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Development of an IoT Platform for Condition Monitoring of Industrial Motors

A PROJECT REPORT

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ABSTRACT

The project's goal is to deploy and utilize IoT technologies to monitor and troubleshoot induction motors. To ascertain what precisely is prompting the induction motor to fail, the various parameters of the induction motor are investigated. Furthermore, several studies have discovered the relationship between vibration, temperature, current, voltage, and bearing failures. Several approaches involve IoT-based instrumentation for collecting and processing the induction motor characteristics. IoT is a cloud platform, available on the web, that contains the data that has been gathered. A timely alert notification is sent if any dysfunction is found in the parameters, which saves time and money by eliminating unnecessary downtime. This project examines the advantages of this approach also. Findings show how efforts were rooted and continuously monitored equipment was developed that has access to relevant data for predictive maintenance also.

Data from industrial motors will be collected and stored in the cloud, where it will be accessible from several places through a web application, with the help of different sensors. The health of the motor may be assessed by examining the numerous researchers' collected data on various parameters in real-time. Continuous condition monitoring, prompt alerts, data storage for future use, and data monitoring from any location are all advantages of these systems. The motor's real-time condition monitoring system is always being improved. Because of the Internet of Things, data storage, retrieval, and access have all been made more user-friendly. If a motor fails due to vibration, the IoT will notify the end-user.

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Chapter 1 - INTRODUCTION

1.1. Background

In the age of Industry 4.0, predictive maintenance has elevated the importance of industrial machinery maintenance. Traditional reactive maintenance can only be performed after a problem has been identified. Considering previous failures, "large-scale preventive maintenance" refers to procedures that are performed on a regular basis. Industry 4.0 predicts equipment failures using real-time data from sensors embedded in industrial equipment. Ideal for small to medium-sized businesses, predictive maintenance of induction motors reduces downtime while increasing efficiency and reliability. Analyzing a slew of data from a wide range of features of the machine may help forecast its performance. An in-depth examination of the vibration signals might show whether or not a motor is working correctly. Creep delay problems might be reduced with the development and use of Internet of Things (IoT) technology that monitors and analyzes induction motor performance and records important operational parameters. In this research, induction motor characteristics are routinely collected and processed using an IoT-based platform.

1.2. Aims and Objectives

- Propose a low-cost condition-based maintenance device for industrial motors
- To keep an eye out for impending equipment failure and arrange preventative maintenance before it happens.
- Perform real-time monitoring which will give maintenance teams enough lead time
- Predict a failure before performance drops below an optimal level.
- The idea behind a less-costly device is to incubate this practice in small-scale local industries hence boosting their productivity.

1.3. Deliverables

- Perform the whole diagnosis and monitor the process on a single Induction Motor (IM).
- Comparing the health monitoring of faulty machinery with a healthy one and analyzing the results.
- Development of an IoT platform to store the data acquired from sensors and display it using a Cloud Platform.
- Introducing multiple Actuating systems (motor/generators) and monitoring their behavior of them.
- Concluding it by demonstrating the real-time working of the project.

1.4. Research and Layout

Complete research is divided into several chapters that can be reviewed through the table of contents. A summary of chapters is provided here.

The Literature review is discussed in *Chapter 2*, which contains the relevant works in our area of research. In this chapter, a discussion is made about different faults and their detection, different types of diagnostics using sensors, and alert system using the IoT platform.

Chapter 3 is about the hardware involved in the project. It starts by discussing all of the hardware pertaining to the electronics side which includes the different sensors that were tested and were used. It also contains Arduino, Temperature Sensor, Vibration Sensor, Current Sensor, WIFI Module, and most importantly three-phase induction motors.

Chapter 4 is about the software portion of the project. It details information about the Arduino used. It explains how data from sensors is being processed by the microcontroller and then the WIFI module serves as a gateway between the microcontroller and cloud platform where data is stored, which in return relates to an app. Also, the acquired signals from the vibration sensor are further analyzed using Short-Time Fast Fourier analysis (STFF) and then sent to the cloud platform.

In *Chapter 5*, we discuss the implementation of different software used and how they are connected. A discussion about Arduino IDE, MATLAB, and Firebase which is a cloud storage platform.

In *Chapter 6*, we conclude our thesis and point toward our future goals regarding this project.

Chapter 2 - LITERATURE REVIEW

The project's goal is to deploy and utilize IoT technologies to monitor and troubleshoot induction motors. To ascertain what precisely is prompting the induction motor to fail, the various parameters of the induction motor are investigated. Furthermore, several studies have discovered the relationship between vibration, temperature, current, voltage, and bearing failures. Several approaches involve IoT-based instrumentation for collecting and processing the induction motor characteristics. IoT is a cloud platform, available on the web, that contains the data that has been gathered. A timely alert notification is sent if any disfunction is found in the parameters, which saves time and money by eliminating unnecessary downtime. This review examines the advantages of this approach also. Findings show how efforts were rooted and continuously monitored equipment was developed that has access to relevant data for predictive maintenance also.

In the age of Industry 4.0, predictive maintenance of industrial equipment has become crucial. Maintenance actions are only carried out in traditional reactive maintenance when a failure has been detected. Preventive maintenance on a large scale refers to operations that are performed regularly based on previous failure patterns. In Industry 4.0, sensors in industrial equipment collect real-time data to forecast failures. Predictive maintenance of induction motors is ideal for small to medium-sized businesses, reducing downtime, increasing efficiency, and increasing reliability. It is necessary to study several aspects of the induction motor to get information that may be utilized to predict performance. It is possible to tell the difference between a working motor and a malfunctioning one by analyzing its vibration signal. Creep delay problems may be alleviated with the development and application of Internet of Things (IoT) technology that records important operational indicators and monitors and diagnoses induction motor status. An IoT-based platform is typically used to collect and process induction motor parameters in this literature review, which compares the methods that have been used to date.

2.1. Development Environment and Gateway

2.1.1. Boards

Different boards can be used for signal processing and to implement the processing language. Most used are Arduino Uno because of easy to use, cheap, and compatible with almost all types of hardware components. In the research, the authors have used Arduino Uno as a microcontroller board [12]. It is an open-source microcontroller board based on the Atmega328P microcontroller and is developed by Arduino. cc. Equipped with a set of digital and analog I/O pins which are easy to be interfaced with the sensors being used. Having 32KB of flash memory and 2KB of SRAM, have an operating voltage of 5V.

2.1.2. Integrated Development Environment (IDE)

IDE is a program running on your PC which will make you capable to write a code/sketch for the Arduino board in a very simple language understandable by the microcontroller used after the processing language. After that, the code is uploaded to the board using the upload button on IDE. The Arduino board is used so Arduino IDE will be used. In our findings, a substitute for Arduino can be used which is Eclipse [13].

2.1.3. Sensors

Different parameters can be monitored for the health of Industrial motors like bearing and winding temperatures, current, voltage, and the number of starts and stops. Different sensors are used depending upon what are the requirements of the project and to what extent, the researcher has gone. Symposium used just the temperature and vibration sensors [14]. But in other papers, the sensor count has been increased by the addition of voltage sensors and current sensors along with the accelerometer. By my observation, the whole sensors depend upon the project requirement and can vary from project to project.

2.1.4. Wi-Fi Module

Researchers have employed ESP 8266, a low-power IoT chip developed for mobile and wearable electronics and other IoT applications, to communicate effectively across devices [15]. Wi-Fi modules may be used to add IoT capability to microcontroller applications through a UART serial connection. Espressif Systems' Wi-Fi SoC powers the ESP8266-firmware. 01's With 3.3 volts of power and 2 digital I/O pins and flash memory of 4 megabytes, it is ready to go.

Another source has used different protocols for Wi-Fi functionality [16]. The simple link Wi-Fi CC 3100 Booster pack adds Wi-Fi capabilities. It is the industry's first Wi-Fi chip used in the wireless networking solution. It takes care of all the internet protocols taking place in the process.

2.2. Diagnostics and Fault Detection of IM Rotors

2.2.1. Voltage Detection

In the papers we studied, a voltage sensing circuit is used that measures the voltage and creates an output voltage that meets the microcontroller's requirements. A 230v/9v potential transformer is employed, and the output is converted to DC using a rectifier as needed. The rectifier output is rippled out using a capacitor. The output remains high enough to be transmitted to the microcontroller. As a result, a potential divider circuit is utilized to provide the needed 5V voltage, which is then fed into the microcontroller's input.

2.2.2. Current Detection

The most common method in every source we analyzed, the current detected by the ACS712 is a Hall Effect current sensor that measures current. It is not only cost-effective, but it also offers a precise solution for AC and DC sensing in a variety of applications, including industrial ones.

It operates based on the Hall Effect. Its output sensitivity ranges from 66 to 185 mV/A.

2.2.3. Temperature Diagnostics

The LM 135 is a very accurate and simple-to-calibrate temperature sensor. Straight lines may be drawn from this situation. It can withstand temperatures as low as -55°C and as high as 150°C without deteriorating in quality. This board has all of the necessary connections for a computer. In most circumstances, there are four levels of insulation. Insulation must be able to withstand the maximum temperature, as well as any extra temperatures that may arise from normal operating circumstances at full load, in each of the four classes [17]. A motor's insulation class has a bearing on what kind of operation it is suited for.

2.2.4. Vibration Diagnostics

Various analysis techniques were applied in different modes by many engineers according to the problem faced. One major technique was vibration diagnostics. Motor vibration is caused by a variety of factors, including loose components, motor imbalance, resonance, and bearing failure. The most common method for taking fundamental vibration measurements is to use a piezoelectric accelerator [18]. Quefrency analysis, Short-Time Fast Fourier analysis (STFF), and Power Density Spectrum analysis can be used to further evaluate the signals obtained (PDS).

In another study, the vibration sensor utilized is the ADXL 335, a tiny, thin, low-power, and three-axis accelerometer with signal-conditioned voltage outputs. It has a range of 3g and measures full-scale acceleration. Both static and dynamic accelerations are measured. This is where the dynamic acceleration caused by motion, shock, or vibrations is monitored. Different bandwidths for three axes can be chosen depending on the application. The X and Y axes have bandwidths ranging from 0.5Hz to

1600Hz, while the Z-axis has bandwidths ranging from 0.5Hz to 550Hz. It displays three values for each of the three axes that represent motor vibrations. Vibrations are measured based on the values acquired in three axes.

