Condition Monitoring for Induction Motor using Wireless Vibration Monitoring System

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Abstract. Induction motors have an important role and have long been the most widely used components in various industrial applications. To preserve, proper care and maintenance are required. So far, regularly recording vibration values on electric motors to detect potential problems early has become an important aspect of avoiding losses. However, this activity has drawbacks because measurements are carried out conventionally. As a result, the measurement data is difficult to analyze before damage occurs. This research proposes an induction motor vibration monitoring system that can be used as a portable measuring instrument for direct measurements or used as a wireless vibration sensor that can be installed on electric motors for real-time monitoring. The sensor used is a 9-axis WTVB01 vibration sensor connected to an ESP32 microcontroller, which functions as a sensor node that can send data using the MQTT protocol to local server nodes or Servers running in the cloud. Through a monitoring system accessed via the Web, machine vibrations can be detected in real-time and record alarms when abnormal conditions occur in the induction motor. Parameters that can be monitored in real time are vibration displacement, vibration velocity, and body temperature.

Keywords: vibration, abnormal, displacement, motor, wireless

1. Introduction

Induction motors are a key component in a wide range of industrial applications that play an important role in maintaining productivity and operational efficiency. Reliable performance of these motors is essential to maintain productivity and prevent unexpected production interruptions. Timely maintenance and early detection of potential problems in induction motors are critical aspects in ensuring operational reliability and avoiding significant production losses. Therefore, monitoring the condition of the induction motor is crucial in maintaining system reliability.

In the context of motor condition monitoring, vibration analysis has proven to be an effective method for detecting anomalies and possible failures. Vibration is one of the important parameters that can be used to monitor the condition of the induction motor[1]. Abnormal vibrations such as excessive vibration or unusual vibration frequencies can be an early indication of a problem with the motor. Some problems that can be detected through vibration monitoring include unbalancing, misalignment, load variations, mechanical looseness, belt damage, bearing damage and gear damage[2]. Therefore,

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continuous vibration monitoring and accurate data analysis are key in maintaining optimal performance of induction motors.

However, using cables to connect vibration sensors with monitoring systems is often challenging in an often-changing industrial environment. These cables can suffer damage from extreme environments or machine movement, which in turn can interfere with consistent data acquisition. Therefore, the development of a wireless-based vibration monitoring system is a promising solution to overcome this obstacle[3]. The wireless-based vibration monitoring system utilizes multi-axis vibration sensor technology with a Microcontroller Unit (MCU) that is able to communicate wirelessly with the central monitoring system. This eliminates the need for complex and damage-prone wiring installations, and enables real-time collection of vibration data.

Some of the works related to this research are. Zuev and Vodka[4] presents a new design for a wireless vibration measurement and monitoring system. The system is based on a network of wireless sensor nodes, each of which contains a triaxial accelerometer and a microcontroller. The sensor nodes communicate with each other using a wireless mesh network protocol. The data collected by the sensor nodes is transmitted to a central server for analysis and visualization. Mukherjee, et al. [5] proposes UDA framework for vibration-based machine status monitoring at the edge. The proposed framework is based on a two-stage approach that first learns a shared latent representation from a source domain and a target domain, and then uses this representation to train a classifier for the target domain. The proposed framework is designed to be computationally efficient and scalable, making it suitable for deployment on edge devices. Popaleny and Antonino-Daviu[6] presents a methodology for condition monitoring of electric motors using current and vibration analyses. The methodology is based on the assumption that the motor's design and malfunction behaviour are reflected in the current spectrum using Motor Current Signature Analysis (MCSA) and in the vibration spectrum using Vibration Analysis (VA). The results show that MCSA and VA are effective techniques for condition monitoring of electric motors. MCSA is particularly useful for detecting rotor faults, while VA is particularly useful for detecting bearing faults. Amin, et al. [7] proposes a vibration monitoring system for wind turbine gearboxes using a convolutional neural network (CNN). The CNN is trained on a dataset of vibration signals collected from healthy and faulty gearboxes. The CNN is able to accurately identify the presence of faults in the gearbox, with a sensitivity of 99% and a specificity of 98%. Hossain, et al. [8] presents a wireless sensor network (WSN)-based vibration monitoring system using an ARM processor. The system uses a number of accelerometers to collect vibration data from a machine or structure. The system uses an ARM-based microcontroller to collect vibration data from sensors and transmit it to a central server for analysis. Al-Rasyid, et al.[9] proposes the development of an IoT-based vibration monitoring system using 3 ADXL335 accelerometer sensors connected to each Arduino-nano and Raspberry Pi then send vibration data to a cloud server using the MQTT protocol.

