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Guardian ROMV – Smart Rescue Operations Monitoring Vehicle

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Abstract: The rise in natural and human-induced disasters necessitates advanced autonomous systems for rescue and surveillance. Guardian ROMV (Rescue Operations Monitoring Vehicle) is a smart rover integrated with AI, IoT, and sensor technologies designed to assist in hazardous environments. The system leverages Arduino, NodeMCU, GPS, and various sensors like gas, sound, fire/smoke, and motion detection to autonomously monitor and react to environmental conditions. Controlled via Wi-Fi or Bluetooth, the rover supports voice command operations and geo-fencing capabilities. Results from simulated tests confirm the prototype's utility in enhancing situational awareness in disaster response. This work emphasizes future integration with cloud computing and advanced AI for real-world deployment.
Keywords: Rescue Rover, IoT, AI, Arduino, NodeMCU, Environmental Monitoring, Smart Vehicle, Disaster Response

I. INTRODUCTION

In modern disaster-prone environments and hazardous zones, the demand for intelligent, autonomous monitoring and rescue systems has significantly increased. Traditional approaches such as manual surveillance, use of detection animals, or fixed Closed-Circuit Television (CCTV) systems are not only limited in coverage and flexibility but also pose serious safety risks to human operators. These conventional systems often fail to provide effective monitoring in confined spaces, unstable terrains, or areas exposed to toxic gases, fire hazards, or structural damage.

To address these limitations, the development of mobile and compact robotic systems has emerged as a promising alternative. *Guardian ROMV* (Rescue Operations Monitoring Vehicle) is a smart AI-powered rover specifically designed for real-time environmental and human activity monitoring in rescue operations. It integrates Internet of Things (IoT) technologies with sensors capable of detecting motion, fire/smoke, gas, and sound anomalies. Furthermore, it supports GPS-based geo-fencing for restricted area alerts and incorporates voice command-based control for enhanced operational flexibility.

The core design philosophy of Guardian ROMV focuses on modularity, cost-effectiveness, and deployability in dangerous or inaccessible environments. Built using components like Arduino, NodeMCU, PIR sensors, GPS modules, and gas detectors, it facilitates real-time sensing, remote navigation, and environmental data collection. In addition, a mobile application is under development to provide an intuitive user interface for remote control and monitoring.

This paper presents the complete design, implementation, and testing of Guardian ROMV. It highlights its contributions as a viable solution for enhancing situational awareness in emergency and rescue scenarios, thereby bridging the gap between safety, affordability, and technological advancement in robotics-based rescue operations.

II. LITERATURE REVIEW

Over the past decade, technological advancements in robotics and the Internet of Things (IoT) have fueled the development of intelligent systems for surveillance and rescue operations. Traditional methods of environmental monitoring—such as the deployment of personnel with handheld devices or fixed installations like CCTV—are increasingly inadequate for ensuring safety in confined, hazardous, or inaccessible environments. Studies have shown that fixed surveillance systems face limitations in flexibility, blind spot coverage, and cost-effectiveness, particularly when deployed over large areas or complex terrains [1].

To address these challenges, researchers have proposed mobile robots capable of autonomous navigation and data collection. Panfil et al. [2] introduced a mobile robot for visual inspection in ventilation ducts, but its application was restricted to narrow-use cases. Nguyen et al. [3] employed Gaussian Markov Random Fields to model environmental data using robotic sensors, demonstrating the feasibility of mobile sensing in uncertain environments. However, such models often require computationally expensive systems like laptops or PCs.

More recent efforts have focused on compact, sensor-integrated rovers that use Raspberry Pi or Arduino platforms. Razak et al. [4] developed a confined space monitoring robot, though it lacked comprehensive sensor integration. Similarly, Singh et al.
[5] designed a Raspberry Pi surveillance robot, but it relied heavily on external computing resources. Systems like iRovers [6] utilized IoT vehicles for air and noise pollution monitoring, highlighting the potential of low-cost mobile solutions but fell short on mobility in cluttered or rugged terrains.