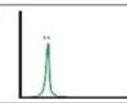
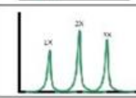
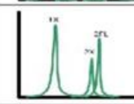
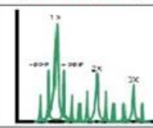
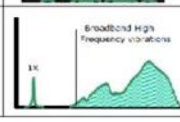
Mechanical faults	Typical vibration pattern	Typical Spectrum
Mass unbalance	1X	
Misalignment	2X, 3X	
Stator eccentricity	2XFL* *FL = Freq. line, e.g. 50/60 Hz	
Rotor eccentricity	PPF** sidebands around 1X, 2X, .. **PPF = Pole Pass Frequency	
Bearings wear	High freq. broadband vibrations	

Table 1. Vibration diagnostic table for Induction Motor faults [6]

2.2.5. Rotors Fault

Broken rotor bars are a typical rotor problem that causes IM rotor asymmetry. Overheating owing to frequent starts under load, imbalanced thermal load due to air gap eccentricity, manufacturing faults, and rotor material corrosion caused by chemicals or moisture are all possible causes of rotor bar failures [19]. The rotor bar(s) may be wholly or partially destroyed because of the aforementioned factors, causing rotor cage asymmetry and asymmetrical rotor current distribution. When a rotor bar cracks, the fractured bar will overheat and eventually break. As a result, the adjacent bars must carry greater currents and, as a result, they are more vulnerable to damage, resulting in multiple bar fractures. Furthermore, broken parts from damaged bars may strike the motor's end winding, causing substantial mechanical damage to the Induction Motor [20].

To identify rotor bar fracture, the research [21] used the technique of Fast

Fourier Transform (FFT) for spectral analysis of IM current measurements. When rotor bars are destroyed, the IM current signal becomes non-stationary, according to reports. However, FFT is only effective for stationary signal analysis, as it is incapable of capturing transitory properties such as drifts, abrupt shifts, and frequency trends. To counter this, in another research, the Short-Time Fourier Transform (STFT) was used to detect IM rotor bar defects. Due to its fixed-length windowing features, the STFT cannot offer information corresponding to multiple time and frequency resolutions [22].

The wavelet transform (WT) can be used to investigate the information associated with different frequency resolutions. Antonino-Daviu tackled this challenge by employing discrete WT to identify IM broken rotor bars defect. The complete frequency band was explored with great resolution using wavelet packet decomposition (WPD) [23].

2.2.6. Bearing Fault

A broad range of rotating equipment, including electric motors, may benefit from the use of rolling element bearings. Bearing components are exposed to dynamic stress, which causes fatigue pitting to be the most prevalent problem. Bearing difficulties may affect the outer race, the inner race, and the rolling sections. Frequency domain indicators from typical stator current frequencies may help identify bearing faults in spectrum analysis. Stator current signals have been used in the literature to identify IM-bearing defects.

The authors [24], used IM stator current spectrum analysis to diagnose bearing defects. Under deterministic motor conditions, FFT can be utilized to undertake spectrum analysis to discover IM-bearing defects. Discrete WT was used in the research by Konar and Chattopadhyay to detect IM-bearing defects [25]. The WPD can also be used to investigate transient fault information to discover IM-bearing faults (Lau and Ngan, 2010). Nonetheless, the WPD creates a large amount of non-fault-related data, which may obscure the fault characteristics in the map and make fault detection more difficult [26].

For bearing fault identification, Frosini and Bassi used stator current indications and IM efficiency [27]. Furthermore, Wei Zhou, Bin Lu, Habetler, and Harley used the Wiener filter to reduce noise to detect IM-bearing problems [28]. In another research, Romero-Troncoso used information entropy and fuzzy inference to detect online IM faults [29]. Nonetheless, these algorithms perform IM-bearing fault identification based on restricted fault information rather than completely exploring fault features in the time, frequency, and time-frequency domains.

2.3. Neural Networks

The neural network incipient fault detection method relies on the ability to identify an incipient failure in an induction motor in real-time. Neural network simulations in [1] reveal that a neural network-based fault detector is possible when applied to the issue of incipient stator and rotor-bearing faults. A neural network detector was used in real-time on an induction motor to illustrate the viability of deploying artificial neural networks in an industrial context.

Insufficient or contaminated lubrication, inappropriate application, or misalignment may cause rotor bearing degradation in an induction motor. It has long been accepted that bearing temperature and vibration levels may be utilized to measure bearing conditions [2]. Just with the stator winding, the use of temperature sensors on motors with more than 100 horsepower is restricted by cost and space considerations. Because of the high cost of sensors and data processing, only large equipment can make use of vibration sensors. Insulation failures and bearing wear are examined as part of this research.

Training data is needed to determine the stator winding's relative condition in relation to the presence or absence of an incipient failure in the induction motor. Based on his or her expertise, an expert is usually called in to classify. The artificial neural network defect detection is quantitatively validated by constructing two cost functions as criteria for assessing the winding and bearing conditions. For incipient flaw detectors in real-world applications, experts offer an operational environment for determining criteria.

As a consequence of the reduced number of winding equivalent spins, the current flowing through the stator's windings will rise, causing an extra loss of 12 rpm. As a result of the increased warmth, the stator winding insulation's lifetime will be reduced. Stator winding insulation failure will lead to more shorted turns, higher temperatures, and faster degradation. Stator winding damage may occur if this procedure goes unchecked. [3] suggests a criterion based on the correlation between stator currents, motor temperature, and insulation life to determine the state of the stator winding.

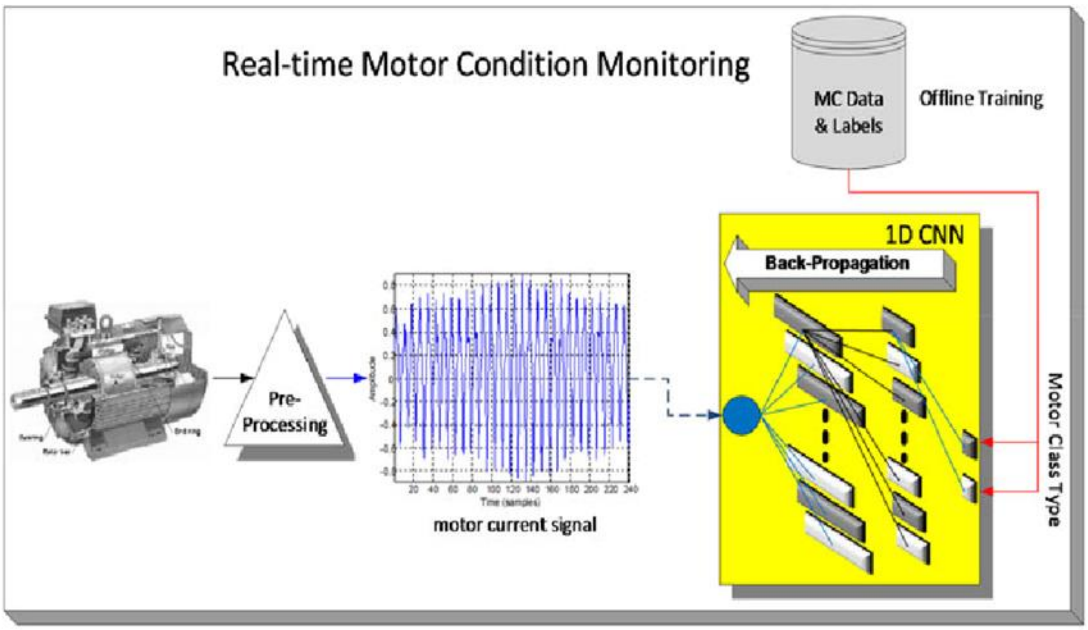


Figure 1. Fault detection using CNN

The state of the motor bearings is determined by the number of frictional losses they experience. The motor may be considered satisfactory with bearing losses of less than 5% of overall losses. Bearing failure may permanently harm rotor or stator windings, thus it is critical to identify and fix the problem quickly. Using bearing efficiency and motor nameplate data, it is possible to quantify bearing losses and determine the relative bearing condition.

2.4. IoT Platform and Alert System Technology

2.4.1. IoT

The Internet of Things (IoT) is a network of devices and items that have been made intelligent by adding sensors, actuators, and network connectivity, allowing them to gather and exchange data, as well as allowing users to become a part of the network.

The IoT platform is the heart of the Internet of Things architecture, as it connects the physical and virtual worlds, allowing items to communicate with one another. Thingspeak, an analytic platform service that lets to visualize and analyses live data available in the cloud and is operated by Math Works, is the IoT platform used in this article. It generates visualizations for data uploaded to the platform by devices in real-time. Thingspeak is frequently used for prototyping and proof-of-concept IoT solutions.

2.4.2. IoT Platform

A variety of strategies for machine diagnostics and prognostics were used in industry in the early 2000s, before the broad adoption of the Internet of Things idea. Data collecting, data processing, and maintenance decision-making are the three primary steps of Condition-Based Maintenance (CBM). Conditions monitored by condition monitoring serve as the basis for this preventative maintenance program. Firms are realizing that a single product is no longer sufficient in today's dynamic market climate, thus they are attempting to deliver integrated offerings of products and services. A general form for a product-service integrated roadmap was created in this regard [4].

Manufacturing is shifting from a reactive to an anticipatory paradigm, and the role of the maintenance function is becoming more important as a value-creation function. New methods of maintenance are proposed in this context. Different IoT-based failure prediction systems have been established to assure sustainable operations [5]. IoT platforms enable devices to communicate with one another and with other IoT platforms. Data from machines are typically presented and processed using an IoT platform as the front end or dashboard. There are a number of commercial or open-source platforms that are ready to go for simple IoT applications.

Programming libraries for common developer boards like Arduino, Linux-based devices (Raspberry Pi), or ARM-based devices are included with the majority of IoT platforms. There are a variety of IoT platforms available to developers for more advanced industrial applications [6]. All these platforms provide a server and SDK libraries for a variety of operating systems.

