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Review Article

Comparison of Fault Diagnosis Approaches in Industrial Wireless Networks: A Review

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Abstract: Wireless sensor networks have received increasing research attention and they can be found in every field of life. The industrial wireless sensor network is one of the boosting and emerging technologies for machine fault diagnosis and monitoring. This study provides a review on vibration fault diagnosis approaches in industrial wireless applications and discusses the causes of machine faults and challenges. Several advanced vibration approaches have been used to quantify machine operating conditions. These approaches provide a fault diagnosis mechanism and expert maintenance solutions through analysis of vibration. The review also shows a broad scope of research for developing a robust fault diagnosis approaches in the field of industrial wireless sensor networks.

Keywords: Artificial intelligence, challenges, fault diagnosis, industries

INTRODUCTION

Modern industries are composed with different devices and equipment to improve the process efficiencies and meet financial objectives. The unexpected breakdowns of machinery not only cause of financial loss but also damage the equipment itself. Recently, many industries have been changed into intelligent and low-cost industrial automation systems with the collaboration of industrial wireless sensor networks. These new wireless technologies bring several advantages to control and monitor the systems with reliability, self-healing, flexibility and intelligent processing capabilities. Induction machines are the significant part in modern industries due to many economical and technical aspects. These machines face many issues related to operating functions, conditions and lead to different modes of failures. To deal with these faults, several different types of technologies have been implemented such as electromagnetic field monitoring, radio frequency emissions, noise and vibration monitoring, chemical analysis, etc. (Nandi *et al*., 2005). Fault diagnosis and condition monitoring are considered as an effective approach to improving the efficiency and safety. In recent years, fault detection and monitoring of electrical machines have moved traditional approaches to artificial intelligence techniques. The fault detection decisions are made through automated tools such as neural networks and fuzzy logic systems (Henao *et al*., 2014).

Wireless Sensor Networks (WSNs) are considering one of the promising technology and alternate solution to address the industrial challenges. These networks have several inherent advantages such as low-cost solutions, high reliability, self-organizing mechanism and feasible for re- allocation and installation. Wireless sensor networks have been applied in different fields of life and prove its resource constrained nature. Most of the wireless applications are used for data acquisition, transmission and for fault diagnosis functions. Sensors feature extraction and fault diagnosis are feasible approaches and have various positive impacts such as reduction of transmitted data, energy saving and long node lifetime, etc. The most of the applications do not capture the all required information of device faults by the single sensor.

The industrial environment is harsh with interference and noise and leads to uncertainty and poor quality of communication. Data fusion techniques have been used to reduce the amount of data and save the energy of measuring and processing units. These approaches for induction motor fault diagnosis are based on different techniques such as fuzzy data fusion (Liu *et al*., 2009), Bayesian method (Niu *et al*., 2007),

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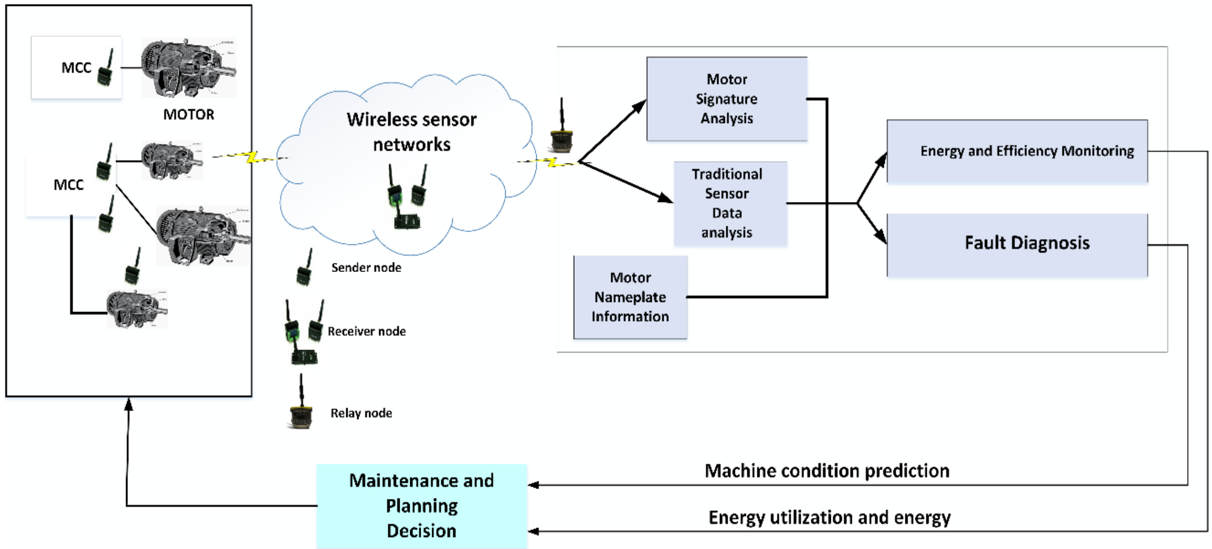

