iJRASET
International Journal For Research in Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** IV **Month of publication:** April 2026

DOI: https://doi.org/10.22214/ijraset.2026.81355

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International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 14 Issue IV Apr 2026- Available at www.ijraset.com

IoT Based Coal Mine Safety Monitoring and Alerting System

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Abstract: ***Coal mining is a critical industry for global energy and industrial production, yet underground mining environments remain highly hazardous due to methane gas accumulation, elevated temperatures, water seepage, and fire accidents. Traditional monitoring systems are inadequate in addressing these risks, often resulting in frequent disasters and significant loss of life and property. An IoT-based coal mine safety monitoring and alerting system that integrates wireless sensor networks with cloud connectivity to enhance worker safety. The system employs DHT11 temperature sensors, MQ-2 gas sensors, and water sensors to continuously monitor environmental parameters, with data processed by the Raspberry Pi Pico and transmitted via the ESP8266 module to an IoT cloud platform. Local alerting mechanisms, including buzzers and LCD displays, provide immediate warnings to workers, while supervisors can remotely access data through the cloud dashboard. By combining real-time sensing, local alerts, and remote monitoring, the proposed system offers a scalable and reliable solution for modernizing coal mine safety infrastructure, reducing accident risks, and contributing to safer and more sustainable mining operations.***
Keywords: ***Raspberry Pi Pico, Moisture Sensor, LED, LCD Display, ESP8266 WiFi module, MQ-2, DHT11***

I. INTRODUCTION

Coal mining continues to play a vital role in industrial development, serving as a primary source of energy and raw material for industries such as steel production, cement manufacturing, and electricity generation. Despite its importance, coal mining is widely recognized as one of the most hazardous occupations due to the complex underground environment. Workers are con stantly exposed to risks such as methane gas accumulation, elevated temper atures, water seepage, and fire accidents, making safety a critical concern in mining operations.

Traditional safety monitoring systems in coal mines are often inadequate, relying heavily on manual inspections and outdated technologies. These methods fail to provide real-time alerts, resulting in delayed responses to hazardous conditions. Consequently, accidents such as explosions, suffoca tion, and flooding occur frequently, leading to severe loss of life and property. The limitations of existing systems highlight the urgent need for advanced, automated solutions that can continuously monitor underground conditions and provide immediate warnings.

The advent of Internet of Things (IoT) technology has opened new pos sibilities for enhancing safety in coal mines. IoT enables the integration of wireless sensor networks (WSN) with microcontrollers to monitor critical pa rameters such as methane concentration, temperature, humidity, and water levels. By employing sensors like MQ-2 gas sensors, DHT11 temperature sensors, moisture sensors, and flame sensors, data can be collected in real time and transmitted to cloud platforms through communication modules such as the ESP8266.

This ensures that supervisors can remotely access live data and make informed decisions to safeguard workers. 2025-2026 In addition to remote monitoring, the system incorporates local alerting mechanisms such as buzzers, LEDs, and LCD displays to provide immediate warnings to miners inside tunnels.

This dual-layered approach ensures that workers are promptly notified of unsafe conditions while supervisors maintain oversight through IoT dashboards. Such integration significantly reduces response times, improves evacuation procedures, and enhances overall safety outcomes compared to traditional monitoring methods.

The proposed IoT-based coal mine safety monitoring and alerting system is designed to be scalable, cost-effective, and reliable. It reduces dependency on human vigilance by automating hazard detection and provides flexibility for future enhancements, such as mobile app integration, miner localization, and battery backup for uninterrupted operation. By combining real-time sensing, cloud-based monitoring, and local alerts, the system represents a modern solution to one of the oldest industrial safety challenges.

II. LITERATURE SURVEY

The integration of Internet of Things (IoT) technology in coal mine safety systems has significantly improved the monitoring and management of haz ardous underground conditions. IoT-based monitoring systems have been developed to continuously track critical environmental parameters such as methane gas concentration, temperature, and humidity, enabling early de tection of dangerous situations and timely alerts to prevent accidents. These systems represent a major advancement over traditional manual inspections, which were often reactive and limited in scope.