The capacity of different IT systems and applications to connect, share, and use data is called interoperability, which is based on communication protocols and standardization levels. Whether a business creates its IoT system in-house or works with a provider, it is critical to crafting a successful and resilient solution. Web protocols like HTTP GET and HTTP POST are used to exchange data between devices and IoT platforms (JSON). Using Arduino as a translator between industrial machines and IoT platforms is a quick solution given that most of these communication protocols are not supported on industrial devices (Figure 2.)

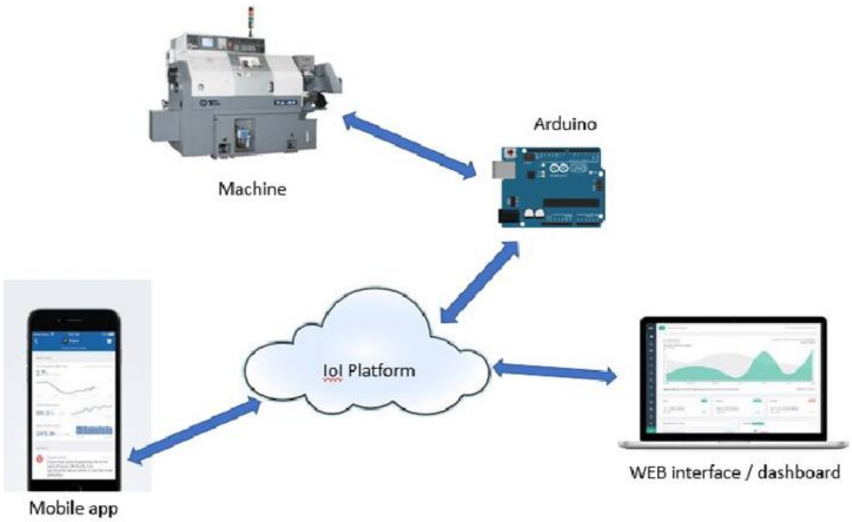


Figure 2. Simplified scheme of an IoT platform that uses an Arduino board

2.4.3. Alert System

The monitoring system collects vibration and temperature data. The system has been set up to recognize excessive vibration or temperature readings on a given motor by setting a threshold value of 0.9 for vibration and 70 degrees for temperature. The motor will fail before any maintenance can commence if the failure mark is utilized as a threshold value. It has been determined that at the time of motor failure, the threshold value has been set to the maximum vibration intensity that a motor can handle.

The vibration of a new motor might increase from 0.1443 to 0.2237 G. Tolerable for a medium-sized engine. It will alert the maintenance team if it exceeds this threshold. Figure 3 depicts a schematic representation of the warning system's operation.

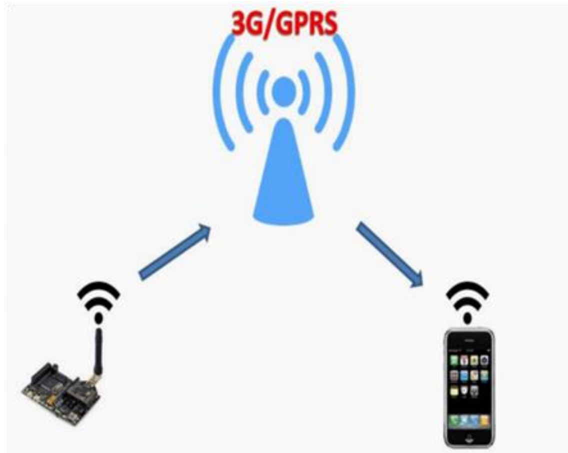


Figure 3. Working of the warning system

The alerting method makes use of a GPRS system (local network) connected to a microcontroller. Microcontrollers use GPRS shields to communicate wirelessly. Remote repair technicians will get alarm messages or phone calls from the microcontroller. It activates immediately when the selected threshold value is triggered five times in 15 minutes after the first trigger.

At various levels of vibration, as shown in Figure 4, the alarming phases progress. Green indicates that the motor is working normally, orange suggests that it needs to be examined, and red indicates that some action has to be made for motor maintenance or a replacement of the motor.

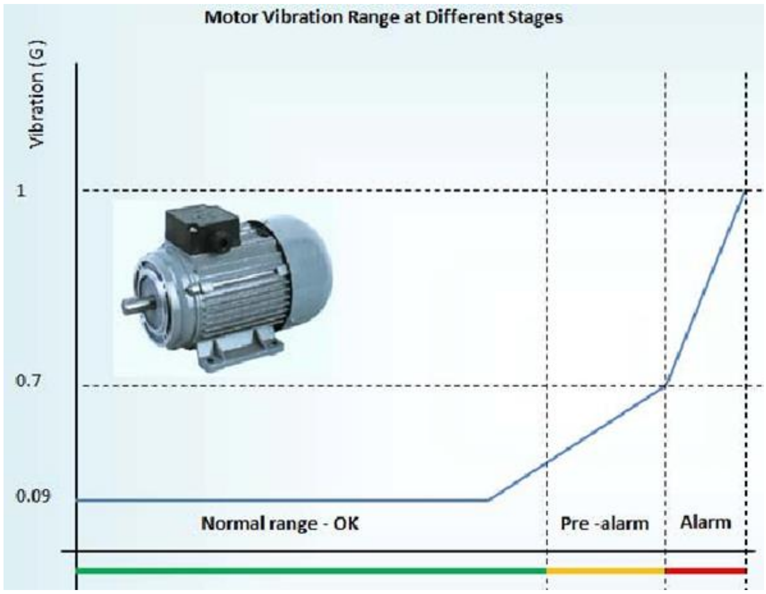


Figure 4. Alarming stages at different vibration levels

Figure 5. below is the overview of the system design hierarchy which shows the three important levels of this research on motor condition monitoring.

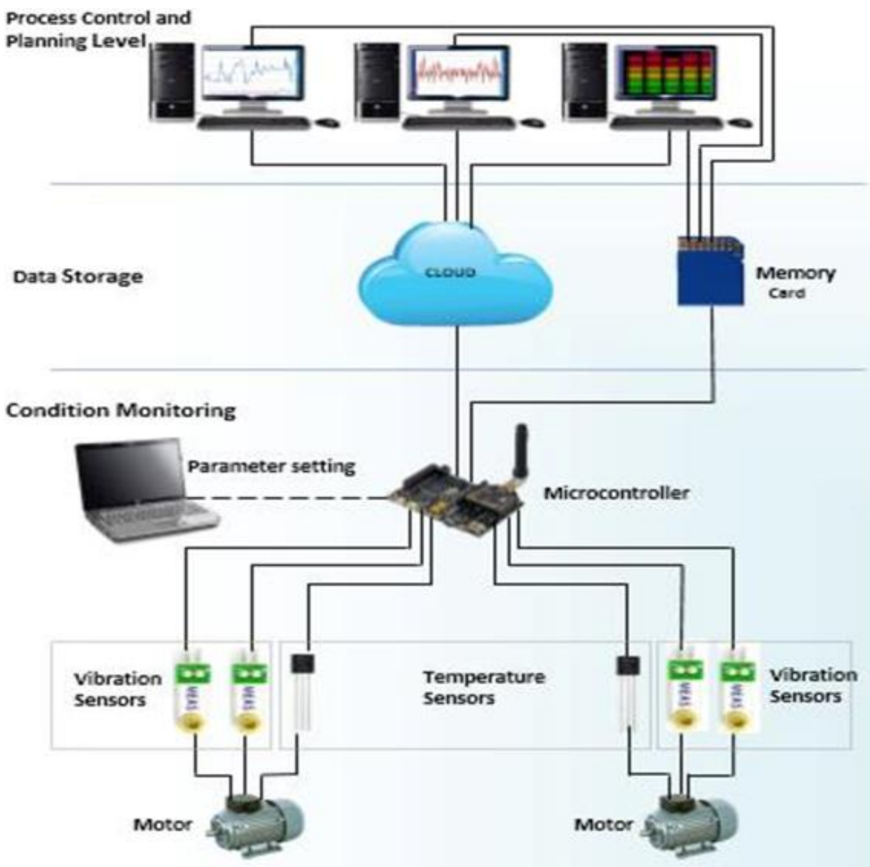


Figure 5. Overall Design of the Project

Chapter 3 - HARDWARE

All hardware parts used in this project and their components have been written in detail below with their working principles.

3.1. Arduino

Arduino is a physical computing platform that is open source and built on a simple input/output (I/O) board and a development environment that implements the processor programming language.

3.1.1. Arduino Board

The ATmega328 is the foundation of the Arduino Uno, a microcontroller board that can be seen in Figure (datasheet). It possesses 14 digital input/output pins, six of which can be utilized as PWM outputs, in addition to six analog input pins. In addition to that, it possesses a crystal oscillator running at 16 MHz, a power jack, an ICSP header, a reset button, and a USB connection [7]. Its working voltage is 5v. It has 32 KB of flash memory for storing code (of which 0.5 KB is utilized for the bootloader), as well as 2 KB of SRAM and 1 KB of EEPROM. The Atmega328 also has a bootloader that uses 0.5 KB of its flash memory. The following is a list of the power pins: The voltage that is supplied to the Arduino board from an external power supply and denoted by the acronym VIN. The microcontroller and the other components on the board are powered by the source of regulated power that is located on the board. A supply of 3.3 volts is created by the regulator that is on board. The maximum amount of current draw is 50 milliamps. GND. Pins for grounding.