Fig. 1: Basic architecture of industrial wireless sensor network

Dempster-Shafer theory (Yang and Kim, 2006), etc. For fault diagnosis monitoring, there are many studies have been applied and developed based on artificial intelligence techniques for early fault diagnosis. The artificial intelligence techniques are adaptive with new data and easy to modify and extendable compared to conventional diagnosis approaches. In this study, we review and compare the artificial intelligence based fault diagnosis approaches in industrial wireless applications. Further, the paper emphasizes detailed causes of fault conditions in different aspects.

The main aim of this review is providing a detail comparison of fault diagnosis approaches in industrial wireless networks and it highlighted advantages and disadvantages.

INDUSTRIAL WIRELESS SENSOR NETWORKS AND INDUSTRIAL ENVIRONMENT

Industrial wireless sensor networks target the low cost and smart applications, with feasible data throughput for fault diagnosis and monitoring in industries. The IEEE 802.15.4 standard is intended to achieve high-quality wireless communication. The sensor network brings significant advantages over traditional wired networks. Sensor nodes use for There is many standards have been proposed to achieve the industrial data communication requirements such as Wirelss HART, ZigBee, ISA100.11a (Qureshi and Abdullah, 2014, 2013). The sensor network brings significant advantages over traditional wired networks. Sensor nodes use for machine fault diagnosis and monitoring. Figure 1 shows the basic architecture of industrial wireless sensor network for maintenance and planning decision. Basically the motor electric data such as voltage, vibration analysis, collected by the sensor nodes and transmitted to the central supervisory station.

ADVANTAGE AND DISADVANTAGE OF THE WIRELESS SYSTEMS IN INDUSTRIES

Wireless technologies have various advantages for industrial environment. The main and significant advantage is save cabling and overcome the cost and maintenance issues. The cost and time needed for installation and maintenance the traditional cables system. The wireless technologies have been reduced these difficult and costly configuration systems. The wireless technologies are more feasible especially in harsh environments such as in high vibration, chemicals environments. The wireless sensors are coupled to any mobile subsystem in order to provide communication services.

Furthermore, the tasks involved for diagnose the faults are more flexible and can be greatly simplified with wireless technologies. The operations are more simplified and localization and tracking of unfurnished parts are more simplified in industrial environments. Most of industrial applications are served by fieldbus systems like WordFIP (Thomesse, 2004), PROFIBUS (Jecht *et al*., 2005) and CAN (ISO 11898, 1993). These systems are specifically designed for controlling and automation tasks of digital controllers and sensor actuators. The main objective of these systems is to provide real-time communication services. The wireless technologies have various benefits and offered a range of voice oriented, large scale cellular network services by wireless LAN, Wireless personal area networks and IEEE 802.11 family of standards. Industrial applications have stringent requirements in terms of reliability and

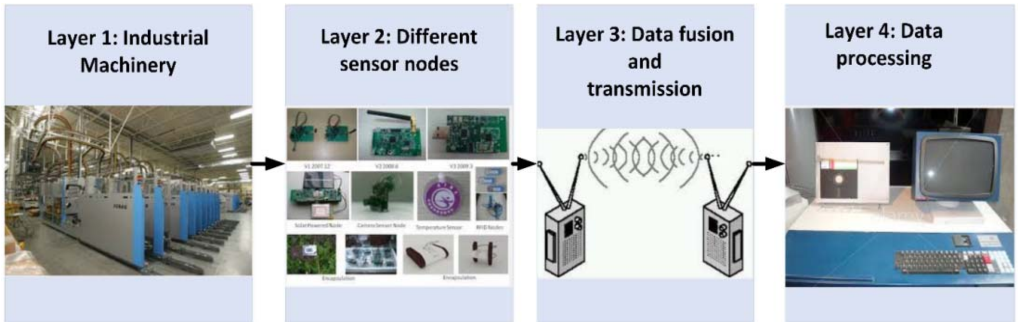

Fig. 2: Architecture of wireless network system for fault detection in industries

timing. In traditional wired systems, the reliability and timings are well catered by fieldbus systems. Fieldbus system refers to communication between sensors and actuators for physical process. In the presence of various benefits, the wireless technologies have been suffered with various issues and challenges.

