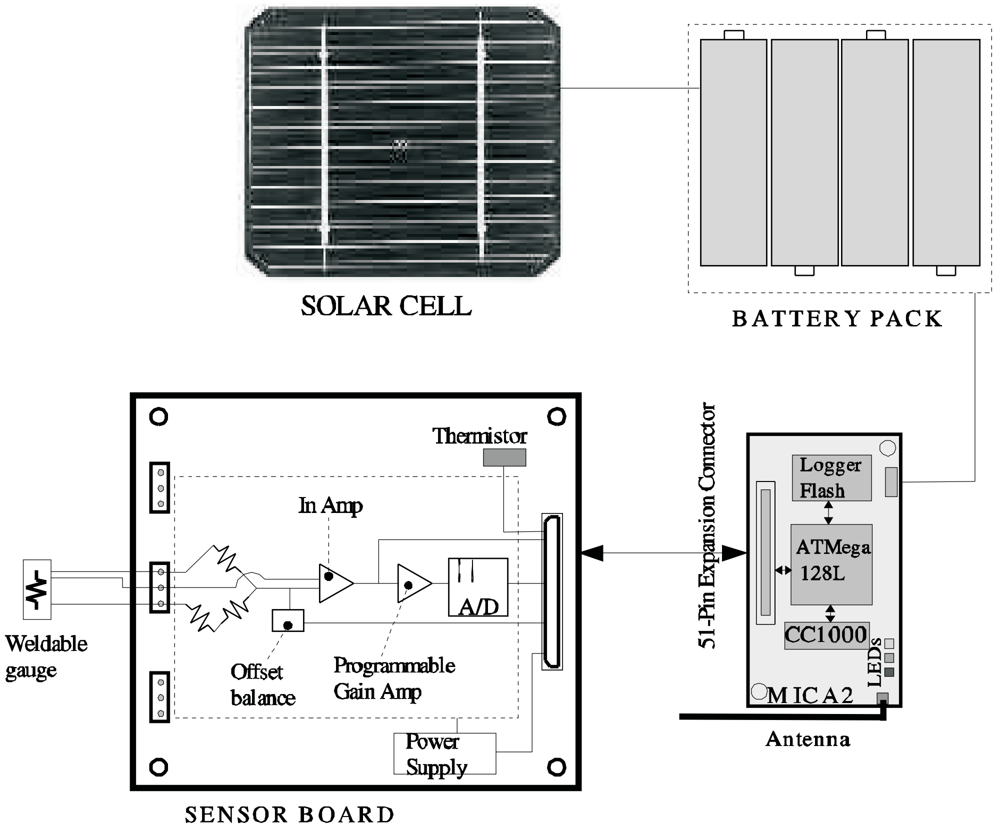

FIG 1 - Schematic of the sensor unit, showing the sensor board layout, the mote layout and the power supply. The combination of sensor board, mote, and battery pack will fit inside a 10 × 10 × 7.5 cm box.

Wireless unit

Our duty meter application uses the Mica2 motes, developed at UC Berkeley as a research platform for low-power wireless sensor networks (Hill and Culler, 2002). The Mica2 mote is based on the ATMega 128L processor, a low-power AVR eight-bit processor with 128 kbytes of flash program memory and 512 kbytes of on-board storage. Along with the eight-channel, ten-bit ADC, several bus interfaces are available for communication with sensors, including SPI, I2C, and USART.

In addition to the on-board computation and the sensor interfaces, the Mica2 is responsible for communication with the sensor network. The integrated 916 MHz wireless transceiver (Chipcon CC1000) used by Mica2 is designed for very low power and very low voltage wireless applications. It is programmable for operation at frequencies in the 300 - 1000 MHz range, with a range of approximately 100 m when operated at 916 MHz. The Mica2 form an ad hoc network as they come within range of each, dynamically changing the routing of messages depending on which mote is currently in range.

An advantage of working with the Mica series is that it is part of an open-source hardware and software platform that combines sensing, communications, and computing. Development of custom software and hardware is assisted by the open publishing of research. Other wireless platforms are available, for example, Imote, Sensicast, and Moteiv. While more commercial units may offer performance advantages, for the development phase of the duty meter application the Mica series offers a relatively inexpensive and well supported introduction to wireless sensor networks.

Strain gauge sensor board

A variety of Mica-compatible sensor boards are commercially available, offering a range of sensing capabilities. For example, the MTS300CA sensor board (part of the Mica series) includes a microphone, a 4 kHz buzzer, light and temperature sensors, a two-axis ±2 g accelerometer, and a two-axis magnetometer. For the duty meter unit, a strain gauge sensor board has been custom designed.

A schematic of the strain gauge sensor board is shown in Figure 1. Three strain gauge inputs are provided, each with a 16 bit A/D converter. To allow debugging of the software elements, each sample can also be read through the A/D channels provided on the mote connector. Three-wire sensing to the strain gauge is used to remove the resistance of long leads to the gauge. Software programmable gains, offset removal, filtering, and sampling, have been included for flexibility during field deployment.

Power supply

Due to the power requirements of the strain gauge, our system would require eight AA batteries for continuous operation over two days, based on an overall mote and strain gauge current consumption of 100 mA. Since, in general, long-term instrumentation is desired, a rechargeable battery pack with a solar array has been incorporated into the unit design.

