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Internet of things-enabled smart monitoring of induction motors for industrial applications

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ABSTRACT

AC motors, particularly induction motors, remain the most widely used machines in industrial applications due to their simplicity, robustness, and efficiency. Given their critical role, continuous monitoring and regulation of induction motor parameters are essential to ensure reliability and prevent unexpected failures. This research presents an internet of things (IoT-based) system for real-time monitoring and control of a three-phase induction motor. Various sensors are employed to measure key parameters such as motor temperature, current, and voltage, with the collected data transmitted to a processing unit and displayed on a server for remote access. To enhance fault resilience, the system integrates both automatic and manual control mechanisms for starting or stopping motors under abnormal conditions. The proposed approach enables continuous monitoring, early fault detection, and predictive maintenance, thereby improving overall operational efficiency and reducing downtime. Induction motors, first introduced by Nikola Tesla, account for over 50% of global electricity consumption and are deployed in nearly 90% of industrial operations. Their dominance stems from inherent advantages, including being self-starting, cost-effective, reliable, and maintenance-friendly, as well as offering a strong power factor, compact design, and high efficiency. By leveraging IoT technology, this work bridges the gap between traditional motor operation and modern Industry 4.0 practices, providing a scalable solution for smart industrial environments.

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1. INTRODUCTION

Electric motors are the backbone of modern manufacturing systems, serving as the primary driving force behind mechanical and electromechanical processes. Historically, DC motors dominated industrial applications; however, with the advent of AC induction motors, their superior efficiency, durability, and adaptability have made them the preferred choice in industrial automation [1], [2]. A key advantage of AC motors lies in their simple rotor design, which results in low cost, high reliability, long service life, and minimal maintenance requirements [3], [4]. Despite these advantages, induction motors are prone to various faults that can disrupt industrial operations. These faults can be broadly classified into electrical problems, mechanical defects, and environmental factors. In electrical problems include issues such as single-phasing, under- or overvoltage conditions, unbalanced current, and overloads. In mechanical defects include failures including rotor bar breakage, air-gap eccentricity, bearing wear, stator or rotor winding damage, and mass imbalance. In environmental factors include external influences such as excessive vibration, high ambient temperature, and humidity [5]-[7]. The performance and reliability of AC induction motors are directly affected by these factors, making effective monitoring and control strategies essential to ensure continuous and safe operation [8]-[10]. With the emergence of the internet of things (IoT), significant advancements have been introduced in industrial monitoring and automation [11]-[13]. IoT enables seamless interconnectivity between devices, allowing real-time communication of critical parameters such as operating conditions, performance data, and fault statistics. This improved connectivity not only enhances productivity and control but also aligns industrial systems with modern Industry 4.0 practices [14]-[16].

This work presents an IoT-based system designed for real-time monitoring and control of AC induction motors. Key motor parameters, including voltage, current, speed, and temperature, are continuously measured using sensors [17]-[19]. Speed regulation is achieved through pulse width modulation (PWM) technology, which offers a simple and efficient method of frequency-based input power control. To further enhance reliability, the system integrates an alert mechanism that detects anomalies such as overheating, overcurrent, or abnormal speed variations. Upon detection, the Arduino Uno processes the sensor data and, through cloud connectivity, can automatically shut down the motor to prevent further damage. Simultaneously, an alert message is transmitted to a mobile device, enabling rapid corrective action and minimizing downtime [20]-[22]. By combining IoT technology with predictive and protective control mechanisms, the proposed system improves the operational efficiency, fault tolerance, and overall dependability of induction motors in industrial environments [23]-[25].

