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Survey on Smart Embedded Platforms for Motor Condition and Severity Analysis

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***Abstract:** The significance of induction motors lies in their robustness, simplicity of design, durability, and minimum maintenance, which makes them essential components in industry. Nevertheless, constant exposure to electrical, thermal, and mechanical stresses results in problems like overheating, winding deterioration, bearing damage, rotor imbalance, and vibrations. Without timely identification of these issues, they lead to breakdowns, delays, and additional expenses. The suggested innovation refers to a smart embedded system to monitor the operational state of an induction motor and analyze fault levels in real time. It measures the parameters of temperature, currents, and vibrations that reflect motor conditions. These measurements are carried out with sensors and analyzed by means of a microcontroller through comparison with predefined thresholds, resulting in fault recognition and classification. Existing systems lack remote monitoring and instant alerts. To address these gaps, the proposed system provides local monitoring along with IoT-based remote transmission. A buzzer/LED alert mechanism ensures immediate notification during critical conditions.*

***Keywords:** Induction motors, fault detection, embedded systems, Internet-of-Things, predictive maintenance, temperature sensors, vibration sensors, current sensors, real-time monitoring, microcontrollers.*

I. INTRODUCTION

Induction motors power most machinery such as conveyors, pumps, compressors, blowers, and grinders, because they are energy-efficient, reliable, and cheap. In most factories, these are the biggest consumers of electricity, and they must operate reliably for uninterrupted production [8].

Although induction motors are rugged and durable, they are susceptible to variations in voltage, mechanical shocks, heating, vibrations, and environmental factors. These factors can cause various problems such as faulty stator windings, faulty rotor, bearing deterioration, and insulation breakdown [4].

Using preventive maintenance programs often results in unnecessary servicing or failure to service the machine until the next scheduled check-up. Consequently, today's industries are adopting condition-based and predictive maintenance strategies to detect fault anomalies at an early stage using sensor [4].

Some common parameters that can be measured to detect faults include temperature, current, voltage, vibrations, and rotational speed. Anomalies in these parameters may signal the occurrence of particular kinds of faults such as overheating which is often caused by insulation failure, vibrations from deteriorated bearings, and electrical faults in stators or rotors [3].

Recent technological breakthroughs in Internet of Things, cloud computing, and machine learning have led to better fault diagnosis capabilities. The IoT-based systems send real-time sensor data to the cloud for analysis and notifications, while machine learning methods like K-Nearest Neighbors (KNN), Support Vector Machine (SVM), and Random Forest can help diagnose faults accurately. Intelligent fault diagnosis using the latest technologies like Industry 4.0 becomes essential as industries move towards these new technologies [3, 5].

In this regard, the current proposed project 'Smart Embedded Platforms for Motor Health Fault Diagnosis' is aimed at meeting the requirement of a cost-effective fault diagnosis system based on the integration of traditional electrical engineering principles and recent technologies like sensors, microcontrollers, and IoT. Detecting faults early is very much essential. Therefore, proposing the new system prevents financial losses and save time.

II. INDUCTION MOTOR

An induction motor refers to an AC machine whose operation involves the process of conversion of electrical energy to mechanical energy through the induction process. The current in the rotor is induced in relation to the RMF (Rotating Magnetic Field), which is produced by the stator windings in accordance with Faraday's Law of induction. The RMF in this case results from the application of three-phase alternating current in the stator, and the field revolves at the synchronous speed. When the RMF cuts the rotor conductors, an EMF gets induced in the rotor that creates currents. These rotor currents interact with the stator's magnetic fields producing torque that rotates the rotor. In order for there to be an induction of rotor currents, the rotor must be behind the RMF.

A. Key Properties

Simple, robust construction with no brushes or commutators. Self-starting (three-phase types) with good overload capacity. Cost-effective, efficient, and low maintenance. Wide application: fans, pumps, compressors, conveyors, elevators.

B. Important Parameters

Key parameters include stator/rotor resistance and reactance, magnetizing reactance, synchronous speed, slip, torque, power factor, and efficiency. These quantities - typically represented in an equivalent circuit similar to a transformer - determine motor performance and are essential for health monitoring and fault analysis.