Base station

For our experiments a Stargate (400 MHz Intel X-Scale processor) base station is to be used for interfacing with the sensor network. The base station allows aggregation of information from the sensor network, and transfer to another platform, which may be an operator display, or a PC remote to the machine. A Mica2 mote is attached to the 51-pin connector on the Stargate, to provide the wireless linkage to the sensor network.

SOFTWARE COMPONENTS

A range of software components are needed for running the sensor network, covering sampling, computation, and communication on the Mica2 mote, and the main base station tasks of listening and broadcasting to the network and logging information. The Mica series of motes run a specifically designed open-source operating system, called TinyOS. TinyOS is an event driven operating system, implemented using nesC – a programming language for network embedded systems (Gay *et al*, 2003).

Many of the components needed by the sensor units exist as part of the open-source distribution. For example, the multi-hop network components needed for the implementation of the ad hoc network are available for wiring into any custom application. Similarly, interfacing with the LEDs on-board the motes is simply a matter of implementing the LED interface. The hardware interfaces for these components exist at the lowest level of the component hierarchy. The application component configured for the strain gauge unit is illustrated in Figure 2. Arrows pointing down are commands to lower level components, while the dashed arrows indicate hardware triggered events. A series of tasks

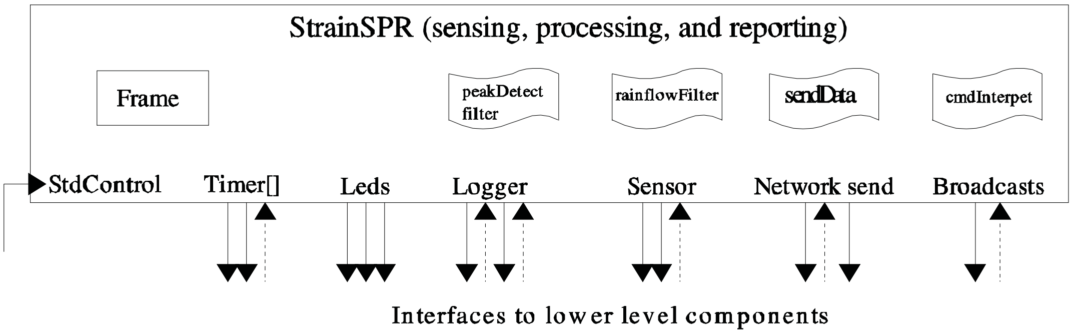

FIG 2 - High level application component (module) for the sensing, processing, and reporting of data.

are implemented to process the data and handle transmission and reception of messages. Tasks are asynchronous code sections, the running of which is handled by the TinyOS scheduler.

The basic computational functions of the sensor unit are peak filtering and rainflow cycle counting. These two actions compress the 25 Hz strain data prior to transmission of the resulting fatigue information. Peak detection is a preprocessing task for the counting of loading cycles. Rainflow filtering is the most common and practical form of counting load cycles, applicable to uniaxial loading (Downing and Socie, 1982). The scheme implemented is a single-pass algorithm which allows processing of data as each new peak value is received. When the message buffer is full, the sensor units transmit the load cycles to the base station.

PROTOTYPE TESTING

To test the distributed duty meter concept, the P&H/CRCMining electric rope shovel, located at the Bracalba Quarry, will be used. This shovel will allow testing of a small-scale sensor network, up to 20 sensor nodes. Significantly, the shovel also allows demonstration of the wireless network for fatigue damage measurements on moving (translating and rotating) machine elements.

Figure 3 shows the planned instrumentation of the rope shovel. For this initial system test, the positioning of the strain gauges is not targeting known fatigue hotspots. Rather, ease of installation and network feature demonstration is the focus. These tests will address the following: mote computation of loading cycles, mote communication, operation of the base station, and overall system capability and reliability. A preliminary trial of the technology on the shovel indicated that radio communication from any part on the boom or handle is possible with, at most, a single transfer node to link the sensor to the base station.

The strain gauge sensor unit is still under development. It is expected that results from the deployment of the sensor network on the electric rope shovel will be presented at the 2005 Australian Mining Technology Conference.

CONCLUSIONS

Recent developments in wireless sensor networks have provided an opportunity for the development of a distributed duty meter concept. The idea is to have low-cost sensor units with computation and wireless communication features, distributed within an ad hoc network local to a machine. This will provide greater instrumentation flexibility and facilitate highly instrumented machine components. Development has focused on the commercially available Mica2 wireless unit and the design of a strain gauge sensor

FIG 3 - Layout of trial sensor network on the 2100 BLE P&H/CRCMining electric rope shovel. The base station will be located inside the operators cabin and sensor nodes distributed around the handle and boom. Note that sensors on the non-visible side of the shovel will also be used, with a transfer node located on the shovel house body for transmission to the base station.

board suitable for application to fatigue damage studies on mining equipment. Following the field trials on the P&H/CRCMining electric rope shovel, we are looking at the possibilities for application to dragline booms, hydraulic excavators, truck chassis, and other mine machine components.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of CRCMining.

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