Further developments introduced automated systems that not only mon itor these parameters but also incorporate control mechanisms to reduce human intervention. For example, IoT-enabled controllers can automatically activate ventilation fans or shut down equipment when gas concentrations exceed safe thresholds. This automation improves operational efficiency and ensures that safety measures are implemented without delay, thereby reduc ing the likelihood of accidents caused by human error.

Additionally, multi-sensor integrated systems with wireless communica tion have been designed to provide real-time alerts. These systems combine gas sensors, temperature sensors, humidity sensors, and flame detectors into a unified platform, transmitting data wirelessly to control centres. The inte gration of multiple sensors ensures comprehensive monitoring, while wireless communication enables rapid dissemination of alerts across the mining net work, minimizing risks and improving response times.

Recent research has also focused on enhancing worker safety and system automation. IoT-enabled wearable devices, such as smart helmets equipped with gas sensors and environmental monitoring units, have been introduced to ensure individual worker safety. These devices allow real-time location tracking, which is crucial for effective rescue operations in case of emergen cies. Automated detection and alert systems have been designed to identify hazardous conditions such as gas leakage or fire without manual intervention, ensuring faster and more reliable safety responses.

Comprehensive reviews of IoT-based mining systems have highlighted challenges such as network reliability, scalability, and energy consumption. Underground environments often interfere with wireless signals, while large scale deployments require efficient energy management to sustain sensor nodes over extended periods. These challenges emphasize the need for ro bust and efficient system design, incorporating fault-tolerant communication protocols and low-power hardware.

III.PROPOSED METHODOLOGY

A. Block Diagram

The block diagram representation of the IoT-based Coal Mine Safety Monitoring and Alerting System using the Raspberry Pi Pico, ESP8266 Wi-Fi module, and the ThingSpeak cloud, which works as a smart, connected safety network. In this setup, multiple sensors such as gas sensors (for methane and carbon monoxide), temperature sensors, smoke detectors, and vibration sensors are deployed inside the mine to continuously capture environmental data. The Raspberry Pi Pico acts as the central controller, collecting and processing sensor readings. It then communicates with the ESP8266 Wi-Fi module, which provides wireless connectivity and uploads the data to the ThingSpeak cloud platform. ThingSpeak not only stores the data but also offers real-time visualization through graphs and dashboards, enabling supervisors to monitor underground conditions remotely.

When sensor values exceed predefined safety thresholds, ThingSpeak can trigger alerts in the form of SMS, emails, or mobile notifications, while the Raspberry Pi Pico can simultaneously activate local alarms such as buzzers or sirens inside the mine for immediate warning. This ensures that miners are alerted quickly, and supervisors in the control room can initiate emergency protocols like evacuation or ventilation. The overall flow is: Sensors → Raspberry Pi Pico → ESP8266 Wi-Fi → ThingSpeak Cloud → Control Room Dashboard → Alerts.

This system provides real-time monitoring, remote accessibility, automated alerts, and historical data logging for predictive safety analysis. It reduces risks of accidents by ensuring quick response to hazards, though challenges like underground network reliability, sensor calibration, and stable power supply remain important consider ations. By combining low-cost hardware (Pico + ESP8266) with a free IoT cloud service (ThingSpeak), the solution is both cost-effective and scalable, making it suit able for deployment in coal mines of varying sizes.

In the cloud layer, ThingSpeak stores the incoming data, generates real-time graphs, and provides dashboards for supervisors to monitor underground conditions remotely. It also supports data logging for historical analysis and predictive safety measures. The control room accesses this dashboard to track mine conditions continu ously. If any sensor reading crosses a predefined threshold, ThingSpeak triggers alerts via SMS, email, or mobile notifications. Simultaneously, the Raspberry Pi Pico can activate local alarms (buzzers or sirens) inside the mine to warn workers immediately.