The primary objective of this work is to design and implement an IoT-enabled smart monitoring system for induction motors in industrial applications. The specific objectives are:

a. To develop a real-time monitoring system that continuously measures key motor parameters such as voltage, current, speed, and temperature using appropriate sensors.
b. To integrate IoT technology for seamless data acquisition, transmission, and visualization through a cloud/server platform accessible remotely.
c. To implement intelligent control mechanisms (automatic and manual) for starting, stopping, and protecting the motor under abnormal or fault conditions.
d. To enhance fault detection and predictive maintenance by analyzing motor performance data to identify potential issues before failures occur.
e. To improve reliability, safety, and efficiency of induction motors in industrial environments by minimizing downtime and optimizing performance.
f. To provide alert and notification systems (e.g., mobile alerts) that inform operators about abnormal conditions or faults in real time.
g. To contribute towards Industry 4.0 practices by integrating traditional motor operation with smart, connected, and automated monitoring solutions.

Section 1 described the introduction. Section 2 described the literature review and section 3 described the proposed methodology. Section 4 described the experimental setup and results discussion. In section 5 conclusions have been given.

2. LITERATURE REVIEW

The following are some literature reviews:

a. Shyamala *et al.* [26] proposed an IoT-based platform for continuous condition monitoring of industrial induction motors using embedded sensors and cloud connectivity. The system monitored critical parameters such as temperature and vibration in real time and transmitted the acquired data to an online platform for remote supervision. The proposed framework generated alarms during abnormal operating conditions, enabling preventive maintenance and reducing unexpected motor failures. However, the study focused primarily on real-time monitoring and notification, without incorporating intelligent fault diagnosis or AI-based predictive maintenance techniques.
b. Kunthong *et al.* [27] proposed an IoT-based wireless condition monitoring system for electric vehicle traction motor drives using the ESP8266 microcontroller and cloud connectivity. The developed prototype acquired motor vibration, current, and temperature data in real time and transmitted the information to a cloud server for continuous monitoring. The system automatically generated notifications when abnormal

operating conditions were detected, demonstrating the feasibility of IoT for real-time motor health assessment in electric vehicles. However, the study focused mainly on monitoring and alert generation and did not incorporate advanced AI-based fault diagnosis or predictive maintenance algorithms.

c. Prakash and Thakur [28] proposed an IoT-enabled smart shutdown and recovery mechanism for industrial machines to improve equipment safety and operational reliability. Their system continuously monitored machine operating conditions and automatically shut down the equipment when abnormal parameters exceeded predefined thresholds. A backup mechanism was incorporated to restore operation after fault clearance, thereby minimizing production downtime and enhancing system reliability. However, the proposed framework primarily focused on monitoring and protection and did not incorporate intelligent fault diagnosis or predictive maintenance algorithms.
d. Şen and Kul [29] proposed an IoT-based wireless condition monitoring system for induction motors using a TCP/IP communication protocol to enable continuous remote supervision. The system monitored motor current, voltage, operating cycle, and temperature, transmitting the acquired data to a central condition monitoring system for real-time analysis. The proposed framework facilitated early fault detection, predictive maintenance, and mathematical modeling, thereby minimizing production interruptions and maintenance costs. However, the study primarily focused on wireless monitoring and data acquisition without incorporating advanced AI-based fault diagnosis techniques.
e. Amaro *et al.* [30] proposed a low-cost wireless sensor network for in-field monitoring of three-phase induction motors in industrial environments. The developed system acquired motor operating parameters such as line current, line voltage, temperature, power consumption, power factor, and load factor, and transmitted the processed information wirelessly to a central monitoring station. The proposed WSN architecture enabled continuous condition monitoring, improved maintenance planning, and enhanced motor energy efficiency through remote supervision. However, the study did not employ IoT cloud platforms, Arduino UNO, ESP8266 modules, or mobile applications, as its primary focus was on wireless sensor network implementation for industrial motor monitoring.

