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The Design and Development of an Internet of Things-Based Condition Monitoring System for Industrial Rotating Machines †

Alagumariappan Paramasivam [1,*], Jaya Prakash Abimanyu [1], Pavan Sai Kiran Reddy Pittu [1], Sankaran Vijayalakshmi [2] and Mohana Krishnan Kaushal Mayur [1]

1 Department of Biomedical Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai 600062, India; vtu12390@veltech.edu.in (J.P.A.); vtu18106@veltech.edu.in (P.S.K.R.P.); vtu12076@veltech.edu.in (M.K.K.M.)
2 Department of Electronics and Communication Engineering, Vel Tech Rangarajan Dr. Sagunthala R&D Institute of Science and Technology, Chennai 600062, India; drvijayalakshmis@veltech.edu.in
* Correspondence: draparamasivam@veltech.edu.in or parama.ice@gmail.com; Tel.: +91-984-378-0801
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Abstract: In general, the industries utilize more rotating machines and the efficient functioning of these machines is vital for the smooth operation of industrial processes. Further, the detection and identification of motor issues in a timely manner is crucial to prevent unexpected downtime and expensive repairs. In this work, a novel approach is proposed to monitor and assess the condition of motors in real-time by analyzing the environmental parameters using sensors which are capable of measuring temperature and humidity, to gather data about the operating environment of motors in industrial settings. Also, by continuously monitoring these environmental factors, deviations from optimal conditions can be detected, allowing for proactive maintenance actions to be taken. The proposed system consists of a network of temperature and humidity sensors strategically placed in proximity to the motors being monitored. Further, these sensors collect temperature and humidity data at regular intervals and transmit them to an Internet of Things (IoT) cloud platform. Finally, the data are analyzed using a fuzzy logic decision-making algorithm and are compared against predefined threshold values to determine if the motor is operating within acceptable conditions. This work appears to be of high industry relevance since automated notifications or alerts are to be sent to maintenance personnel when abnormal conditions are detected.

Keywords: fuzzy logic control; internet of things (IoT); motor condition assessment; proactive maintenance; real-time monitoring

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1. Introduction

In this modern era, industries are mainly concerned with the quality and quantity of production over a period of time. The deployment of motors to complete operational requirements is a practice that has been embraced by all sectors [1]. Induction motors are the most common among AC motors used in industries nowadays. The motors are subjected to several electrical and mechanical stresses during prolonged operation. An initial fault results in motor disfunction, which leads to downtime and loss and if it is not diagnosed it will lead to decreased safety, dependability, and motor overheating problems [2,3]. The main problems in the induction motors are single phase failures and overheating. So, the insulation fails and produces high heat for the motor windings to handle. In overheating, the supply mechanism drawing more current than necessary leads to the motor overheating. At the time of overloading, the motor draws an excessive amount of current from the power source, which increases the heat [4]. To avoid such failures, a method of condition-based monitoring techniques for the prediction and prevention of motors bearing health conditions on a timely basis is used. A fair number of those industries have progressed towards the decreasing activity of human reliability and proceeded further over the area of automation; this in turn has led to a new domain called the fourth industrial revolution, or industry 4.0. The mentioned industry 4.0 depends highly on Wireless Sensor Networks (WSNs) and the Internet of Things (IoT). IoT devices work by contributing to the main application of processing acquired data from WSN devices and transmitting them to various remote locations [5].

The Industrial Internet of Things (IIoT) is relatively a new approach for existing and fairly new industries; it is opening horizons to a wide range of opportunities in aiding industries to operate more effectively and ensure safety while fairly increasing the efficiency percentage and cutting an ample amount of cost. Businesses are expected to pay out around 80 percent of their initial investment in technology and it is predicted that this would grow to a value close to USD 4 trillion in the specific market of technology by the year 2025 (Nasscom, 2018). Thus, the help of the connectivity of all devices into one network gives the ability for a human being to access technology in a very effective and efficient way; hence, the IIoT will revolutionize the ways of production and distribution in industries in a very productive way, while offering safety at the same time [6,7].