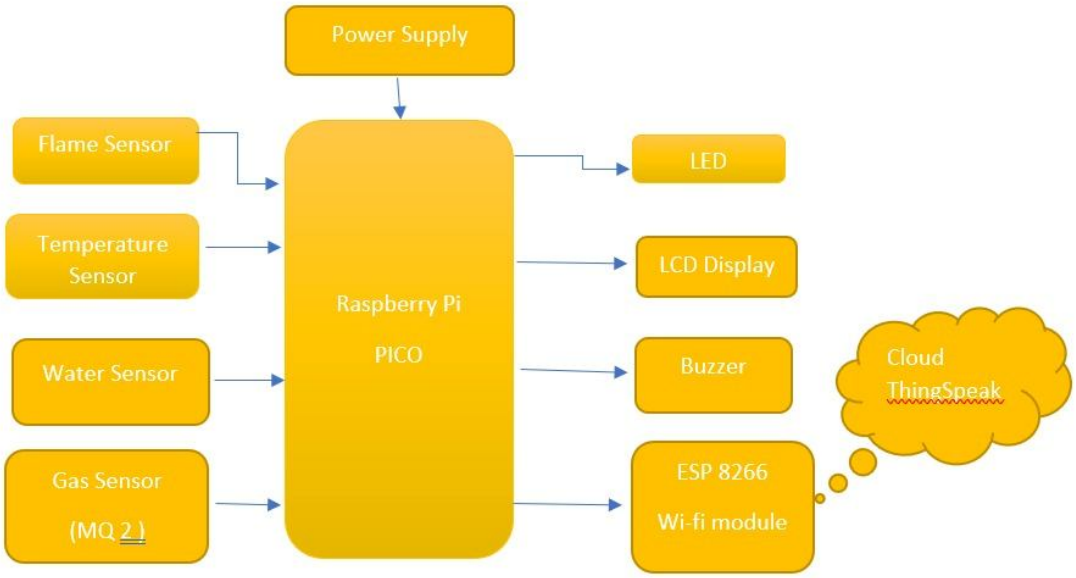

Fig. 1. System Architecture

B. Advantages

1) Real-time hazard detection: Continuous monitoring of methane, temperature, humidity, flame, and water leakage ensures early identification of dangerous conditions.
2) Automated local alerts: Buzzers, LEDs, and LCD displays provide immediate Department of ECE, AIT Tumkur 9 IoT Based Coal Mine Safety Monitoring and Alerting System 2025-2026 warnings to workers underground.
3) Remotemonitoring: Cloud platforms like ThingSpeak allow supervisors to track conditions from anywhere.
4) Worker safety enhancement: IoT wearables (e.g., smart helmets) can track worker location and personal exposure levels.
5) Predictive analytics: Data-driven insights can forecast risks before they occur, enabling proactive safety measures.
6) Reduced human intervention: Automation minimizes manual checks and human error. • Scalability: Multi-sensor networks can cover large mining areas effectively.

C. Applications

1) Worker Safety Monitoring.
2) Detects hazardous gases (methane, CO, etc.), fire, water leakage, and abnormal temperature/humidity.
3) Provides immediate alerts via buzzer, LEDs, and LCD displays to protect miners in real time.
4) Remote Supervision.
5) Cloud platforms (e.g., ThingSpeak) enable supervisors to monitor underground conditions from control rooms.
6) Supports centralized dashboards for multiple mines.
7) Predictive Risk Management.
8) Historical sensor data can be analyzed to predict potential hazards before they occur.
9) Enables proactive safety measures rather than reactive responses.
10) Emergency Response.
11) IoT-enabled wearables (smart helmets, trackers) allow real-time worker location tracking.
12) Facilitates faster rescue operations during accidents.
13) Automation of Safety Protocols.
14) Reduces reliance on manual inspections by automating hazard detection and alerting.