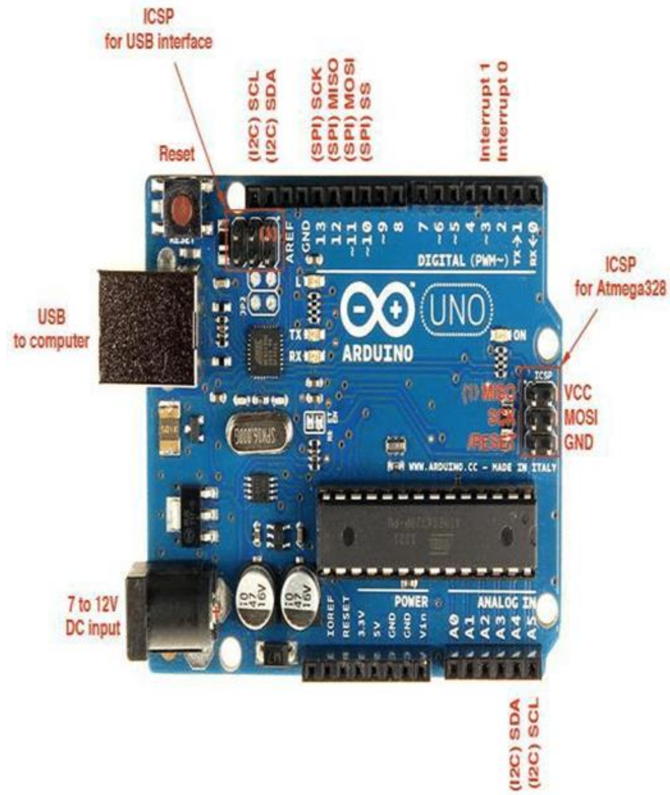


Figure 6. Arduino Uno

3.1.2. Arduino Integrated Development Environment (IDE)

The Integrated Development Environment, sometimes known as the IDE, is a specialized program that can be run on a computer that enables users to write sketches for the Arduino board in a straightforward language that is based on the Processing language. The Upload button on the integrated development environment (IDE) is used to transfer the code to the board.

3.1.2.1. Arduino IDE Definition

- Open-source software called Arduino IDE is used to write and compile the code for the Arduino Modules.
- To make things even easier, this is an official Arduino program, which means that anyone with no prior technical expertise may start learning how to use it.
- It works on the Java Platform, which has built-in functions and

commands that are critical for debugging, editing, and compiling code in the environment, and is readily available for operating systems including MAC, Windows, and Linux.

- A wide variety of Arduino modules are available, including the Uno, the Mega, the Leonardo, and even the Micro.
- There is a microcontroller on each board that is programmed and accepts information in the form of code.
- A Hex File is generated from the main code on the IDE platform and then copied and uploaded to the controller on the board. This is known as a "sketch."
- The IDE environment generally consists of two parts: the Editor and the Compiler, which are used to write and compile the required code, respectively.
- It is possible to use this environment with the C and C++ languages.

3.1.2.2. IDE Information

There are three key sections to the IDE environment.

- The Menu Bar
- Text Editor (Optional)
- Output Window

It will look like the below when we download and open the IDE software.

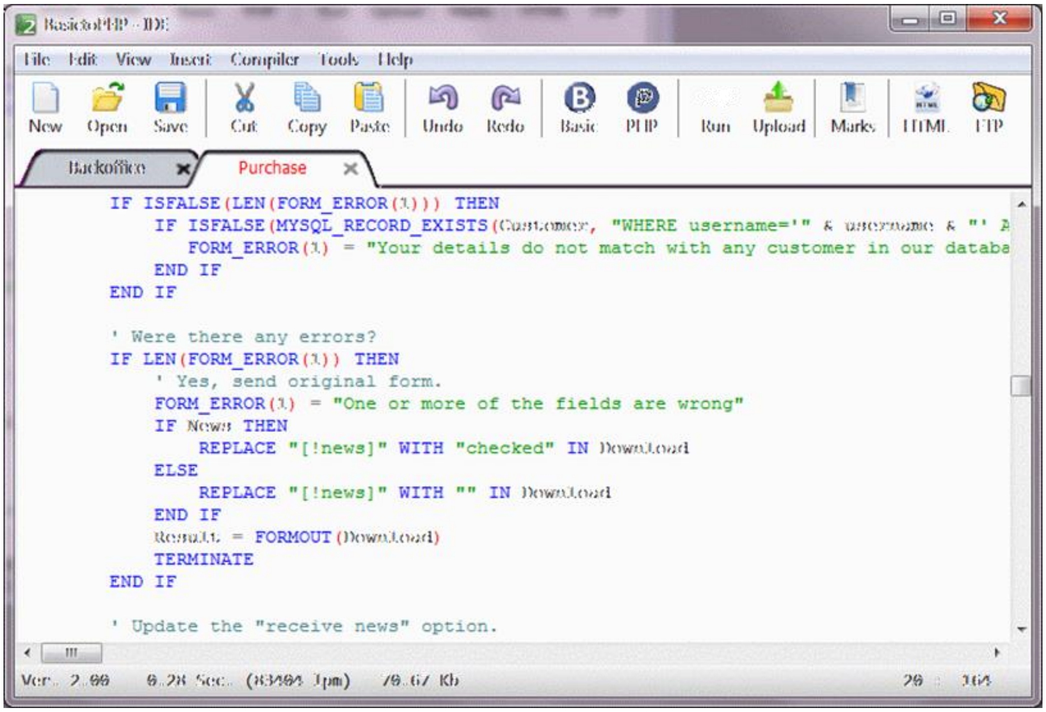


Figure 7. IDE environment

3.1.3. Gateway

A gateway is a network node that joins two networks that use different base protocols; in other words, a gateway connects two networks that are distinct from one another. Software, hardware, or a combination of the two can be used to implement a gateway [8]. Alternatively, a gateway could be physically built. The ESP8266-12E (Node MCU 1.0 Development board), which was employed as the gateway in this work, can be seen in Figure 8.

3.1.4. ESP8266-12E (Node MCU 1.0 Development Board)

The ESP8266 microcontroller, in its most basic form, was developed for use in mobile, wearable, and Internet of Things applications to obtain the lowest possible power consumption by combining several different methodologies that are exclusively theirs. It is an outstanding Wi-Fi module that can be used for adding Wi-Fi capability to current microcontroller projects by means of a serial connection to a UART port.

The module's price is also very reasonable. Node MCU contains firmware that may be run on the ESP8266 wireless System-on-a-Chip (SoC) manufactured by Espressif systems [9]. Lua is the language that is utilized for scripting by the Node MCU. It has 11 digital input/output pins and operates at 3.3v, which is its operating voltage. The circuit board has a flash memory that is 4 megabytes in size.

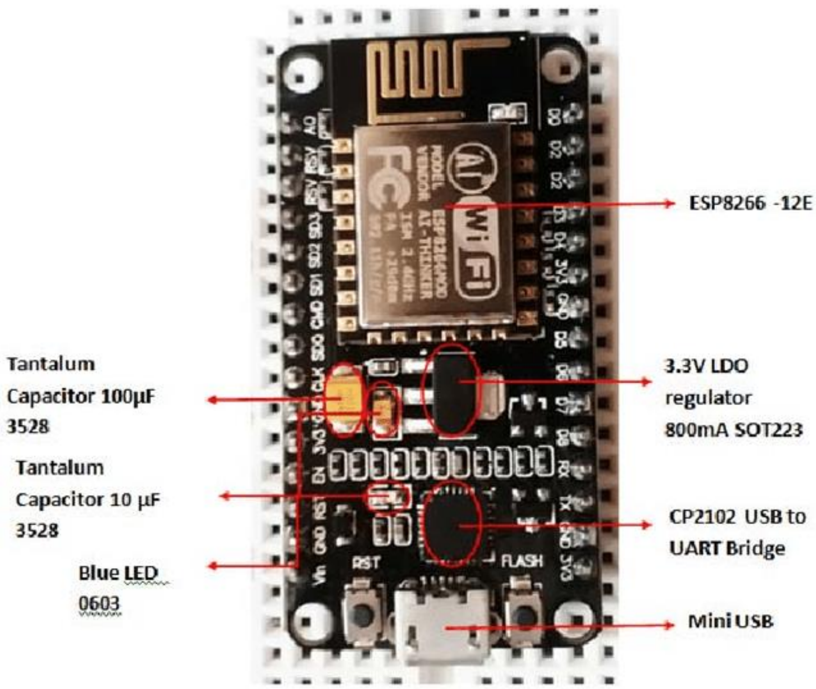


Figure 8. ESP8266-12E board

3.2. Sensors

The temperature of the bearings and windings, the current, the voltage, the vibrations, and the number of starts and stops are some of the parameters that are taken into consideration when monitoring the health of an induction motor. For this purpose, a variety of sensors are utilized to record the relevant data for the parameters.

3.2.1. Temperature Sensor

A temperature sensor known as the LM 135 is utilized for the purpose of measuring the temperatures of the windings and bearings, as can be shown in Figure. The LM 135 is a temperature sensor with high precision that is also very simple to calibrate. It produces linear results. It runs at a temperature range of -55°C to 150°C. It is equipped with three pins, which are labeled as V_{cc}, output, and ground pins.

Figure 9. LM135 Temperature sensor

In other research papers, temperature classes were also analyzed as temperature plays an important role in determining motor state. The motor temperature rises in tandem with vibration and noise as the motor condition deteriorates. Temperature data for various motor insulation classes are shown in table 1.

Insulation Class	**Hot Spot Temperature (°C)**	**Typical Surface Max Temperature (°C)**
A	105	80
B	130	105
F	155	130
H	180	155

Table 1. Maximum allowable temperature values for different temperatures

3.2.2. Vibration Sensor

ADXL 335 is the vibration sensor or accelerometer that is utilized. It is a device that is compact, thin, uses a low amount of power, and has three axes. Additionally, it has signal-conditioned voltage outputs. It measures a full-scale acceleration with a range of 3g (g is the SI unit for acceleration). It monitors accelerations in both the static and dynamic states. This is where the dynamic acceleration that is experienced because of motion, shock, or vibrations is monitored. The figure depicts the sensor in its entirety. It is possible to pick different bandwidths for each of the three axes, depending on the application. For the X and Y axes, the range of bandwidths is from 0.5 Hz to 1600 Hz, and for the z-axis, the range is from 0.5 Hz to 550 Hz [10]. It provides three values, one for each of the three axes that indicate the vibrations of the motor. Vibrations are measured in a manner that is dependent on the values acquired along three axes.

