IJARSCT

ISSN: 2581-9429

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Volume 6, Issue 3, May 2026

Impact Factor: 8.2

Analysis of Motor Health Monitoring and Predictive Maintenance Using IoT and Machine Learning

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Abstract: *The rapid growth of industrial automation has increased the dependence on electric motors, making their reliability and performance critically important. Unexpected motor failures can lead to significant production losses, increased maintenance costs, and safety risks. This project presents an intelligent system for motor health monitoring and predictive maintenance using IoT and machine learning techniques.*

Additionally, a relay mechanism is incorporated to automatically shut down the motor in case of abnormal conditions, ensuring safety and preventing damage. A Flask-based web dashboard provides real-time visualization, alerts, and insights to users. This system enhances operational efficiency, reduces downtime, and supports predictive maintenance strategies aligned with Industry 4.0.

Keywords: IoT, Predictive Maintenance, Machine Learning, ESP32, Raspberry Pi, Motor Health Monitoring, RUL, Smart Industry

I. INTRODUCTION

Industrial automation has significantly increased the reliance on electric motors, particularly induction motors, which play a vital role in manufacturing, processing plants, and various mechanical operations. These motors are continuously subjected to varying loads and environmental conditions, making them prone to wear and failure over time. Unexpected motor breakdowns can lead to costly downtime, reduced productivity, and safety hazards in industrial environments. Traditional maintenance strategies such as reactive and preventive maintenance often fail to detect faults at an early stage, resulting in inefficient operation and increased operational costs (1). Therefore, there is a growing need for intelligent systems that can monitor motor health in real time and predict potential failures before they occur (2). With the advancement of the Internet of Things (IoT), it has become possible to connect physical devices and sensors to collect and transmit real-time data for analysis. IoT-based monitoring systems enable continuous tracking of key motor parameters such as temperature, current, voltage, and vibration, which are critical indicators of motor performance and condition (3). By integrating sensors like DS18B20, ACS712, and ADXL345 with microcontrollers such as ESP32, data can be efficiently collected and transmitted using lightweight communication protocols like MQTT (4). This real-time data acquisition and communication framework forms the backbone of modern smart monitoring systems, enabling remote supervision and control of industrial equipment (5).

In addition to IoT, machine learning (ML) techniques have emerged as powerful tools for analyzing large volumes of sensor data and identifying patterns associated with motor faults. ML algorithms can be trained on historical data to detect anomalies, classify fault conditions, and estimate the Remaining Useful Life (RUL) of the motor (6). Libraries such as scikit-learn provide efficient implementations of algorithms that can be deployed on edge devices like Raspberry Pi for real-time analysis (7). The combination of IoT and ML facilitates predictive maintenance, where maintenance actions are performed based on the actual condition of the equipment rather than scheduled intervals, thereby improving efficiency and reducing costs (8).

This project focuses on developing an intelligent motor health monitoring and predictive maintenance system using IoT and machine learning techniques. The system integrates sensor data acquisition, wireless communication, edge processing, and a web-based dashboard for visualization and alerts. A Raspberry Pi acts as a central server to store data, run ML models, and generate insights, while a relay mechanism ensures automatic motor protection during abnormal conditions (9). By adopting this approach, the system aims to enhance reliability, minimize downtime, and contribute to the implementation of Industry 4.0 smart manufacturing practices (10).

II. PROBLEM STATEMENT

Industrial systems heavily depend on induction motors for continuous operation, yet these motors are highly susceptible to faults caused by overheating, overcurrent, voltage fluctuations, and mechanical vibrations. Conventional maintenance approaches, such as reactive and preventive maintenance, are inefficient as they either respond after failure occurs or rely on fixed schedules without considering the actual condition of the motor. This often leads to unexpected breakdowns, increased downtime, higher maintenance costs, and reduced operational efficiency. Moreover, the lack of real-time monitoring and intelligent analysis makes it difficult to detect early warning signs of failure. Therefore, there is a critical need for an advanced system that can continuously monitor motor health parameters, analyze data intelligently, predict potential faults, and enable timely maintenance actions to ensure reliability, safety, and cost-effective industrial operations.