These studies underscore the growing importance of small, autonomous systems that can operate independently in complex environments. However, many existing models either lack sensor diversity, depend on large infrastructures, or are cost-prohibitive for large-scale deployment. The proposed Guardian ROMV aims to bridge these gaps by offering a lightweight, low-cost, and multi-sensor rover capable of real-time monitoring and control through a mobile app. By combining AI, voice control, and GPS-based geofencing with core IoT functionalities, Guardian ROMV enhances operational flexibility and safety in rescue missions..

III. SYSTEMDESIGN ARCHITECTURE

The Guardian ROMV (Rescue Operations Monitoring Vehicle) is designed as a modular, low-cost, and flexible mobile rover for use in disaster response, environmental monitoring, and hazardous environments. The system integrates multiple hardware and software components to enable autonomous and semi-autonomous functionalities such as human detection, environmental hazard identification, voice-command control, obstacle avoidance, and location-based alerts. The architecture follows a hybrid model combining microcontroller-based sensor control with cloud-connected communication interfaces for data exchange and remote monitoring

A. Hardware Architecture

The hardware subsystem of Guardian ROMV comprises an integrated set of embedded components designed to facilitate autonomous sensing, navigation, environmental monitoring, and remote communication. At the center of the system is the Arduino UNO, which serves as the primary microcontroller. It handles the collection and processing of sensor data, as well as control of motors and other actuators for obstacle detection, fire and gas sensing, and motion control. The NodeMCU ESP8266 operates alongside the Arduino to provide Wi-Fi-based wireless communication, enabling data exchange with mobile applications or cloud services in real time. For environmental hazard detection, the rover is equipped with multiple sensors. An MQ-series gas sensor (such as MQ-135 or MQ-2) is used to detect harmful gases including carbon monoxide, smoke, and other airborne pollutants. A fire/smoke sensor is incorporated to provide early alerts in the presence of flames or smoke, improving safety during rescue operations.

To ensure efficient navigation, HC-SR04 ultrasonic sensors are positioned in all four directions—front, back, left, and right—allowing the rover to detect obstacles and automatically stop or reroute as necessary. A sound sensor contributes to the rover's ability to detect unusual noises or vibrations, which can be crucial in collapsed or low-visibility environments. The system also includes a Neo-6M GPS module for real-time geolocation tracking and geo-fencing, alerting users if the rover exits predefined zones. An optional camera module can be mounted to enable live video streaming or visual data analysis using computer vision. The rover's movement is facilitated by a DC motor-driven four-wheel chassis, controlled via an L298N motor driver for efficient and stable mobility over rough terrain.

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In addition, the system includes a **Neo-6M GPS module** for real-time geolocation tracking and geo-fencing. This enables the rover to operate within defined zones and send
alerts if it strays beyond them. An optional **camera module** can be mounted for video surveillance, live monitoring, or integration with computer vision systems. Mobility is provided by a **DC motor-driven Six-wheel chassis**, controlled via an **L298N motor driver**, allowing the rover to traverse rugged or debris-filled terrains with stability and precision.

B. Software Architecture

The software architecture of Guardian ROMV governs the processing of sensor data, communication between modules, user interaction, and system decision-making. It is structured into three functional layers to ensure modularity and maintainability. At the base is the Sensor Control Layer, where code written in Arduino C continuously reads real-time data from sensors such as gas, fire/smoke, ultrasonic, and sound sensors. This layer processes data locally and triggers immediate responses, such as stopping the rover upon obstacle detection or activating alerts when hazardous conditions are sensed.

The Communication Layer serves as the bridge between the sensor unit and the external environment. Using the NodeMCU , the system transmits sensor data to cloud platforms and receives control commands from the user interface. Depending on the use case, data transmission is handled through standard communication protocols such as MQTT or HTTP. For short-range scenarios, Bluetooth communication is used to enable direct pairing with a

smartphone or nearby control unit11 was also used, to detect a higher temperature change.

