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IoT-PHMNet: A Real-Time Prognostics and Health Management Framework for Industrial Motor Systems

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Abstract: Industrial motors are critical components in manufacturing, power generation, oil and gas, mining, and automated production systems, where continuous and reliable operation is essential for maintaining productivity and reducing operational losses. Unexpected motor failures caused by overheating, excessive vibration, overcurrent conditions, and electrical abnormalities can result in costly downtime and equipment damage. This study presents IoT-PHMNet, a Multi-Sensor Real-Time Prognostics and Health Management Framework for Industrial Motor Systems, designed to enable intelligent condition monitoring and predictive maintenance. The framework integrates a PZEM-004T sensor for electrical parameter measurement, a DHT11 sensor for temperature monitoring, and an ADXL335 accelerometer with a vibration sensor for mechanical fault detection. An Arduino Uno performs data acquisition and processing, while an ESP8266 NodeMCU provides wireless connectivity for cloud-based monitoring through an IoT platform. Real-time sensor data are analyzed against predefined threshold values to identify abnormal operating conditions and generate alerts. A relay-based protection mechanism automatically disconnects the motor during critical fault events. Experimental implementation demonstrates improved reliability, reduced downtime, enhanced safety, and effective maintenance decision support.
Keywords: Industrial Motors, Predictive Maintenance, Internet of Things (IoT), Prognostics and Health Management (PHM), Condition Monitoring, ESP8266 NodeMCU, Arduino Uno, Vibration Analysis, Fault Detection, Industry 4.0.

I. INTRODUCTION

The rapid advancement of Industry 4.0 technologies has transformed conventional industrial operations by enabling intelligent monitoring, automation, and data-driven decision making. The integration of the Internet of Things (IoT), cloud computing, and embedded sensing technologies has created new opportunities for improving equipment reliability, operational efficiency, and maintenance management. Modern industries increasingly require smart systems capable of continuously monitoring critical assets, detecting abnormal conditions, and supporting timely maintenance actions. Traditional maintenance strategies, including reactive and preventive approaches, often fail to provide accurate information about the actual condition of equipment, resulting in unexpected failures, unnecessary maintenance activities, and increased operational costs. Consequently, predictive maintenance has emerged as an effective solution for enhancing industrial productivity and reducing downtime. Industrial motors are among the most important assets in manufacturing plants, power generation facilities, mining operations, water treatment systems, oil and gas industries, and automated production environments. These motors drive essential equipment such as pumps, compressors, fans, conveyors, and processing machinery. Since industrial motors frequently operate under varying load conditions for extended periods, they are exposed to electrical and mechanical stresses that may lead to overheating, excessive vibration, bearing wear, shaft misalignment, insulation degradation, overcurrent conditions, and voltage fluctuations. Failure to detect such abnormalities at an early stage can result in severe equipment damage, production interruptions, safety risks, and significant financial losses. To address these challenges, this project presents IoT-PHMNet, a Multi-Sensor Real-Time Prognostics and Health Management Framework for Industrial Motor Systems. The proposed framework combines electrical and mechanical condition monitoring using a PZEM-004T multifunction sensor, DHT11 temperature sensor, ADXL335 accelerometer, and vibration sensor. Sensor data are acquired and processed through an Arduino Uno, while an ESP8266 NodeMCU enables wireless communication with a cloud-based IoT platform for remote monitoring and analysis. The framework continuously evaluates critical motor parameters and compares them with predefined operating thresholds to identify potential fault conditions. In addition, an automated relay-based protection mechanism disconnects the motor during critical events to prevent damage and enhance operational safety.

By integrating real-time monitoring, cloud connectivity, fault detection, and predictive maintenance capabilities, the proposed system contributes to improved reliability, reduced maintenance costs, extended equipment lifespan, and enhanced industrial performance in smart manufacturing environments.

II. LITERATURE SURVEY

Article[1] "An IoT and Machine Learning-Based Predictive Maintenance System for Electrical Motors" by Noor A. Mohammed and Osamah F. Abdulateef in 2023: This paper presents an intelligent predictive maintenance framework for electrical motors using Industrial IoT and machine learning techniques. The system collects real-time vibration, temperature, and current data from motors. MQTT communication is used for efficient data transfer to cloud platforms. Machine learning algorithms analyze the collected data to identify abnormal operating conditions. The proposed system supports early fault detection and minimizes unexpected equipment failures. Experimental results demonstrate improved maintenance planning and enhanced equipment reliability. The study highlights the importance of integrating IoT technologies with predictive analytics in smart manufacturing environments.