In this paper, a vibration monitoring system was developed with the ability of two working modes, including measurement mode and wireless sensor mode based on the internet of things. In measurement mode, this device can be used like a handheld device to measure vibrations in electric motors directly. While in IoT-based wireless sensor mode, this device will be connected to the wireless network and work as a sensor that sends measurement data to the monitoring application server in real-time. The monitoring system can be displayed on the website interface as well as the HMI interface that supports the MQTT protocol. To determine vibration parameters and maximum permissible values for various classes of electric motors, this study refers to the ISO 10816-1 vibration severity chart[10] which includes three vibration parameters, including vibration speed, effective vibration speed and vibration displacement. In this study, the sensor used was the Witmotion WTVB01 multi-axis vibration sensor to measure 3 parameters of motor condition, including 3-axis displacement vibration, 3-axis velocity vibration and motor body temperature. In the monitoring system application, the threshold value of 3 parameters is adjusted to the maximum vibration value allowed to trigger the alarm.

2. System Design

The design of the wireless vibration monitoring system consists of two major parts: the sensor node and the server node. Sensor nodes are designed to work in two modes, including measurement mode and wireless sensor mode. By default, the working mode of the sensor node is the measurement mode. In both ways, the vibration sensor module will actively take measurements but only connect and send data to the node server if wireless sensor mode is enabled. There are several of data drawn from the WTVB01 multi-axis sensor with RS485 Modbus communication: XYZ-axis displacement in µm (micrometre) units, XYZ-axis velocity in mm/s units, XYZ-axis amplitude in degrees, and Temperature with °Celsius units. This WTVB01 sensor also has an IP67 standard and has been equipped with a protective body with magnets so that it is easily attached to the induction motor body. Figure 1 shows the system design in this paper. The data acquisition results are then sent to the server node using the MQTT protocol in data format JSON arrays storing string values, where the MQTT broker has also been run on the node server.

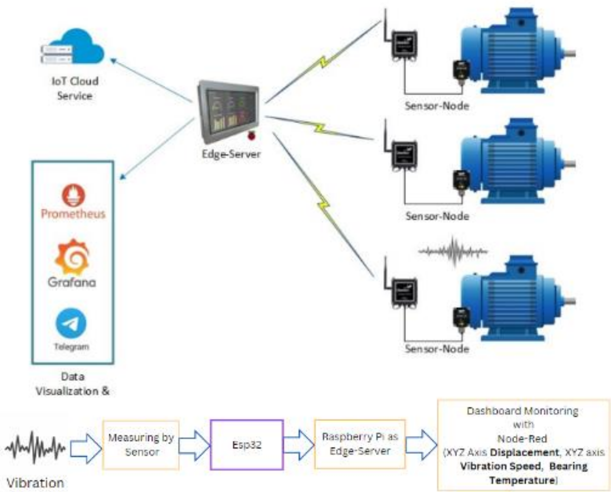

Fig. 1. System Design

2.1 Wireless Vibration Monitoring System

Design of a wireless-based induction electric motor vibration monitoring system, including sensor nodes and edge servers or monitoring nodes. The sensor node is tasked with recording and sending data from the vibration sensor installed on the induction motor to the server node. Meanwhile, the server node receives and processes data and acts as a local MQTT broker. At the sensor node, there are two communication lines used; 802.11b/g/n wireless communication, which is used to send data to the MQTT broker run by the edge-server and Modbus RTU communication to pull data from the sensor based on the registered address of the sensor. Modbus RTU is a simple and efficient communication protocol, so it is often used in industrial applications. Modbus RTU is often used in data acquisition to connect data collection devices (data loggers) with physical devices like sensor[11]. This protocol allows the data logger to read values from sensors and store them in memory.

1) Sensor Node

Sensor nodes play an important role in recording vibration data. To build the sensor node of a wireless vibration monitoring system, three types of components are required: processing unit, sensing system, power supply system and and e-ink display. The following are the components used in sensor nodes to develop a wireless vibration monitoring system.