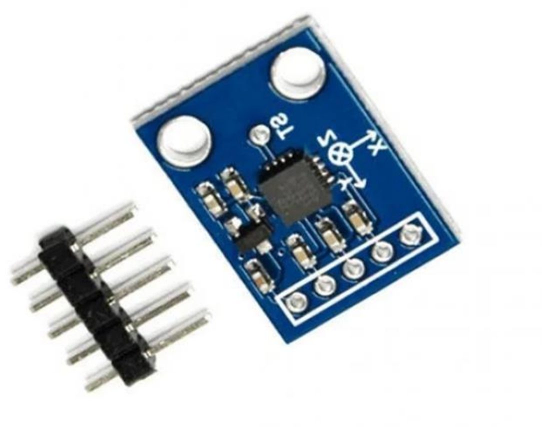


Figure 10. ADXL335 Vibration sensor

3.2.3. Current Sensor

A Hall effect current sensor with the model number SCT-013-050 is used to measure current, as can be seen in Figure. Not only is it cost-effective, but it also offers a precise solution for detecting AC and DC in a variety of applications, including industrial ones. The Hall effect is the foundation for its operation [11].

Figure 11. SCT-013-050 Current Sensor

3.2.4. Number of Starts and Stops of Induction Motor

A motor is only capable of withstanding a certain number of stars, which is typically determined by the manufacturer (number of starts per hour). The longevity of the insulation that is contained within the windings of a motor is directly proportional to that of the motor. The windings of the motor experience a significant increase in temperature as a direct result of the extreme overload that occurs when the motor is first turned on. The lifespan of the insulation is shortened whenever there is an increase in the windings' temperature. The temperature rise will cause problems if there are an excessive number of starts with inadequate time to cool down in between each one. When the engine is first started, there is a significant amount of energy lost in the rotor, which results in a significant increase in the temperature of the rotor bar. It is possible that the thermal protection that is built into the windings will not be enough to avoid damage to the rotor bar or the end ring. The rotor bar and end ring may be damaged if the heat protection built into the windings is insufficient. This is why the National Electrical Manufacturers Association (NEMA) and the International Electrotechnical Commission (IEC) set limits on the number of times a motor can be safely started in a given amount of time, such as two starts in succession with the motor initially at ambient temperature (coasting to rest between starts) or one start with the motor at a temperature that does not exceed its rated load operating temperature [11]. As a result, it is essential to keep track of the number of starts and stops. The software program includes associated coding so that the number of starts and stops can be monitored, and it also permanently retains the record of starts and stops so that they can be referred to in the future.

3.3. Induction Motors

A three-phase induction motor is a device that converts three-phase input electrical power into three-phase output mechanical power. It is an example of an electromechanical energy conversion device.

Figure 12. 3-Phase induction motor

A three-phase induction motor consists of a stator and a rotor. Short-circuiting windings are found in the rotor and three-phase windings in the stator of a DC motor, respectively. A three-phase power supply powers the stator winding. Since the stator winding supplies voltage and power to the rotor winding, the process is known as electromagnetic induction. The operation of a three-phase induction motor can be understood by breaking down the process into its parts and analyzing them as follows:

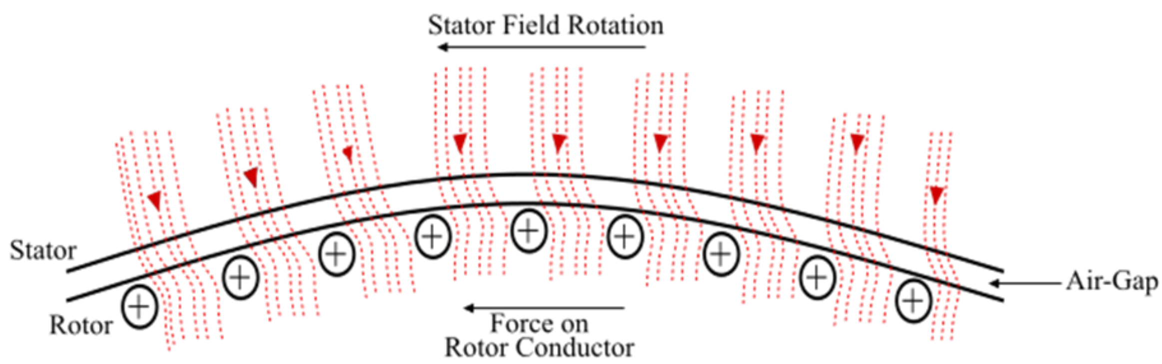


Figure. Operation of a three-phase induction motor [27]

- When the three-phase stator winding is supplied with electricity from a balanced three-phase supply, a rotating magnetic field, or RMF, is created in the motor. As the stator revolves, the RMF moves in lockstep with it.

$$Synchronous\ Speed, NS = 120f/P \qquad (1)$$

- When the RMF moves through the air gap, it cuts the conductors of the rotor, which are still stationary. When the rotor magnetic field (RMF) and stationary rotor conductors are in motion, EMFs are generated in the conductors. The rotor conductors will begin to conduct electricity as soon as a short circuit is completed in the rotor circuit.
- Since the rotor's conductors are positioned within the magnetic field produced by the stator winding, the rotor's current can flow freely. Because of this, these conductors are in direct contact with mechanical forces. By combining the mechanical forces acting on it, each conductor of the rotor generates torque. This torque forces the rotor to move in the same direction as the magnetic field's rotation. Electric power is fed into a three-phase induction motor, which then generates three-phase mechanical power.
- Aside from this, according to Lenz's rule, the rotor must follow the stator field. For example, it is important to ensure that rotor currents flow in an opposite direction from the source of the currents. In this situation, the rotor currents are

generated by the RMF and the rotor conductors' respective speeds. Since this relative speed may be reduced by turning the rotor counter-clockwise, this is how it is done.

Chapter 4 - SOFTWARE DESIGN

4.1. Arduino IDE

This software is used for the programming of Arduino. The microcontroller will be programmed in the ideal environment also called an integrated development environment. Here we will write the code in C++ language. What the code will do? It will communicate with the Bluetooth module and then communicate to the piezoelectric module.

It is used to write and upload programs to Arduino-compatible boards, but also, with the help of third-party cores, and other vendor development boards We must understand Arduino IDE. The Arduino Integrated Development Environment (IDE) is a simple platform for Arduino lovers. Here applications with various examples can be installed that are written in functions from C and C++. Arduino uses its programming language, which is like C++. However, it's possible to use Arduino with Python or another high-level programming language.

4.2. Microcontroller's Study and Implementation

For the data logging of signals, the specs needed include high-frequency operations and greater memory. Previously, Arduino mega was being used as a controller. The controller was provided with pre-processed digital signal hence the requirement was fulfilled. In the new approach, a higher sampling rate was desired. To perform calculations on big data, the crystal frequency was to be considered as well. As part of the research, various controllers were being tested. The pros and cons of each were analyzed. Also, to alert the user about possible malfunction of the motor an android app was developed. To communicate with the app, the options included WIFI Module. Preference was given to the controller with added communication Feature. Size and cost were also the major concerns during the selection of the controller. The chart below is developed to provide a comparative analysis of controllers being considered for application.

Microcontroller	Frequency	Memory	Operating Voltage	Built-in Bluetooth/Wi-Fi
ATMEGA 2560	16 MHz	8kB	5V	NO
Arduino UNO	84 MHz	96kB	3.3V	NO
STM32-F103	72MHz	64kB/128kB	3.3V	NO
Node-MCU	2.4-2.6GHz	128kB	3.3V	YES

Table 3. Comparison of Microcontrollers

4.3. Firebase (Cloud Platform)

Firebase although did not start at google, adheres to some of the principles google tries to have in its cloud products. It is a backend as a service and requires very little server-side code if at all. It scales/load balances without any intervention from you. The support is very good, and the response is quick. There are a lot of libraries available as well from the open-source community. The best part about firebase is that it is built over web sockets so you can build real-time applications with ease. More importantly, you can give a real-time feel to even traditional applications.

Figure 13. Firebase is a cloud platform

Applications of different kinds can benefit from Firebase's offerings. Using it on a variety of platforms is the sole restriction. The Firebase SDKs are mostly geared toward iOS and Android, but web, Flutter, Unity, and C++ are also seeing an increase in support. If you need any backend components, you can utilize the Admin SDK, which is available in a variety of languages. FirebaseUI (Android, iOS, and web) is a library that provides several useful utilities to make development with Firebase even easier on top of those SDKs. AngularFire, for example, provides a wrapper for web SDKs that may be used with Angular. These are available for free. Firebase is a fan of open-source software.

Database services are provided by Firebase Realtime Database and Cloud Firestore. Both databases are "real-time, cloud-hosted, NoSQL databases". Each has its pros and weaknesses, so you may need to conduct some study before making a final decision. Cloud Firestore is a good place to start, as it is likely to meet most of your requirements and can be scaled out significantly. If it is more appropriate for your app, you can combine the two. Note that Firestore is not a Firebase product but rather a Google Cloud product. What is the deal with Firebase including it? Using Firebase's SDKs, your mobile app may access data directly, eliminating the need for middleware.

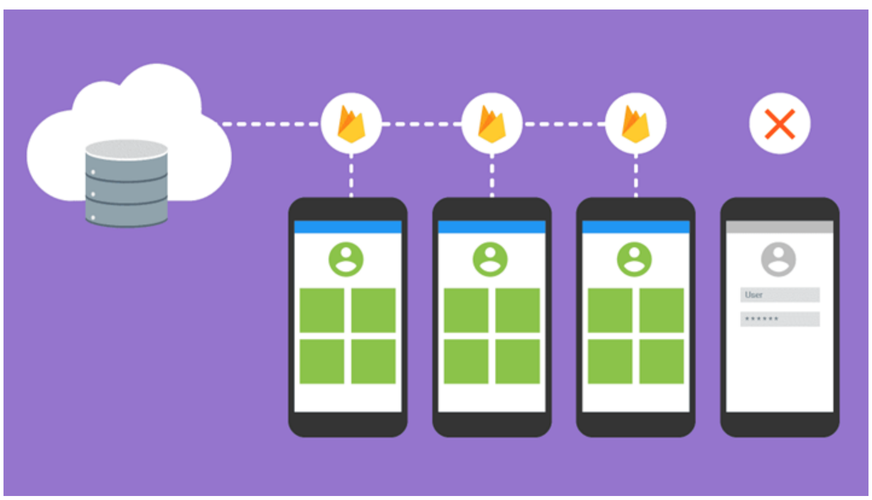


Figure 14. Firebase as a platform for data processing

4.4. Android Application

The basic idea behind developing the android application is to show the real-time results of induction motors. The app will also alert the user when the motor health is about to deteriorate and provide the maintenance team enough lead time.