III. FACTORS AFFECTING MOTOR HEALTH

Motor health is defined as the capacity of the induction motor to function effectively for a long time period. Various issues contribute to poor motor performance:

1) Overheating: Overheating results in insulation damage, hence causing short circuits. Cooling must be effective to ensure proper operation.
2) Overloading: Overloading means operating the motor above its rating and thus exposing it to high temperatures due to high current.
3) Voltage fluctuations: Overvoltage leads to high current whereas undervoltage increases the current to maintain the same torque, thus overheating the motor. In three-phase motors, phase imbalance increases the problem.
4) Bearing wear and poor lubrication: Poor lubrication or excessive wear increases friction, hence generating heat and leading to breakdown.
5) Misalignment and vibration: Misalignment and vibration increase the mechanical and thermal stress on electrical connections and bearing of the motor.
6) Dust and moisture: Dirt in the motor causes overheating while moisture decreases insulation resistance and increases fault.
7) Insulation degradation: Mechanical, electrical, and thermal stress weakens the insulation thus resulting in high leakage and winding failure.
8) Repeated starting: Starting repeatedly leads to overheating because of large current in the winding during each start.
9) Phase failure: Single phasing causes high current in the remaining phases.

Failure due to lack of maintenance: Failure to conduct regular inspection can allow small problems such as loose connections, bearing wear, and dust accumulation to become larger problems.

IV. METHODS USED FOR MOTOR FAULT DIAGNOSIS

Motor fault diagnosis is the process of detecting and identifying faults in electrical motors to ensure reliable operation and prevent unexpected breakdowns. Various diagnostic techniques are used to monitor motor condition and detect electrical, mechanical, and thermal faults at an early stage.

A. Visual Inspection

Visual examination is one of the easiest and most widely used techniques to diagnose faults in motors. Under visual examination technique, inspectors check for any visual symptoms in the motors like overheating, burning odor, smoke, vibrations, loose joints, insulation damage, oil leaks, and strange noises. Thermal imaging can also be done through infrared thermography to locate hot spots and overheated parts that cannot be seen by the human eye. The visual examination process is cost-effective and simple, and therefore appropriate for regular inspection purposes. Nevertheless, visual examinations heavily rely on human observations and skills. Hence, visual examinations are not very accurate in diagnosing motor problems at an early stage [5].

B. Vibration Analysis

Vibration analysis is one of the methods of condition monitoring that is applied in diagnosing any faults in induction motors. The analysis involves placing sensors like accelerometers on the body of the motor to collect vibration data when the motor is operational. The collected vibration data undergoes analysis using methods like FFT and wavelets analysis to detect the faults. Mechanical faults like bearing faults, shaft misalignment, rotor imbalance, looseness, and gear faults result in vibration data with specific characteristics. Vibration analysis produces reliable information about any faults in the machine but does not produce reliable information on electrical faults like those in the stator windings [4].

C. Motor Current Signature Analysis (MCSA)

MCSA stands for Motor Current Signature Analysis and is an effective and economical approach to diagnosing faults in motors. This approach is based on analyzing the frequency components of the motor current waveforms and identifying any harmonic components that may relate to faults in the motor. Certain faults in motors exhibit specific frequencies in the current waveform. Some examples of faults that can be identified via Motor Current Signature Analysis include rotor bar breaks, stator faults, bearing faults, and air gap eccentricities. The fact that current can be obtained without stopping motor operation makes this technique popular in industry.

D. Signal Processing Techniques

Various signal processing techniques have been developed to retrieve useful information from sensor information acquired from motors. These involve analyzing signals in various domains like time, frequency, and time-frequency domains. Techniques like envelope analysis, filtering, spectral analysis, and feature extraction from statistical properties can be used to detect fault-related features from sensor signals. Parameters that are usually considered for fault diagnosis include the root mean square value, kurtosis, skewness, crest factor, and frequency. Signal processing enhances the effectiveness of fault diagnosis [5].

E. Machine Learning-Based Fault Diagnosis

There is an increasing application of machine learning approaches in smart fault diagnosis of motors because of their capacity to detect patterns from large sets of data automatically. Machine learning algorithms include K-Nearest Neighbors, Support Vector Machine, Random Forests, Artificial Neural Network, and Deep Learning models that rely on previous data gathered when the machines were in faulty states to predict future faults. These models enable accurate fault detection and classification in real-time once training is done. Machine learning saves effort through automation and scalability in practical applications. They prove very effective in predictive maintenance approaches although require large data sets for efficient training [5].