3. METHOD

The proposed IoT-enabled smart monitoring system for induction motors is designed to provide real-time tracking, fault detection, and remote-control capabilities for industrial applications. The methodology adopted in this work can be outlined in the following stages.

a. In system design and architecture stages, sensing layer includes sensors for measuring motor parameters such as voltage, current, speed, and temperature. Processing layer uses a microcontroller (Arduino Uno/ESP8266) for data acquisition and processing, and control signal generation and communication and cloud layer: employs IoT modules (ESP8266/NodeMCU) to transmit data to the cloud for storage, visualization, and remote access.
b. In sensor deployment stages, voltage and current sensors measure electrical parameters of the induction motor, temperature sensor (LM35/DS18B20) tracks thermal conditions to prevent overheating. Speed sensor (proximity/IR sensor) monitors motor speed for performance evaluation and the sensor modules are calibrated to ensure accurate and reliable data collection and data acquisition and processing.
c. In data acquisition and processing, sensor outputs are interfaced with the microcontroller, the microcontroller digitizes and processes the data, enabling real-time monitoring of the induction motor's operational state, and abnormal readings are flagged and used to trigger protective control actions.
d. In IoT integration and cloud connectivity, the ESP8266 module is configured to transmit processed data to an IoT cloud platform (e.g., ThingSpeak, Blynk, or MQTT server). Data is visualized in real-time on dashboards accessible via web or mobile applications and cloud storage enables historical data analysis for predictive maintenance.
e. In motor control mechanism, control signals are generated through the microcontroller to operate relays for motor ON/OFF switching. Automatic control: in case of fault detection (e.g., overcurrent and overheating), the system shuts down the motor automatically to prevent damage and manual control: operators can remotely start or stop the motor via the IoT interface.
f. In alert and notification system, the system sends real-time alerts (SMS/email/mobile app notifications) to operators when faults are detected, this ensures timely corrective actions and minimizes production downtime.
g. In testing and validation, the prototype is tested under different load and fault conditions to validate its accuracy and reliability and performance metrics such as response time, data accuracy, fault detection efficiency, and reliability are evaluated.

This amalgamation of research underscores the evolving landscape of industrial motor monitoring through IoT, emphasizing continuous monitoring, preventive maintenance, and innovative hardware implementations. The implementation involves: i) induction motors, ii) Arduino UNO, iii) ESP8266 (Wi-Fi module), iv) traic board, v) voltage sensor, vi) current sensor, vii) temperature sensor, vii) speed sensor, ix) speed controlling device, x) LCD display, xi) mobile application (Mobile Telnet), xii) others, and xiii) software specifications-Arduino compiler, MC programming language C++.

Figure 1 shows block diagram of IoT-enabled smart monitoring of induction motors, Figure 2 describe the flowchart of IoT-enabled smart monitoring of induction motors, and Figure 3 shows circuit diagram of IoT-enabled smart monitoring of induction motors.

