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Fault Diagnostics and Health Monitoring of Machines Using Wireless Condition Monitoring Systems

Prateek Saxena, Naresh Tandon

Abstract— The focus in recent years is shifting from scheduled maintenance to predictive maintenance by observing and predicting the machine condition in advance. The motors used in the machine are being monitored using vibration, current, and temperature sensors which either provide warning signals or shut down the system before any catastrophic failure occurs. Traditional condition based monitoring system is a wired system formed by communication cables and different sensors. This involves high installation cost and difficulty in maintenance especially when the equipment is placed at different location than machine. To overcome these restrictions, the structures can be monitored remotely with the help of wireless transmission media. Wireless sensor network is a control network that integrates sensor, wireless communication and distributed intelligent processing technology. This paper discusses the recent advancement in structural health monitoring of machines using wireless technology.

Index Terms— Condition monitoring, E-Maintenance, Fault diagnostics, Smart sensors, Vibrations, Wireless communication.

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1 Introduction

STRUCTURES such as dams, pipelines, aircraft, ships etc. are subjected to harsh loading and severe environmental conditions during operation. This may lead to the damage and catastrophic failure of the structure [1], [2], [3], [4], [5], [6]. Structural monitoring systems are widely adopted to monitor the behavior of structures during forced vibrations. The monitoring system is primarily responsible for collecting the measurement output from sensors installed in the structure and storing the data within a database. Traditional condition based monitoring systems employ coaxial wires for communication between sensors and database [7].While coaxial wires provide a reliable communication link, their structures of installation can be expensive and labor-intensive. As structural monitoring systems grow in size (defined by the number of total sensors), the expense of the monitoring system can grow faster than at a linear rate [8].

Wireless Condition Monitoring system incorporates wireless sensors. Wireless sensors are initially motivated by their low-cost [9], [10]. The eradication of extensive lengths of coaxial wires in a structure results in wireless systems having low installation costs [11]. With hundreds of wireless sensors installed in a single structure, the wireless monitoring system is also better equipped to screen for structural damage by monitoring the behaviour of critical structural components, thereby implementing local-based damage detection. Wireless sensors are not sensors, but are data acquisition nodes to which traditional structural sensors such as accelerometers, strain gages, inclinometers, linear voltage displacement transducers etc. are attached.

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Wireless sensors deployed in condition based monitoring systems are responsible for screening the measured data to identify the possible existence of damage. Data processing algorithms are embedded in wireless sensors for execution by themselves [12], [13], [14], [15], [16]. Similar to the traditional cabled sensors, majority of the wireless sensors are passive in nature that only measure structural responses due to static and dynamic loadings in contrast to active sensors that can interact with or excite a structure when desired. However power consumption by the wireless sensors is a major challenge in the area of condition based monitoring systems.

2 Fault Diagnostics in Electrical Machines

A vibration sensor for condition monitoring of an electrical machine such as motor must be able to measure vibrations within a broad vibration spectrum [17], [18]. MEMS accelerometer is the most appropriate vibration sensor for an application requiring high frequency monitoring [19], [20]. If the motor is not well balanced or misaligned, this will appear as a high energy vibration signal at the frequency near the rotational speed, typically in the range of 50 Hz [21], [22], [23]. If there are bearing defects, a low energy signal at higher frequencies will appear, typically in the range of 1–5 kHz [21], [22], [23]. In order to detect both kinds of problems with one single sensor, the sensor must have a large bandwidth and a resonance frequency above the range [23]. The complete sensor node that is mounted on the motor for condition monitoring must itself not have any strong natural frequencies within the desired range.

2.1 Quality of Interface

The quality of the sensor interface is a function of conversion resolution, sample rate and number of channels available on its analog-to-digital converter (ADC) [24]. Selection of an appropriate sensing interface must be done in consultation with

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the needs of the monitoring application. For most wireless structural monitoring applications in non-destructive engineering and acoustics, an analog-to-digital conversion resolution of 16-bits or higher with lower sampling rates is preferred [24], [25], [26].

Once measurement data have been collected by the sensing interface, the computational core takes responsibility of the data, where they are stored, processed, and used for communication. To accomplish these tasks, the computational core is represented by a microcontroller that can store measurement data in random access memory (RAM) and data interrogation programs (such as damage detection routines) in read only memory (ROM) [24]. An internal element of every microcontroller is a clock. The speed of clock is a direct measure of how fast embedded programs will be executed by the microcontroller. As the speed of the microcontroller increases, there is a linear increase in power consumed [27]. If the size of the internal RAM and ROM memory is inadequate, additional external memory can be added to the computational core design. To have the capability to interact with other wireless sensors and to transfer data to remote data repositories, a wireless transceiver is used which is an integral element of the wireless sensor design. A radio transceiver can be used for both the transmission and reception of data. A radio band is capable of sending two types of wireless signals: Spread spectrum and narrow band signals. The performance of narrow-band wireless signals is diminished by interference [28], [29] and multipath effects [28]. The loss in power of wireless signals with distance has been an issue of concern for lot of researchers and different theories are developed and discussed in their work by Rappaport [30], Zhao and Guibas [31] and Pei et al. [32]. Several researchers have worked on quantification of distance of wireless signals, while propagating at multiple frequency bands [33], [34].