F. Motor Monitoring Using IoT

The monitoring of motor parameters through Internet of Things (IoT) systems is done remotely and in real-time. Sensors interfaced with microcontrollers, such as NodeMCU or ESP8266, constantly capture data including temperature, vibrations, voltage, and currents in the motors. The data is sent to cloud platforms through wireless technologies, which include Wi-Fi. It becomes possible for operators to check on the motor's status remotely by means of web interfaces or even mobile applications. Alerts and notifications are triggered automatically when abnormalities are detected in the system [5].

G. Edge Computing for Fault Detection

The edge computing technique is considered to be a highly sophisticated solution where the sensory data is analyzed close to the motor rather than transferring all sensory information to the cloud-based servers. The microcontroller processes the sensed signal and then makes decision about the motor status instantly. Edge computing results in reduced bandwidth consumption, decreased latency times, and reduced load on the server side. Edge computing provides faster fault detection capability. The process does not require internet connection [5].

H. Digital Twin Approach

Edge computing technology has been deemed to be a very advanced approach whereby sensory data analysis takes place near the motor without moving all sensory information to the cloud servers. In edge computing, the microcontroller analyzes the sensory signal, then decides immediately regarding the current state of the motor.

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There is less consumption of bandwidth, low latency periods, and low loading of the servers by using edge computing. Edge computing facilitates quick fault detection. No internet connection is required during the process [5].

I. *Combination of Approaches*

Today, many modern diagnostic systems utilize a variety of methods such as signal processing, machine learning algorithms, Internet of Things monitoring, vibration diagnostics, and digital twin technology in order to be more precise and reliable. Hybrid diagnostic systems can perform detection of both electrical and mechanical faults in one diagnostic session while being able to monitor and analyze data in real time. The use of several methods helps achieve high precision in fault classification, reduce false positives, and make the system flexible in various industrial conditions. Despite their increased complexity, these systems are extremely efficient [4].

J. *Conclusion*

Motor fault detection methodologies used in the current era have made motor monitoring systems much more reliable and efficient. Manual inspections that were conducted previously for detecting any type of fault in the system have been increasingly substituted by advanced motor fault detection techniques including vibration analysis, MCSA, IoT, machine learning, edge computing, and Digital Twins. With the help of such methodologies, it is possible to detect faults in the system immediately and predict any type of malfunction before it occurs.

V. COMPARATIVE ANALYSIS OF MONITORING METHODS

TABLE I Comparative Analysis of Monitoring Methods

Paper / Reference	Method Used	Parameters Monitored	Technology	Advantages	Limitations
Edge-based Deep Learning for Industrial Monitoring	Edge AI / Deep Learning	Vibration, temperature, current	Compact neural networks on edge devices	Real-time processing, low latency	Requires training data and higher compute
TinyML-based Fault Detection	TinyML	Current, vibration	TinyML on microcontrollers	Low power, suitable for embedded devices	Limited model complexity vs. cloud models
IoT-Based Fault Detection System	IoT monitoring	Temperature, current	Sensors + IoT cloud	Remote monitoring and predictive maintenance	Depends on internet connectivity
Digital Twin-Driven Predictive Maintenance	Digital Twin modeling	Bearing vibration, temperature	Virtual simulation + real-time data	Predicts faults before failure	Complex system modeling required
ML-based Condition Monitoring	Machine Learning	Vibration, temperature, acoustic	SVM, Decision Trees	High fault classification accuracy	Requires large datasets
Electric Vehicle Motor Fault Detection	ML-based predictive analysis	Current, speed, temperature	Data analytics + ML	Improves motor lifespan prediction	Training complexity
Smart Motor Monitoring with IoT	IoT monitoring	Voltage, current, temperature	IoT sensors + wireless comms	Remote monitoring and automation	Network dependency
Phase-Shift-based Fault Detection	Phase shift analysis	Current signal phase	Signal processing	Simple implementation	Limited to specific fault types
Deep Neural Network Motor Diagnosis	Deep Learning	Vibration, acoustic signals	Deep Neural Networks	Highly accurate fault classification	High computation requirement
Microcontroller-based Fault Detection	Embedded monitoring	Temperature, current	Microcontroller processing	Low cost, easy implementation	Limited intelligence without AI