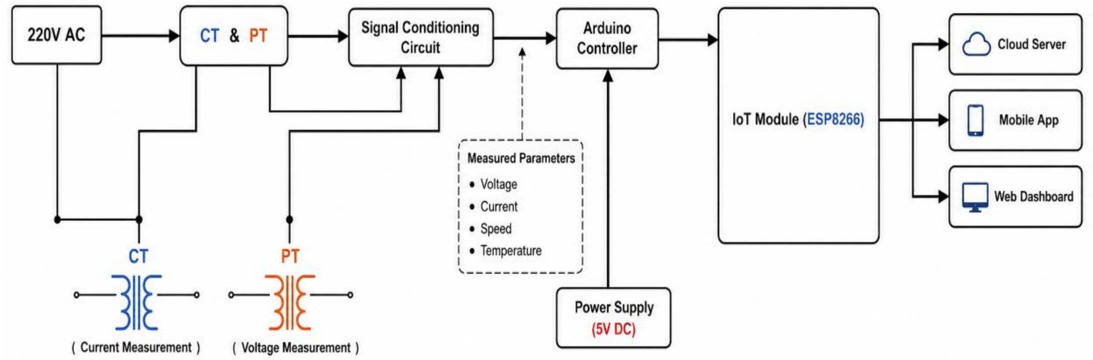

Figure 1. Block diagram of IoT-enabled smart monitoring of induction motors

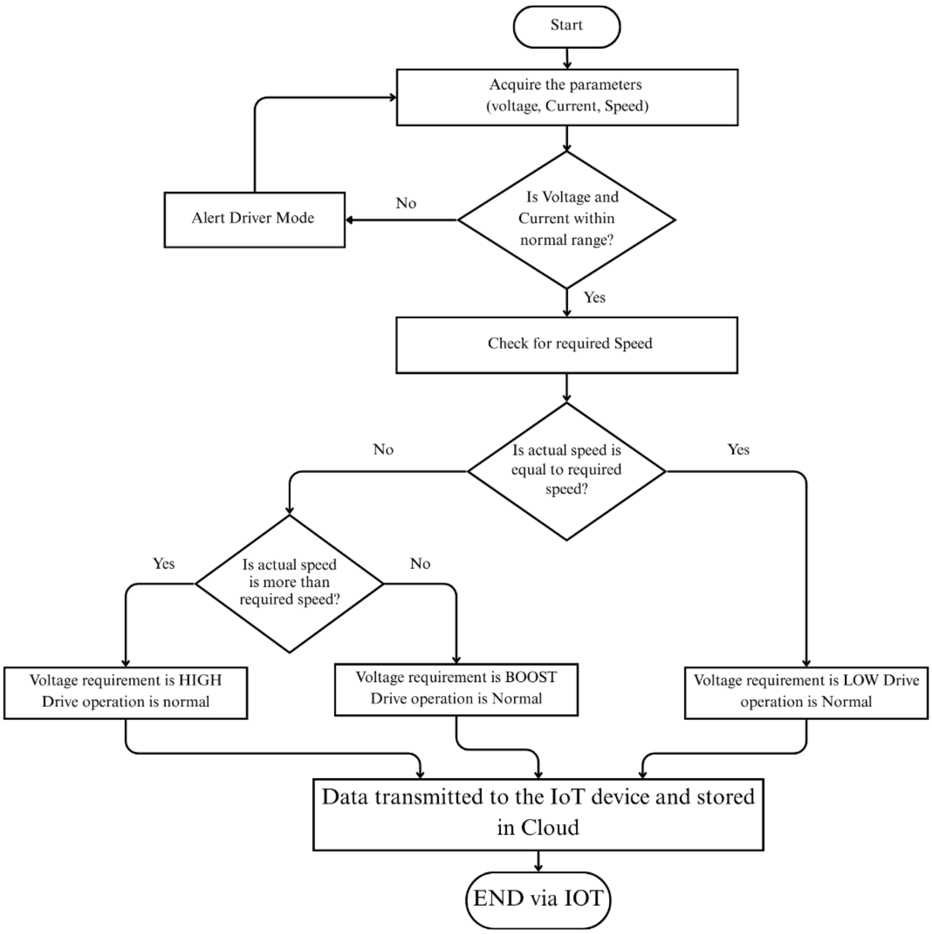

Figure 2. Flowchart of IoT-enabled smart monitoring of induction motors

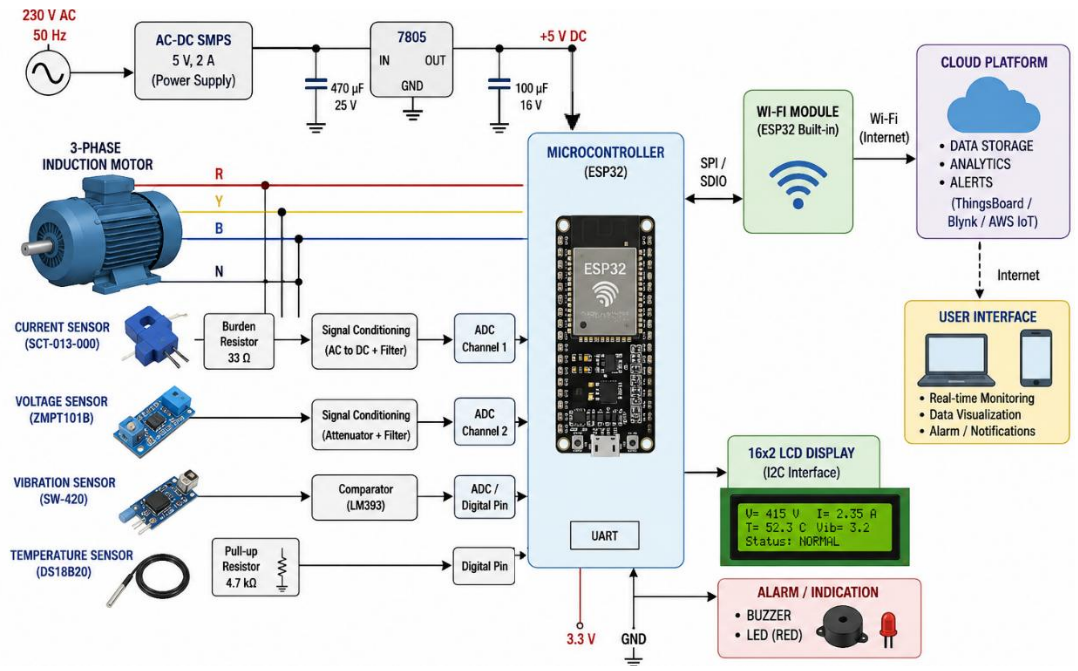

Figure 3. Circuit diagram of IoT-enabled smart monitoring of induction motors

4. EXPERIMENTAL SETUP AND RESULTS

This research introduces an IoT approach for early identification and remote monitoring of motor system problems. The system's design combines real-time data from various parameters, enhancing fault detection comprehensively. Motor system monitoring provides readings for multiple factors, including consumption, speed, temperature, and voltage, offering more data sources than conventional techniques reliant solely on temperature. The article delves into the concept of IoT in the context of remote engine monitoring and control. Through an application developed on a remote device, the data received by the coordinating node is captured and visually presented in real-time. The system simplifies the acquisition of real-time parameters for short-circuit motors, facilitating tasks that promote industry growth and motor performance. Motor parameters are monitored both in hardware and software, with the collected data sent to and stored in the cloud. The hardware settings display motor parameters and waveform visualizations on an LCD screen, allowing the observation of voltage, current, speed, and temperature values. The speed of the short-circuit motor is adjusted by applying voltage based on the values determined during device installation.