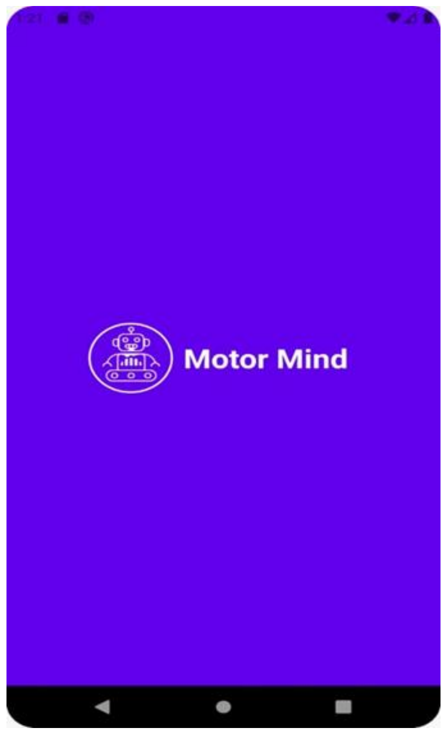


Figure 15. Android app

Then, a login dialog box will appear:

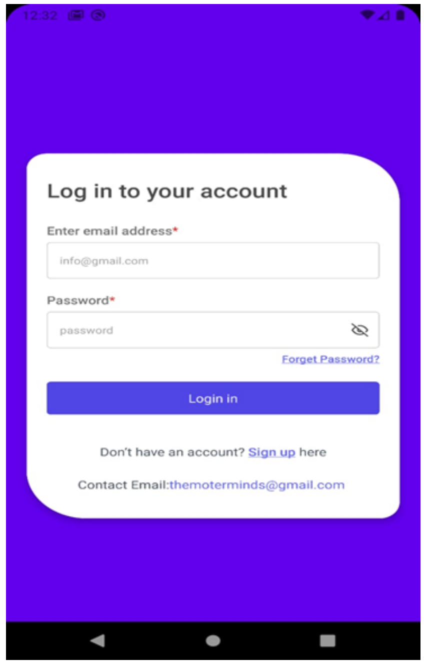


Figure 16. Log-in dialog box

If the user does not have an account, it will ask him to create an account menu.

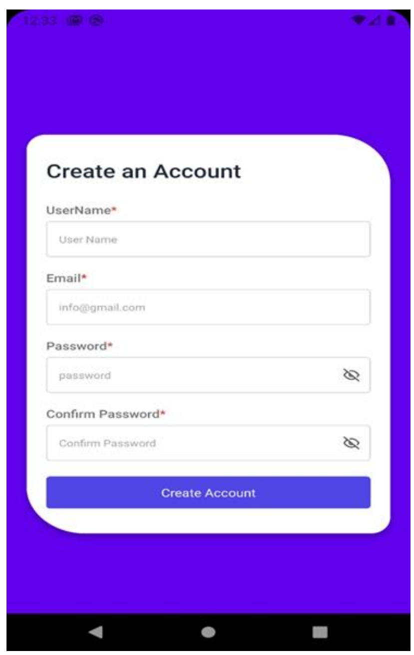


Figure 17. Create an account dialog box

If the user has forgotten their password, this will appear on the app:

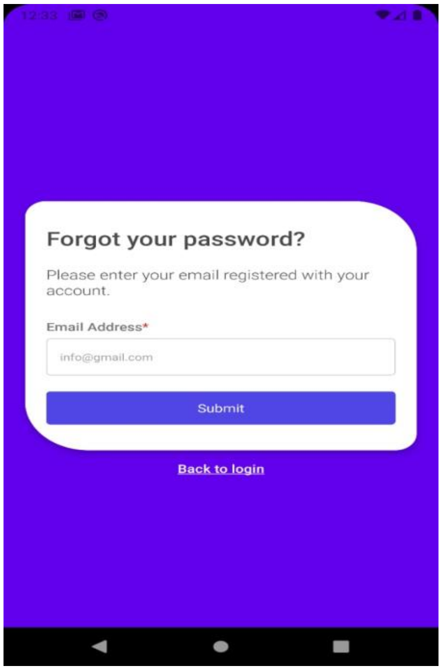


Figure 18. Forgot password dialog box

The number of motors connected with WIFI through Node MCU will appear on the app screen.

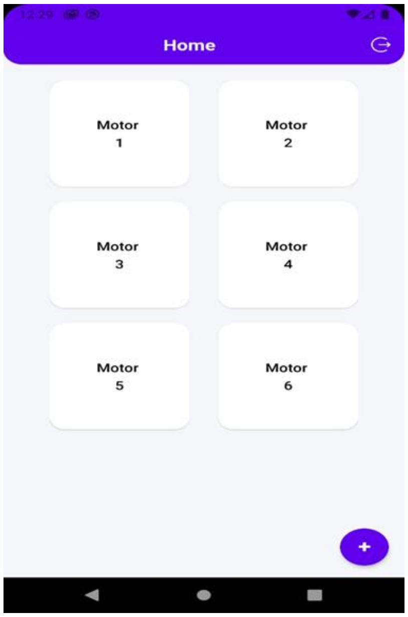


Figure 19. Motors connected through WIFI with the app

When the user clicks on the motor, the app will show the condition of the motor you have clicked. Data of all the sensors are shown and if the values are close to optimum value the status will be shown as "OK" otherwise an alarm will go off on the status of "NOT OK".

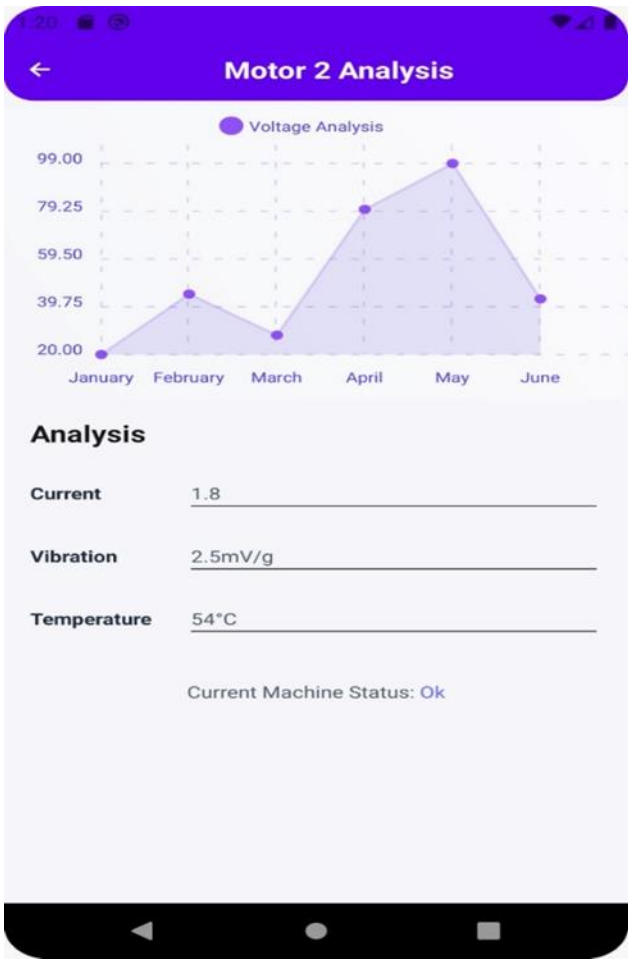


Figure 20. Motor analysis dialog box

4.5. Wi-Fi Communication

Instead of Arduino, we can also use the wife module as an alternative. Where we have to work from far places. The controller we choose after the comparative analysis is Node MCU. The features of this controller include:

- It is considered a low-cost Wi-Fi technology.
- It has ESP12 that is based on serial Wi-Fi integrated on board to provide

GPIO, PWM, ADC, and I2C interface.

- It can be programmed easily using Arduino IDE.
- The prototyping development kit can be bought easily and is the best platform for IOT application development at a very low cost.

ESP-8266 module integrated with Node MCU is used for communication with the Android application. The Wi-Fi module can be configured as a client or a server. While a server is configured as an access point for multiple clients to connect to and perform operations. A client responds according to the requests made by the server. In client-server communication, multiple clients in a system cannot communicate with each other except through the server.

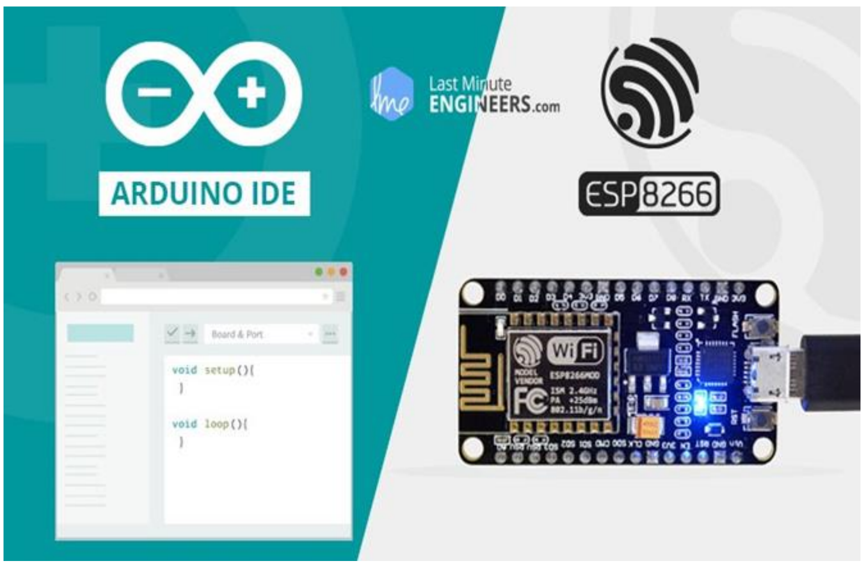


Figure 21. Using ESP 8266 with Arduino IDE

As part of our project, the communication between ESP8266 and the Android application is carried out using a bit different approach. Here, the ESP8266 is not configured as a Wi-Fi access point, it is configured as a client which gets connected to a particular IP address provided to it using a Wi-Fi hotspot. A Wi-Fi hotspot is needed for the two devices to communicate and share data. It listens to the port it is connected to. The android application sends data to that IP address on that port.