VI. RESEARCH GAP

Despite a considerable amount of work being done regarding AC motor fault detection and condition monitoring, there are still many limitations associated with the available technologies. For instance, most of the existing systems concentrate on a particular parameter like vibrations, temperature, or electrical current, which negatively impacts the efficiency of the fault detection process. Another common problem associated with existing solutions is that these systems depend on the use of Internet-of-things (IoT) based platforms coupled with complex machine learning algorithms, causing delays and high levels of complexity to occur. Furthermore, most of the currently used techniques concentrate solely on fault detection while not providing any information about the fault severity and lifetime left of the motor.

VII. EXISTING SYSTEM VS. PROPOSED SYSTEM

TABLE II EXISTING SYSTEM VS. PROPOSED SYSTEM

Aspect	Existing System	Proposed System
Monitoring Method	Periodic manual inspection	Continuous real-time sensor monitoring
Fault Detection	Detected only after major failure	Early detection via temperature, current, and vibration
Maintenance Strategy	Reactive (repair after failure)	Predictive, based on motor health analysis
Data Monitoring	Limited or no real-time data	Real-time data with microcontroller processing
Technology Used	Conventional electrical measurements	Embedded system with IoT and sensor integration
Parameters Monitored	Mostly current or voltage only	Temperature, current, and vibration
Data Processing	Manual or basic circuits	Microcontroller-based intelligent processing
Fault Severity Analysis	No severity classification	Fault severity levels detected and indicated
System Intelligence	Low automation	Smart platform with automated decision-making
Reliability	Lower	Higher
Cost	Low (single sensors)	Moderate (multiple sensors)

Traditional motor monitoring systems are largely dependent upon regular inspections by personnel and use simple electrical sensors, where faults are usually detected after a considerable amount of damage has occurred.

The proposed solution eliminates these deficiencies through the implementation of a smart embedded system capable of constantly measuring temperature, current and vibrations. Sensor data is analyzed by the system's microcontroller in real-time and compared against predefined safe ranges. As a result, the proposed platform will offer real-time monitoring, fault classification based on collected data, and IoT-based remote connectivity.

VIII. BLOCK DIAGRAM OF PROPOSED SYSTEM

Architecture of the proposed system as in Figure 1. comprises of sensors such as temperature, vibration, and current that have been interfaced with the ESP32 embedded system. The collected data is processed on the basis of the set threshold limits and in case any deviation from the normal operating conditions is observed, faults in the motor can be classified as critical or non-critical based on the data analysis.

The flowchart highlights the entire process involved in the proposed intelligent embedded system. The sensor information collected through the motor is analyzed using the ESP32 microcontroller in which the fault analysis is done, followed by severity classification. The results are then presented using the monitoring dashboard and alarm system.

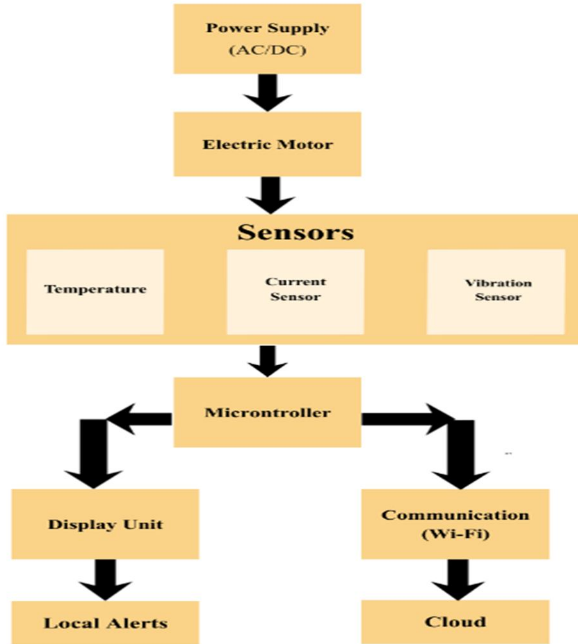

Figure 1: Block diagram of proposed system

IX. FLOW DIAGRAM OF THE PROPOSED SYSTEM

Figure 2 below shows the working process of the proposed intelligent embedded system used to perform real-time analysis of the condition of the motor as well as its fault severity. The embedded system is continuously collecting the sensor data that represents the motor's parameters, including vibration, temperature, and current, by using sensors linked with the embedded system based on the ESP32 processor. The sensor data is analyzed based on the thresholds defined to detect any fault condition. The severity of the fault is determined from the results, and accordingly, appropriate action is performed.