IV. IMPLEMENTATION

A. *Hardware Implementation*

- Microcontroller (Raspberry Pi Pico H) :- Acts as the brain of the system, processing data received from sensors. Controls communication, decision-making, and alert triggering.
- Gas sensors MQ-2 (smoke, LPG) :- Detect harmful gases like methane, carbon monoxide, and smoke in the mine. Provide analog signals indicating gas concentration levels.
- Temperature & humidity sensor (DHT11) :- Measures environmental temperature and humidity conditions. Helps detect overheating or unsafe climatic changes.
- Flame sensor:- Detects the presence of fire or flames in the mining area.
  Provides early warning to prevent fire accidents.
- Buzzer and LED alerts :- Acts as a local alert system for miners.
  Activates immediately when dangerous conditions are detected.
- LCD display:- Displays real-time sensor readings locally.
  Helps workers monitor conditions without needing a mobile device.
- Power supply:- Provides required voltage to all components.
- ESP 8266 Wifi Module:- Enables wireless communication with cloud servers.
  Transfers sensor data for remote monitoring.

B. *Software Implementation*

- Python Programming (Micropython for Thonny IDE):- Python is a high-level programming language used to process sensor data and implement system logic.
  It enables easy integration with IoT platforms for data analysis, visualization, and alert generation.
- Thonny IDE application:- Thonny is a lightweight and user-friendly development environment used for writing and debugging Python code.
  It is especially useful for programming microcontrollers like Raspberry Pi or ESP modules in IoT projects.
- ThingSpeak Cloud Platform:- Stores and visualizes sensor data in real time.
  Allows remote monitoring through dashboards.

V. RESULT

An IoT-based coal mine safety monitoring and alerting system demonstrates significant improvements in real-time hazard detection, worker safety, and operational efficiency. The results typically show that the integration of sensors for parameters such as methane gas concentration, carbon monoxide levels, temperature, humidity, and air quality enables continuous environmental monitoring inside the mine. Using wireless communication technologies and cloud or edge platforms, the system successfully transmits data with minimal latency, allowing supervisors to track conditions remotely. Experimental findings often indicate that the system can detect abnormal conditions—such as gas leaks or temperature spikes—within seconds and trigger automated alerts through alarms, mobile notifications, or control room dashboards. The reliability and accuracy of sensor readings are generally validated against standard instruments, showing high correlation and acceptable error margins. Furthermore, the system reduces the need for manual inspections, thereby minimizing human exposure to hazardous environments. Power consumption analysis highlights the feasibility of long-term deployment using battery-powered or energy-efficient modules. Overall, the results confirm that such a system enhances early warning capabilities, reduces accident risks, and supports proactive decision-making, making it a practical and scalable solution for modern coal mine safety management.

The experimental results of the IoT-based coal mine safety monitoring and alerting system further highlight its robustness, scalability, and practical applicability in hazardous mining environments. Extended testing under simulated and real mine conditions shows that the system maintains stable communication even in low-signal underground areas by using optimized wireless protocols and repeaters where necessary. Data logging over long durations demonstrates consistent performance with negligible packet loss and high system uptime, indicating reliability for continuous deployment. The alerting mechanism proves highly responsive, with threshold-based triggers activating alarms and notifications almost instantaneously when parameters exceed safe limits, thereby enabling rapid evacuation or corrective action.

Overall, the results validate that the proposed system not only enhances safety through real-time monitoring and early warning but also contributes to smarter mine management by leveraging data-driven insights, reduced operational risks, and improved emergency preparedness.