The graphic illustrates the implementation of IoT technology in a lab setting to monitor and regulate the speed and direction of several single-phase induction motors (SPIMs). Users can remotely observe the system and input commands for the motors to operate as intended. The system uses a mobile application to establish communication between the cloud and internet sources, employing an open-source program called Mobile Telnet for data transmission. The internet, now a popular and growing technology, has seen significant integration with IoT in various sectors. The study specifically focuses on motor speed control using the PWM approach and IoT-based condition monitoring parameters. The LCD displays and monitors important motor parameters such as voltage, current, speed, and temperature, enabling the generation of real-time data for communication with social media platforms and other connected devices. By integrating a hotspot module, the system facilitates the display of voltage, current, temperature, and speed waveforms through a mobile application. Continuous monitoring of motor parameters using the ThingSpeak platform enables early fault detection and generates warning notifications on the mobile application. The research emphasizes the importance of IoT-based real-time monitoring for improving motor performance, reliability, and predictive maintenance in industrial and electric vehicle applications.

Figure 4 deals with laboratory prototype of IoT-based bidirectional speed of a single-phase AC motor. Figure 5 shows monitoring parameter of voltage vs. speed. Figure 6 shows monitoring parameter of current vs. speed. Figure 7 shows IoT transmission latency over time. Figure 8 shows vibration over time. Figure 9 shows motor temperature over time and Figure 10 shows fault detection performance. The importance of constant monitoring for energy consumption and maintenance applications in the industry, ensuring the safety and protection of the motor. Practical aspects, such as creating a genuine cable, hardware mounting using a Simulink model, and viewing the LCD screen, are also covered.

