01 Apr 2008

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Missouri S&T Mote-based Demonstration of Energy Monitoring Solution for Network Enabled Manufacturing using Wireless Sensor Networks (WSN)

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1. Introduction

In this work, an inexpensive electric utilities monitoring solution using wireless sensor networks is demonstrated that can easily be installed, deployed, maintained and eliminate unnecessary energy costs and effort. The monitoring solution is designed to support network enabled manufacturing (NEM) program using Missouri University of Science and Technology (MST), formerly the University of Missouri-Rolla (UMR), motes.

Contemporary factories require constant maintenance and streamlining of operations to operate efficiently and to improve competitiveness. The use of preventive maintenance allows almost continuous operation but incurs large capital overhead. Many industrial applications are moving towards condition based maintenance using network enabled manufacturing (NEM) techniques. NEM methods provide the required visibility allowing for status updates to key personnel in charge of planning and logistics.

The presented effort provides a low-cost and easily deployable solution that accomplishes two main goals: (1) energy usage monitoring for cost savings, and (2) health monitoring of poly-phase motors to support intelligent maintenance practices. The former provides estimation of annual energy usage and costs, identification of inefficiencies due to faults and out of specification power factors (PF's), which all result in utility costs. The later provides a feedback to maintenance efforts to allow visibility of individual fault conditions as they progress. Moreover, distributed embedded diagnostics, and prognostics, applications are supported through joint monitoring of energy, vibration and temperature sensors.

This demonstration presents the capabilities of the network enabled MST/Boeing utility monitoring platform and its support of intelligent maintenance applications. Power, vibration, and temperature monitoring capabilities are demonstrated on the testbed. The experimental setup is equipped with a MST mote that providing measurands visibility and performing diagnostics in real-time through a wireless sensor network (WSN).

2. MST Hardware

Hardware developed at MST balances low-power, low-cost, and high performance 8-bit computing to provide distributed computation, prognostic, and diagnostics abilities for poly-phase power facility utilities. Use of Silicon Laboratories® 8051 variant hardware was selected for its ability to provide fast 8-bit processing, low-power consumption, and ease of interfacing to peripheral hardware components. The interface board utilizes Analog Devices ADE7758 poly-phase monitoring chip to provide monitoring capabilities for electric utilities. It is also equipped with three-axis accelerometer and thermocouple interfaces to support additional sensing capabilities for diagnostic and prognostic applications.

2.1 Monitoring Hardware Capabilities

The monitoring hardware is shown in Fig. 1. The setup provides support for three sensor types: poly-phase power, accelerometers and thermocouples.

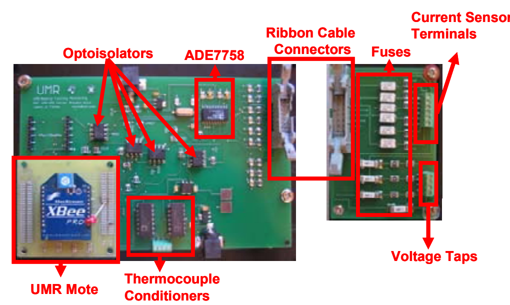

Fig. 1. UMR Power Monitoring Board

The three-phase power measurements are handled using Analog Devices ADE7758 chipset. Its capabilities include monitoring of electric utilities up to 500 VAC with amperage ranges depending on current transformer configuration. The ADE7758 has built in detection capabilities for: (1) over-current, (2) over and under volt, (3) PF, and (4) line frequency.

The power monitoring board was designed to provide maximum flexibility through separation of the high power interface, in Fig. 1 the left board, from the low-power monitoring hardware. This allows for designing sensor interfaces specific for the application and sensor types, for example various voltage and current ranges, inline vs. inductive current sensors.

Furthermore, the main board includes an interface to a multiple range, three-axis accelerometer, the Freescale MMA7261QT, supporting selectable acceleration ranges of ±2.5, 3.3, 6.7 and 10g. The accelerometer is employed to track vibration levels and detect abnormal vibration signatures.

Additionally, the monitoring board is equipped with two thermocouple amplifiers. The AD594/595 family thermocouple amplifier provides laser trimmed accuracy from the factory for a wide range of temperatures. The thermocouples can be used to detect temperature of motor casings and bearings, and to trigger alarms. The processing and communication functionalities are facilitated by MST Mote platform, which is presented in the next section.

