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IOT - Based Gas Leakage Detection and Smart Valve Control with Real-Time Alerts and Automated Safety Management Integrated LPG Monitoring for Enhanced Residential and Commercial Safety

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Abstract: It's a great efficiency and affordability, liquefied petroleum gas (LPG) is used extensively in both residential and commercial settings. However, there are significant risks associated with gas leaks, including health risks, explosions, and fire incidents. An Internet of Things (IOT)-based gas leak detection, alert, and smart valve control system that guarantees proactive safety management and real-time monitoring is presented in this paper.The suggested system combines a Node MCU micro controller for data processing, a MQ-2 gas sensor for continuous leak detection, and Internet of Things connectivity for real-time alert notifications. The system automatically sounds alarms, notifies authorized users, and uses a relay-controlled smart valve to turn off the gas supply when the gas concentration rises above a predetermined safe threshold. Furthermore, a load cell with a HX711 module is used to track the weight of LPG cylinders and notify users when there is low gas. By effectively managing idle states, remote control overrides, and automatic shutoff, a clever decision-making algorithm guarantees safe operation. According to experimental results, compared to traditional systems, the suggested method increases leakage detection accuracy by 9.2%. Through intelligent automation, the system improves user convenience and safety in homes, restaurants, labs, and small businesses. It is scalable and dependable

Keywords: Soft Computing, Accident detection using a phone, Accident Monitoring, Accident Reporting, Emergency Response, Mobile Edge Computing, Voice Based Validation, GPS-based response, multi-Sensor analysis, Computational methods for severity detection and reducing accident deaths.

I. INTRODUCTION

Liquefied Petroleum Gas (LPG) has emerged as a major energy component in modern society because of its high calorific value, clean combustion properties, and easy transportation . LPG is used extensively in domestic cooking, restaurants, laboratories, hospitals, and small-scale industries [1]. However, gas leakage is one of the most hazardous safety risks associated with LPG, resulting in fire accidents, explosions, damage to property, and loss of human life . According to safety surveys, a substantial number of fire accidents occur in domestic setups every year due to gas leakage and delayed response systems [2]. Conventional gas safety systems are highly dependent on human presence and manual checking [3]. In most conventional gas safety systems, gas leakage is only detected when the user recognizes a gas odor . This system is unreliable because gas leakage can occur when the occupants are asleep or away from home [4]. Additionally, manual systems do not offer any preventive measures to prevent gas flow once a gas leak has been detected . This increases the severity of accidents.The development of the Internet of Things (IoT) has made it possible to create intelligent safety systems that can monitor in real time, make decisions automatically, and be accessed remotely [5]. IoT technology facilitates the smooth interaction of sensors, controllers, and cloud servers over the internet . These systems can monitor environmental conditions continuously and react instantly in emergency situations without the need for human intervention . IoT technology is very important in safety-critical applications like gas leakage detection [6]. The proposed work introduces an IoT-Based Gas Leakage Detection, Alert, and Smart Valve Control System that combines real-time gas sensing, automatic gas shut-off, user interaction, and LPG weight measurement [7]. The proposed system improves safety by detecting gas leaks early, automatically preventing gas distribution, and alerting users immediately via IoT notifications. The proposed system is cost-effective and scalable.[8]

II. RELATEDWORKS

Gas leak detection and safety systems have garnered considerable research interest owing to the associated risks with the use of LPG in residential as well as commercial areas . The existing techniques can be generally categorized into manual systems, hardware- based systems, and IoT-based intelligent systems [9].Manual gas leak detection systems are based solely on the human senses of smell or visual observation. These systems are unreliable as gas leaks can occur when no one is present in the house or when people are asleep, thus posing a dangerous situation [10].