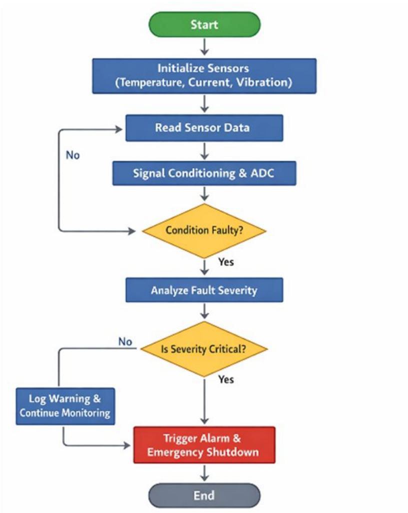

Figure 2: Flow Diagram of proposed system

The flow diagram explains the complete work method of the proposed system from the initialization of sensors to real-time data collection, detection of faults, and analysis of their severity. Under normal operational circumstances, the system continuously keeps track of motor performance and updates it in real time. In case of any abnormality, the embedded controller detects the severity of the problem and categorizes it under warning or critical conditions. In case of critical faults, the system triggers the alarm and takes necessary measures to ensure that the motor is protected from more damage.

X. APPLICATIONS

A. Motor Monitoring in Manufacturing

Various manufacturing facilities make use of motors in their conveyors, pumps, compressors, robotic systems and so forth. Monitoring of such systems' parameters in real-time allows fault detection and thus predictive maintenance and prevention of unplanned stops of production [7, 10].

B. Predictive Maintenance

As a result of analyzing sensor data in real-time, fault predictors can be determined and used to develop efficient maintenance schedules - minimizing costs and extending lifespan of equipment [15].

C. Smart Factories (Industry 4.0)

The system can easily become part of the Industry 4.0 infrastructure and send motor data to cloud analytics software to monitor several motors from a single place [1, 9].

D. Remote Monitoring of Motor Performance through IoT

Motor performance can be assessed remotely using dashboards or smartphone apps. This is especially important in large facilities where motors may be scattered throughout the plant, making manual monitoring difficult [3, 13].

E. Motor Health Monitoring in Electric Vehicles

An electric vehicle needs an engine to run. The use of sensors together with intelligent monitoring allows detecting problems and enhancing safety and reliability of the vehicle [6, 14].

F. Energy Saving

Issues such as vibration imbalances and overheating contribute to increased electrical losses. Regular monitoring allows detecting such problems earlier to avoid inefficiency [10].

G. Education and Laboratory Experimentation

The system can help students and researchers learn more about motor behavior and its performance using condition monitoring technologies.

H. Smart Buildings

Monitoring the performance of elevators, pumping stations, and other automated buildings that have motors allows ensuring their smooth operation at all times.

XI. DISCUSSION AND CONCLUSION

The suggested smart embedded device provides a solution that responds to a real need in the maintenance of industry motors. The detection of motor faults, including overheating, overload, mechanical issues such as faulty bearings or shaft misalignment, and electrical problems, is possible due to the implementation of sensors for measuring current, temperature, and vibration.

Thermometers prevent winding insulation degradation because of overheating. Overloads or electrical issues can be determined by measuring currents. Mechanical faults can be found by assessing vibration rates. Thus, the use of the three parameters discussed above gives a comprehensive picture.

The application of a microcontroller will allow determining the type of the fault based on thresholds without relying on IoT technology and clouds. Visual and sound alerts are used to notify an operator about faults instantly.

A. Advantages

Real-time, continuous monitoring eliminates the gaps inherent in periodic inspection. Multi-parameter sensing improves fault detection coverage. IoT integration enables remote accessibility. Low-cost, scalable embedded design suitable for diverse industrial applications.

B. Future Scope

The future improvements include the use of machine learning and methods to recognize complex patterns of faults, addition of acoustic and voltage harmonic sensors for the detection of faults and creation of an interactive dashboard to monitor a fleet of motors. Introduction of RUL (Remaining Useful Life) estimations will enhance the predictive maintenance functionality of the system.