The data transmitted through the Node MCU is received on the other end at the specified port. Focusing on the transport layer protocol as our major concern, the choice between the two (UDP and TCP) was available as they are being widely used for data communication purposes. The network layer protocol chosen for our application due to the fast transmission is UDP.

4.6. MATLAB

Millions of engineers and scientists rely on MATLAB for data analysis, algorithm development, and model creation. Iterative analysis and design procedures can be carried out using MATLAB's desktop environment and a programming language that directly defines matrix and array mathematics. Code, output, and formatted text can all be combined in an executable notebook using the Live Editor. Toolboxes for MATLAB have been built by experts, tested to the hilt, and are well documented. You can see how different algorithms function with your data in MATLAB applications. MATLAB may automatically develop a program to repeat or automate your work once you have iterated until you get the results you want. Analyses can be executed on clusters, GPUs, and clouds with just little alterations to the underlying source code. Rewriting your code or learning about huge data and out-of-memory approaches is not necessary.

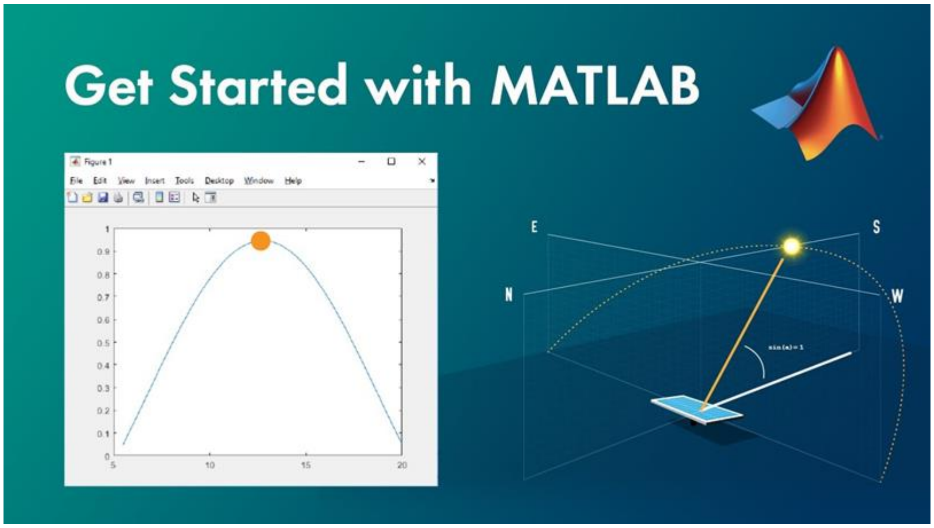


Figure 22. MATLAB software

Chapter 5 - SOFTWARE IMPLEMENTATION AND RESULTS

5.1. ARDUINO

We are taking data from sensors that include data from vibration, current, and temperature sensors and storing it in Arduino's virtual memory.

Figure 23. Sensors' code

Here, we are accessing the sensors' data from the virtual memory and using the WIFI module, sending the data to Firebase. Data from Firebase which we will later bind to the Android Application.

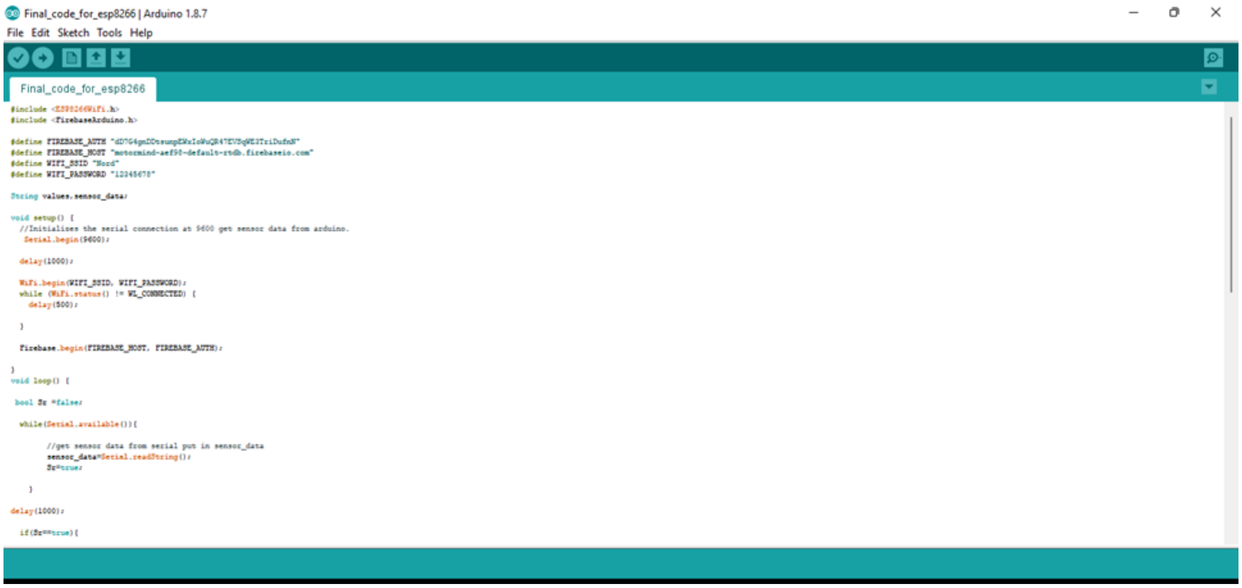


Figure 24. ESP8266 code

Figure 25. ESP8266 code (2)

5.2. MATLAB

We are accessing data from the vibration sensor and performing FFT on it to generate a comparison between a healthy vs. faulty motor. This data is sent to Firebase which will later be used to alarm the user of an upcoming failure on the application.