- Vibration Sensor WTVB01-485
- ESP32-DevKitC-V4
- RS485-TTL
- Li-Ion Battery Charger
- DC-DC Step-up
- Li-Ion 18650 Battery
- E-ink Display Screen

The design configuration for the sensor node is shown in Figure 2.

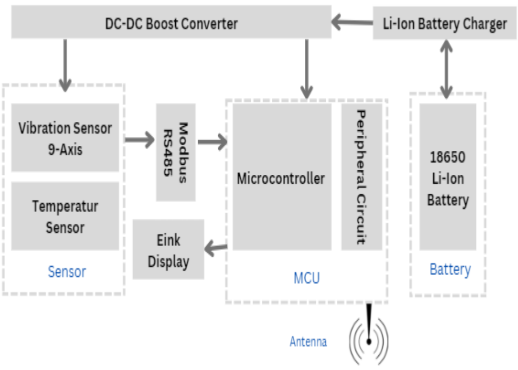

Fig. 2. Sensor Node

2) Data Acquisition and Processing

The data sent by the sensor is in hexadecimal form, and for each register address, the number of read registers read data is expressed in two bytes. The register address is represented by address-high and address-low, the number of read registers is represented by length and data represent the data read. Table 1 shows the registered address of the sensor data to be withdrawn.

Table 1. Register Address table.

Address	Symbol	Meaning
0x3A	VX	X-axis vibration speed
0x3B	VY	Y-axis vibration speed
0x3C	VZ	Z-axis vibration speed
0x3D	ADX	X axis angle vibration angle
0x3E	ADY	Y axis angle vibration angle
0x3F	ADZ	Z axis angle vibration angle
0x40	TEMP	Temperature
0x41	DX	X-axis displacement
0x42	DY	Y-axis displacement
0x43	DZ	Z-axis displacement

The ESP32 microcontroller retrieves data from the sensor in the form of data that is ready to be processed. Because the vibration sensor used produces data that has been processed and filtered. Figure 4 shows the reading results from the vibration sensor that have been processed and will be displayed on the E-ink display screen in the vibration meter working mode. Figure 5 shows the results of the sensor readings which are converted into JSON data format to be sent to the MQTT protocol Node Server.

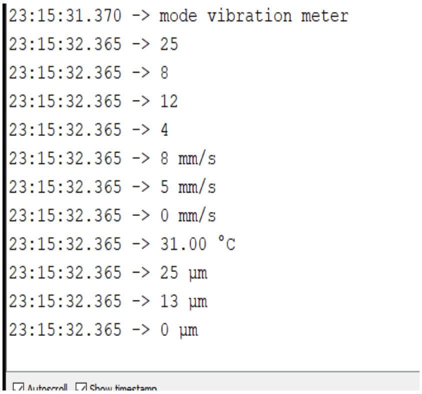

Fig. 3. Sensor Reading

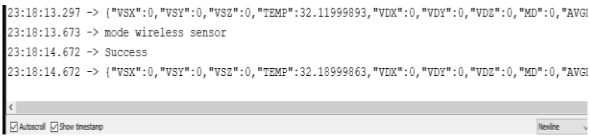

Fig. 4. Sending Data

3) Server Node / Monitoring Node

Node servers are built using Raspberry pi SBCs located near data sources, such as sensors or IoT devices. The Node Server shown in Figure 6, will process the data sent by the sensors, thereby reducing latency and increasing application performance via wireless communication.

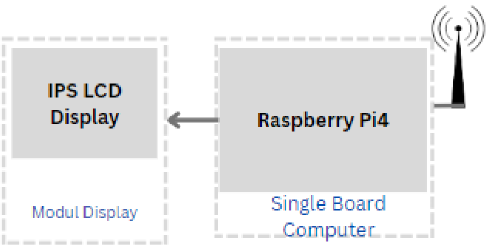

Fig. 5. Server Node

2.2 Web Dashboard

The monitoring system is created using Node-Red which is installed on the Server-Node. Apart from that, the Server-Node also runs the MQTT Broker service using the Mosquitto server. Figure 7 is a dashboard display of the monitoring system which can be monitored in real time using web interface.

