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A Novel IoT-Driven Battery Management System with Automated Fire Protection for Enhanced Electric Vehicle Safety

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Abstract: Electric vehicle safety has become a critical concern due to the increasing use of lithium-ion batteries, which are susceptible to overheating, thermal runaway, and fire hazards under abnormal operating conditions. This study presents a novel IoT-driven Battery Management System integrated with an automated CO_2 fire suppression mechanism for enhanced electric vehicle safety. The proposed system continuously monitors key battery parameters including voltage, current, and temperature through dedicated sensors connected to an Arduino-based control unit. Real-time data acquisition and IoT communication enable remote monitoring and instant fault notifications. When abnormal temperature rise, overcharging, or unsafe operating conditions are detected, the system automatically disconnects the battery using a relay-based protection circuit to prevent further damage. In critical situations involving fire detection, a solenoid-actuated CO_2 cylinder is triggered to suppress flames rapidly and minimize the risk of battery propagation. The integration of battery monitoring, fault protection, IoT connectivity, and automatic fire suppression improves operational reliability, battery lifespan, and user safety. Experimental evaluation demonstrates effective fault detection, timely protective actions, and enhanced protection for electric vehicle battery systems.

Keywords: Electric Vehicle (EV), Battery Management System (BMS), Internet of Things (IoT), CO_2 Fire Suppression, Thermal Runaway, Battery Safety, Temperature Monitoring, Fault Detection, Lithium-Ion Battery, Smart Protection System.

I. INTRODUCTION

The rapid growth of sustainable transportation technologies has accelerated the adoption of electric vehicles as an environmentally friendly alternative to conventional fuel-powered automobiles. Rising concerns regarding air pollution, greenhouse gas emissions, and depletion of fossil fuel resources have encouraged governments, industries, and consumers to embrace electric mobility solutions. Electric vehicles offer several advantages, including high energy efficiency, reduced operating costs, lower maintenance requirements, and minimal environmental impact. As the global demand for electric transportation continues to increase, greater emphasis is being placed on improving battery performance, reliability, and operational safety.Electric vehicle safety has become a critical area of research because lithium-ion battery packs, which serve as the primary energy source of electric vehicles, are susceptible to various operational and environmental challenges. Factors such as overcharging, excessive current flow, deep discharge, internal short circuits, and elevated temperatures can adversely affect battery performance and lifespan. In severe cases, these conditions may trigger thermal runaway, leading to battery failure, fire incidents, and significant safety risks. Consequently, advanced monitoring and protection mechanisms are required to ensure secure battery operation under varying conditions.A Battery Management System (BMS) plays a fundamental role in maintaining battery health by continuously monitoring important parameters such as voltage, current, temperature, and state of charge. The BMS helps prevent unsafe operating conditions, balances battery cells, improves charging efficiency, and extends battery life. Recent advancements in Internet of Things (IoT) technology have further enhanced battery management capabilities by enabling real-time data acquisition, remote monitoring, predictive maintenance, and instant fault notification through connected communication platforms.This study presents a novel IoT-driven Battery Management System integrated with an automated CO_2 fire suppression mechanism for enhanced electric vehicle safety. The proposed system continuously monitors battery conditions using dedicated sensors and intelligent control circuitry. IoT connectivity enables real-time supervision and rapid fault reporting, while protective relays provide automatic battery isolation during abnormal conditions. Furthermore, a CO_2-based fire suppression unit is activated upon fire detection to control thermal incidents and prevent fire propagation. The integration of battery monitoring, fault protection, remote accessibility, and automated fire mitigation contributes to improved reliability, operational efficiency, and safety of modern electric vehicle battery systems.

II. LITERATURE SURVEY

Article [1] "Smart IoT-Enabled Battery Management System for Electric Vehicle" by Karan Gupta and Vilas H. Gaidhane in 2021: This paper presents an intelligent IoT-enabled battery management system developed for electric vehicles to improve battery monitoring and operational reliability. The study focuses on real-time acquisition of battery voltage, current, and temperature parameters through interconnected sensing modules. IoT communication enables remote supervision of battery conditions and fault reporting. The proposed architecture enhances battery utilization efficiency and supports predictive maintenance. Battery protection strategies are incorporated to prevent overcharging and excessive discharge conditions.