The IIoT is one of the most dependable ways of connecting sensors and industrial machinery with one another, providing the user with the ability and accessibility to connect these devices and process the acquired data in a very efficient manner. IoT technology architectures include the technology of cloud computing. Before the IoT, Bluetooth and Radio Frequency (RF) methods were employed in industrial applications, which enabled the user to control the device remotely but was limited only to a short distance. The operator or the user had to be in the range of the Bluetooth or RF in order to operate; with the help of the IIoT, this tedious process is replaced, as they can be connected via the internet and the range can extend as much as the user requires [8].

Humidity and temperature are condemning ecological factors that can remarkably affect the performance and life span of industrial motors. Fairly high humid levels can lead to the reduction of resistance of insulation in the motor windings. This could gradually lead to electrical leakage and failures. Also, temperature changes can lead to condensation inside the motor; this could result in electrical shorts [9]. The overall efficiency of industrial motors can be lowered by both high temperatures and humidity. This might result in drastic changes such as a greater loss in energy efficiency and an increase in running expenses [10]. Sudden temperature changes might result in the failure of cooling systems, which may lead to the overheating and gradual failure of the motor. Cooling systems such as fans and heat exchangers work less comparatively to normal temperatures. Temperature fluctuations can result in thermal expansion; that is, the motor components may become contracted and they may lead to excessive stress and misalignment [11].

The objective of this work is to propose a novel approach to monitor and assess the condition of motors in real-time by analyzing the environmental parameters using sensors which are capable of measuring temperature and humidity.

2. Literature Survey

Recently, several researchers have proposed the IoT-based condition monitoring of induction machines [12–20]. Jeyalakshmi et al. [13] (2020) have developed a smart motor condition monitoring system to monitor the vibration and temperature of the motor using MyRio software platform. Agyare et al. [14] (2019) have developed a three-phase induction motor model in MATLAB/Simulink software with a FL controller. Furthermore, the authors have showed the results by monitoring the health condition of motors using a fuzzy logic controller.

Lilo et al. [15] (2020) have proposed a wireless system for detecting and monitoring the faults of induction motors. Further, the authors have used a FL controller and showed the results that the proposed system detects at a faster rate and reduced the maintenance costs. Purwanto et al. [16] (2018) have proposed a fuzzy logic-based microcontroller to monitor the temperature and humidity controller of the server room. Further, the authors have stored and monitored the data in an IoT-based system, also accessed using remote control. Caicedo [17] (2020) has devolved a monitoring system to detect and collect the thermal and magnetic parameters of coil winding during short circuits. Further, the author has proposed a cloud-based storage system to store the monitored data.

Kang et al. [18] (2020) have proposed the detection method of high voltage motors during end-to-end winding faults. Further, the authors have proposed an online monitoring partial discharge identification method to detect and identify the pattern of faults under different temperature conditions. Li et al. [20] (2020) have proposed a machine-learning-based IoT technique to collect data during the condition monitoring of machineries. Mykoniatis [21] (2020) has developed an IoT-based real-time condition monitoring system which detects and monitors the temperature and vibration data of industrial motors.

3. Materials and Methods

In general, rotating machines are the most commonly used device in industries such as manufacturing, power systems, textiles, etc. To overcome the heating issues of the rotating machines due to its continuous operation, cooling systems are provided. Further, the cooling shall be given through natural and artificial methods. The natural cooling occurs due to the presence of air around the environment. This air is otherwise known as coolant air, which sucks in the heat produced the rotating machines and is delivered to the outside environment. Also, the coolant air can be purposely provided to any rotating machine to remove heat by artificial methods. However, the coolant air with high humidity degrades the insulation quality of windings and in turn reduces the life of the machine.

Figure 1 shows the overall block diagram for the proposed work. Further, the temperature and humidity of the coolant air for the rotating machine is monitored and stored. Also, the temperature of the rotating machine is monitored and stored. The proposed system consists of device components such as sensors, a microcontroller unit and an IoT cloud platform with Graphical User Interface.