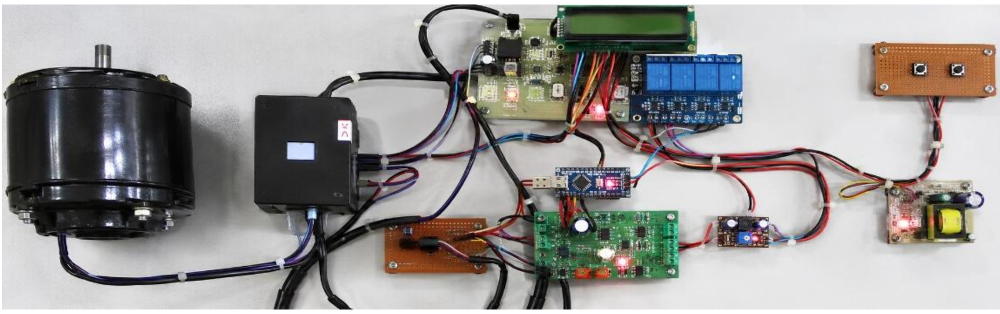

Figure 4. A laboratory prototype of IoT-based bidirectional speed of a single-phase AC motor

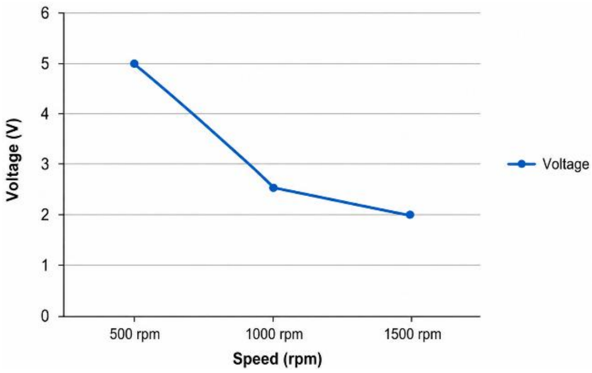

Figure 5. Monitoring parameter of voltage vs. speed

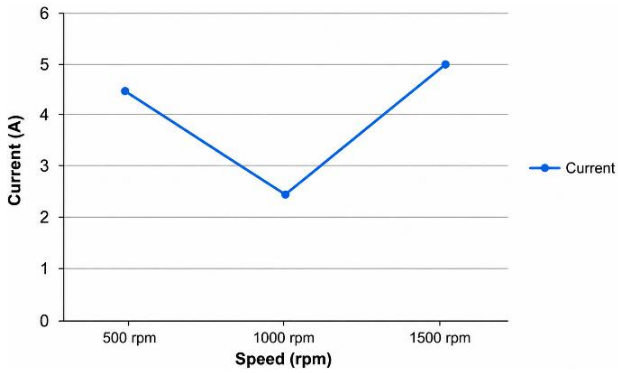

Figure 6. Monitoring parameter of current vs. speed

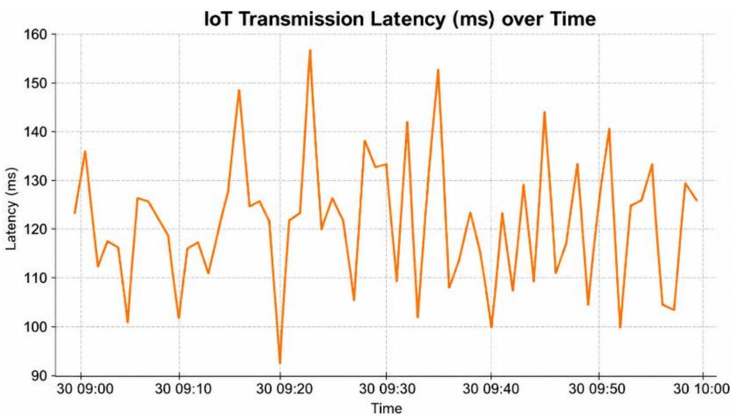

Figure 7. IoT transmission latency over time

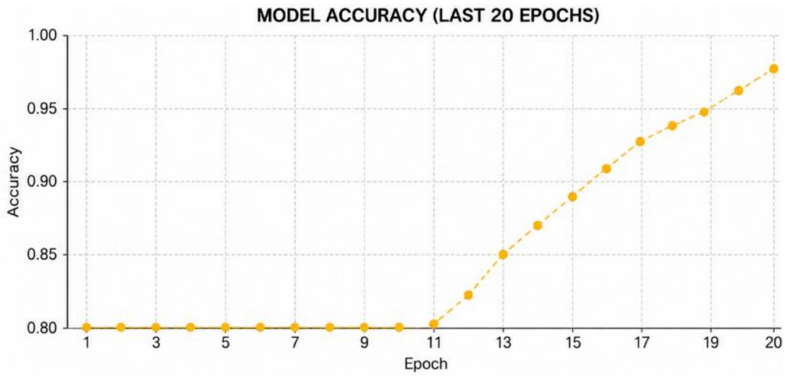

Figure 8. Vibration over time

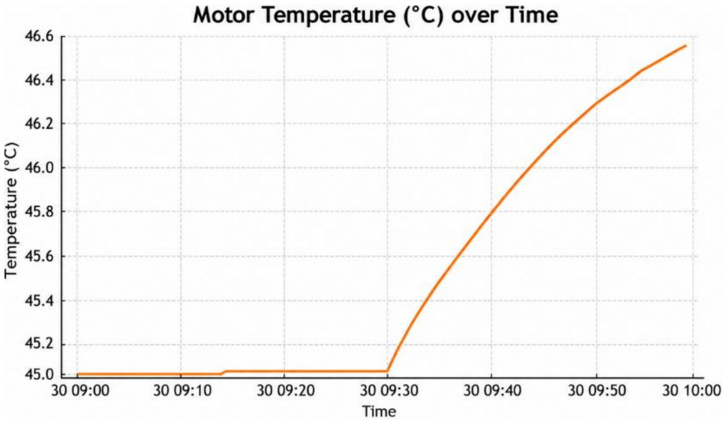

Figure 9. Motor temperature over time

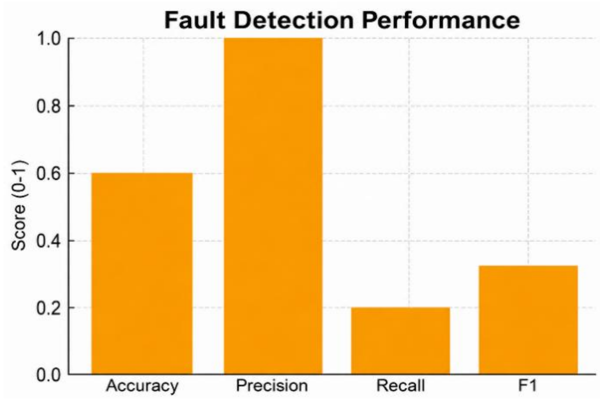

Figure 10. Fault detection performance

5. CONCLUSION

The proposed IoT-enabled smart monitoring system for induction motors demonstrates effective real-time monitoring of key parameters such as temperature, vibration, and current, improving fault detection and operational reliability in industrial environments. The findings indicate that continuous IoT-based data acquisition and remote monitoring significantly reduce unexpected motor failures and maintenance costs. The system also enhances predictive maintenance by enabling early identification of abnormal operating conditions. Overall, the implementation improves efficiency, safety, and asset management in industrial motor operations. Future work can focus on integrating advanced analytics, artificial intelligence, and cloud-based platforms to further enhance predictive diagnostics and large-scale industrial deployment.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
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R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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