Article [2] "AI and ML Powered IoT Applications for Energy Management in Electric Vehicles" by Mathankumar M and Gunapriya B in 2022: This research explores the integration of artificial intelligence, machine learning, and IoT technologies for advanced energy management in electric vehicles. The proposed framework continuously monitors battery behavior and energy consumption patterns. Machine learning algorithms are utilized to predict battery conditions and optimize energy utilization. The system supports intelligent decision-making for battery charging and discharging operations. IoT connectivity enables real-time data transmission and remote monitoring capabilities. The study highlights improvements in battery efficiency, operational reliability, and energy conservation. Experimental results indicate enhanced battery health management and vehicle performance.

Article [3] "Research on Fire Performance Test Technology of Electric Vehicle Power Battery System" by Zhou Li and Liao Changlong in 2022: This paper investigates fire performance characteristics of electric vehicle battery systems under various thermal conditions. The study evaluates battery behavior during overheating and thermal runaway events. Different fire testing methodologies are analyzed to understand battery safety limitations. Temperature distribution and fire propagation characteristics are examined in detail. The research emphasizes the importance of thermal monitoring systems in preventing catastrophic failures. Results provide valuable insights for designing effective fire protection mechanisms. The findings contribute significantly to battery safety enhancement in modern electric vehicles.

Article [4] "Optimization of the Energy Efficiency in Smart Internet of Vehicles Assisted by MEC" by Jiafei Fu and Pengcheng Zhu in 2023: This study proposes an Internet of Vehicles architecture supported by mobile edge computing for improving energy efficiency in electric vehicles. The framework enables intelligent battery resource management and computational task optimization. Energy consumption is minimized through optimized communication and processing strategies. The proposed approach supports battery-aware decision-making and efficient energy utilization. Advanced optimization algorithms are employed to improve vehicle performance. Simulation results demonstrate enhanced energy efficiency and battery utilization. The study highlights the role of IoT-based technologies in future electric transportation systems.

Article [5] "Optimal Battery Thermal Management for Electric Vehicles with Battery Degradation Minimization" by Yue Wu and Zhiwu Huang in 2023: This paper presents a thermal management strategy designed to reduce battery degradation in electric vehicles. The study develops an electrical-thermal-aging model to evaluate battery behavior under different operating conditions. Temperature control mechanisms are optimized to maintain safe battery operation. The proposed strategy minimizes battery aging while improving energy efficiency. Various cooling control techniques are analyzed and compared. Experimental evaluations indicate reduced battery degradation and improved lifespan. The research emphasizes the significance of thermal management in battery safety and reliability.

Article [6] "IoT-Based Smart Battery Management and Monitoring System for Electric Vehicles" by Khaleque Insia Khaleque and Md. Shahriar Hossain in 2023: This research introduces an IoT-based battery monitoring system that continuously supervises battery health and performance. The system monitors voltage, current, and temperature parameters to identify abnormal operating conditions. Real-time notifications are generated whenever unsafe battery conditions are detected. The proposed framework helps reduce the risk of battery failure and fire incidents. IoT communication supports remote monitoring and data accessibility.

Article [7] "Evaluation of Battery Management Systems for Electric Vehicles Using Traditional and Modern Estimation Methods" by Mumtaz Noreen and Mohammad Hossein Fouladfar in 2024: This paper evaluates modern battery management approaches for electric vehicle applications. The study investigates methods for estimating State of Charge and State of Health with high accuracy. Multiple sensing mechanisms are utilized for monitoring voltage, current, and temperature. IoT interfaces enable real-time visualization and battery diagnostics. Different estimation techniques are compared based on accuracy and computational efficiency.

Article [8] "Review of Electric Vehicle Battery Technologies and Safety Challenges" by D. Grebtsov and A. Ivanov in 2024: This review paper examines recent developments in electric vehicle battery technologies and associated safety challenges. Various lithium-ion battery chemistries and their performance characteristics are analyzed.

The study discusses thermal runaway risks, overheating issues, and battery degradation mechanisms. Existing battery management and thermal protection techniques are reviewed comprehensively.