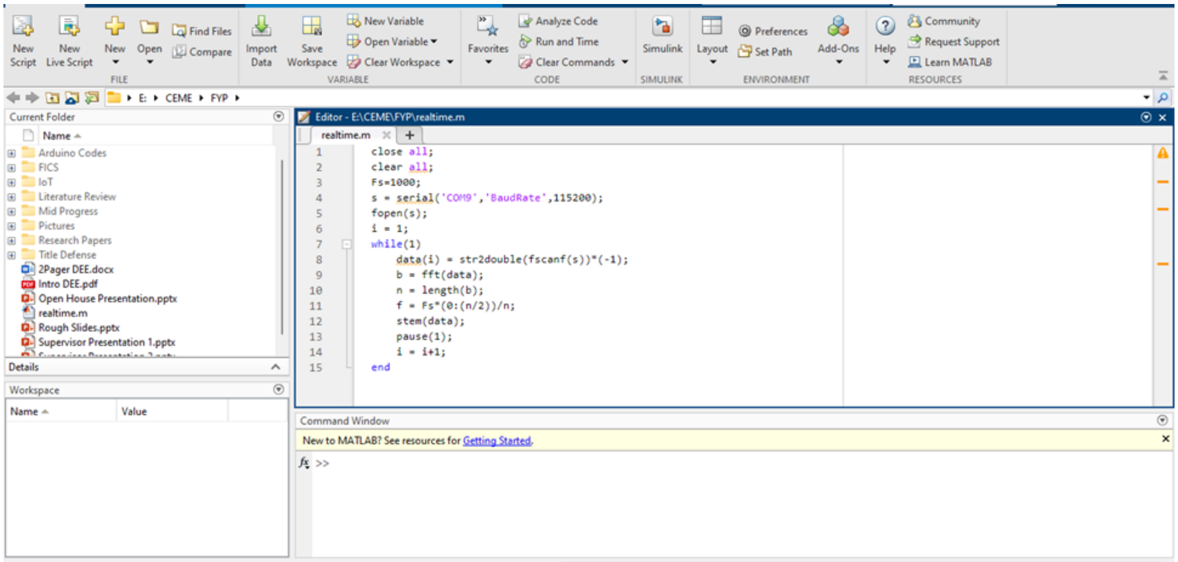


Figure 26. MATLAB Code

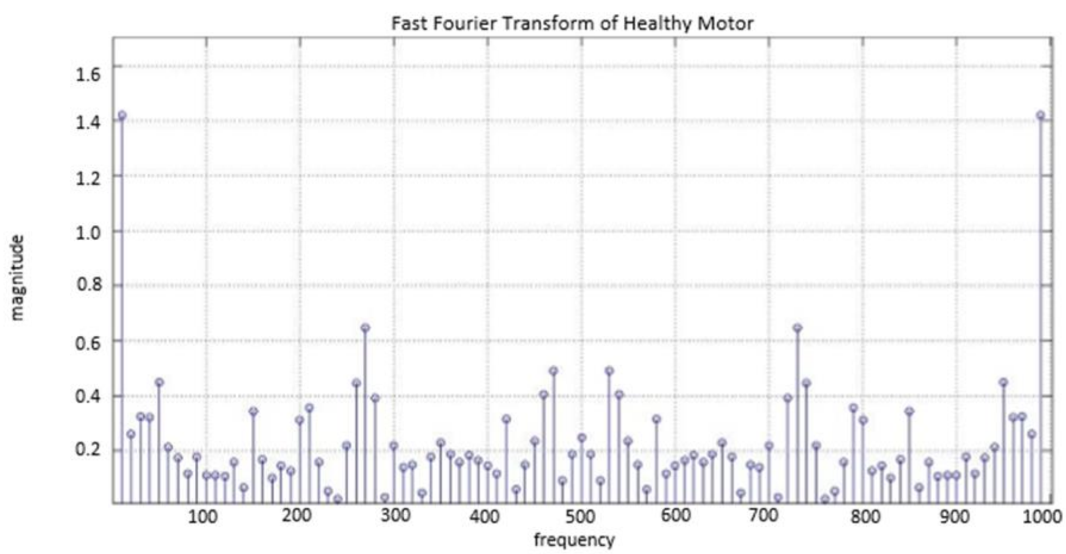


Figure 27. Healthy Motor graph on MATLAB

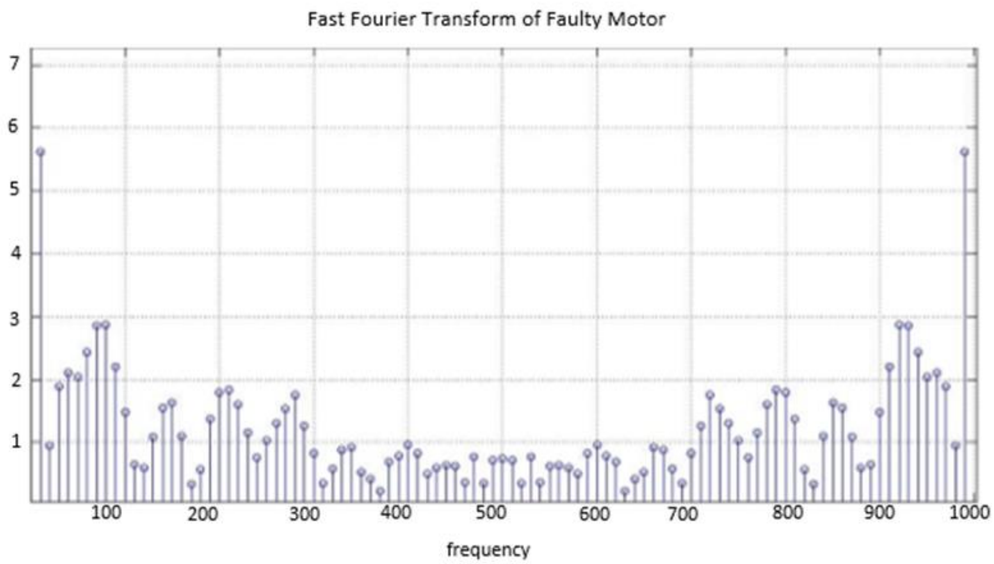


Figure 28. Faulty Motor graph on MATLAB

5.3. Firebase

The data sent from the WIFI module is displayed on this cloud platform. This interim is later transformed into a user-friendly android application for ease.

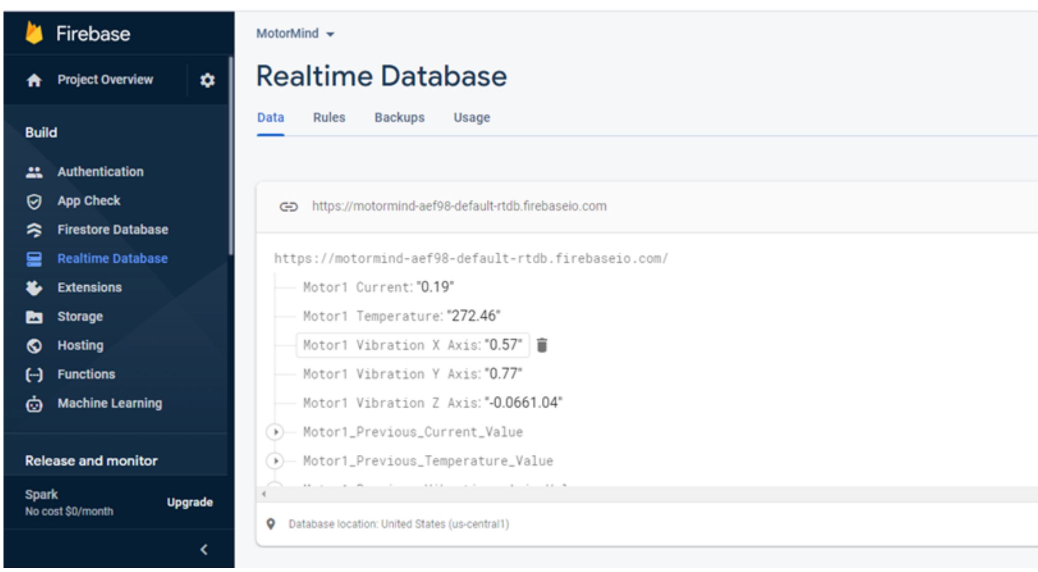


Figure 29. Motor 1. analysis on Firebase

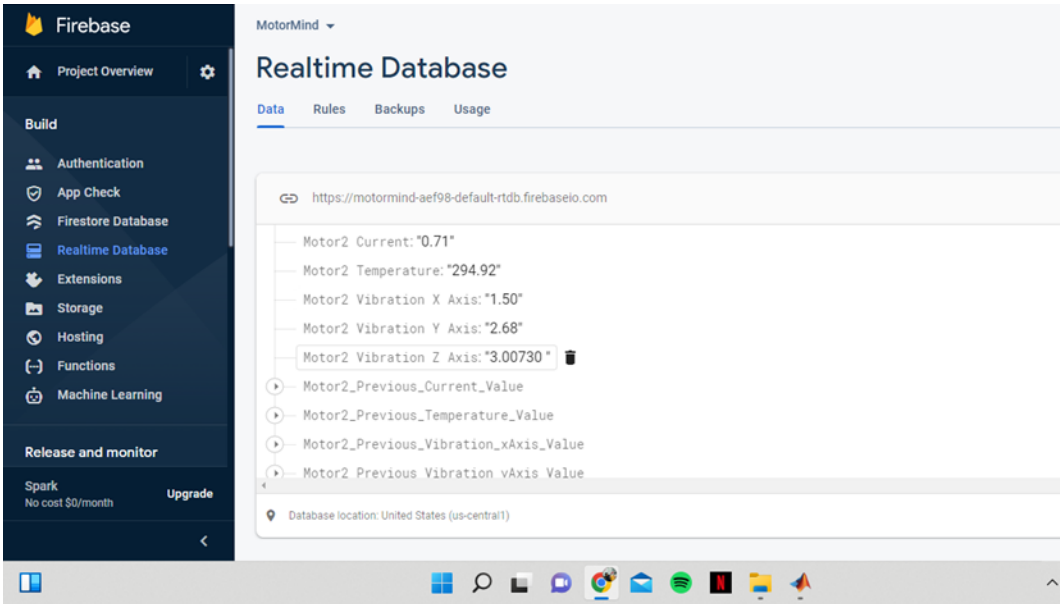


Figure 30. Motor 2. analysis on Firebase

The whole overview of the whole project is:

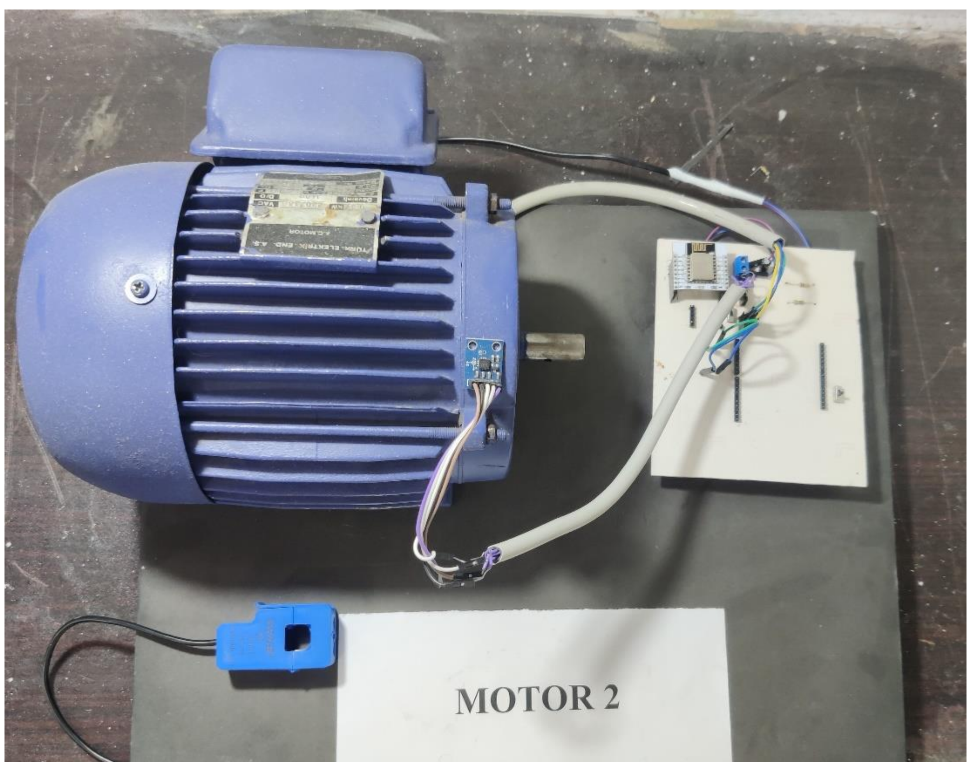


Figure 31. Overview of the complete operation

Chapter 6 - CONCLUSION AND FUTURE PLANS

6.1. Conclusion

In this review, a complete study map of an industrial motor effectively and continuously monitored using various sensors, with the resulting data being saved in a cloud platform and accessed from many locations via a web application is established. The motor's health is determined by analyzing the obtained continuous parameter data by various researchers. Those methods have additional benefits, such as continuous condition monitoring, timely notifications, storage of recorded copious data for future use, and data monitoring from any place. The monitoring system for the motor's real-time condition is upgraded with time. Data storage, retrieval, and access have all been made more user-friendly thanks to the Internet of Things. Any motor failure caused by vibration can be simply communicated to the end-user via IoT.

The study successfully built and implemented a modular motor status monitoring system using remote sensing (RS) and Internet of Things (IoT) technologies, which might help numerous industries and manufacturing businesses reduce downtime. Other intelligent methods, such as the Short-Time Fast Fourier Transform (STFT) and Power Spectrum Density (PSD), which are now under development in this research effort, can also improve detection accuracy. Looking at the MATLAB plots of Fast Fourier Transform of the data between healthy and faulty motors we can determine the type of fault in a particular motor. The consequence of our project is that our product will help small-scale local industries that can’t afford the heavy investment to reduce their maintenance cost as well as motor stoppage time by installing a condition-based monitoring system for their Industrial Motors.

6.2. Future Work

- Web App/iOS App
- Customization of the product as per requirements of the customer
- Make it more advanced by using high-precision sensors

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