The top layer, the Application Layer, focuses on user interaction and data visualization. A mobileapplication using Android Studio, provides manual control of the rover, real-time display of sensor readings, and live camera feed. This app is designed to communicate with a cloud-based database, such as Firebase or a MySQL backend, allowing for centralized data logging, remote monitoring, and alert notifications. The structured software design enhances the reliability and adaptability of Guardian ROMV, ensuring smooth operation in both manual and semi-autonomous modes.

Figure1BlockdiagramoftheoverallsystemarchitectureoftheIoTbasedenvironmentalmonitoringrover

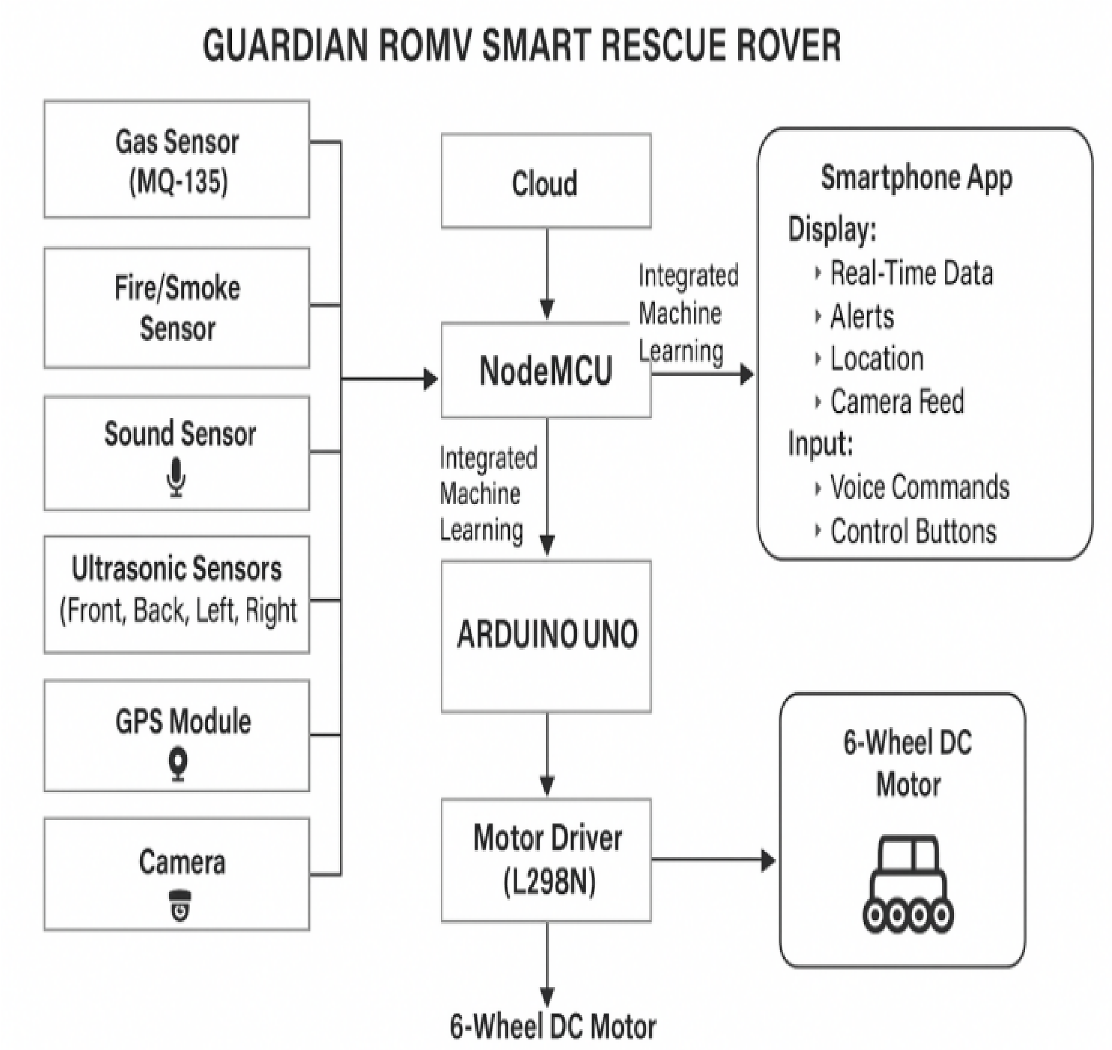


Figure2Hardwareoftheenvironmentalmonitoringrover

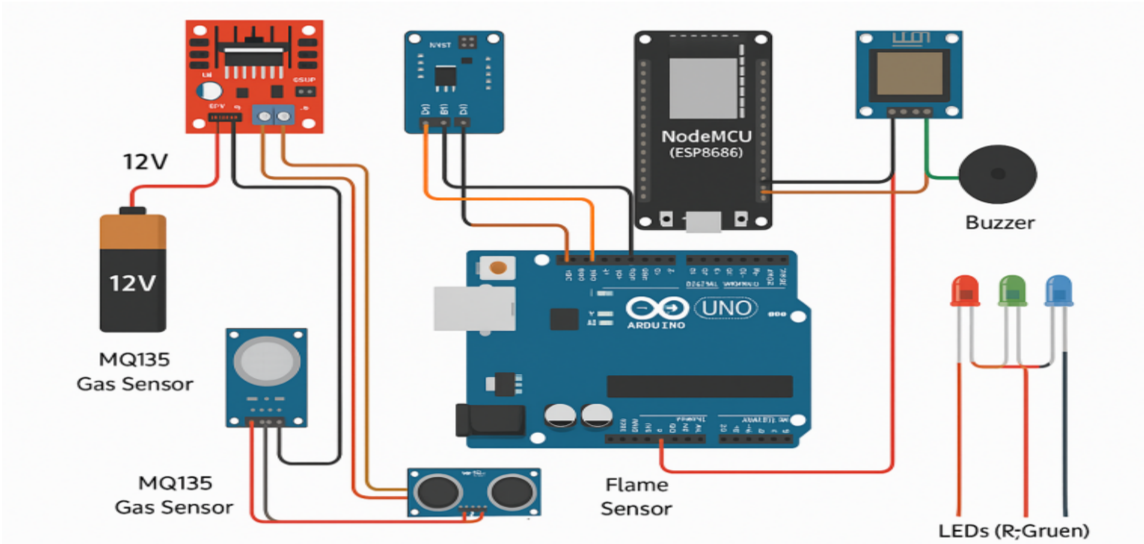
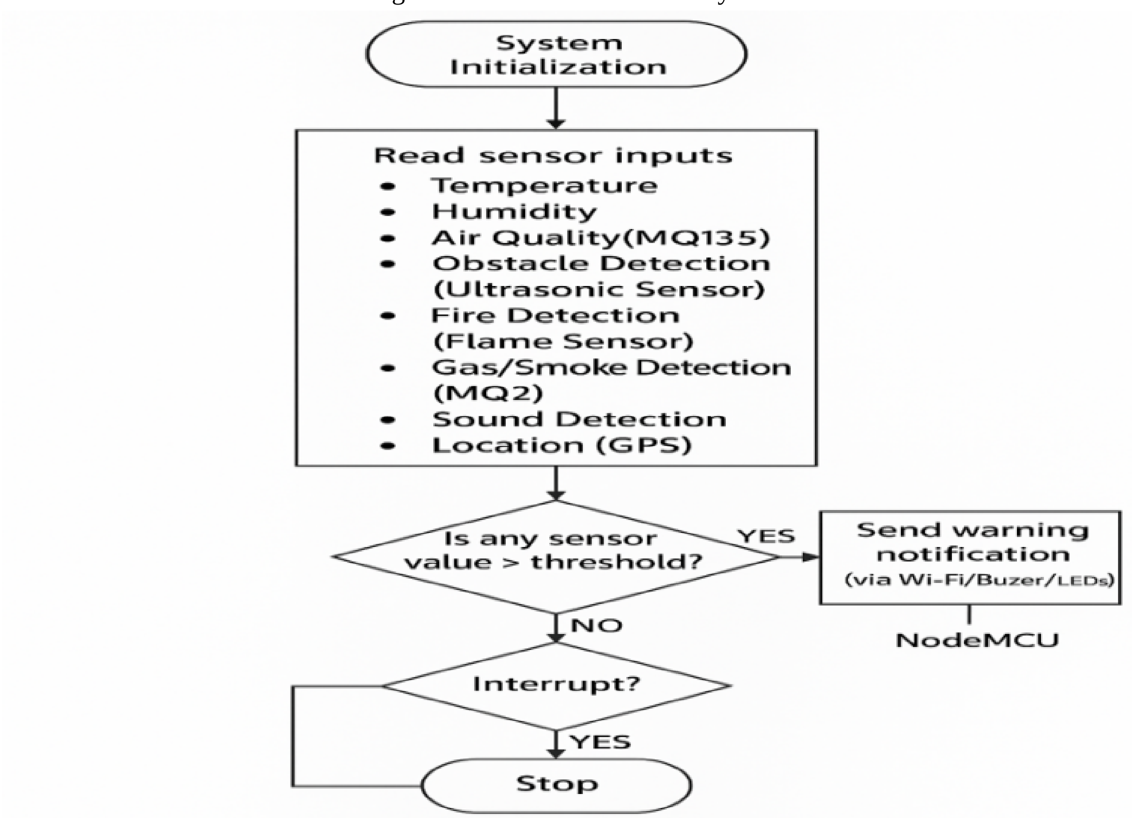