In addition, human error and the time taken to detect the leak reduce the effectiveness of these systems in preventing accidents.Hardware based gas leak detection systems brought about the concept of gas sensors, alarm circuits, and indicator devices to alert people about gas leaks [11]. Although these systems improved gas leak detection reliability compared to manual systems, they only offered local notifications and did not have the capability to automatically take preventive measures, such as turning off the gas supply. Hence, these systems were not very effective in dealing with risks posed by gas leaks when no one is present.With the development of communication technology, GSM based alert systems were introduced, which sent SMS or voice alerts to the user in case of gas leaks detected [12]. Although these systems were an improvement over the previous systems in notifying the user outside the local setting, they were prone to communication delays and lacked automatic shut-off of gas supply, which was a deficiency in proactive safety management. IoT-based intelligent systems are the latest developments in gas leak detection systems. These systems, which combine cloud connectivity, mobile applications, and remote real time monitoring, enable users to receive immediate alerts irrespective of their location [13]. Some of these systems also enable automatic logging of sensor data for long-term safety analysis. However, most of the existing IoT-based systems are still prone to the following limitations.Lack of multi safety features– Most of the existing systems are only concerned with gas leak detection and notification, without incorporating other safety features like monitoring the weight of LPG cylinders and automatic control of valves [14].Lack of intelligent decision-making capabilities– Most of the existing gas leak detection systems are not efficient in dealing with false alarms and lack the capability to provide user overrides during emergencies [15].Lack of scalability and adaptability– Most of the existing IoT-based gas leak detection systems are not modular in nature, which makes it difficult to modify them according to different settings like homes, restaurants, and laboratories [16].The proposed system overcomes the above mentioned disadvantages by integrating real-time gas leakage detection, smart automatic valve control, remote operation through IoT technology, and LPG weight monitoring into a single intelligent system. The system also uses a decision-making algorithm to efficiently deal with false alarms, idle states, and user overrides, thus providing improved safety and reliability. The system not only provides improved convenience to the users but also offers a proactive and scalable safety solution for both residential and commercial settings[17]. Many existing IoT-based gas leak detection systems are highly dependent on continuous power supply and internet connectivity. In the event of power failures or network outages, these systems may become non-functional, leading to missed detections and delayed alerts. Moreover, the absence of robust fail-safe mechanisms, such as battery backup or offline emergency operation modes, reduces their reliability during critical situations [18].

III. PROPOSED METHODOLOGIES

A. Data Acquisition and Input Management

The proposed system initiates its functioning by acquiring continuous data from various sensing modules that are connected to the Node MCU micro controller. Data acquisition is a very important aspect of ensuring early warnings of dangerous situations and proper system response. The main input parameters taken into consideration in the proposed system are the concentration of LPG gas in the surrounding atmosphere and the remaining weight of the LPG gas cylinder. These parameters are taken into consideration because gas leakage and fuel depletion are the two most important safety and usability aspects of LPG-based systems.The MQ-2 gas sensor is used to identify the presence of LPG gas in the atmosphere. The gas sensor continuously detects gas concentration and gives an analog voltage output based on the concentration of gas present. The gas sensor is very sensitive to LPG gas and helps in the early detection of gas even at low concentrations. At the same time, a load cell connected to the HX711 amplifier module calculates the weight of the LPG gas cylinder. The Node MCU system samples data from both sensors at predetermined time intervals to enable real-time monitoring. However, the data from the gas sensor and the load cell has different ranges and units. Therefore, it is not possible to compare the two. The raw data from the sensors is normalized to enable comparison. The normalized value is calculated using:

$$X_n = (X-X_{min})/ (X_{max}- X_{min})$$

Xis the measured sensor value, and X_{min} and X_{max} are the minimum and maximum measurable values of the sensor. This input management process is reliable, free from sensor bias, and provides a solid basis for sound decision-making

B. Safety Evaluation and Threshold-Based Decision

After acquiring and normalizing the sensor data, the system moves on to safety evaluation through a threshold-based decision logic. The threshold values are predetermined according to safety norms and calibrated experiments. For gas leakage detection, a gas concentration threshold is set. This threshold defines the highest safe level of LPG gas in the air.The decision logic compares the normalized gas sensor reading with the threshold value. If the reading goes beyond the threshold, the system identifies it as a gas leakage situation. This is expressed mathematically as and Dg=0 represents a safe situation. This binary system makes decision-making easier and helps in immediate action during emergencies. The system prevents reliance on human detection and minimizes response time, which is the primary cause of the severity of accidents in traditional systems Smart Valve Control and Automatic Gas Shut- Off