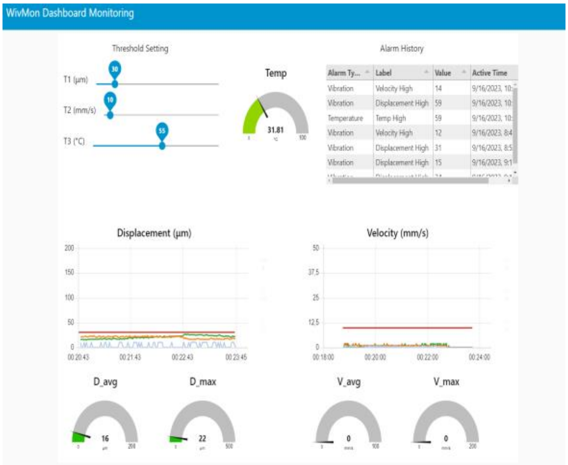

Fig. 6. Web Dashboard

3. Experimental study

To test the reliability of the system, experiments were carried out in research which included several stages including testing the vibration sensor module, testing the vibration measuring mode and wireless sensor mode, as well as notification of abnormal conditions.

3.1 Vibration Meter Mode

Testing in vibration meter mode was carried out on a single-phase induction electric motor. The screen display on the Sensor-Node displays several vibration data that are usually measured by technicians when checking the condition of the motor, including displacement, velocity and body temperature of the electric motor. In Figure 8 it can be seen that the Sensor-Node can work like a mobile device because it is equipped with a power supply from a battery.

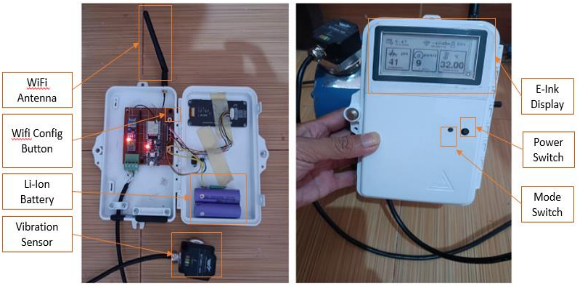

Fig. 7. Vibration Meter Mode

Fig. 8. Measurement result on display

3.2 Wireless Sensor Mode

Testing in Wireless Sensor mode was carried out on an induction motor, as shown in figure 10. When in sensor mode, the sensor mode symbol on the screen will be displayed, as shown in figure 11.

Fig. 9. Wireless sensor mode testing

Fig. 10. Screen display in wireless sensor mode

At the same time when the measurement data is sent to the Server-Node, the chart and gauge display on the monitoring system dashboard will be displayed in real time, as shown in the figure 12.

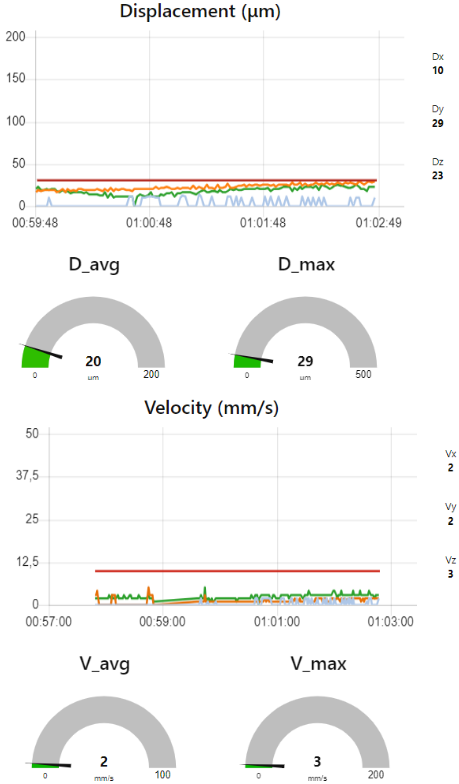

Fig. 11. Vibration Chart and Gauge

4. Alarm based Abnormal Vibration Experiments

Vibration sensor testing also carried out on abnormal induction motor conditions. Simulation of disturbances in the electric motor is provided by loosening the bolts on the frame foundation to trigger high vibrations in the induction motor.

