iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 14 **Issue:** III **Month of publication:** March 2026

DOI: https://doi.org/10.22214/ijraset.2026.78918

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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 III Mar 2026- Available at www.ijraset.com

IoT Based Manhole Detection & Monitoring

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Abstract: Urban drainage systems face frequent hazards such as manhole overflow, toxic gas accumulation, and unauthorized lid opening, which may lead to accidents and health risks. Conventional manual inspection is inefficient and unsafe. This paper presents an IoT-based smart manhole monitoring system employing a master–slave architecture using ESP32 and Arduino Nano controllers. Wireless communication between nodes is achieved through NRF modules, while GSM provides emergency alert messaging. Multiple sensors including float, tilt, gas (MQ-2), and temperature (DHT11) are utilized for real-time environmental monitoring. RTC modules enable low-power operation through scheduled sleep cycles and event-based wake-up.A novel hollow manhole cover design is introduced, where all electronics are protected inside the cover while sensors remain externally exposed for accurate detection. Instead of GPS, predefined coordinates are assigned to each manhole to reduce power consumption and system cost. The system supports emergency-triggered communication even during sleep mode, ensuring immediate alert transmission. The proposed design enhances public safety, reduces manual inspection, and offers a scalable and cost-effective solution for smart city infrastructure.
Keywords: IoT, Smart Manhole, ESP32, Arduino Nano, NRF24L01, GSM, RTC, Hollow Manhole Cover, Environmental Monitoring.

I. INTRODUCTION

Efficient sewage management is essential for maintaining public health and urban safety. Rapid urbanization has increased pressure on underground drainage systems, making regular monitoring crucial. Manual inspection of manholes is dangerous due to toxic gases, rising water levels, and poor ventilation, while displaced or open manhole covers pose serious risks to pedestrians and workers. These challenges demand an automated system capable of detecting hazardous conditions and providing real-time alerts.

This work presents an IoT-based smart manhole monitoring system using a master–slave architecture, where an ESP32 acts as the master controller and Arduino Nano nodes operate as slaves. The system monitors sewage water level, temperature, toxic gas presence, and manhole cover movement using float, DHT11, MQ-2, and tilt sensors. A hollow manhole cover houses the main circuitry, while sensors are mounted externally for accurate detection. Wireless NRF communication links slave nodes to the master, and GSM technology sends alert messages to municipal authorities during abnormal conditions.

The proposed system reduces manual inspection, improves response time, and enhances worker safety. With low- power operation, secure hardware placement, and real-time alerting, the design offers a cost-effective and scalable solution for smart city sewage infrastructure monitoring.

II. LITERATURE REVIEW

Underground sewage monitoring has gained increasing attention due to rising urban safety concerns and the risks associated with manual manhole inspection. Conventional methods expose workers to toxic gases, overflow, and harsh environmental conditions. To overcome these issues, several IoT-based monitoring systems have been proposed using sensors and wireless communication for real-time detection of water level, gas concentration, and temperature.

Early systems mainly employed Arduino or NodeMCU platforms with GSM modules to transmit SMS alerts during abnormal conditions. Although functional, these systems suffered from high power consumption and limited scalability. Later studies introduced ESP32-based designs and multi-sensor integration to improve reliability and data processing. Some solutions incorporated GPS for location tracking; however, most required continuous power and lacked protection of electronics from harsh underground environments.

Recent research emphasizes low-power wireless sensor networks for long-term deployment, yet very few systems address secure physical installation. Most existing designs mount electronics openly inside manholes, making them vulnerable to water damage and tampering. In contrast, the proposed system introduces a **hollow manhole cover concept**, where the main master circuitry (ESP32, GSM, NRF, RTC, battery) is safely enclosed inside a lockable hollow cover, while sensors are placed outside for direct exposure to sewage conditions.

Arduino Nano– based slave nodes communicate wirelessly with the master using NRF modules, enabling distributed monitoring. This architecture improves durability, simplifies maintenance, and enhances system reliability.