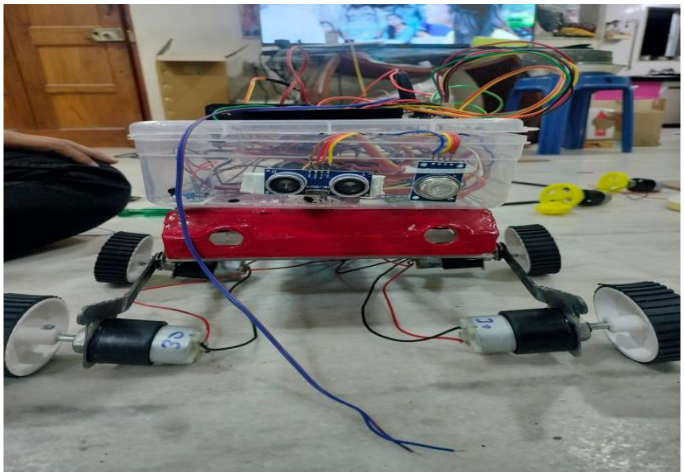
Figure 2: Hardware of the environmental monitoring rover

Figure3Theflowchartoftheroversystem

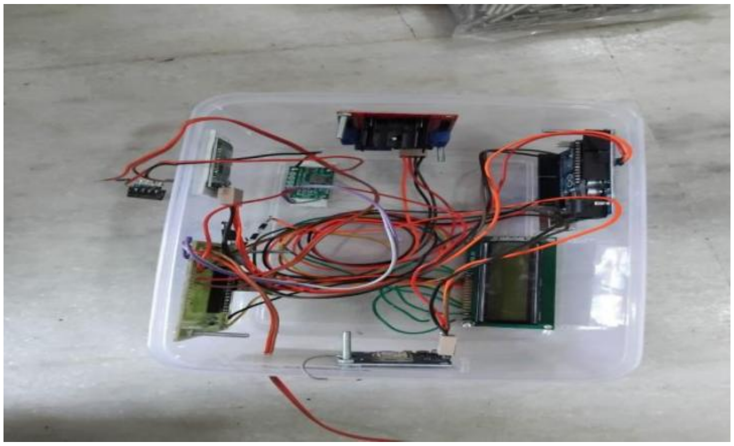


IV. RESULTS AND DISCUSSION

The Guardian ROMV prototype was tested under various simulated conditions to evaluate its ability to perform environmental monitoring and autonomous navigation in real-time. Key parameters observed include gas detection accuracy, obstacle detection reliability, geo-fencing response, and mobile app communication latency.



protectioncoveroftheroverandtosecurethecamera position of the rover. The 3D design software usedfor the drawing is Blender. The chassis of this prototype was used to gather data and conduct the monitoring of several environmental surroundings. All the sensors onboard were calibrated before the rover was assembled.