III. OBJECTIVES

• To develop an IoT-based system for real-time monitoring of motor health parameters such as temperature, current, voltage, and vibration.
• To design and implement a data acquisition system using ESP32 and sensors for continuous collection of motor performance data.
• To transmit sensor data efficiently using the MQTT protocol to a central server (Raspberry Pi) for processing and storage.
• To apply machine learning algorithms for fault detection, anomaly identification, and prediction of Remaining Useful Life (RUL) of the motor.
• To create a web-based dashboard and automatic protection mechanism for real-time visualization, alerts, and safe motor operation.

IV. LITERATURE SURVEY

1. Low-Cost IoT-Based Predictive Maintenance Using Vibration ‖ (2025) – Peter Kolok et al.

This paper presents a cost-effective IoT-based predictive maintenance system using ESP32 and MEMS sensors such as accelerometers and microphones to monitor machinery conditions. The system collects vibration and acoustic data continuously and applies signal processing techniques like FFT and RMS for feature extraction. Machine learning models are then used to detect anomalies and identify faults such as imbalance and wear. The study highlights that low-cost IoT solutions can achieve effective fault detection with reasonable accuracy while reducing implementation complexity and cost. The system achieved around 73% fault detection efficiency, proving its feasibility for small-scale industrial applications .

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2. IoT-enabled Predictive Maintenance for Mechanical Systems ‖ (2025) – Astro Global et al.
This research focuses on the transformation of traditional maintenance strategies into intelligent predictive maintenance using IoT technologies. The study explains how sensor networks, edge computing, and cloud infrastructure work together to enable real-time monitoring and diagnostics. It emphasizes the importance of continuous data collection and intelligent analytics for predicting failures before they occur. The paper also discusses system architectures, communication protocols, and machine learning integration, demonstrating how IoT-based predictive systems significantly improve operational efficiency and reduce downtime in industrial environments .

3. IoT-based Health Monitoring and Fault Detection of Industrial AC Induction Motor ‖ (2024) Muhammad Yousuf et al.
This paper proposes an IoT-based system for monitoring and fault detection in induction motors using multiple sensors such as temperature, vibration, current, voltage, and speed sensors. The collected data is transmitted through IoT platforms for real-time analysis and visualization. The system enhances reliability by enabling early detection of motor faults and reducing unexpected breakdowns. The study demonstrates that integrating IoT with sensor-based monitoring significantly improves maintenance efficiency and ensures safe motor operation in industrial settings .

4. Predictive Maintenance of Electric Motors Using Supervised Learning Models ‖ (2024) Amir Hossein Baradaran et al.
This research investigates the use of supervised machine learning models such as Support Vector Machines (SVM), Random Forest, k-NN, and Gradient Boosting for diagnosing motor health conditions. The study classifies motor states into categories such as healthy, requiring maintenance, or faulty. It compares different algorithms and identifies the most accurate model for fault prediction. The results indicate that machine learning models can effectively predict motor conditions and assist in maintenance scheduling, thereby reducing unplanned downtime and improving system reliability .

5. Predictive Maintenance using Machine Learning in Industrial IoT ‖ (2024) – Jesu Narkarunai Arasu Malaiyappan et al.
This paper explores the role of machine learning in industrial IoT-based predictive maintenance systems. It highlights how ML algorithms can analyze large datasets collected from IoT sensors to identify patterns and predict failures in advance. The study emphasizes that predictive maintenance reduces maintenance costs, minimizes downtime, and improves operational efficiency. It also discusses the integration of AI techniques such as deep learning and neural networks to enhance prediction accuracy and enable intelligent decision-making in smart industrial systems .

IV. WORKING OF SYSTEM

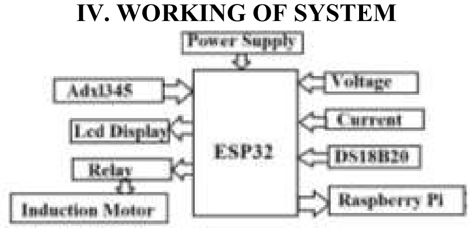

Fig 1: System architecture

A. Data Acquisition and Sensing
The system begins with real-time data acquisition from the motor using multiple sensors. A temperature sensor (DS18B20) measures the surface temperature of the motor to detect overheating conditions. The current sensor (ACS712) monitors the current drawn by the motor, which helps in identifying overload or short-circuit conditions. A voltage sensor is used to track fluctuations in the power supply, while the ADXL345 accelerometer detects vibration

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patterns that indicate mechanical faults such as imbalance or bearing wear. These sensors continuously capture analog and digital signals, providing essential parameters required for analyzing motor health.