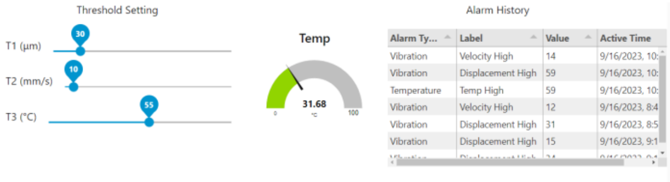

Fig. 12. Threshold and Alarm Setting

Figure 13 shows that the abnormal condition detection test to trigger a value above the specified threshold succeeded in producing an alarm which is shown in the alarm history table. The threshold values for the three parameters can also be set according to requirements or specifications for the maximum vibration values permitted based on the ISO 10816-1 vibration severity chart. As a reference for the maximum permitted vibration values, it can be seen in table 2.

Table 2. Vibration Severity Chart (ISO 10816-1)

<table>
<tr><th colspan="2">Range of Vibration Severity</th><th colspan="2">Maximum Values</th><th colspan="4" rowspan="1">Class of Vibration of Machine</th></tr>
<tr><th>Range Classification</th><th>Effective Velocity: RMS (mm/s)</th><th>Vibration Velocity (mm/s)</th><th>Vibration Displacement (µm)</th><th>Class I</th><th>Class II</th><th>Class III</th><th>Class IV</th></tr>
<tr><td>0.28</td><td>0.28</td><td>0.4</td><td>1.25</td><td rowspan="3">Good</td><td rowspan="4">Good</td><td rowspan="5">Good</td><td rowspan="6">Good</td></tr>
<tr><td>0.45</td><td>0.45</td><td>0.63</td><td>2</td></tr>
<tr><td>0.71</td><td>0.71</td><td>1.0</td><td>3.15</td></tr>
<tr><td>1.12</td><td>1.12</td><td>1.6</td><td>5</td><td rowspan="2">Acceptable / Allowable</td></tr>
<tr><td>1.8</td><td>1.8</td><td>2.5</td><td>8</td><td rowspan="2">Acceptable / Allowable</td></tr>
<tr><td>2.8</td><td>2.8</td><td>4.0</td><td>12.5</td><td rowspan="2">Improvement Required</td><td rowspan="2">Acceptable / Allowable</td></tr>
<tr><td>4.5</td><td>4.5</td><td>6.3</td><td>20</td><td rowspan="2">Improvement Required</td><td rowspan="2">Acceptable / Allowable</td></tr>
<tr><td>7.1</td><td>7.1</td><td>10</td><td>31.5</td><td rowspan="6">Not Acceptable</td><td rowspan="2">Improvement Required</td></tr>
<tr><td>11.2</td><td>11.2</td><td>16</td><td>50</td><td rowspan="5">Not Acceptable</td><td rowspan="2">Improvement Required</td></tr>
<tr><td>18.0</td><td>18</td><td>25</td><td>80</td><td rowspan="4">Not Acceptable</td></tr>
<tr><td>28.0</td><td>28</td><td>40</td><td>125</td><td rowspan="3">Not Acceptable</td></tr>
<tr><td>45.0</td><td>45</td><td>63</td><td>200</td></tr>
<tr><td>71.0</td><td></td><td></td><td></td></tr>
</table>

Legend:
Class I: Small machines; electric motors up to 15kW power.
Class II: Medium-size machines; electric motors of 15 to 300kW power.
Class III: Large prime-movers or machines on rigid foundations; electric motors of above 300kW power.
Class IV: Large prime-movers and other machines, Turbo Machines.
Good: Colour coded green.
Acceptable/Allowable: Colour coded blue.
Improvement Required: Colour coded yellow.
Not Acceptable: Colour coded red.

5. Conclusion

This paper shows that a wireless vibration monitoring system has been successfully built using a multi-axis vibration and temperature sensor based on Modbus RTU. The system consists of two key components, including Sensor-Node and Server-Node, but this Sensor-Node can also be used in IoT applications or other servers that use the MQTT protocol. The sensor node was successfully tested in two working modes: the vibration meter mode, which can be used like a handheld device to take direct measurements, and the Wireless Sensor-Node mode, used for remote real-time monitoring via a web-based monitoring system. The real-time monitoring system can also record abnormal events on electric motors according to threshold values that can be adjusted to trigger alarms.

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