Signal strength and transmission quality is always considered as a significant requirement for wireless technologies. Signal strength decreases with the distance between transmitter and receiver. The weak signal strength is known as path loss. The path loss depends on various parameters such as antenna technology, interference and environmental conditions. These challenges leads to data loss, delay in data delivery. Another disadvantage of wireless technologies is half duplex operation of transceivers, where transceivers are not able to transmit and receive by same channel due to their own signal from any other stations. The disadvantage is time loss in data delivery. Channel errors occurs due to wireless propagation into multiple spatial directions at same time and result in the shape of multiple copies of the same waveform with different relative lengths and time.

There are some other distortions are exist in the form of co-channel interference, thermal noise, Doppler shifts (Stüber, 1996). In industrial environment, distortion and significant noise of transceiver and circuitry created by strong motors, electrical discharge devices. These issues lead to data loss and delay issues in industries.

CAUSES OF MACHINES FAULTS AND DIAGNOSIS

Fault detection of industrial machines has moved to traditional techniques to artificial intelligence techniques. These techniques need minimum configuration intelligence and fault detection and evaluation can be completed without any expert. The artificial intelligence techniques require different many quantities such as input signals, voltage, vibration and magnetic field. There are many causes of machinery failures in industries. Basically, the machinery fault refers to the loss of usefulness of machine or any component. This will happen due to obsolescence, accident and surface degradation. Some other faults are happening because of frame vibration, circulating currents, loss of coolants, earth faults, etc. To diagnose these faults can be categorized into fault identification, signature extraction and fault severity evaluation (Filippetti *et al*., 2000). The fault diagnosis is a process to detect the cause of any unexpected behavior. Diagnostic applications make use of system information from design phases such as failure modes, hazard analysis, effects analysis, functional modes and testability analysis. In the presence of the variety of failures and complex environment, a diagnostic system is based on artificial intelligence. In these applications, the data analysis carries out to extract a set of uncorrelated features and detect the fault modes in order to solve the problem.

The application must take the input of sensor values and command stream and ideally performs fault detection and detecting the fault isolation (location of fault) and fault identification and prognostics. The above Figure 2 shown the basic architecture of wireless network system for fault detection.

LITERATURE REVIEW

There are many faults exist and studied in the recent decade. These faults are divided into machine stator and rotor faults. The applications of wireless sensor network not only monitoring the temperature but also used to detect vibration faults. Vibration fault diagnosis needs higher sampling rate and faster transmission rate for a large amount of data. In this section, we discuss the recently proposed approaches to deal with fault diagnosis in the industrial sector.

Recently, artificial intelligence, fuzzy, or neuro-fuzzy systems are used to detect speed, torque estimation for machines in industries. These approaches are suitable for industrial applications and further extended into as a decision-making tool for fault detection. The machine health monitoring based on artificial intelligence is a new novel technique for fault diagnosis and maintenance. Advancements in the field of information and communication technologies have led to increased interest in artificial intelligence tools such as Knowledge-Based Systems (KBS), expert systems and neural networks (Zhao *et al*., 2000). These systems provide failure detection, diagnosis, testing and experience based tasks. These systems have knowledge of system behavior, understanding of fault diagnosis and maintenance activity.

The history of fault diagnosis through expert systems was started in 1980s (Nelson, 1982) with successful applications such as machinery and electrical fault diagnosis, nuclear reactors, etc. It was theoretical model based on first-generation expert systems. Some other efforts were continued for developing similar models in 1983 (Chandrasekaran and Mittal 1983; Fink *et al*., 1985; Fink and Lusth 1987). First time in the 1990s, the artificial intelligence techniques were used for machinery fault diagnosis. These applications were planned for condition based maintenance applications. After a short history, we discuss some recent studies on fault diagnosis approaches.

West *et al*. (2012) was proposed intelligent decision support systems for monitoring the nuclear plants using latest computing tools and approaches to analysis the vibration data critically. In this application of intelligent systems the data gather and refuel from nuclear plants in the UK and provide automated decision support.

This technique supports the existing manual analysis through repeatable, automated and auditable means of assessing the data and decreeing the reliance on individual experts by creating their skills available within the developed system.

Machine condition monitoring application based on artificial intelligent was proposed in Nadakatti *et al*. (2008), it covers a wide range from machinery conditions, quality improvements and e-maintenance concepts. The model using vibration characteristics including velocity, acceleration and vibration. It was for general purpose system for vibration analysis and monitoring using tri-axial and demodulated frequency and time-domain.

Another effort was done in Hou and Bergmann (2011), with a novel induction motor fault diagnosis system for industrial wireless sensor networks for fault diagnosis. This system is based on start topology with one coordinator and two end sensor nodes. The first sensor node measures x-direction vibration and extracts the fault features. The other sensor node performs the same task but takes y-direction into account. The data acquisition and signal conditions feature extraction and fault classification using neural network performed on each sensor node and decision implement in network coordinator. After this process, the results present to host computer with the help of IEEE802.15.4 and ZigBee protocols. The author claimed that system reduce transmission data and energy consumption and improve the certainty of the diagnosis results.