B. IoT-Based Data Transmission

The collected sensor data is processed by the ESP32 microcontroller, which acts as the main IoT device in the system. The ESP32 converts sensor readings into digital format and transmits them using the MQTT (Message Queuing Telemetry Transport) protocol. MQTT is a lightweight communication protocol suitable for real-time applications and ensures efficient data transfer with minimal bandwidth usage. The data is sent to a central server (Raspberry Pi) through a wireless network, enabling seamless communication between hardware components.

C. Data Processing and Storage

At the receiving end, the Raspberry Pi acts as a central processing unit and data server. It subscribes to MQTT topics and collects incoming sensor data from the ESP32. The data is stored in CSV files for historical analysis and future reference. This stored data forms the dataset required for training machine learning models. The Raspberry Pi also performs initial preprocessing such as filtering noise, handling missing values, and organizing data into structured formats suitable for analysis.

D. Machine Learning-Based Fault Detection

Machine learning algorithms are implemented on the Raspberry Pi using Python libraries such as scikit-learn. The system analyzes historical and real-time data to identify patterns associated with normal and faulty motor conditions. Based on trained models, the system can detect anomalies such as overheating, excessive vibration, or abnormal current flow. It also predicts the Remaining Useful Life (RUL) of the motor, allowing maintenance to be scheduled before a failure occurs. This predictive capability enhances reliability and reduces unexpected downtime.

E. Visualization, Alert System, and Motor Protection

A Flask-based web dashboard is developed to display real-time sensor data, graphical trends, and system status. Users can monitor motor performance remotely through this interface. If any abnormal condition is detected, the system generates alerts and notifications. Additionally, a relay module is integrated to automatically cut off the motor power in case of critical faults, ensuring safety and preventing damage. This combination of visualization, alerting, and automatic protection makes the system highly efficient and user-friendly.

V. SYSTEM DESIGN

The proposed system is designed as an integrated IoT-based architecture that combines sensing, data acquisition, communication, processing, and visualization to monitor motor health and predict failures. The system follows a layered approach consisting of the sensing layer, controller layer, communication layer, processing layer, and application layer. Sensors collect real-time motor parameters, which are processed by the ESP32 microcontroller and transmitted via MQTT to the Raspberry Pi. The Raspberry Pi performs data storage, machine learning analysis, and hosts a web dashboard for visualization and alerts. A relay mechanism ensures automatic motor protection during abnormal conditions.

1. ESP32 Microcontroller

The ESP32 acts as the core controller of the system and is responsible for interfacing with all sensors. It collects real-time data such as temperature, current, voltage, and vibration, and processes it into a suitable digital format. With built-in Wi-Fi capabilities, the ESP32 transmits data using the MQTT protocol to the Raspberry Pi. Its low power consumption, high processing capability, and wireless communication features make it ideal for IoT-based applications.

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Fig 2: Microcontroller

2. DS18B20 Temperature Sensor

Fig 3: DS18B20 temperature sensor

The DS18B20 is a digital temperature sensor used to measure the motor's surface temperature. It provides accurate readings and communicates using a one-wire interface, which simplifies wiring and reduces hardware complexity. Monitoring temperature is crucial for detecting overheating conditions that may lead to insulation failure or motor damage.

3. ACS712 Current Sensor

Fig 4: ACS712 sensor

DOI: 10.48175/568

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The ACS712 sensor is used to measure the current flowing through the motor. It helps in identifying abnormal current conditions such as overload, underload, or short circuits. By continuously monitoring current, the system can detect electrical faults at an early stage and prevent damage to the motor.

4. Voltage Sensor Module

Fig 5: Voltage sensor module

The voltage sensor module measures the supply voltage provided to the motor. It helps in detecting over-voltage and under-voltage conditions that can affect motor performance and lifespan. Stable voltage monitoring ensures the motor operates within safe limits.

5. ADXL345 Vibration Sensor

Fig 6: ADXL345 accelerometer

The ADXL345 accelerometer is used to detect vibration patterns in the motor. It plays a key role in identifying mechanical faults such as misalignment, imbalance, and bearing defects. Abnormal vibration is often an early indicator of mechanical failure, making this sensor essential for predictive maintenance.