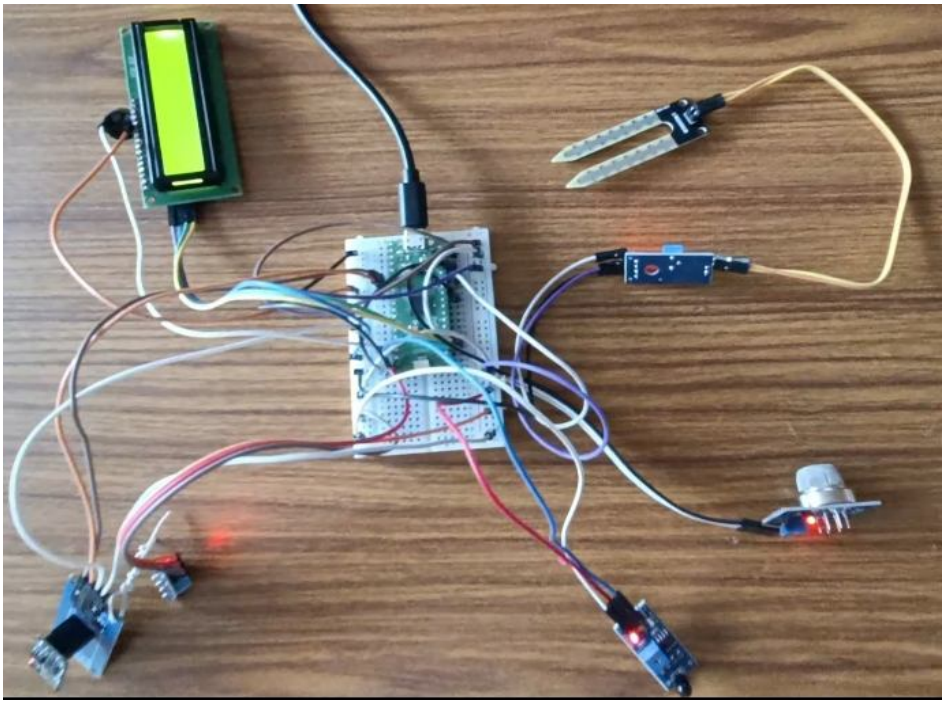

Fig. 2. Hardware Connections

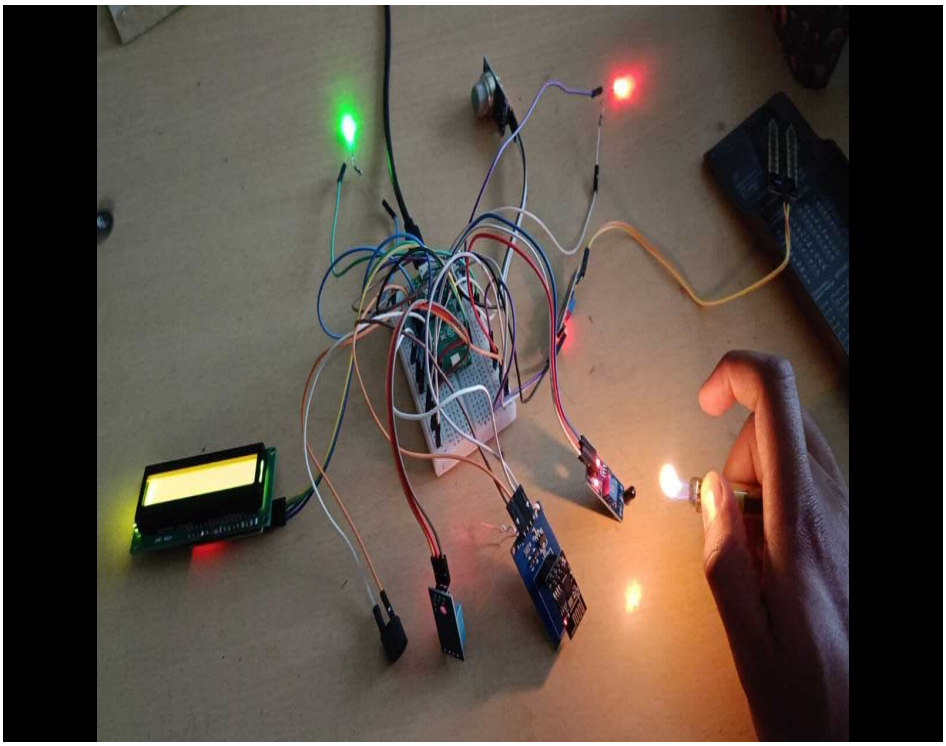

Fig. 3. LED Glow for alerts and Buzzer on

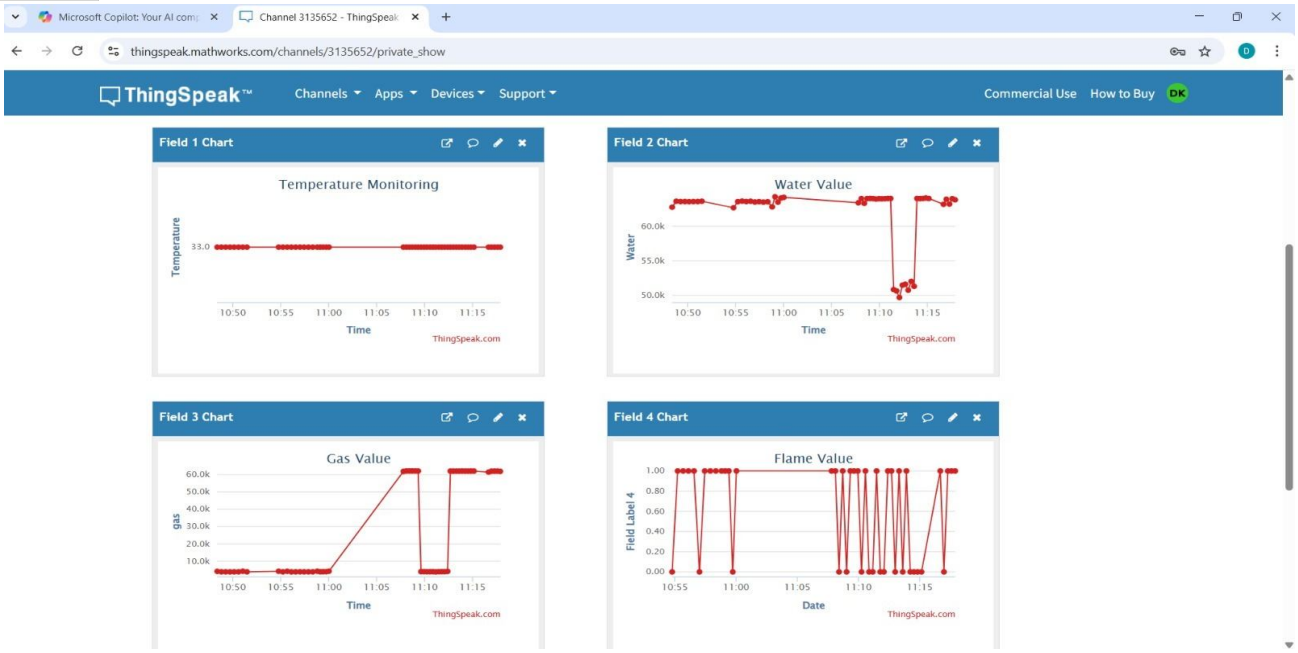

Fig. 4. ThingSpeak Cloud Output Window of data logging

VI. CONCLUSION

The IoT based Coal Mine Safety Monitoring and Alerting System presents a practical and scalable solution to one of the most hazardous industrial envi ronments. By integrating sensors for gas, temperature, humidity, flame, and structural movement with real-time data transmission, the system ensures continuous monitoring of underground conditions that are otherwise difficult to track manually. The automated alerting mechanism reduces human reac tion time during critical events like gas leaks, fires, or roof collapses, thereby minimizing risk to miners' lives.

This project bridges the gap between traditional safety protocols and modern technology, making mines smarter and safer. Further more, the system's ability to log data and send remote alerts to supervisors enhances decision-making and preventive maintenance. It reduces dependency on pe riodic manual inspections and enables a proactive safety culture instead of a reactive one. With low-cost microcontrollers and wireless modules, the so lution is cost-effective for large-scale deployment across mining operations. Overall, this project demonstrates how IoT can transform worker safety, im prove operational efficiency, and potentially save lives in the coal mining sector, aligning technological advancement with humanitarian responsibility.