Article[2] "Predictive Maintenance Model Based on Anomaly Detection in Induction Motors: A Machine Learning Approach Using Real-Time IoT Data" by Sergio F. Chevtchenko and Monalisa C. M. dos Santos in 2023: This research proposes an anomaly detection model for induction motors using IoT sensor data. The framework utilizes vibration, temperature, and noise measurements for condition monitoring. Signal processing techniques such as FFT and Wavelet Transform are applied for feature extraction. Multiple machine learning models are evaluated to detect motor abnormalities. The system achieves a balance between detection accuracy and computational efficiency. Real-time implementation demonstrates practical applicability in industrial environments. The work contributes toward low-cost predictive maintenance solutions.

Article[3] "IoT-Driven Predictive Maintenance for Energy-Efficient Industrial Systems" by T. H. Prasad and V. Krishna in 2024: This study investigates the use of IoT technologies for predictive maintenance in industrial facilities. Various sensors continuously monitor machine health and operational performance. Predictive algorithms analyze equipment behavior to identify developing faults. The framework focuses on reducing energy consumption while improving reliability. Cloud-based monitoring enables remote supervision and decision-making. The implementation shows reduced operational costs and improved asset utilization. The research demonstrates the role of predictive maintenance in sustainable industrial systems.

Article[4] "Fault Analysis and Predictive Maintenance of Induction Motor Using Machine Learning" by Kavana Venkatesh and Neethi M in 2024: This paper develops a machine learning model for induction motor fault detection. Three-phase voltage and current signals are used as input parameters. Artificial Neural Networks are employed to classify different fault conditions. The framework identifies overvoltage, undervoltage, overload, and ground faults. Real-time motor data are used for model training and validation. The proposed approach improves fault diagnosis accuracy and supports preventive actions. Results confirm the effectiveness of machine learning for industrial motor monitoring.

Article[5] "A Deep Learning Approach for Electric Motor Fault Diagnosis Based on Infrared Thermal Images" by Lei Xu and Xiang Wang in 2024: This research introduces a thermography-based motor fault diagnosis system. Deep learning models are utilized to analyze infrared thermal images of motors. Advanced image enhancement techniques improve fault identification accuracy. The framework detects abnormal thermal patterns associated with motor degradation. Experimental evaluation shows superior performance compared with conventional approaches. The study enables non-contact monitoring of motor conditions. The proposed method supports reliable predictive maintenance applications.

Article[6] "IoT-Enhanced Predictive Maintenance for Industrial Machinery with NodeMCU Integration" by S. Rajalakshmi and K. Bhuvanesh in 2024: This paper presents an IoT-enabled monitoring framework using NodeMCU technology. Multiple sensors collect operational data from industrial machinery. Cloud connectivity provides real-time visualization and remote access. Threshold-based analysis is employed to identify abnormal equipment conditions. The framework reduces manual inspection requirements and enhances maintenance efficiency. Experimental results indicate improved fault detection capability. The research supports Industry 4.0 based smart maintenance strategies.

Article[7] "Low-Cost IoT-Based Predictive Maintenance Using Vibration Monitoring" by Panagiotis Kolok and George Papadopoulos in 2025: This study proposes an affordable predictive maintenance solution using vibration and acoustic sensing. An ESP32-based architecture is utilized for continuous condition monitoring. RMS and FFT techniques process collected sensor signals. The system detects mechanical anomalies before catastrophic failures occur. Cloud-based storage enables historical trend analysis. Experimental validation demonstrates reliable fault detection performance. The solution is suitable for small and medium-scale industrial applications.

Article[8] "Predicting Remaining Useful Life of Induction Motor Bearings Using Machine Learning" by N. Z. Zulkifli and M. N. Abdullah in 2025: This research develops a predictive framework for estimating bearing remaining useful life. Motor current signature analysis is employed for health assessment. FFT-based feature extraction techniques are integrated with machine learning models. The system predicts degradation trends and maintenance requirements. Experimental results show accurate bearing life estimation. The framework supports proactive maintenance scheduling. The study improves equipment availability and operational reliability.