Article [9] "IoT Based Battery Management System" by Raj Patel and Muhammad Nizam in 2024: This paper presents a comprehensive overview of battery management technologies used in electric vehicles and energy storage systems. The research discusses monitoring of voltage, current, temperature, and battery health parameters. Different charging strategies and battery balancing techniques are evaluated. The study highlights the importance of real-time monitoring for battery safety. IoT integration enhances data collection and predictive maintenance capabilities.

Article [10] "EV BMS with Charge Monitoring and Fire Protection" by Navajeevan and Rakesh in 2025: This paper proposes a battery management system integrated with charge monitoring and fire protection functions for electric vehicles. The framework continuously supervises battery operating conditions and identifies abnormal thermal events. Temperature monitoring mechanisms are incorporated to prevent thermal runaway. Fire detection and protective actions are implemented to enhance battery safety. The system improves charging efficiency while reducing operational risks.

Article [11] "Thermal Runaway Warning and Fire Suppression Techniques for Lithium-Ion Batteries" by P. Shi and L. Huang in 2025: This study investigates advanced warning systems and fire suppression techniques for lithium-ion batteries. The research focuses on early identification of thermal runaway conditions. Various fire suppression technologies are compared for effectiveness and response time. Battery temperature monitoring and emergency mitigation mechanisms are evaluated. The study highlights the importance of rapid intervention during battery failures.

Article [12] "Battery Management System and Fire Protection in EVs" by M. Kumar and S. Sharma in 2025: This research presents an integrated battery management and fire protection framework for electric vehicles. The proposed system combines battery monitoring, fault diagnosis, and fire detection technologies. Real-time sensing modules continuously track battery operating parameters. Protective mechanisms are activated automatically when abnormal conditions are identified. Fire suppression measures are incorporated to minimize damage caused by thermal incidents.

III. PROBLEM STATEMENT

The increasing adoption of electric vehicles has introduced significant challenges related to battery safety, reliability, and thermal management. Lithium-ion batteries are highly sensitive to overcharging, excessive current flow, deep discharge, overheating, and internal short circuits, which can result in thermal runaway and fire incidents. Existing battery protection mechanisms often provide limited real-time monitoring and delayed fault detection, increasing the risk of severe battery damage and safety hazards. Furthermore, the absence of integrated fire suppression systems can allow battery fires to spread rapidly, causing substantial losses and operational risks.

Therefore, there is a critical need for an intelligent system capable of continuous battery monitoring, early fault detection, rapid emergency response, and effective fire mitigation.

IV. OBJECTIVES

The primary objective of this study is to develop an intelligent IoT-driven Battery Management System for enhancing the safety and reliability of electric vehicle battery packs. The study aims to continuously monitor critical battery parameters such as voltage, current, and temperature to ensure safe operation under varying conditions. Another objective is to detect abnormal battery behavior at an early stage and prevent damage caused by overcharging, deep discharging, overheating, and short circuits. The study also focuses on enabling real-time remote monitoring and fault notification through IoT technology. Furthermore, it aims to incorporate an automated CO_2 fire suppression mechanism to mitigate fire hazards, improve battery protection, and enhance overall electric vehicle safety.

V. METHODOLOGY

The methodology adopted in this study focuses on developing an IoT-driven Battery Management System integrated with an automated CO_2 fire suppression mechanism for electric vehicle safety. The system continuously monitors battery voltage, current, and temperature through dedicated sensors. Real-time monitoring, fault detection, battery protection, and fire mitigation functions are incorporated. Figure 1 indicates the proposed system architecture.