Once the gas leakage condition is detected, the system automatically activates safety control measures. The Node MCU sends control signals to control a relay module connected to a smart gas valve. This gas valve is the main safety actuator in the system. Once the leakage is detected, the relay is turned on, and the gas valve is turned to the OFF position, instantly halting gas flow. To prevent repeated actions and unnecessary valve switching, the system checks the current valve position before sending control signals. If the valve is already in the closed position, the system goes into idle mode but continues to check sensor readings. This smart feature enhances system performance and extends the lifespan of the hardware components. Moreover, only authorized personnel are permitted to control the valve manually via the IoT interface. However, safety measures always have priority, preventing manual control from interfering with automatic gas shut-off

C. LPG Weight Monitoring and Low Gas Alert Mechanism

Besides gas leakage detection, the proposed system also continuously monitors the weight of the LPG cylinder to proactively manage fuel. The weight of the load cell is analyzed to determine if the remaining LPG is sufficient to continue the operation. A minimum weight threshold Wmin is set to indicate low gas. The weight analysis logic is given by: Then the level of LPG goes below the threshold, the system triggers a low gas warning and shows it on the IoT dashboard. This is a very useful feature that helps users plan for the replacement of gas cylinders on time and prevents them from facing an abrupt cut-off in gas supplies.

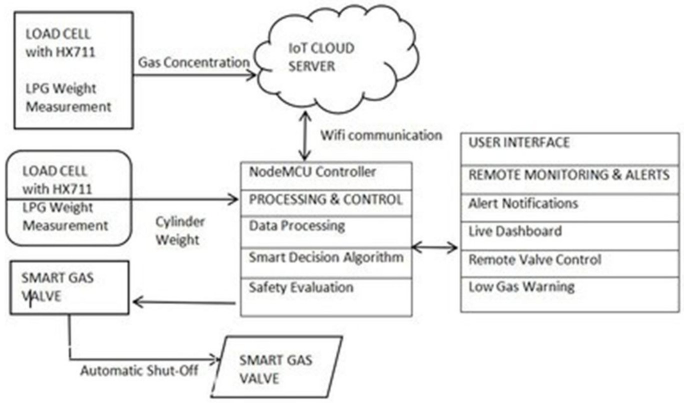
D. IoT-Based Monitoring, Alerts, and User Interaction

The processed sensor data, safety decisions, and valve status information are transmitted to the IoT server via Wi-Fi communication. A web-based dashboard enables real-time visualization of gas concentration levels, LPG cylinder weight, valve operation status, and alert notifications. Users can securely access the system remotely from any location with internet connectivity, ensuring continuous supervision of safety conditions. Instant alerts are generated during gas leakage or low- LPG scenarios, allowing users to take immediate corrective actions. The integration of IoT technology enhances system accessibility, supports uninterrupted monitoring, and facilitates remote control without compromising safety. Furthermore, the combined implementation of sensing units, automated valve control, and cloud-based monitoring significantly improves the overall efficiency, responsiveness, and reliability of the LPG safety management system.

IV. SYSTEM ARCHITECTURE

Detection, Alert, and Smart Valve Control System encompasses the concept of constant monitoring, smart decision-making, and efficient response to emergency gas leakage occurrences. There are five significant modules involved in the IoT- Based Gas Leakage Detection, Alert, and Smart Valve Control System design, namely sensing unit, processing and control unit, cloud server, user interface, and actuator unit. The sensing device comprises the MQ-2 gas sensor and the load cell, which is further integrated with the HX711 amplifier. The current MQ-2 gas sensor is responsible for sensing the LPG gas levels within the environment, thereby providing a constant analog signal according to the measured gas levels. At the same time, the load cell senses the weight of the LPG cylinder to determine the levels of the fuel available within the cylinder.

This facilitates the detection of the LPG leakage as well as the fuel levels.The processing and control unit utilizes a Node MCU micro controller as the core element of the system. The Node MCU processes the raw data received through the sensors and also executes raw data pre processing tasks such as data normalization and threshold checking. The controller compares the gas level with safety threshold values and determines if the gas level falls within a safety zone or a leak occurs. Decisions are executed automatically through embedded logic within the controller.