The literature reveals that existing systems rarely combine low-power operation, cover displacement detection, protected hardware placement, and master–slave communication. The proposed design bridges these gaps by integrating multi-sensor monitoring, hollow-cover protection, NRF-based slave communication, and GSM alert transmission, providing a practical and scalable solution for smart city manhole management

III. SURVEY AND IDEOLOGY OF IOT BASED MANHOLE DETECTION & MONITORING

A. Design Space of Wireless Sensor Networks

Authors: Römer, K., Mattern, F.

This study highlights key challenges in wireless sensor networks such as power management, hardware limitations, and communication reliability. It emphasizes the importance of low-power design and optimized architecture, which are essential for underground applications like manhole monitoring.

B. IoT-Based Environmental Condition Monitoring

Authors: Kelly S. D. T., Suryadevara N. K., Mukhopadhyay S. C.

The authors present an IoT framework using low-cost sensors for real-time monitoring of temperature and gas levels. The work demonstrates that IoT sensor networks can reliably detect environmental changes, supporting their use in sewage and manhole condition monitoring.

C. Smart City Monitoring Using IoT Platforms

Authors: Prof. S. A. Shaikh, Suvarna A. Sonawane

This research proposes an IoT-based smart city monitoring system using multiple sensors and centralized data processing. While effective for urban applications, it mainly focuses on surface monitoring and does not address underground power constraints.

D. IoT-Based Smart Manhole Monitoring Systems

Existing systems mainly detect water level and gas accumulation. Although they improve safety, most lack efficient power management and manhole cover tamper detection, limiting their suitability for long-term deployment.

E. Research Gap Identified

From the survey, it is evident that current systems do not fully integrate low-power operation, secure cover monitoring, and multi-parameter sensing in a single platform. Hence, there is a need for a reliable, energy-efficient smart manhole system capable of detecting overflow, toxic gases, temperature variation, and cover displacement while ensuring timely communication with municipal authorities.

IV. IDENTIFICATION OF PROBLEM

Rapid urbanization has increased pressure on underground sewage systems, leading to frequent problems such as manhole overflow, toxic gas accumulation, and displacement of manhole covers. These issues pose serious risks to public safety and sanitation workers, especially during manual inspections conducted in hazardous underground environments.

At present, manhole monitoring is largely manual, time-consuming, and unsafe due to the presence of poisonous gases like hydrogen sulfide (H_2S), poor ventilation, and unpredictable conditions. Delayed detection of blockages or overflow can cause accidents, road damage, and environmental contamination. Moreover, unauthorized opening of manhole covers further increases safety risks.

Existing systems lack an integrated, low-power, and secure solution capable of continuously monitoring multiple parameters and providing real-time alerts. Therefore, there is a need for an automated IoT-based manhole monitoring system that senses water level, gas concentration, temperature, and cover displacement, with the main circuitry safely housed inside a hollow manhole cover and wireless communication to authorities. Such a system can improve safety, reduce manual effort, and support smarter urban infrastructure.

V. PROPOSED METHODOLOGY

The proposed smart manhole monitoring system is designed to continuously observe underground sewage conditions and provide real-time alerts to municipal authorities in order to prevent accidents, flooding, and environmental hazards. The overall system architecture is illustrated in the block diagram showing interaction between master control unit (Figure a) and a slave sensor nodes (Figure b). Each manhole is equipped with a slave node installed inside a hollow and lockable manhole cover, while the sensors are mounted outside the hollow enclosure for direct environmental exposure. This hollow-cover concept protects the main electronics from moisture and physical damage while allowing accurate sensing. Each slave node contains:

1) Water level / float sensor to detect overflow or blockage
2) Temperature sensor (DHT11) to monitor abnormal temperature rise
3) Gas sensor (MQ2) to detect harmful gases
4) Tilt sensor to detect unauthorized opening or displacement of the manhole cover

An Arduino Nano is used as the controller for each slave node. It collects sensor readings and transmits data wirelessly to the master unit using NRF24L01 modules. An RTC module maintains accurate timing, and a low- power sleep mechanism is implemented to conserve battery energy during idle periods. To further reduce power consumption, slave nodes remain in sleep mode for predefined intervals. However, if the tilt sensor detects sudden cover movement or opening, the slave node immediately wakes up and transmits emergency data to the master node without waiting for the next interval.The master node, built using ESP32 WROOM-32, also has its own set of sensors and operates similarly in low- power mode. When abnormal conditions are detected locally or when data is received from any slave node, the ESP32 wakes instantly and activates the GSM module to send alert messages to municipal authorities.

