THE APPLICATION OF WIRELESS SENSOR NETWORKS FOR CONDITION MONITORING IN THREE-PHASE INDUCTION MOTORS

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Abstract: The most commonly used technique for the detection of faults in large three-phase induction motors is to measure the supply current fed into the motor and analyze the signal spectrum. This technique is well established and has been shown to be indicative of a faulty condition. However, current signature analysis is usually used by very skilled technicians using expensive equipments. A cost effective condition monitoring technique is needed for smaller motors (those smaller than 200 HP). This paper explores the possibilities of using wireless sensors inside the motor. Wireless sensors are gaining popularity in condition monitoring applications because of their relatively low cost and ease of installation. This paper proposes a system of condition monitoring of the three-phase induction motor using wireless sensor networks (WSN) to measure the temperature and the vibration signals. The sensor nodes are placed on the rotor and the stator. The data acquisition is accomplished at a base station located at a distance of 6 feet. Issues related to electromagnetic interference between the wireless devices and the magnetic fields present within the motor are investigated.

Key Words: Wireless Sensor Networks, Three-phase Induction Motor Condition Monitoring

I. INTRODUCTION

Condition monitoring is important to maintain sustained operability of machinery. The ability to effectively and efficiently monitor the condition of industrial machines allows the user to have a clear understanding of any problems that may arise during machine operation. Condition monitoring has the clear advantage of offering the ability to perform just-in-time maintenance i.e. before failure occurs but only as necessary. This aspect allows companies to reduce downtime when repairing machinery and ensures that productivity does not suffer.

The U.S. Department of Energy estimates that electric motors consume 63% of all electricity used in industry. U.S. Industry consumes 33% of U.S. energy and presents significant opportunities to save cost and energy [1]. In an effort to reduce power consumption, condition-based maintenance employs many different technologies [2, 3] to monitor the performance of motors used in industrial applications. It is believed that a reduction in machine failures increases plant efficiency and productivity. Wireless sensors are becoming a much more feasible monitoring option because of their desirable characteristics. They are small and lightweight, allowing for placement in limited spaces. Since they are wireless, they can be mounted on moving parts, thus eliminating the need for flexible connectors, slip rings etc. The sensors require very little power and are very low cost. The low power requirement makes energy scavenging from the environment attractive [4]. Their ability to continuously observe the vibrations and temperature provide the continuous monitoring of the performance of the motor. This allows the motor to be repaired quickly and effectively as and when needed.

A survey explaining motor failures by Austin Bonnett and Chuck Yung [5] estimate that roughly half of motor failures that occur are due to the rotor and the bearings. These failures cannot be easily predicted by merely monitoring current. Implementation of sensors to directly measure the phenomena in the rotor are not easy because of the rotation of the rotor. A wireless sensor network containing temperature and vibration sensors would be ideal in collecting the necessary information to determine maintenance requirements. We have built a prototype system, which is comprised of two thermocouples, two thermisters and two vibration sensors. This prototype wireless sensor network is used to monitor a three-phase induction motor. The electromagnetic interference between the wireless devices and the magnetic fields present within the motor is investigated by analyzing the package loss of the wireless sensors located in different positions.

II. ELEMENTS OF WIRELESS SENSOR NETWORKS

In condition monitoring, wireless sensors can help alleviate the problems of embedding a data acquisition system into existing machinery. It is not always easy to install new, wired sensors into existing machinery because of wiring requirements and limited accessibility. Machine condition monitoring systems include measurement hardware and software that acquire and interpret signals generated by the machine being monitored. Figure 1 provides an overview of the motor monitoring system three-layer framework.