Another novel industrial wireless sensor network was proposed in (Hou and Bergmann, 2012), for industrial machine condition monitoring and fault diagnosis. In this model on sensor, feature extractions are used for fault diagnosis and only transmit fault diagnosis results with fixed interval. Further, the motor vibration and stator current uses for processing and analysis. This approach is feasible for node lifetime especially when node monitors continuously to equipment. The proposed approach reduces the payload transmission and decreases the node energy consumption. Moreover, through Dempster-Shafer theory the certainty improves of fault diagnosis.

Wulandhari *et al*. (2015) was proposed a new hybrid technique of genetic algorithm with adaptive operator probabilities and back propagation neural networks called AGAs-BPNN. This technique uses two bearing systems and ten extracted features from system vibration signals data as input and sixteen bearing conditions as the target output. The experimental results show the proposed approach has higher classification accuracy in short CPU time and number of iterations compared with the standard BPNNs.

Table 1 shows the comparison of proposed approaches in terms of technology, methodology and objectives.

CHALLENGES

There are many challenges exist in industries due to adopting new technologies and the complex industrial The poor quality of radio signals disturb the data communication process in industries due to noise, weak signals, long path lengths and machinery obstacles, fading and high interference. The vibrator and motors in industries produce electromagnetic noise and interference. These interference and noise have same frequency band, interrupt and eliminate the data signal. To deal with these challenges, industries need an efficient data transmission technology in order to overcome the noise interference and increase reliability.

Sensor nodes should be smarter in industries to change their transmission power to achieve different transmission range. The industries process control and monitoring need real-time information such as temperature, vibration, etc. These applications belong to time critical family and excessive delay may cause of process failure and accident (Song *et al*., 2006). The industrial wireless sensor networks are limited in resources such as memory, energy and processing power. These limited resources always consider as a challenge for researchers to make new standards and protocols in order to deal with industrial harsh and complex conditions. The below Table 2 shown the main challenges of industrial wireless sensor networks.

Table 1: Comparison of approaches

S/No	Approach	Technology	Objective
1	Intelligent decision support systems (West *et al*., 2012)	Wireless	The main goal is to provide automated decision support
2	Machine condition monitoring (Nadakatti *et al*., 2008)	Wireless	Efficient for testing and monitoring of an integrated plant maintenance management.
3	Induction motor fault diagnosis system (Hou and Bergmann, 2011)	Wireless	The system is used for induction motor fault diagnosis system and improves the certainty of the diagnosis results.
4	Industrial machine condition monitoring and fault diagnosis model (Hou and Bergmann, 2012)	Wireless	The main objective of this model is reduces the payload transmission and decreases the node energy consumption.
5	Hybrid technique of genetic algorithm (Wulandhari *et al*., 2015)	Wireless	The approach main objective is provide higher classification accuracy in short CPU time and number of iterations compared with the standard BPNNs

Table 2: Challenges of industrial wireless sensor networks

S/No	Challenges	Description
1	Resource constraints	Sensor nodes are limited in power, computation power and memory. These limited resources are restricted the sensor nodes for computational capabilities.
2	Harsh environment conditions	Harsh and complex industries environment causes of network failure due to link breakage and also one reason of sensor nodes malfunctioning.
3	Data redundancy	Due to the high density of sensors nodes in industries the sensor nodes observations are highly correlated in the space domain.
4	Quality of services	To maintain and provide quality of services in the presence of different obstacles and interference, data transmission, routing are always considered as major challenges.
5	Packet error	The sensor node attainable capacity varies on interference level and high bit error rate. Wireless links are exhibited over time and space due to obstructions and noisy environment.
6	Long scale deployment	A large number of nodes are deployed in industries and due to predetermined network infrastructure it is important to establish connection autonomously.
7	Integration with other networks	For commercial deployment of sensor networks in industries allow the network to retrieve information from anywhere. The sensor network should be integrated with other networks.
8	Security	Security is always a major challenge in order to safe the network from external denial-of-services attacks.

CONCLUSION

The industrial wireless sensor network applications provide a range of monitoring and controlling features to machinery. To detect the fault in machinery considers as a significant part for smooth operations of machinery in industries. Artificial intelligence approaches are more feasible for fault diagnosis and for complex machines. In this study, we reviewed the fault detection gnosis approaches, which are related to industrial wireless sensor networks and highlight the machine faults and causes of failures. These artificial intelligence based techniques promise to play a great role for fault detection in machinery. The review is helpful for researchers to capture the broad area of industries and challenges for adopting these new technologies in the field.

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