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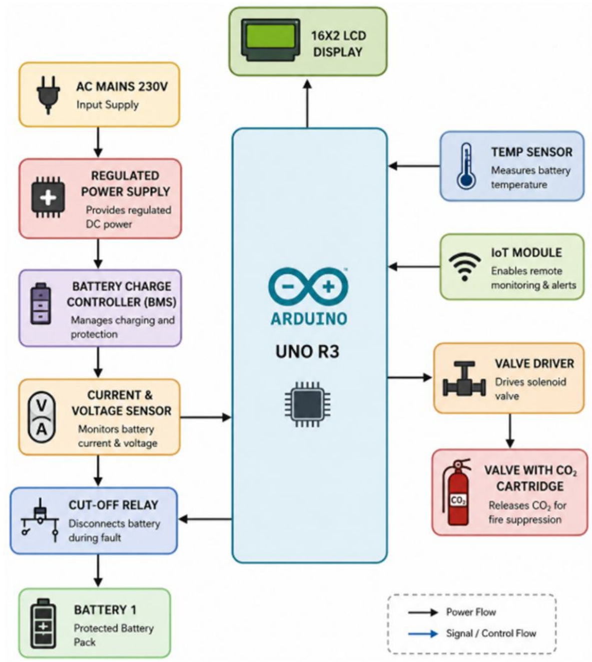

Figure 1. System Architecture of the Proposed EV Battery Monitoring and Fire Protection System

A. *Battery Parameter Monitoring*

Battery parameter monitoring forms the foundation of the proposed safety framework by continuously measuring critical operating conditions of the lithium-ion battery pack. Voltage sensors are employed to monitor battery voltage levels, while current sensors track charging and discharging currents under different load conditions. Temperature sensors are strategically positioned to detect abnormal thermal variations within the battery pack. The collected sensor data is transmitted to the central controller for processing and analysis. Continuous monitoring helps identify deviations from safe operating limits before they develop into serious faults. Accurate observation of battery parameters enables improved battery utilization, enhances operational stability, supports preventive maintenance strategies, and contributes significantly to maintaining safe and reliable battery performance throughout electric vehicle operation.

B. *Battery Management and Protection Control*

The battery management and protection module is responsible for maintaining battery operation within predefined safety limits. Sensor readings are continuously analyzed to detect conditions such as overcharging, over-discharging, excessive current flow, and abnormal temperature rise. When unsafe conditions are identified, the controller initiates protective actions to prevent battery damage and operational failures. Protective relays are utilized to isolate the battery from charging or load circuits whenever fault conditions exceed acceptable thresholds. The management system also assists in maintaining battery efficiency and extending battery lifespan through effective control strategies. This protection mechanism reduces the probability of battery degradation, minimizes operational risks, and ensures safe functioning of the electric vehicle battery system.

C. *IoT-Based Communication and Remote Monitoring*

IoT technology is incorporated to facilitate real-time communication between the battery system and remote monitoring platforms. Sensor information related to voltage, current, temperature, and fault status is transmitted through an IoT communication module to authorized users. The transmitted data can be accessed remotely for continuous supervision and analysis. Instant alerts are generated whenever abnormal battery conditions or fault events are detected. Remote accessibility improves system transparency and allows timely corrective actions before critical failures occur. Historical operational data can also be utilized for trend analysis and predictive maintenance purposes. The integration of IoT communication significantly enhances monitoring capabilities, operational awareness, and overall reliability of the battery management framework.

D. Thermal Runaway and Fire Detection

Thermal runaway detection is an essential component of the proposed system due to the fire risks associated with lithium-ion batteries. Temperature sensors continuously monitor battery heat levels and identify abnormal temperature increases that may indicate unsafe operating conditions. Additional fire detection mechanisms are incorporated to recognize early signs of combustion or thermal incidents. The controller compares sensor readings with predefined safety thresholds and evaluates potential risks in real time. Early identification of overheating conditions enables preventive measures before fire propagation occurs. This detection framework minimizes the likelihood of severe battery failures and supports rapid emergency response. Accurate thermal monitoring significantly improves battery safety and operational security in electric vehicle environments.

E. Automated CO_2 Fire Suppression Mechanism

The automated CO_2 fire suppression mechanism is designed to mitigate battery fire incidents rapidly and effectively. Upon confirmation of a fire event or critical thermal condition, the controller activates a solenoid-operated valve connected to a CO_2 cylinder. The released carbon dioxide suppresses flames by reducing oxygen concentration around the affected battery area and limiting combustion activity. Automatic activation eliminates delays associated with manual intervention and improves emergency response efficiency. The use of CO_2 is particularly suitable for electrical fire protection because it is non-conductive and leaves no residue after discharge. This suppression mechanism helps contain thermal incidents, minimize equipment damage, and enhance overall electric vehicle safety under hazardous conditions.