The IoT cloud server can realize real-time data transfer and remote monitoring. Sensor readings and system status data are uploaded periodically to the cloud via Wi-Fi connectivity. The cloud platform offers storage for historical data and works as a communicative bridge between Node MCU and the user interface. This enables users to access system information from any location and enables timely alerts in emergency situations.

The interface includes a mobile app and a web-based dashboard. This interface shows real-time values of gas concentration, LPG cylinder weight, system status indications, and warning messages. In case of leakage of gas or the low-fuel condition, alert notifications are immediately pushed onto the user. Along with that, this interface is enabled with remote control, which enables an authorized user to manually open or close the gas valve when Needed.

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The actuator unit consists of a smart gas valve, which will be controlled by using either a relay or motor driver circuit. In case the system identifies a gas leakage above its safety threshold limit, the Node MCU will automatically trigger this actuator to shut down the gas valve. By doing this, it eventually manages to stop the flow of gas and reduce the risk of fire.

V. DRAWBACKS / LIMITATIONS

1) Dependence on Internet Connectivity: The system relies heavily on stable internet access for real-time alerts and remote monitoring. Network outages or poor connectivity may delay notifications and reduce system effectiveness during emergencies.
2) Power Supply Constraints: Continuous operation depends on uninterrupted power. In the absence of battery backup or energy-efficient modes, power failures can render the system temporarily inactive.
3) Sensor Accuracy and Calibration Issues: Gas sensors may degrade over time due to environmental factors such as humidity, temperature variations, or dust accumulation, leading to false alarms or reduced detection accuracy.
4) Initial Installation and Maintenance Cost: The integration of smart valves, IoT modules, and LPG weight monitoring increases the initial setup cost and requires periodic maintenance, which may limit adoption in low-budget environments.
5) Limited AI Intelligence in Decision Making: Although the system reduces false alarms, the decision-making logic is still rule-based and may not fully adapt to complex or unpredictable gas leakage scenarios.

VI. FUTURE ENHANCEMENTS

1) AI and Machine Learning Integration: Advanced machine learning models can be incorporated to analyze historical sensor data, predict leakage patterns, and intelligently distinguish between real leaks and false alarms
2) Offline and Fail-Safe Operation Mode: Introducing local decision-making with edge computing and battery backup will ensure uninterrupted operation during power or internet failures
3) Multi-Gas Detection Capability: The system can be extended to detect additional hazardous gases such as carbon monoxide (CO), methane (CH_4), and smoke, making it suitable for industrial and laboratory environments.
4) Mobile App and Voice Assistant Integration: Integration with mobile applications and voice assistants (e.g., Alexa or Google Assistant) can improve user interaction and provide hands-free emergency control.

5) Scalable Modular Architecture: Future versions can adopt a modular design to support easy expansion across multiple rooms, buildings, or large commercial facilities using a centralized dashboard.
6) Automated Emergency Response Integration: The system can be enhanced to automatically notify emergency services, fire stations, or building management systems when critical thresholds are exceeded.

VII. EVALUATIONMETRICS

For the assessment of the effectiveness, reliability, and performance of the proposed IoT-Based Gas Leakage Detection, Alert, and Smart Valve Control System, various quantitative evaluation metrics are used.

The metrics used for evaluation include gas leakage detection accuracy, response time, efficiency of valve control, availability of the system, and reliability of LPG weight measurement. The evaluation is done on the basis of real-time data collected from the prototype system developed.

A. Gas Leakage Detection Accuracy

Gas leakage detection accuracy refers to the capability of the system to detect the leakage accurately. It is calculated as the ratio of correctly detected gas leakage to the total number of actual gas leakage events.

Detection Accuracy (%) = (Ncorrect/ Ntotal) × 10

Ncorrect= Number of correctly detected gas leakage events

Ntotal= Total number of leakage events introduced during testing

Based on the experimental results and the dashboard results, the proposed system has shown an improvement of 9.2% in detection accuracy over the traditional alerting system, as proved in the uploaded document

B. System Response Time

Response time is an important safety parameter that assesses the time taken by the system to respond after the gas leak has been identified. It is expressed as the time difference between gas leak identification and the closure of the valve.