Article[9] "Condition Monitoring of Electric Machines: Modern Data-Driven Approaches" by Willem Doorsamy and Anand Singh in 2025: This paper reviews modern condition monitoring methods for electrical machines. The study emphasizes data-driven maintenance strategies and intelligent analytics. Various sensing technologies and diagnostic approaches are discussed. Machine learning techniques are evaluated for fault prediction applications. The research highlights challenges associated with industrial deployment. Future opportunities involving AI and edge computing are identified. The work provides valuable guidance for predictive maintenance implementation.

Article[10] "A Review of Artificial Intelligence Techniques in Fault Diagnosis and Predictive Maintenance of Electric Machines" by Christos Zachariades and George A. Papakostas in 2025: This review examines recent advances in AI-based fault diagnosis systems. Machine learning and deep learning models are analyzed extensively. The study evaluates predictive maintenance techniques for electric machines. Various sensor technologies and feature extraction methods are compared. The review highlights improvements in reliability and operational efficiency. Challenges related to interpretability and deployment are discussed. The paper offers recommendations for future industrial applications.

Article[11] "Predictive Maintenance of Electrical Motor Applications" by A. M. Noor and M. F. Rahman in 2025: This study explores predictive maintenance techniques for industrial motor applications. Multiple monitoring parameters are used for equipment condition assessment. Data-driven analytics improve fault identification accuracy. The framework supports maintenance optimization and resource management. Experimental observations demonstrate reduced downtime and improved reliability. The study emphasizes integration with Industry 4.0 technologies. Results indicate significant benefits for industrial operations.

Article[12] "Smart Predictive Maintenance of Induction Motor Using Machine Learning" by R. Srinivasan and P. Kumar in 2025: This review discusses machine learning techniques applied to induction motor maintenance. Algorithms such as ANN, SVM, Random Forest, and Deep Learning are analyzed. The study examines fault diagnosis and remaining useful life estimation methods. Various datasets and feature extraction approaches are compared. The research highlights the effectiveness of intelligent maintenance systems. Challenges related to real-time implementation are addressed. The paper identifies future research directions in predictive maintenance.

III. PROBLEM STATEMENT

Industrial motor systems are frequently subjected to continuous operation, varying load conditions, electrical disturbances, and mechanical stress, making them vulnerable to faults such as overheating, excessive vibration, overcurrent, bearing wear, shaft misalignment, and insulation degradation. Conventional maintenance approaches primarily rely on reactive repairs after failure or preventive servicing at fixed intervals, which often result in unplanned downtime, increased maintenance costs, reduced productivity, and inefficient resource utilization. Additionally, the absence of continuous condition monitoring makes it difficult to identify early signs of motor deterioration and predict potential failures. Manual inspection methods are time-consuming and may fail to detect hidden abnormalities in real time. Therefore, a significant challenge exists in developing an intelligent monitoring solution capable of continuously assessing motor health, detecting abnormal operating conditions at an early stage, and preventing unexpected failures before they affect industrial operations and equipment reliability.

IV. OBJECTIVES

The primary objective of this study is to develop an intelligent IoT-based framework for continuous monitoring and predictive maintenance of industrial motor systems. The study aims to monitor critical parameters such as voltage, current, temperature, vibration, power consumption, and frequency in real time to assess motor health accurately. Another objective is to detect abnormal operating conditions at an early stage and generate timely alerts to prevent unexpected failures. The framework also seeks to enable cloud-based remote monitoring through wireless communication technologies. Additionally, the study focuses on improving equipment reliability, reducing maintenance costs, minimizing downtime, enhancing operational safety, extending motor lifespan, and supporting Industry 4.0-based smart industrial maintenance and automation practices.

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V. METHODOLOGY

The methodology adopted in this study focuses on developing an IoT-enabled predictive maintenance framework for industrial motor systems using multi-sensor monitoring, cloud connectivity, and automated protection mechanisms. The framework continuously acquires, processes, and analyzes motor operating parameters to identify abnormal conditions and support maintenance decisions. Figure 1 illustrates the overall system architecture of the proposed IoT-PHMNet framework and its functional components.