F. System Integration and Safety Response

System integration combines sensing modules, battery management functions, IoT communication, protection circuitry, and fire suppression components into a unified safety framework. The controller acts as the central decision-making unit by continuously collecting sensor data and coordinating protective actions. Whenever abnormal operating conditions are detected, appropriate responses such as fault notification, battery isolation, and fire suppression activation are executed automatically. The integrated architecture ensures seamless interaction among all subsystems and supports reliable operation under varying environmental and load conditions. Coordinated safety responses reduce the probability of catastrophic battery failures and improve system resilience. The integrated framework enhances reliability, operational efficiency, user safety, and overall electric vehicle protection performance.

VI. EXPERIMENTAL SETUP

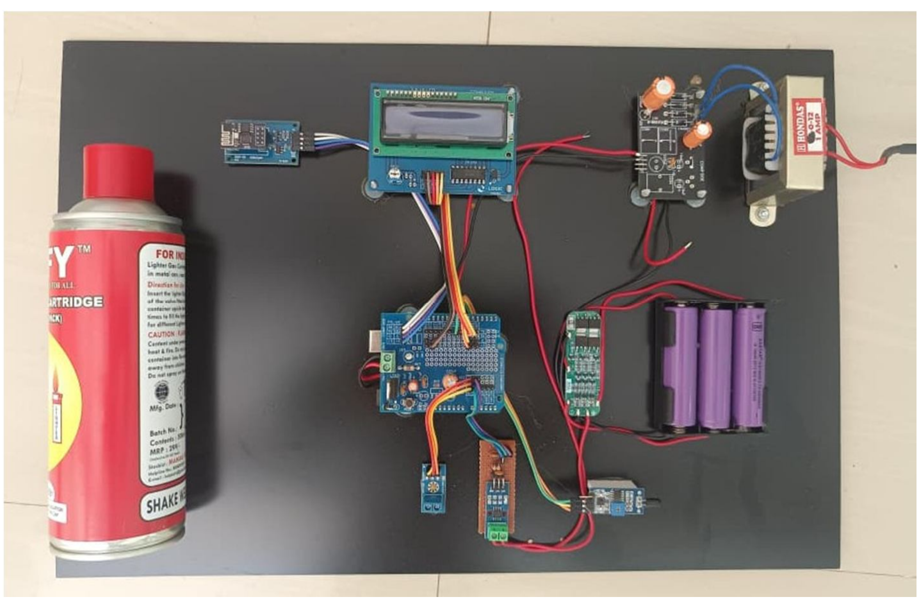

Figure 2. Experimental Prototype of the IoT-Driven Battery Management System with Automated CO_2 Fire Suppression for Electric Vehicle Safety

The developed hardware prototype integrates an Arduino-based Battery Management System, IoT communication module, voltage and temperature sensors, lithium-ion battery pack, LCD display, and CO_2 fire suppression unit. The system continuously monitors critical battery parameters and detects abnormal operating conditions in real time. Upon identifying overheating or fire-related incidents, the controller automatically initiates protective actions and activates the CO_2 suppression mechanism. This integrated framework enhances battery safety, fault management, and operational reliability in electric vehicle applications.

VII. CONCLUSION

In this research, a novel IoT-driven Battery Management System with automated CO_2 fire suppression was presented to enhance the safety, reliability, and operational efficiency of electric vehicle battery systems. The proposed framework integrated voltage, current, and temperature monitoring with intelligent protection mechanisms to continuously supervise battery conditions and identify abnormal operating states. Real-time data acquisition and IoT connectivity enabled remote monitoring and instant fault notifications, improving system awareness and response capabilities. The battery management unit effectively protected the battery pack from overcharging, excessive discharge, overheating, and other hazardous conditions that could affect performance and lifespan. Furthermore, the incorporation of an automated CO_2 fire suppression mechanism provided an additional layer of protection against thermal runaway and battery fire incidents. The integrated architecture demonstrated improved battery safety, reduced operational risks, and enhanced system reliability. Future work can focus on incorporating advanced machine learning algorithms for predictive fault detection and battery health estimation. Cloud-based analytics and digital twin technologies may further improve monitoring accuracy and maintenance planning. The integration of additional gas, smoke, and thermal imaging sensors can strengthen fire detection capabilities, while scalable battery management architectures can support larger electric vehicle platforms and next-generation energy storage systems.