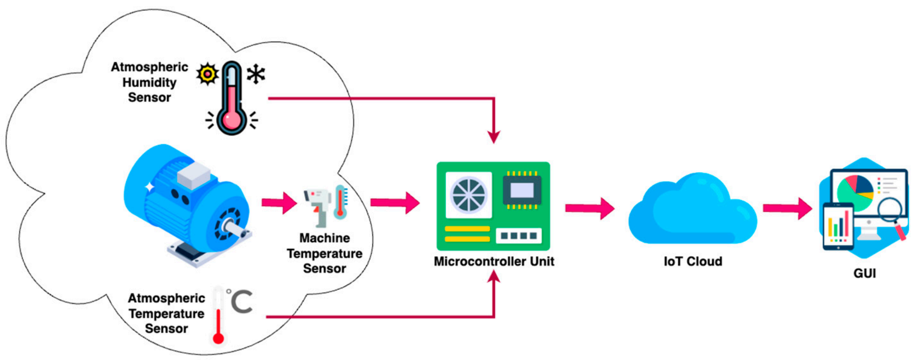


Figure 1. Overall block diagram for the proposed work.

3.1. Sensors

In this work, three different sensors such as ambient temperature sensors, humidity sensors (DHT11) and machine temperature sensors (MLX90614) are explored. The DHT11 measures both temperature and humidity, which are easy to interface with a microcontroller unit. Furthermore, the DHT11 measures temperature ranges from 0 to 50 degrees Celsius and measures humidity ranges from 20 to 90% (relative humidity). Also, the MLX90614 is a non-contact temperature sensor module which can be used to measure object temperature ranges from −70 to 380 degree Celsius. The output of the non-contact-type machine temperature sensor module is transferred to the microcontroller unit through inter-integrated circuit (I2C) protocol.

3.2. The Microcontroller Unit

An ESP8266 microcontroller unit is utilized in this work to read the temperature and humidity from the appropriate sensors. Further, the ESP8266 or Node MCU has an in-built Wi-Fi module, which helps to feed sensor data to IoT cloud platform. Also, the DHT11-based temperature and humidity sensor module is connected to the analog pin of ESP8266. The MLX90614-based object temperature measurement sensor is connected to the serial clock (SCL) and serial data (SDA) pins of the node MCU controller. The sensor values such as machine temperature, ambient temperature and ambient humidity are measured and the data is fed to the microcontroller unit.

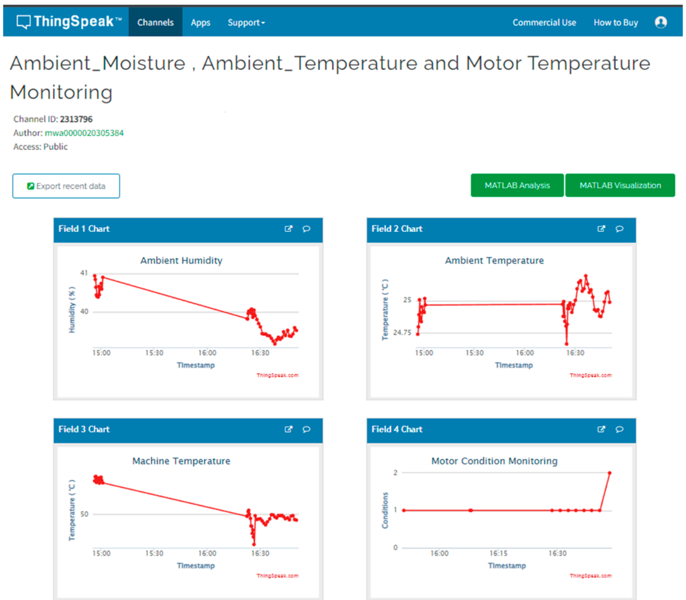
3.3. IoT Cloud Platform

The sensor data are stored to the user account of the ThingSpeak platform, and these data are accessed by MATLAB R2023a software. For every user account, the unique read and write Application Programming Interface (API) key is created. Further, any data sent to the user's account is be stored or accessed with the help of read and write API key, respectively. Fuzzy logic control algorithm is coded In the MATLAB software and the sensor data stored in the ThingSpeak are accessed by the MATLAB software using write API key. Fuzzy Logic Controller (FLC) is most popular nowadays in automatic process control and it has four main steps, namely, fuzzification, fuzzy inference, fuzzy rule base and de-fuzzification [22]. Further, FLC uses a fuzzifier for the fuzzification process and the most commonly used type of fuzzifier is the Mamdani fuzzifier. In this work, the same Mamdani fuzzifier is utilized as a fuzzifier. The input values given to fuzzifier are machine temperature, ambient temperature and ambient humidity, which derives the condition of the machine. The error (E) and the change in error (ΔE) from the fuzzifier is provided as an input to the fuzzy inference system. Also, the fuzzy inference is performed by a decision-making algorithm named fuzzy rule base. Finally, the output of the fuzzy inference system is provided to de-fuzzifier and these outputs are the conditions of the machine.