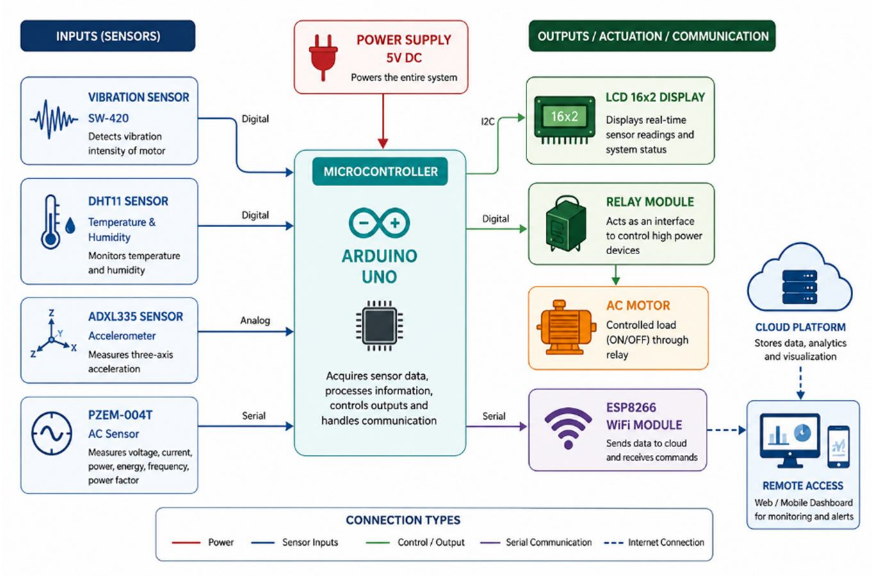

Figure 1. System Architecture of IoT-PHMNet: A Multi-Sensor Real-Time Prognostics and Health Management Framework for Industrial Motor Systems

A. Sensor-Based Data Acquisition

The first stage of the methodology involves the acquisition of real-time data from various sensors installed on the industrial motor system. A PZEM-004T sensor is utilized to measure electrical parameters including voltage, current, frequency, power factor, and power consumption. A DHT11 sensor is employed to monitor temperature conditions, while an ADXL335 accelerometer and vibration sensor are used to capture mechanical behavior and vibration characteristics. These sensors continuously collect information related to motor health and operating performance. The acquired data represent critical indicators of electrical and mechanical conditions that may influence motor reliability. Continuous sensing enables the framework to detect parameter variations and provides the necessary input for condition monitoring, fault identification, and predictive maintenance analysis throughout motor operation.

B. Data Processing and Integration

After data acquisition, the collected sensor readings are transmitted to the Arduino Uno microcontroller for processing and integration. The microcontroller acts as the central unit responsible for gathering information from multiple sensing devices and organizing it into a unified monitoring structure. Raw sensor outputs are converted into meaningful engineering values suitable for analysis and display. The processing stage ensures synchronization of electrical and mechanical parameters collected from different sources. Data validation procedures are applied to eliminate inconsistencies and improve reliability. The integrated dataset provides a comprehensive representation of motor operating conditions. This stage establishes a structured information flow that supports efficient monitoring, abnormality detection, and communication with cloud-based monitoring platforms used within the predictive maintenance framework.

C. Real-Time Condition Monitoring

The real-time condition monitoring stage focuses on continuously observing motor performance using the processed sensor data. Critical operating parameters such as voltage, current, temperature, power consumption, and vibration levels are monitored throughout motor operation. The framework evaluates parameter variations and compares current operating conditions with expected performance characteristics. Continuous monitoring allows the identification of unusual trends that may indicate developing faults or equipment degradation. A local LCD display provides immediate visualization of important measurements for operators and maintenance personnel. Real-time monitoring enhances situational awareness and enables rapid identification of abnormal operating conditions.

D. IoT-Based Cloud Communication

The communication stage utilizes an ESP8266 NodeMCU module to establish wireless connectivity between the monitoring system and a cloud platform. Sensor data processed by the microcontroller are transmitted through a Wi-Fi network to cloud storage and monitoring services. This enables remote access to real-time and historical motor information from computers, tablets, and mobile devices. Cloud communication facilitates centralized monitoring without requiring physical presence near the equipment. Data storage capabilities support long-term analysis of operational behavior and maintenance trends. Remote accessibility improves decision-making efficiency and enables maintenance personnel to supervise equipment conditions from different locations. The cloud-based architecture enhances system scalability and supports modern Industry 4.0 maintenance practices within industrial environments.