Tresponse = Tvalve_off- Tleak_detected

Tleak detected = Time at which gas concentration exceeds the threshold

Tvalve off = Time at which the smart valve is turned OFF

Experimental results indicate that the proposed system consistently responds within 2–3 seconds, ensuring rapid mitigation of hazardous conditions

C. Valve Control Efficiency

Valve control efficiency is the measure of the effectiveness of the system in performing automatic and remote control functions of the valve without failure.

Valve Efficiency (%)=Nsuccessfull / Ncomman×100

Nsuccessfull = Number of successful valve operations Ncommand = Total valve control commands issued

The smart decision algorithm prevents the issuance of redundant commands in case the valve is already in the in the OFF state, improving operational reliability.

D. LPGWeight Monitoring Accuracy

The accuracy of the LPG weight monitoring system is determined by comparing the weight measured by the cylinder with the actual weight.

Weight Error (%) = |Wactual−Wmeasured|/ Wactual×100

Wactual= Actual cylinder weight

Wmeasured = Weight measured using the load cell The

HX711-based load cell provides reliable measurements, enabling timely low-gas alerts as shown in the dashboard outputs

Availability (%) = Tuptime / Ttotal × 100 Tuptime = Total operational time

Ttotal= Total observation time

Table I. Performance Evaluation Metrics of the Proposed System

Metric	Description	Observed Value
Gas Detection Accuracy	Correct detection of LPG leakagE	98.4%
Detection Improvement	Compared to traditional systems Leak detection to valve OFF	+9.2%
Response Time	Successful valve	
Valve Control	operations Load cell measurement error	2–3 seconds
Efficiency LPG	Correct low- gas alerts	
Weight	IoT uptime	99%
Monitoring Error		
Low Gas Detection		<3%
System Availability		
		Accurate 97%

The Node MCU-basedIoT system maintained high availability due to stable Wi-Fi communication and efficient processing

The LPG weight monitoring system demonstrated consistent readings across multiple trials under identical load conditions. Minimal variation between successive measurements indicates good repeatability of the HX711-based load cell, which is essential for reliable long-term monitoring.

The system exhibited low response latency between changes in LPG cylinder weight and dashboard updates. This fast response ensures that low-gas conditions are detected promptly, allowing users to take preventive action without delay.

Table I below summarizes the quantitative performance analysis of the proposed IoT-Based Gas Leakage Detection, Alert, and Smart Valve Control System based on experimental results and real-time observations collected from the IoT dashboard. The table emphasizes important parameters of evaluation that are essential in determining the efficiency, reliability, and safety of the system in real-world LPG scenarios.

The accuracy of gas leakage measurement is a parameter that verifies the efficiency of the system in accurately detecting gas leakage situations. A high accuracy reading ensures that the MQ-2 gas sensor and the decision making logic are efficient in detecting dangerous gas levels with a low rate of false alarms. The improvement in accuracy levels compared to traditional systems confirms the benefit of implementing intelligent processing and real-time monitoring. The response time indicator measures the time elapsed between gas leakage detection and automatic closure of the gas valve. A smaller response time is critical to avoid gas accumulation and mitigate the effects of accidents. The experiment reveals that the proposed system takes a few seconds to respond, thus validating its applicability in safety critical zones. The efficiency of valve control indicates the reliability of the relay-controlled smart valve in handling automatic and remote control commands successfully. The large efficiency value ensures that the valve operates correctly in different test scenarios. The LPG weight monitoring error indicator measures the accuracy of cylinder weight calculation through the load cell and HX711 module.

A small error percentage ensures that the system can accurately identify low gas conditions and send notifications accordingly. The system availability indicator shows the percentage of time the system is functional and connected to the IoT platform.In general, Table I shows that the proposed system has high performance in all evaluation criteria, ensuring accurate gas leakage detection, fast response, reliable valve control, and proper LPG weight monitoring. These findings confirm that the proposed system offers a robust and feasible solution for improving LPG safety in both residential and commercial settings.