4. Results and Discussion

Figure 2a shows the ThingSpeak IoT cloud platform, which was used to log three different sensor values. Further, it is observed that there are three different field charts which were used to store and monitor three different sensor values. Also, the pseudo-code for the proposed work is shown in Figure 2b. At first, the three different sensors' data were logged in the ThingSpeak IoT cloud platform. In the user account of the ThingSpeak IoT platform, the four different field charts were created to log three different sensors' data, namely ambient temperature, ambient humidity and machine temperature, and to log the decision output of the FLC algorithm. All these sensors' data and fuzzy outputs were logged with respect to time and date, which helps the user to have a clear picture about whether the machine is operating at acceptable conditions. Once the sensor data was logged, these data were utilized by the FLC algorithm, which was coded using MATLAB software with the help of the read API key. The output of the FLC algorithm were the conditions of the motor, which were further stored in the Field 4 chart.

The log of the ambient/atmospheric temperature acquired by the DHT11-based temperature is shown in Figure 2a. It is clearly seen that the values of ambient humidity are logged at the Field 1 chart. Also, it is shown that the values of ambient temperature are logged at Field 2 chart. Figure 2a shows the log for the machine temperature acquired using the MLX90614-based temperature sensor. Further, the decision output of the FLC was logged relating to environmental conditions, which is shown in the Field 4 chart. Also, from the figures, it is seen that the increase in ambient temperature increases the temperature of the rotating machine during its continuous operation. In the Field 4 chart, the y-axis of the graph shows the acceptable conditions for the operations of rotating machines. Further, the 0, 1 and 2 scale are worse, poor and good or acceptable conditions, respectively. According to the three different inputs, namely ambient temperature, ambient humidity and machine temperature, the FLC generates the decision of whether the machine is operating within acceptable conditions. Also, if the machine is operated at the permissible conditions, this increases its lifetime.



(**a**)

Step 1 (Initialize):
Initialize the sensors, ThingSpeak API, fuzzy logic controller in MATLAB.

Step 2 (Loop):
Continuously monitor sensor values such as ambient temperature, ambient moisture and machine temperature.

Step 3 (Uploading sensor data to IoT cloud platform):
Send sensor data to ThingSpeak using API and log sensor data to a appropriate channels namely Channel-Field1 = ambient temperature, ChannelField2 = ambient moisture and ChannelField3 = machine temperature

Step 4 (Analyses using FLC):
Run Fuzzy Logic Control algorithm in MATLAB to analyse the sensor data.

Step 5 (Update motor condition):
Update the motor condition variable with the value obtained from the fuzzy logic controller.

Step 6 (Perform motor control actions):
Depending on the motor condition (i.e.) If the motor condition is worse (0), alert the supervisor.

Step 7 (Repeat the monitoring process):
Go back to Step 2 and continue monitoring the sensor values and update the motor condition based on the fuzzy logic system.

Step 8 (End):
Terminate the system when necessary.

(**b**)

Figure 2. (**a**) ThingSpeak IoT cloud Platform. (**b**) Pseudo-code for the proposed work.

5. Conclusions

The main aim of this work is to continuously monitor the air coolant's moisture and temperature provided to the rotatory machine. Due to the increased moisture and temperature content, the degradation of the winding insulation is caused. And this, in turn, reduces the lifetime of the machine when it is operated for a prolonged period of time. Furthermore, an internet of things (IoT)-based condition monitoring technique is utilized to monitor the moisture and temperature of the air coolant continuously. Also, this is performed by placing sensors near to the winding insulation surface. These sensors are connected to the controllers, which receive sensor parameters as input data. A Fuzzy Logic Control algorithm (FLC) is used to alert the user if a high moisture content of the air is sensed. So, the FL-based controller continuously monitors and allows the user to control ambient temperature. The advantage of using IoT-based condition monitoring is that the measured parametric data can be stored in cloud storage and it can be monitored or accessed from any remote place, as it is a web- or Internet-based application. Also, the instant alerts can be received regarding the health condition, which improvises the lifetime of rotating machines.

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