E. Fault Detection and Alert Generation

The fault detection stage analyzes monitored parameters to identify deviations from predefined operating limits. Threshold values are established for temperature, vibration, voltage, current, and other critical indicators based on acceptable motor operating conditions. Whenever measured values exceed these limits, the framework classifies the condition as abnormal and initiates an alert process. Warning notifications are generated to inform maintenance personnel about potential equipment issues requiring attention. Early detection of overheating, excessive vibration, overload conditions, and electrical disturbances helps prevent the progression of faults into severe failures. Continuous analysis of operating parameters improves maintenance effectiveness and supports condition-based maintenance strategies. This stage forms the core predictive maintenance functionality of the proposed framework.

F. Automated Protection and Maintenance Support

The final stage of the methodology focuses on equipment protection and maintenance support. A relay module is integrated with the motor control circuit to provide automatic intervention during critical operating conditions. When severe abnormalities such as excessive temperature, dangerous vibration levels, or abnormal current consumption are detected, the relay disconnects the motor from the power supply to prevent damage. This protective action enhances equipment safety and reduces the risk of catastrophic failures. Historical monitoring data stored in the cloud can be reviewed to identify performance trends and recurring issues. The collected information supports maintenance planning, fault diagnosis, and operational decision making. This methodology contributes to improved reliability, reduced downtime, and extended motor service life.

VI. EXPERIMENTAL SETUP

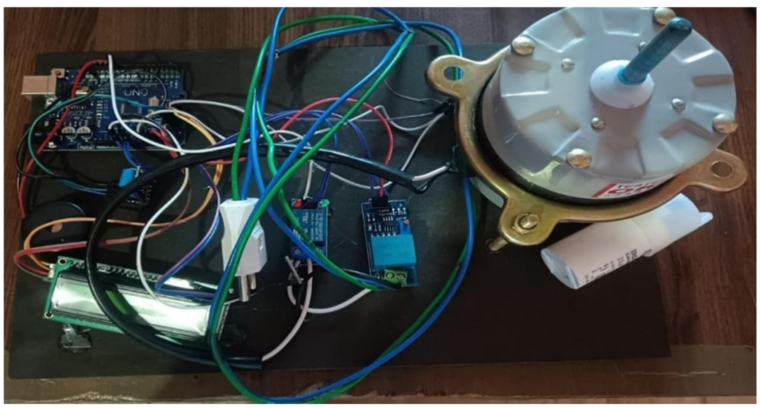

Figure 2. Hardware Prototype of IoT-PHMNet for Industrial Motor Health Monitoring and Predictive Maintenance

The developed hardware prototype integrates an Arduino Uno, LCD display, relay module, sensors, and an AC motor to implement real-time condition monitoring and predictive maintenance. The system continuously acquires electrical and mechanical parameters from the motor and processes the collected data for fault detection. Sensor readings and motor status are displayed locally through the LCD interface, while abnormal conditions can trigger automatic protection through the relay module. This prototype demonstrates the practical implementation of the proposed IoT-PHMNet framework for enhancing motor reliability, safety, and maintenance efficiency.

VII. CONCLUSION

In this research, an IoT-based prognostics and health management framework named IoT-PHMNet was developed for continuous monitoring and predictive maintenance of industrial motor systems. The framework successfully integrated multiple sensors for measuring electrical and mechanical parameters, including voltage, current, temperature, power consumption, and vibration levels. Real-time data acquisition, cloud connectivity, fault detection, and automated protection mechanisms enabled effective monitoring of motor health and operating conditions. The implementation demonstrated the capability to identify abnormal behavior at an early stage, reducing the likelihood of unexpected failures, costly downtime, and equipment damage. Remote accessibility further improved maintenance efficiency by allowing continuous supervision from any location. The proposed framework contributes to enhanced reliability, operational safety, maintenance planning, and equipment lifespan while supporting Industry 4.0 initiatives and smart manufacturing practices. Future work may focus on integrating artificial intelligence and machine learning algorithms for advanced fault prediction, remaining useful life estimation, and automated maintenance scheduling. Additional sensing capabilities, edge computing technologies, mobile applications, and large-scale industrial deployment can further improve system intelligence, scalability, accuracy, and overall maintenance effectiveness significantly.