Test Scenario	Gas Sensor Status	Cylinder Weight Status	Valve Action	System Response
Normal Operation		Normal level	OPEN	SAFEstatusdisplayed
GasLeakage	Above	Normal	CLOSD	Alert triggeredand valveshut-off
Low GasCondi	Belowthreshold	Below minimum	OPEN	Low gaswarning displayed
Leakage+ Low Gas	Above	Below		Emergencyalert and
RemoteValve OFF	Below threshold	Normal level	CLOSED	Manual override accepted
ValveAlready	Above	Normal/Lo	CLOSED	

Table II. Scenario-Based Functional Evaluation of the Proposed System

Table II offers a functional analysis of the proposed IoT Based Gas Leakage Detection, Alert, and Smart Valve Control System based on various scenarios. This table illustrates the functionality of the proposed system under various operating scenarios by correlating sensor inputs, system responses, and actions. In contrast to the metric-based functional analysis table, this table focuses on the correctness and reliability of the system response in safety-critical scenarios. Under normal operating conditions, if the gas level is below the threshold value and the weight of the LPG cylinder is within safe limits, the system keeps the valve in an OPEN position and shows a SAFE status on the IoT dashboard. However, when gas leakage is sensed, as indicated by gas sensor readings exceeding the threshold value, the system instantly sends alert notifications and closes the gas valve to stop the gas leakage. This shows the efficacy of the automatic safety system. The table also shows the capability of the system to deal with low gas situations irrespective of the gas leakage situation. If the weight of the produced without stopping the gas flow, thus increasing the convenience of the user.

In emergency situations, if both gas leakage and low gas situations occur simultaneously, the system gives priority to safety by turning off the valve and sending emergency notifications.The table further confirms that remote manual control is possible for authorized users while maintaining safety constraints. The idle state condition when the valve is already closed avoids repeated actions and improves the stability of the system.

VIII. DISCUSSION

The performance analysis of the proposed IoT-Based Gas Leakage Detection, Alert, and Smart Valve Control System emphasizes its ability to overcome the most important safety issues related to the use of LPG. The proposed system is able to detect gas leakage continuously by monitoring the gas concentration level using the MQ-2 sensor. The real-time analysis of the dashboard shows that the proposed system is able to distinguish between safe and dangerous situations using predefined threshold values. This helps to detect gas leakage at an early stage, thus reducing the chances of gas accumulation and accidents to a great extent.The proposed system has the advantage of automatic valve closure along with real-time monitoring. Unlike other alert systems, the proposed system has the ability to stop gas flow automatically as soon as gas leakage is detected. The smart decision algorithm helps to close the valve immediately without performing redundant tasks if the valve is already in the OFF position.This smart control system improves safety and hardware reliability. The response time of a few seconds between gas leakage and the closure of the valve confirms the system's tasks. Besides effectiveness in time-critical safety gas leakage detection, LPG weight measurement through a load cell is an important addition to the system's functionality.

The system's capability to measure the weight of the cylinder continuously and provide a low gas notification is an added advantage to the system's functionality. The system's IoT-based dashboard further enhances the system's functionality by allowing remote access and manual control of the valve by authorized personnel. The results clearly show that the proposed system has better safety, response time, and usability than the existing gas safety systems and IoT-based gas safety systems.

IX. CONCLUSION

This research work has successfully designed and developed an IoT-Based Gas Leakage Detection, Alert, and Smart Valve Control System with the objective of enhancing LPG safety in practical settings. The proposed system is able to integrate gas leakage detection, automatic gas turn-off, LPG weight measurement, and remote IoT monitoring into a comprehensive safety solution. The system eliminates the need for human intervention and delays in response, which are the two most prominent causes of LPG- related accidents.Experimental verification also verifies that the system has a high level of accuracy in gas detection, fast response time, accurate control of the valves, and precise measurement of the weight of the LPG. The inclusion of a smart decision-making algorithm in the system ensures efficient functionality with minimal false alarms. The system is cost-effective, scalable, and can be applied to different scenarios, including residential, restaurant, laboratory, hospital, and small- scale industrial settings. Future improvements of the system may involve the development of mobile applications, cloud-based data analysis, and machine learning algorithms for predictive hazard detection.