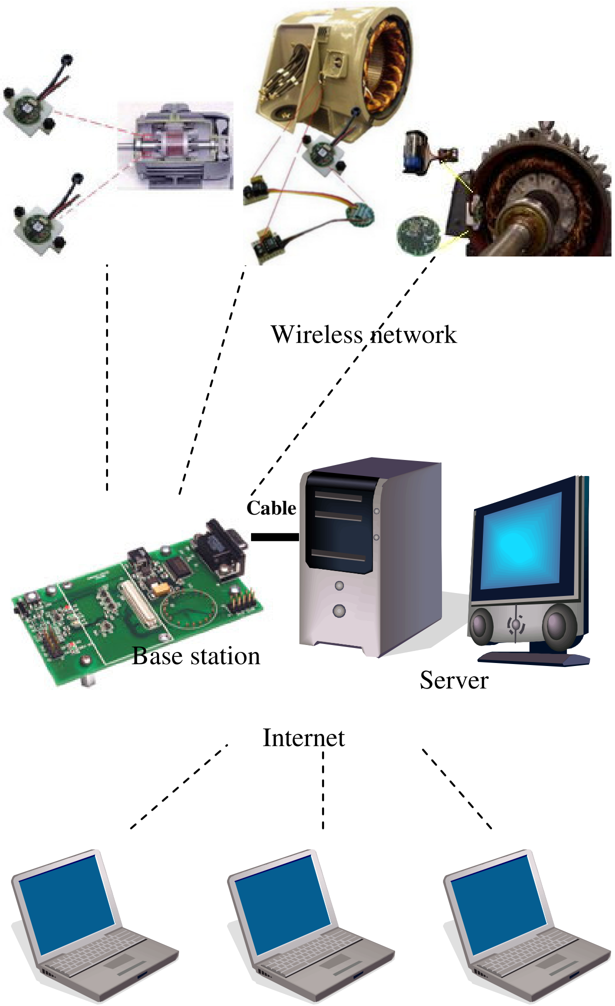

Figure 1. Three-layer Condition Monitoring System Framework

The first layer is the data acquisition layer which is composed of integrated sensor nodes. In the second layer, a base station board collects the data from different wireless sensor nodes. The base station is connected to a server computer through a serial port cable. A laptop can be used as a server computer as well. All the data collected is saved in the data base and the signals can be processed by using various signal processing techniques. The decision for maintenance thus can be made based on the wider view of the information. The third layer provides a connection for human user interfaces to the system. The user can catch the global view of the machine and the condition monitoring can be carried out remotely.

A. Sensor Nodes

A sensor node is comprised of a sensor board and a sensor mote. Figure 2 shows one of these sensor nodes in the first layer. The sensor board and the mote are connected through the pins. The sensor motes host an Atmel 128L CPU that runs the Tiny Operating System (TinyOS). The operating system executes programs independently written in the programming language nesC [6]. Our sensor motes and prototyping boards are commercially available from Crossbow, Inc.

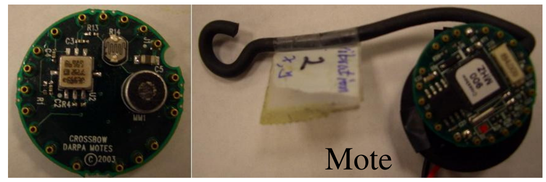

Figure 2. Accelerometer Sensor Node

The accelerometer has an analog voltage output and has a measurement range of +/- 2g with a sensitivity of 2mg at 60Hz. The accelerometer sensor board is designed by Crossbow, Inc. To calibrate it, the accelerometer is first oriented vertically facing up and the output voltage (Vp) is measured. It is then turned 180 degrees to point vertically down and the voltage is again measured (Vn) The calculation of acceleration from ADC output is as follows:

$$a(g) = 1 - 2 * (Vp - Vout)/(Vp - Vn) \qquad (1)$$

Where Vp is the +1g calibration reading and Vn is the -1g calibration reading, a is the acceleration, $Vout$ is the ADC output reading.

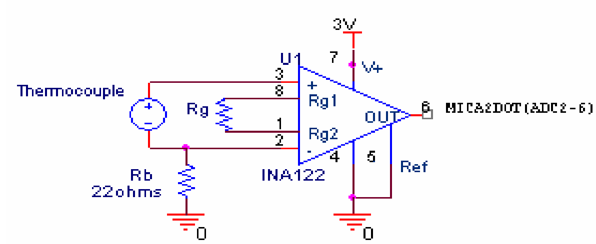

Figure 3. Thermocouple Sensor Board Circuit

There are two types of temperature sensors used in our experiment. One is an integrated thermistor that has a range from 0°C to +50°C and calibrated by Crossbow, Inc. The other is a thermocouple with its sensor board designed by ourselves. The sensor board circuit is shown is figure 3. Thermocouple readings contain noise from the environment that can be reduced by common-mode current path. Resistor R_b provides a bias current return path. The signal generated by the thermocouple is amplified by a single supply, low power amplifier. Gain is controlled by a single resistor R_g as the equation (2). The output voltage yields equation (3). The temperature range depends on the gain needed. Calibrations are done by using the temperature controlled water bath.

$$G = 5 + \frac{200k}{R_g} \qquad (2)$$

$$V_o = \left(V_{IN}^{+} - V_{IN}^{-}\right)G \qquad (3)$$

Figure 4. Sensor Node Casing

A three-phase induction motor is our signal source. The sensor nodes are mounted outside the motor as well as inside the motor. Power is supplied to these sensors via batteries. Almost all of the power that the sensors consume is due to the wireless communication between the sensors and the base station. In industrial applications, magnet mounting is the easiest way to set up the senor nodes. A magnet is integrated to the bottom layer of the sensor node case as shown in figure 4.