3 E-MAINTENANCE

If a structure is maintained by adopting a proper maintenance strategy, this can lead to the increase in life-span of that structure. Waeyenbergh and Pintelon [35] have documented the evolution in maintenance strategies with time. The concept of evolution of maintenance strategies began after examining the pre-existing concepts of Total Productive Maintenance (TPM) [36], Reliability-Centered Maintenance (RCM) [37], Logistic Support Analysis [38] and Business-Centred Maintenance (BCM) [39]. A recent approach in the maintenance strategies is the concept of e-maintenance [40], [42], [43].

The concept of e-maintenance is dynamic in nature [44], [45]. This maintenance strategy requires the use of wireless, internet etc. for its operation. This feature enables to approach zero downtime for manufacturing operations by allowing a quick transfer of data on a sharable platform with the integration of existing technologies and sources located remotely at different places. E-maintenance comprises of two subordinate systems: local maintenance and maintenance center. Both systems if work effectively can increase the reliability of the system [46], [47].

3.1 Case Based Reasoning (CBR)

A CBR system is a part of e-maintenance strategy and is dynamic in nature. Yu et al. [48] in their work describes the integration of e-maintenance with CBR. This system works on continuous updating of the case base. The case base is a large data set which contains many problems with their solutions. It keeps on adding new problems to the database, eliminating the repeated ones and combining the existing problems [49], [50]. CBR gives solution to a new problem by looking at the solutions adapted to solve earlier problems. Whenever a new problem is encountered, the system retrieves a similar case from the case base and provides the optimal solution by looking at the similarity between the cases.

3.2 Fault diagnostics of induction motors using CBR

Induction motors are mainly subjected to mechanical and electrical faults [51]. These faults may be inherent to the machine itself or caused by operating conditions. Several techniques are available for detection of faults in motors. These techniques include motor current signature analysis (MCSA) [52], vibration monitoring [52], chemical analysis [53], electromagnetic field monitoring [54], temperature measurement, infrared measurement [55] etc. Han and Yang [46] in their work discussed a technique for fault diagnostics using case based reasoning. Once the signal is processed, the sensors send a data packet to the module designated for condition monitoring. The module sees the data trend and makes an online comparison with the existing data values. An alert is generated if the abnormal condition is matched depending upon the operational limits already set in the database. These operational limits are based on the standard settings.

4 SMART SENSORS DEVELOPED FOR MONITORING MOTORS

The design of the wireless and powerless sensing node can work independently inside a motor. Lee [56] in his work on wireless and powerless node system for CM of motors outlines a comparison between traditional and wireless CM systems. A communication module is set up to generate response to an output sensor in the form of electromagnetic pulses. These EM pulses are capable to penetrate the casing of the motor to send the signal to the data collection terminal. This makes the system self-sustaining and doesn’t make use of any signal cable; the rotation of shaft generates the power by induction. The aim of developing wireless sensing nodes is to lower the cost and increasing the reliability of CM system.

Fig. 1 (a) shows the sensing node integrated in the motor, which is absent in the traditional CM system as shown by Fig. 1 (b). The antenna is fitted inside the motor and is in contact with the motor casing. EM waves pass through the motor casing and reach the terminal for acquisition of data. The signal is transmitted with the help of a signal cable on the motor casing which acts as an antenna. This antenna receives the signal and transmits to the data center. This is in contrast with the traditional CM systems which make use of cables and wire for data transmission.