V. LIMITATIONS

While the Guardian ROMV presents a promising solution for rescue operations and environmental monitoring, several limitations currently affect its full-scale deployment and operational efficiency. One of the foremost challenges is its terrain handling capability. The six-wheel chassis design provides moderate stability on even ground, but the rover struggles significantly when navigating through highly uneven, sandy, or debris-filled terrains typical of disaster zones. Without a dedicated suspension system or terrain-adaptive wheels, its mobility remains limited in real-world conditions..

Another notable limitation is the dependency on precise sensor calibration. Sensors such as the gas detector (MQ-135), ultrasonic modules, and fire sensors can show fluctuating readings due to ambient temperature, humidity, and electromagnetic interference. This may result in false alarms or missed detections, particularly in complex or changing environments. Moreover, the accuracy of these low-cost sensors is not at par with industrial-grade alternatives, which limits the rover’s performance in high-risk scenarios where precision is critical.

Power supply remains a major constraint. The current model uses a basic lithium-ion battery setup that offers limited operational time — approximately 1 to 2 hours under continuous usage. This is inadequate for extended search and surveillance missions. The addition of real-time video streaming further accelerates battery drain. Future models must incorporate efficient power management systems, potentially using solar panels or swappable modular batteries to extend operational endurance.

The system's reliance on stable internet connectivity for data transmission and remote control poses another limitation. In many disaster-struck or remote areas, internet access is either weak or completely unavailable. While local control through Bluetooth is possible, it severely restricts the rover’s range and usability. Integrating offline decision-making algorithms and long-range communication protocols like LoRa or RF modules can improve its independence and utility in disconnected environments.

Furthermore, while the mobile application offers essential control features, it is still under development and lacks several advanced capabilities. Features like autonomous navigation, real-time mapping, sensor data logging, multi-rover coordination, or AI-based obstacle avoidance are either absent or in a nascent stage. These limitations, though expected in a prototype stage, highlight the need for continued development and testing before deployment in critical scenarios.

Lastly, the system does not currently include security features such as data encryption or user authentication. In sensitive operations, especially those involving real-time surveillance or disaster response, data security and privacy are paramount. Future enhancements should also address the need for robust cybersecurity measures

VI. CONCLUSION

The *Guardian ROMV Smart Rescue Rover* marks a noteworthy step forward in the development of cost-effective and accessible technology for disaster response and environmental monitoring. Designed with the integration of embedded systems and IoT communication, the rover is built to perform essential tasks in environments that are either hazardous or difficult for humans to reach. The system incorporates Arduino and NodeMCU microcontrollers to interface with various sensors, including modules for air quality (MQ-135), temperature and ultrasonic obstacle detection, ensuring a robust sensing capability. Additionally, a real-time video feed is enabled through a camera module, while GPS tracking provides location awareness critical for rescue coordination. Data collected by the sensors is transmitted wirelessly and can be accessed remotely via a cloud-based platform and mobile application, providing emergency responders with actionable insights.