In summary, the proposed system centers on the design of a smart embedded system that will be able to carry out motor condition and severity analysis using various measurements like temperature, vibration, and current. The acquisition of sensor data in real time is carried out via the embedded system developed by utilizing an ESP32, and then analysis of the parameters based on certain threshold values. The motor condition will then be classified according to the level of severity of the fault, where three major categories will include normal, warning, and critical.

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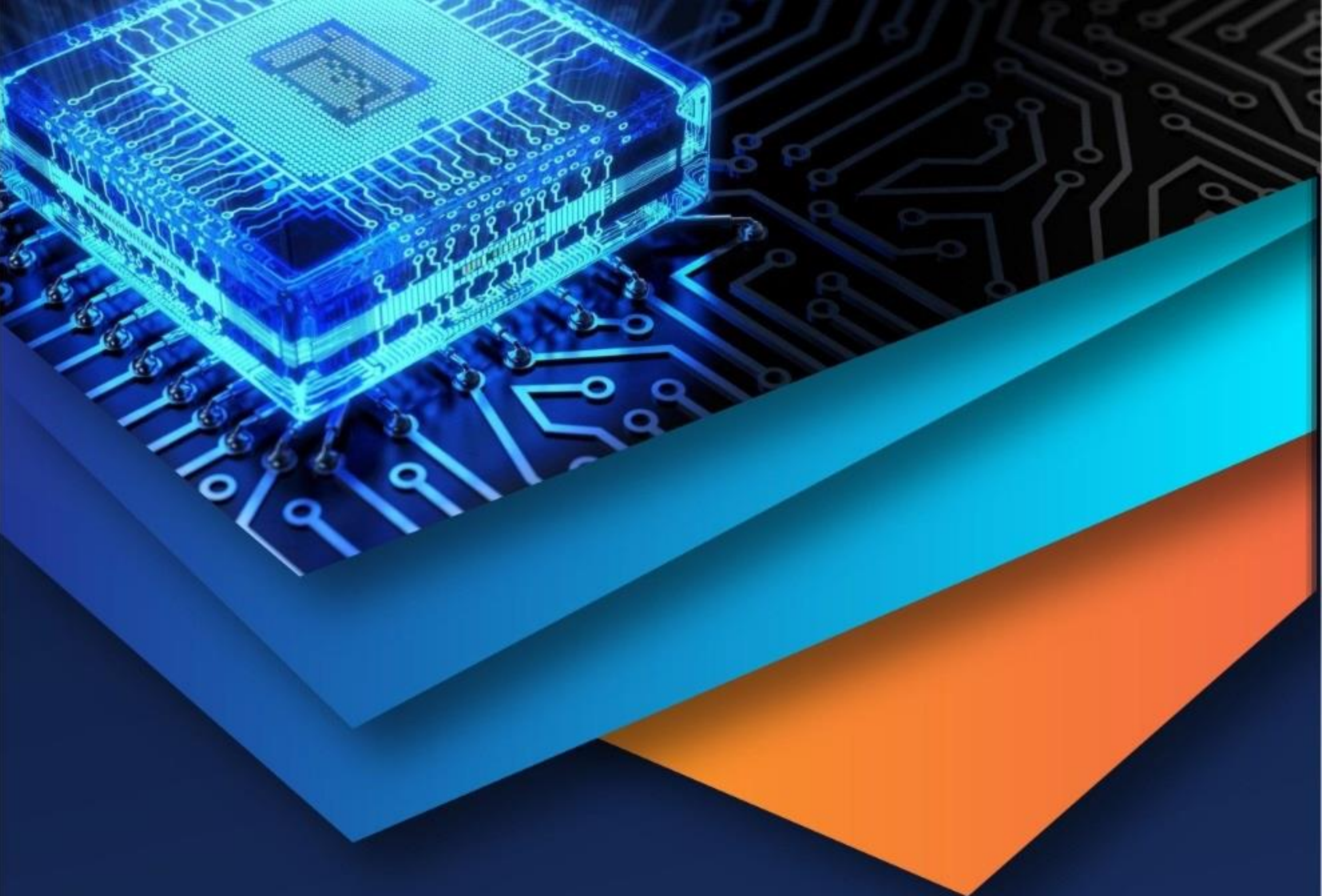

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