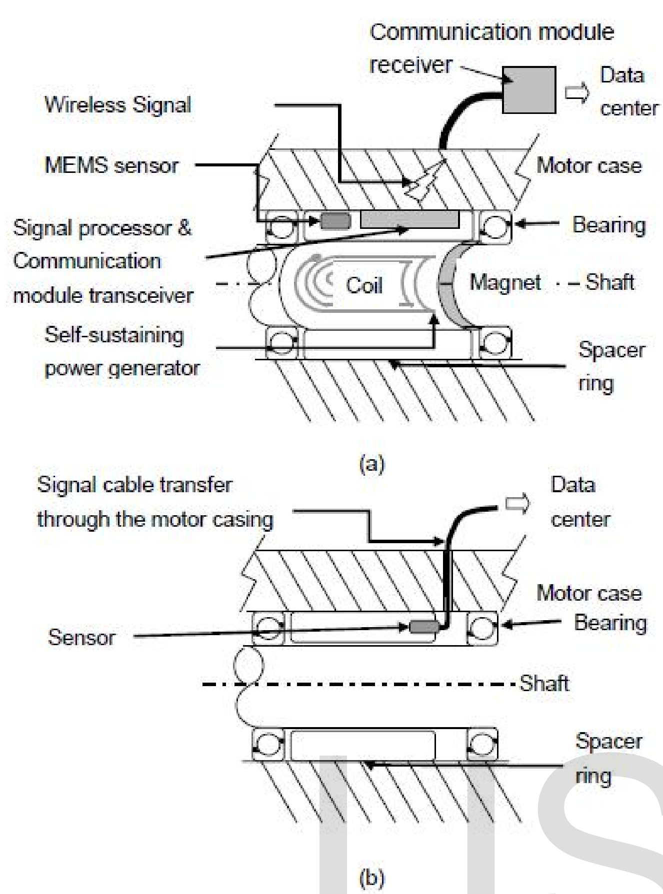

Fig 1. (a) CM system with wireless sensing node; (b) Traditional CM system (adaped from work done by Lee [56]).

5 Challenges in Deploying Wireless Networks for CBM

The following challenges exist in deploying wireless condition based monitoring systems:

1. *Fault Tolerance:* Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures. Few sensor nodes may fail or be blocked due to physical damage, lack of power or environmental interference. The misprision of sensor nodes should not affect the overall task of the sensor network.
2. *Scalability:* The sensor nodes implemented in studying a phenomenon may be in the order of hundreds or more. Depending upon the application, the number may reach an out most value of millions. The new schemes should be able to work with this number of nodes. Also, they must utilize the high density nature of the sensor networks. The density can range from few sensor nodes to few hundred sensor nodes in a region.
3. *Production Cost:* The sensor network is made up of many sensor nodes; the cost of a single node determines the cost of the complete network. If the expenditure in implementing sensor network is higher than that for traditional sensors, the sensor network is not profitable. Hence, the cost of each sensor node should be kept low in order to optimize the overall cost of the sensor network.
4. *Hardware Constraints:* A sensor node comprises of the following components: a transceiver unit, a processing unit, a sensing unit and a power unit. There are also other subunits, which are application dependent. All of these subunits may need to fit into a matchbox-sized module. Apart from the size, there are also some other constraints for sensor nodes. These nodes should:
   a. Consume extremely low power.
   b. Operate in high volumetric densities.
   c. Have reasonable production cost and be dispensable.
   d. Be autonomous and operate unattended.
   e. Be adaptive to the environment.
5. *Power Source:* Since the sensor nodes are often not accessible, the life of a sensor network mostly depends on the life of the power resources of the nodes. Power is also a sparse resource due to the size limitations. For eg: the total stored energy in a smart dust mote is on the order of 1 J. For wireless integrated network sensor, the total average system supply currents must be less than 30 μA to provide long operating life.
6. *Sensor network topology:* Sheer numbers of inaccessible and unattended sensor nodes, which tend to of fail often, make topology maintenance a tough task. Hundreds to several thousands of nodes are installed throughout the sensor field. Deploying high number of nodes densely requires careful handling of topology maintenance.
7. *Transmission Media:* In a multihop sensor network, wireless medium is used for communicating between the sensor nodes. These links can be formed by radio, optical or infrared media. To enable global operation of these networks, the selected transmission medium must be available worldwide.

6 Conclusion

The work presented in this study, gives an overview of the recent advancements in the area of fault diagnostics and condition monitoring of the machines using wireless technology. The hardware and software design of a wireless condition monitoring system for induction machines is discussed. Advanced techniques and communication technologies are used to create a new e-maintenance system. Using such techniques, it is possible to achieve near zero downtime in carrying out processes and operations. The e-maintenance strategy consists of two subsystems: maintenance centre and local maintenance. This division can effectively reduce the maintenance cost, design period for maintenance system, and can also solve the problem due to lack of experts in handling maintenance tasks. The development of smart sensors for fault diagnostics is discussed. The wireless health monitoring system is tested under various operating conditions by different researches and is

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found to work satisfactorily. However certain challenges do exist in implementing these techniques which are also discussed as the part of this research study.

7 Comments and Future Work

E-maintenance needs development in certain areas which can be summarized as:

1. Cost-effectiveness of the necessary items such as smart sensors, MEMS etc.
2. Standardization of built-in sensors for large motors, pumps, turbines and other critical components.
3. The development of fusion techniques in overall maintenance activities to improve reliability.
4. Increasing integration, and accepting common standards for integrating maintenance software. General platform needs these standards to share information, transfer data and in decision making.

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