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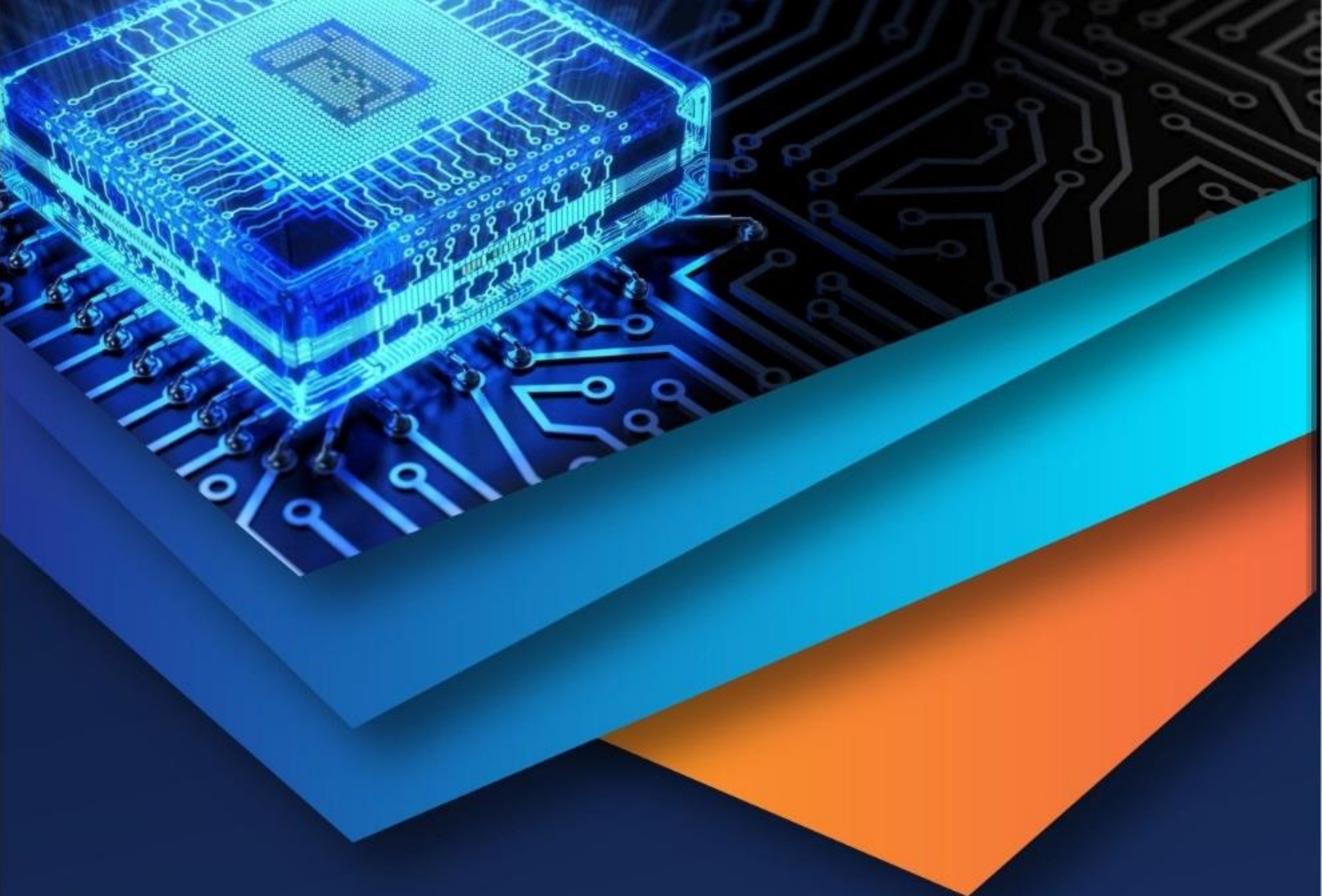

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