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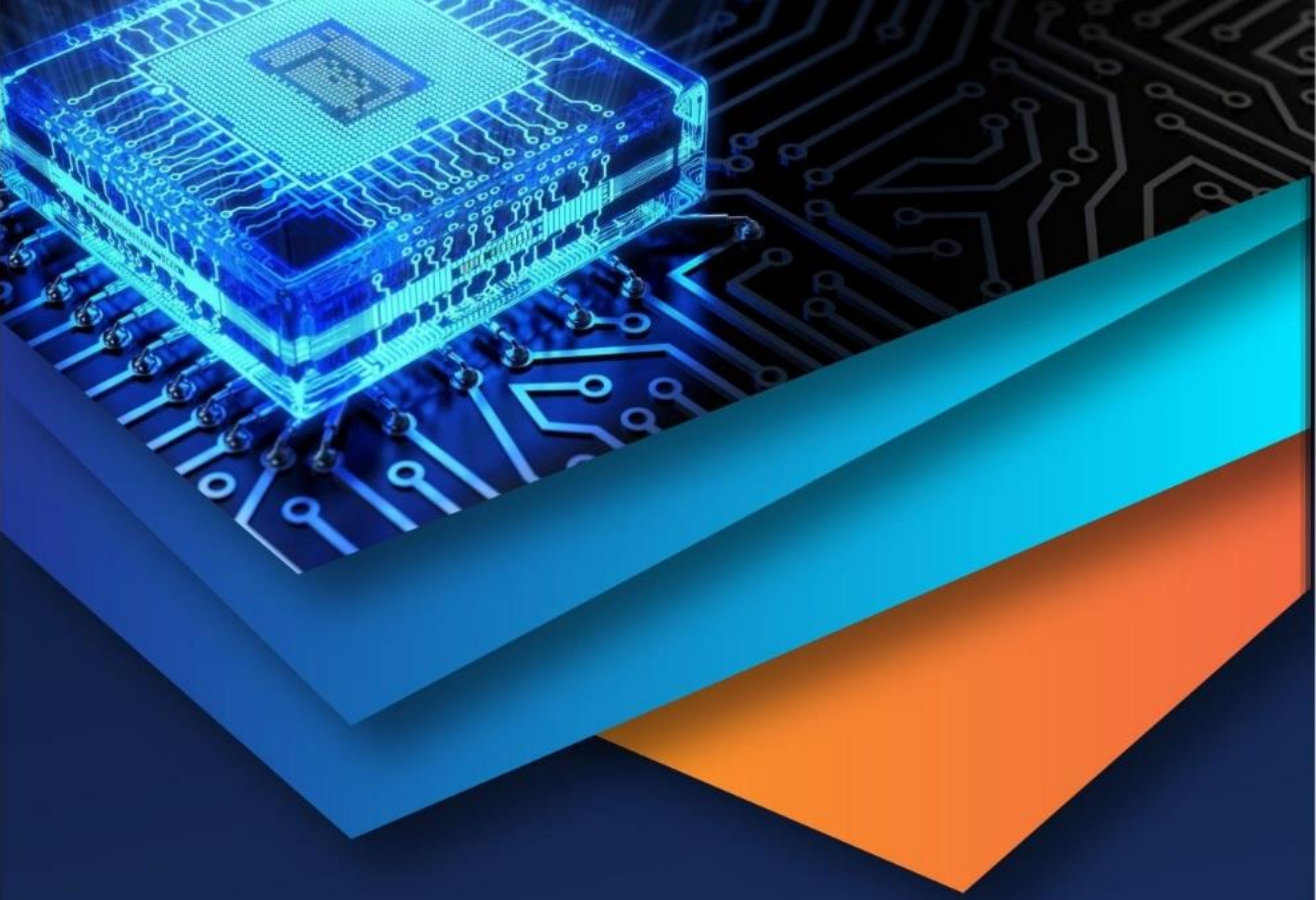

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