B. Base Station

The data acquisition task is achieved by a data logger, which consists of one sensor node and a programming board. The programming board is connected to the computer server by a serial cable. The sensor node and the programming board together are called a base station. The purpose of the base station is to collect the data from each sensor node and transfer all the data to the computer server.

III. EXPERIMENT AND RESULTS

A three-phase induction motor from Newman Electric Motors, Inc. is mounted on a steel plate. It is a 1 hp three-phase induction motor and is connected to an adjustable speed drive from Toshiba International Corporation. The running speed can range from 0 to 900 rpm.

There are six sensors and five motes used in the experiment. Two thermocouples are connected to one mote because each mote has multiple Analog to Digital converters (ADC) and we can design the sensor board to use two ADCs. The thermocouples are both glued on the stator winding and their leads pass the side box to connect the mote outside the motor. The other four nodes are all placed inside the motor. Two thermister nodes and two accelerometer nodes are installed on the shaft and on the shell beside the stator winding respectively. The sampling rate of the temperature sensors is set to 10 Hz, and that of the accelerometer sensors is set to 100 Hz.

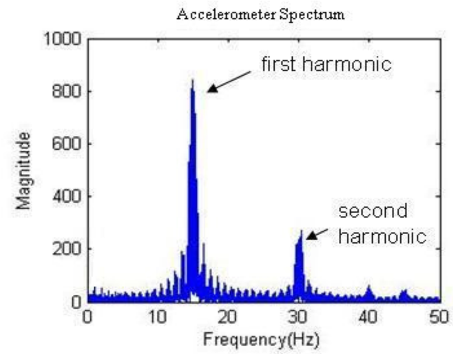

Figure 5. Accelerometer signal spectrum

The wireless accelerometer sensor node attached on the shaft gives a clear response signal as displayed in figure 5. The peak frequency known as the fundamental frequency is the shaft rotation frequency which is 15 Hz when the motor is running at 900 rpm. Another frequency peak is the second harmonic.

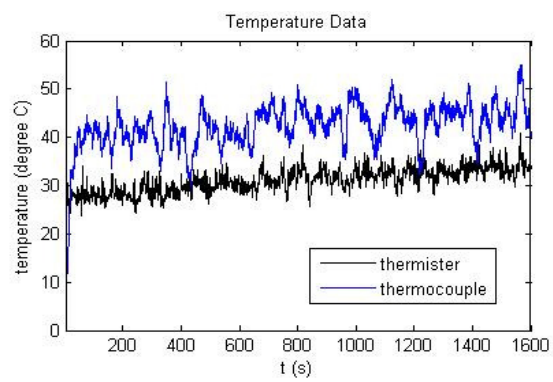

Figure 6. Temperature Data

The data collected from wireless thermocouple sensor attached on the stator and the thermister beside the stator are shown in figure 6. The temperature measured by thermocouple quickly increased after the motor started.

Wireless sensor networks can be used to undertake the task of condition monitoring in a wide variety of environments. Many of these environments can be harsh for wireless communication, especially in manufacturing environments. The most basic aspect of wireless communication is the packet delivery performance: the characteristics of packet loss, and its environmental dependence [7]. In our three-phase induction motor, there is a strong magnetic field inside the motor when it is running which can cause more packet loss during the period of data transmission from sensor nodes to the base station. By tracking the packet loss of the sensors which are placed at different positions, we can investigate the strength of the magnetic field and its effect to wireless communication. In each packet, a cyclic redundancy check (CRC) code is embedded at the end of the packet data. TinyOS networking stack uses the CRC coding scheme to drop the corrupt packet. In order to determine packet corruption, we investigate both the individual bytes that are corrupted as well as the packets that fail the CRC check. By tracking the percentage of these packets, we found the packet CRC loss rate is less than 10%.

IV. CONCLUTIONS

The possibility of using wireless sensors in the three-phase induction motor condition monitoring is explored in this paper. We have conducted experiments to gather vibration and temperature data from motors. The wireless sensor data is not as reliable as wired sensors. However, it is an important way to collect data when wired sensors can not reach the place. Due to the magnetic field, the wireless communication between the sensor nodes and the base station is affected. Although the magnetic field causes more packet loss of the data transition, there are still enough data to analyze the analog signal. By placing several sensor nodes around the motor, we will also be able to gather enough data to perform accurate data analysis and condition monitoring.

The problem of electromagnetic interference could be solved by increasing the power of the wireless transmission. This has the disadvantage of increasing power consumption, but rotating shafts have enough energy that can be directly scavenged from the environment and used to supply the required energy. Also faster sampling rates need to be achieved to perform accurate monitoring with vibrations.

The paper also only minimally exploits the local processing and storage capabilities of the wireless sensor nodes. More sophisticated signal and data processing algorithms could be employed on the nodes. In addition, local communication networks could be set up within the motor to enable collaboration among the sensor nodes.

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