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

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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 is 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 transmits it to an Internet of Things (IoT) Cloud platform. Finally, the data is analyzed using a fuzzy logic decision making algorithm and 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 shall 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 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. The initial fault results in motor disfunction, which leads to downtime and loss if it is not diagnosed it will lead to decreased safety, dependability, and motor overheating problem [2,3]. Main problems in the induction motors are single phase failure 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 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, condition-based monitoring technique prediction and prevention of motor bearing health condition on a timely basis method is used. A fair number of those industries have forwarded 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 the Wireless Sensor Networks (WSN) and Internet of Things (IoT). IoT devices work on contributing to the main application of processing the acquired data from WSN devices and transmitting them to various remote locations [5].

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 costs. Businesses are expected to pay out around 80 percent of their initial investment on technology and it is predicted that it would grow to a close of $4 trillion in the specific market of technology by the year 2025 (Nasscom, 2018). Thus, with the help of 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 IIoT will revolutionize the way production and distribution in industries in a very productive way while offering safety at the same time [6,7].

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 includes technology of cloud computing. Before IoT Bluetooth and Radio Frequency (RF) methods were employed in the 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 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 greater loss of energy efficiency and increase in running expenses [10]. Sudden temperature changes might result in failure of cooling systems which may lead to 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 get 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 is capable of measuring temperature and humidity.

2. Literature Survey

Recently, several researchers have proposed IoT based condition monitoring of induction machines [12–20]. Jeyalakshmi et al. [13] (2020) have developed a smart motor condition monitoring system to monitor 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 FL controller. Furthermore, the authors have showed the results by monitoring the health condition of motor using fuzzy logic controller.

Lilo et al. [15] (2020) have proposed the wireless system for detecting and monitoring the faults of induction motor. Further, the authors have used FL controller and showed the results that the proposed system detects the faults at the 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 monitoring system to detect and collect the thermal and magnetic parameter of coil winding during short circuit. 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 online monitoring partial discharge identification method to detect and identify the pattern of faults under different temperature conditions. Li et al. [19] (2020) have proposed a machine learning based IoT technique to collect data during the condition monitoring of machineries. Mykoniatis [20] (2020) has developed a 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, the rotating machines are most commonly used device in the industries such as manufacturing, power system industries, textiles industries etc. To overcome the heating issues of the rotating machines due to its continuous operation, cooling system is provided. Further, the cooling shall be given through natural and artificial method. The natural cooling occurs due to the presence of air around environment. This air is otherwise known as coolant air which sucks 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 method. However, the coolant air with high humidity degrades the insulation quality of windings 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 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, microcontroller unit, IoT cloud platform with Graphical User Interface.

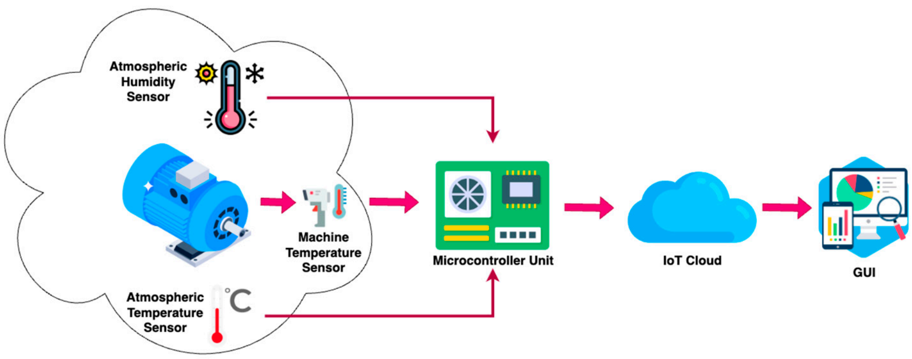


Figure 1. Overall block diagram for proposed work.

3.1. Sensors

In this work, three different sensors such as ambient temperature sensor & Humidity sensor (DHT11), and machine temperature sensor (MLX90614). The DHT11 measures both temperature and humidity which is easy to interface with microcontroller unit. Furthermore, the DHT11 measures temperature ranges from 0 to 50 degree 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. Microcontroller Unit