This work supported by Boeing Company and Missouri University of Science and Technology NSF I/UCRC in Intelligent Maintenance Systems

978-0-7695-3157-1/08 $25.00 © 2008 IEEE
DOI 10.1109/IPSN.2008.46

2.2 MST WSN

The WSN platform for energy monitoring provides flexible communication architecture for embedded prognostics for complex industrial systems for use with NEM. WSN's support real-time monitoring, diagnostic, and prognostics agents. At MST ongoing research into the integration of distributed algorithms to satisfy a wide array of user requirements is being pursued. The optimal energy-delay sub-network routing (OEDSR) [1] and adaptive distributed fair scheduling (ADFS) [2] protocols have been developed and implemented on the MST mote hardware. The integrated platform shows potential for delivering reliable, and deployable, WSN services to targeted applications. In Fonda et. al [1] the OEDSR protocol is contrasted experimentally with AODV protocol to illustrate the capabilities of properly implemented network capabilities.

2.2.1 ISN and G4-SSN Capabilities

The Instrumentation Sensor Node (ISN) was designed to be a simplified sensor node with the abilities to sample, process and transmit data and has a limited ability to process data relative to the Generation-4 Smart Sensor Node (G4-SSN). The abilities of the two nodes are shown in Table I. The ISN is intended to be a 'simple sample and send sensor node' and is used to interface to devices and sensors. In comparison, the G4-SSN is used for networking functionality and other tasks that require more memory and processing capabilities.

Table I. Comparison of G4-SSN and ISN Capabilities

	Ic @ 3.3V [mA]	ROM [bytes]	RAM [bytes]	ADC Rate [kHz]	Footprint [in^2]	MIPS
G4	35	128k	8448	100 @ 10/12-bit	4.00	100
ISN	7	16k	1280	200 @ 10-bit	1.25	25

3. Demonstrated Monitoring Capabilities

The developed energy monitoring hardware has been tested on a three-phase power at 230 VAC and 480 VAC. The following parameters were monitored: per-phase real and imaginary power, PF, watt-hours consumed, accelerometer readings, and temperature measurements. Fig. 2 illustrates the graphical user interface with various monitoring indicators.

Fig. 3 shows the PF plot over time and over varying motor load. Monitoring of the PF allows for:

1. Tracking PF changes that provide indication for prognostics of machinery, detection of failing capacitors and motors.
2. Detection of abnormal loading due to bearing failures, and measurement of performance due to degradation.

Fig. 2. Power Monitoring GUI

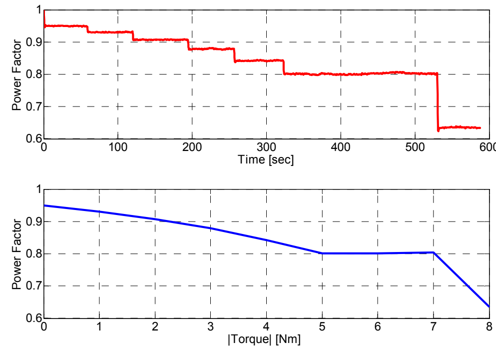

Fig. 3. Power factor tracking over time and varying loads

4. Demonstrable Content

Demonstration of the MST power monitoring project the authors will present a single-phase electric motor testbed equipped with the electric power, vibration, and temperature sensors. The testbed is presented in Fig. 4. Communication support using WSN is provided by MST protocol stack including OEDSR routing protocol [1] and ADFS scheduling protocol [2].

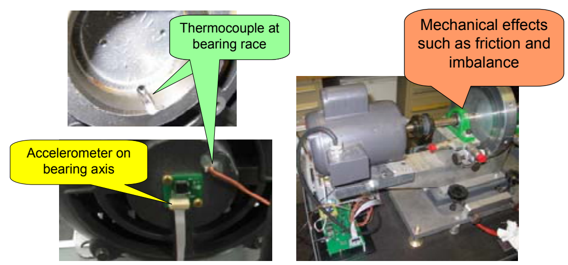

Fig. 4. Motor Testbed

The motor monitoring application will provide remote visibility of power usage and power related health indications, including PF. Additionally, the vibration and temperature measurands are collected to support diagnostics and prognostics of motor and bearing condition. As failures are induced in the electric motor testbed, feedback over the network is given as to the state of the PF, temperature and vibration. The base station will raise an alarm when the measurands exceed nominal levels indicating failure. Future work involves the incorporation of prognostic capability using the WSN as the underlying network for information transfer.

5. References

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