The rover's modular design allows for future scalability, while its mobility and environmental feedback systems support real-time decisions during rescue operations. Although the current prototype has demonstrated stable performance in controlled test scenarios, enhancements such as autonomous navigation, improved chassis durability, and advanced AI-based detection will be essential to make the system fully operational in real-world disaster zones. This project ultimately illustrates how low-cost robotics, when coupled with smart sensing and communication technologies, can contribute significantly to modern search-and-rescue missions and smart city safety infrastructure

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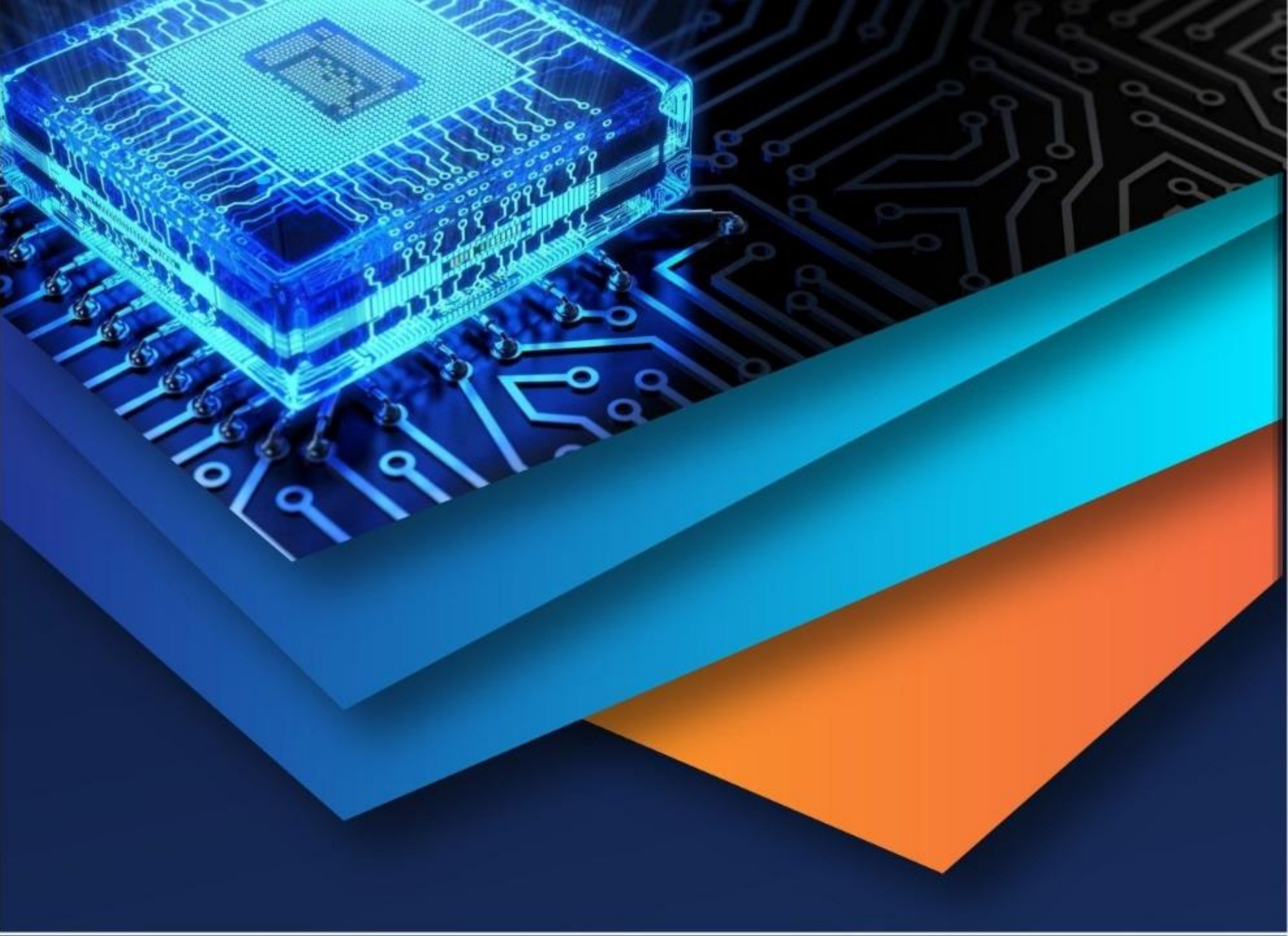

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