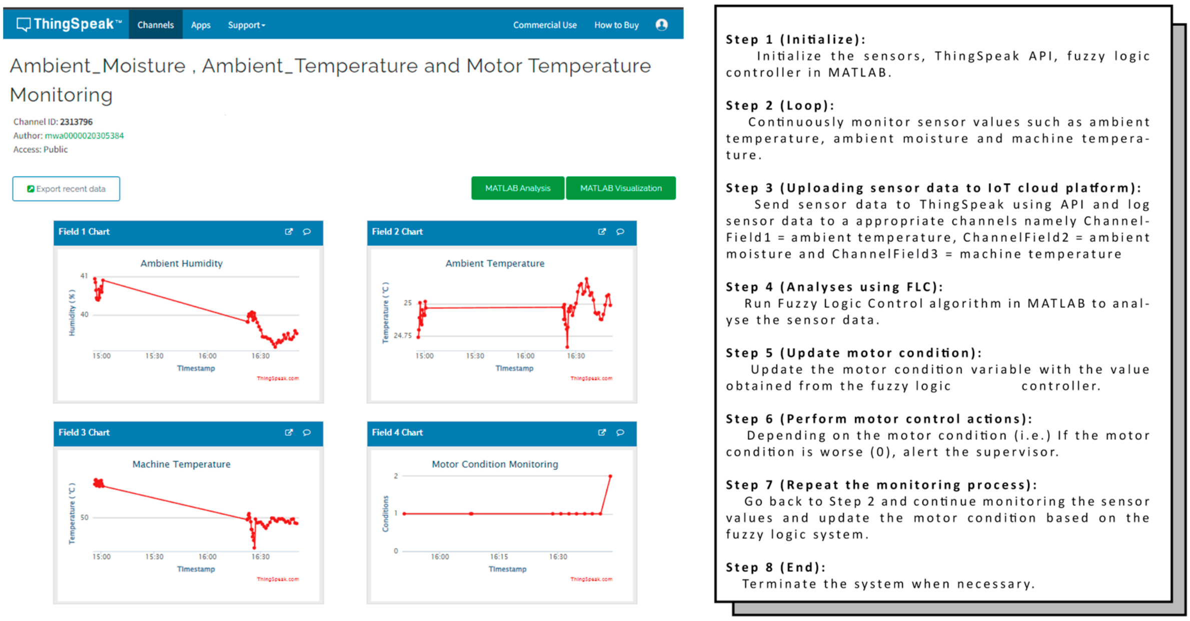
An ESP8266 microcontroller unit is utilized in this work, to read the temperature and humidity from the appropriate sensors. Further, the ESP8266 or Node MCU has inbuilt WiFi module which helps to feed sensor data to IoT cloud platform. Also, the DHT11 based temperature and humidity sensor module is 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 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 software. For every user account, the unique read and write Application Programming Interface (API) key will be created. Further, any data to the user account shall 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 Defuzzification [21]. Further, FLC uses fuzzifier for the fuzzification process and the most commonly used type of fuzzifier is 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 fuzzifier is provided as an input to the fuzzy inference system. Also, the fuzzy inference is performed by decision making algorithm named as fuzzy rule base. Finally, the output of the fuzzy inference system is provided to de-fuzzifier and these outputs are the condition of the machine.

4. Results and Discussion

Figure 3a 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 was used to store and monitor three different sensor values. Also, the pseudo-code for the proposed work is shown in the Figure 3b. At first, the three different sensor data were logged in ThingSpeak IoT cloud platform. In the user account of ThingSpeak IoT platform, the four different field charts were created to log three different sensor data namely ambient temperature, ambient humidity and machine temperature and to log the decision output of the FLC algorithm. All these sensor data and fuzzy output 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 read API key. The output of the FLC algorithm is the conditions of the motor which was further stored in the field 4 chart.



(**a**) (**b**)

Figure 3. (**a**) ThingSpeak IoT cloud Platform (**b**) Pseudo-Code for the proposed work.

The log of the ambient/atmospheric temperature acquired by DHT11 based temperature is shown in the Figure 3a. 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 3a shows the log for machine temperature acquired using MLX90614 based temperature sensor. Further, the decision output of the FLC is logged about environmental conditions which is shown in the field 4 chart. Also, from figures, it is seen that the increase in ambient temperature increases the temperature of the rotating machine at continuous operation. In the field 4 chart, the y-axis of the graphs shows the acceptable conditions for the operations of rotating machines. Further, the scale 0, 1 and 2 are worse, poor and good acceptable conditions respectively. According to the three different inputs namely ambient temperature, ambient humidity and machine temperature, the FLC generates the decision whether the machine is operating within acceptable conditions. Also, if the machine is operated at the permissible conditions increase its life time.

5. Conclusions

The main aim of this work is to to continuously monitor the air coolant's moisture and temperature provided to the rotatory Machine. Due to the increased moisture and temperature content causes the winding insulation degradation. And this in-turn reduces the life time of 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 air coolant continuously. Also, this is done by placing sensors nearby to the winding insulation surface. These sensors are connected to the controllers which receives sensor parameters as input data. Fuzzy Logic Control algorithm (FLC) is used to alert the user if the high moisture content of air is sensed. So, the FL based controller continuously monitors and make the user to control ambient temperature. The advantage of using IoT based condition monitoring is the measured parametric data can be stored in the 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 improvises the life of rotating machines.

Author Contributions: K.M.M., A.J. and P.A. conceptualized the idea for this work. V.S. provided the required resources. P.S.K.R.P. designed and developed the hardware. P.S.K.R.P. and A.J. carried out investigation a data curation. V.S. designed the visualization. P.A. validated the acquired results and prepared the original draft. K.M.M. and A.J. reviewed and edited the original draft. V.S. supervised, and P.A. administered the work. All authors have read and agreed to the published version of the manuscript.

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