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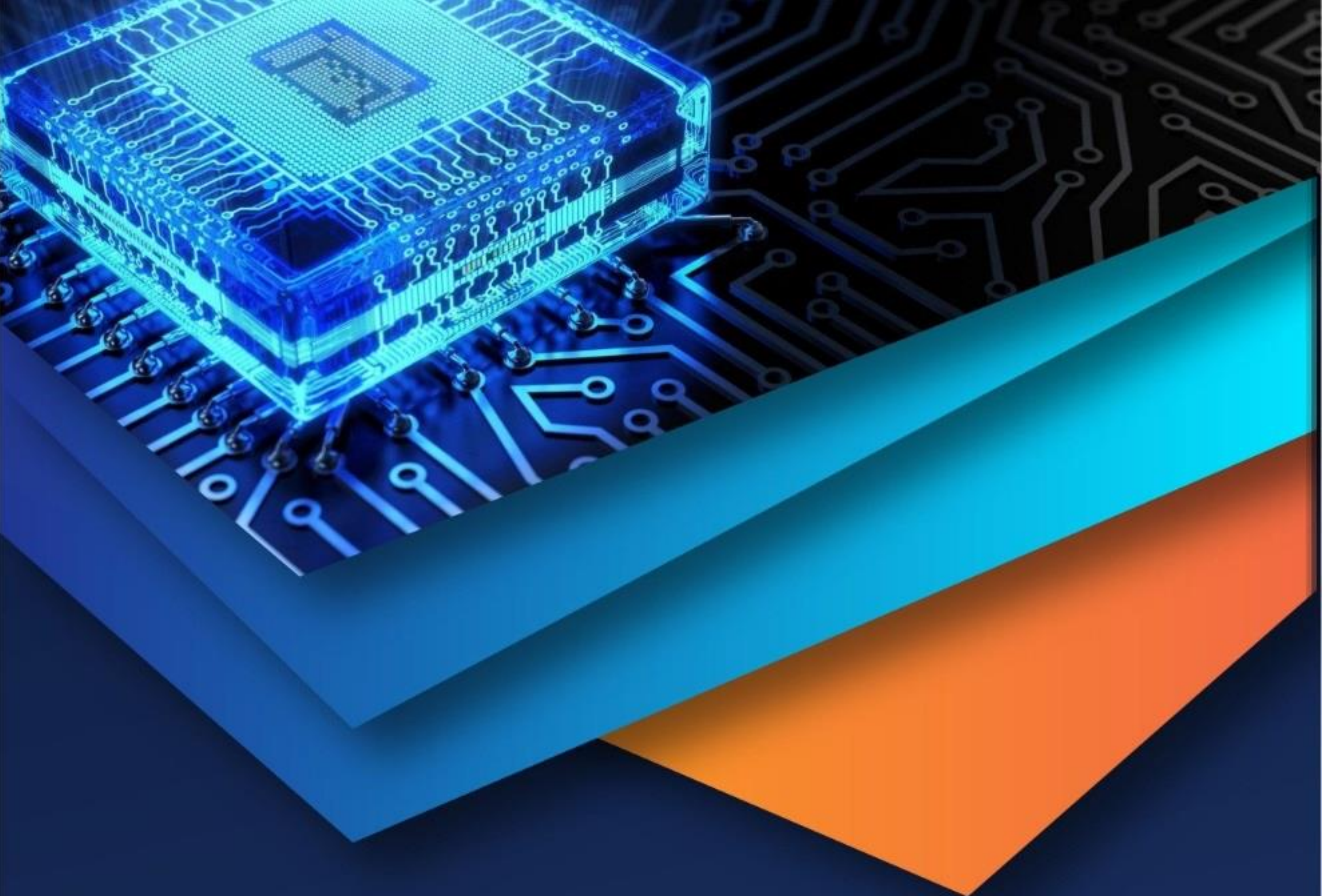

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