6. Raspberry Pi 4

Fig 6: Raspberry Pi

The Raspberry Pi acts as the central processing unit and server of the system. It receives data from the ESP32 via MQTT, stores it in CSV format, and processes it using machine learning algorithms. It also hosts the Flask-based web dashboard for real-time monitoring and visualization. Its ability to run Python-based applications makes it suitable for edge computing.

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7. MQTT Protocol (Mosquitto Broker)

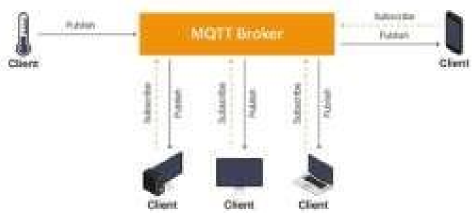

Fig 7: MQTT

MQTT is a lightweight messaging protocol used for communication between the ESP32 and Raspberry Pi. The ESP32 publishes sensor data to specific topics, while the Raspberry Pi subscribes to those topics to receive the data. This publish-subscribe model ensures efficient, reliable, and real-time data transmission.

8. Machine Learning Module (scikit-learn)

The machine learning module is implemented on the Raspberry Pi using the scikit-learn library. It analyzes historical sensor data to detect anomalies and predict motor faults. The module also estimates the Remaining Useful Life (RUL) of the motor, enabling predictive maintenance and reducing unexpected failures.

9. Relay Module

The relay module acts as a protective mechanism in the system. When abnormal conditions such as excessive temperature, current, or vibration are detected, the relay automatically disconnects the motor from the power supply. This prevents severe damage and ensures safe operation.

10. LCD Display (I2C Interface)

The LCD display is used to show real-time sensor readings such as temperature, voltage, current, and vibration levels. It provides a quick local interface for monitoring motor status without requiring access to the web dashboard.

11. Flask Web Dashboard

The Flask-based web application provides a user-friendly interface for monitoring motor health remotely. It displays real-time data, historical trends, fault alerts, and predictive insights. This dashboard enables users to make informed decisions and take timely action.

12. Power Supply Unit

The power supply unit provides the necessary voltage and current to all components in the system, including the ESP32, sensors, Raspberry Pi, and relay module. It ensures stable and reliable operation of the entire system.

VI. RESULTS

The proposed intelligent motor health monitoring system successfully demonstrated reliable real-time data acquisition, transmission, and analysis of key motor parameters such as temperature, current, voltage, and vibration. The ESP32 effectively collected sensor data and transmitted it to the Raspberry Pi using the MQTT protocol with minimal delay. The machine learning model implemented using scikit-learn accurately identified abnormal operating conditions and provided early fault predictions, including estimation of potential failures. The system also responded promptly by activating the relay mechanism to cut off power during critical conditions, ensuring motor protection. Additionally, the Flask-based web dashboard displayed live data, trends, and alerts in an intuitive manner, enabling efficient monitoring and decision-making. Overall, the system achieved improved reliability, reduced risk of unexpected breakdowns, and demonstrated its effectiveness for predictive maintenance applications.

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VII. CONCLUSION

The project successfully develops an intelligent motor health monitoring and predictive maintenance system by integrating IoT and machine learning technologies. The system enables continuous monitoring of critical parameters such as temperature, current, voltage, and vibration, ensuring real-time visibility of motor condition. The use of ESP32 for data acquisition and Raspberry Pi for processing provides an efficient and scalable architecture. Machine learning algorithms enhance the system by detecting faults early and predicting potential failures, which helps in reducing unplanned downtime and maintenance costs. The automatic relay protection further ensures safety by preventing damage during abnormal conditions. Overall, the system proves to be a cost-effective, reliable, and smart solution aligned with Industry 4.0 requirements for modern industrial applications.

VIII. FUTURE SCOPE

The system can be further enhanced by integrating cloud computing platforms such as AWS or Google Cloud to enable remote monitoring and large-scale data storage. Advanced machine learning and deep learning models can be implemented to improve prediction accuracy and handle complex fault patterns. The use of industrial-grade sensors can increase reliability in harsh environments. Mobile application integration can provide real-time alerts and control access from anywhere. Additionally, the system can be expanded to monitor multiple motors simultaneously in large industries, making it more scalable and suitable for smart factory environments. Integration with digital twin technology and edge AI can further improve decision-making and system performance.

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