In conclusion, the proposed IoT-based coal mine safety monitoring and alerting system effectively addresses critical safety challenges in underground mining environments by enabling continuous, real-time monitoring of hazardous parameters such as gas concentration, temperature.

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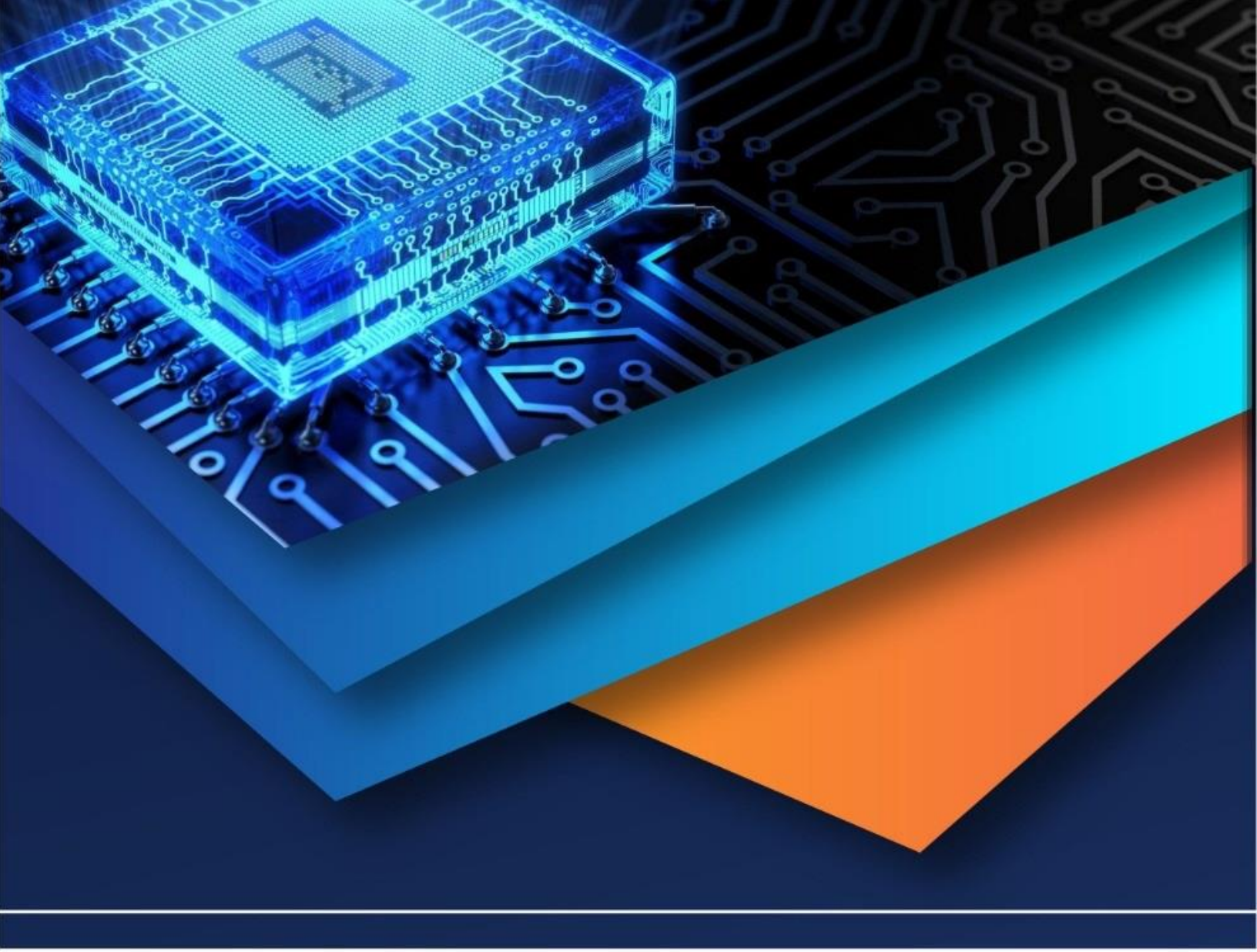

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