The operational methodology is summarized as follows:

- Sensing: Slave nodes periodically wake up and acquire data from gas, temperature, float, and tilt sensors.
- Processing: Arduino Nano processes sensor values and compares them with predefined threshold limits.
- Communication: Sensor data is transmitted wirelessly to the ESP32 master via NRF modules.
- Emergency Wake-Up: If cover displacement or hazardous conditions occur, slave nodes immediately send alerts, waking the master unit.
- Decision Making: ESP32 aggregates data from all nodes and determines system status.
- Alerting: When critical conditions are detected, SMS alerts are sent through the GSM module to authorized personnel.
- Power Management: Both master and slave nodes return to sleep mode after transmission to conserve battery power.

This methodology ensures automated, low-power, and reliable monitoring of sewage manholes. The integration of wireless slave nodes, emergency wake-up through tilt detection, hollow-cover protection for electronics, and GSM-based alerting enhances operational safety and system durability. The architecture is scalable and suitable for smart city deployments, providing improved infrastructure management and public safety.

VI. COMPONENTS USED

Component	Description
ESP32 WROOM-32	Master controller; receives data from slave nodes and sends alerts through GSM
Arduino Nano	Slave controller; collects sensor data and transmits to master via NRF
NRF24L01 Module	Wireless communication between slave nodes and master
GSM Module (SIM800L)	Sends SMS alerts to municipal authorities during abnormal conditions
Float Sensor	Detects sewage water level and overflow
Tilt Sensor	Detects manhole cover opening or displacement
Gas Sensor (MQ2)	Monitors presence of harmful gases inside the manhole
Temperature Sensor (DHT11)	Measures internal manhole temperature
RTC Module	Maintains accurate timing for sleep–wake operation
Rechargeable Li-ion Battery	Power supply for master and slave nodes
Boost Converter	Regulates voltage for Arduino Nano slave nodes
Hollow Manhole Cover	Houses main circuit safely while sensors remain outside
PCB Board	Mechanical support and electrical interconnections
Connecting Wires	Circuit connections

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VII. BLOCK DIAGRAM & PROJECT PHOTOS

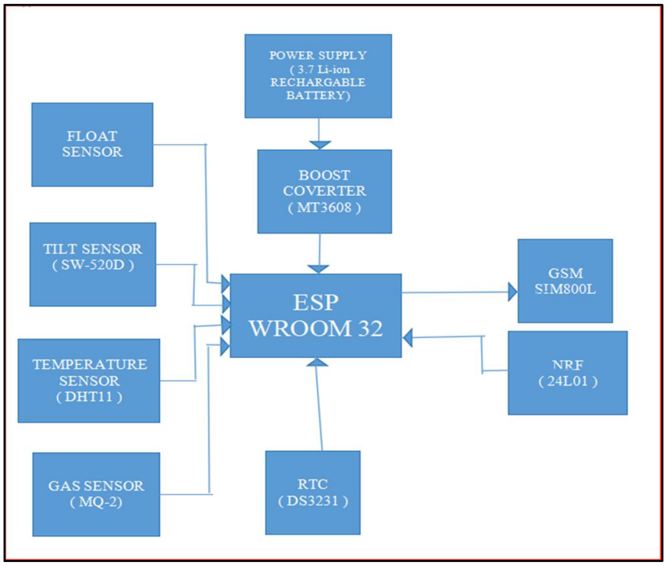


Fig.a (MASTER)

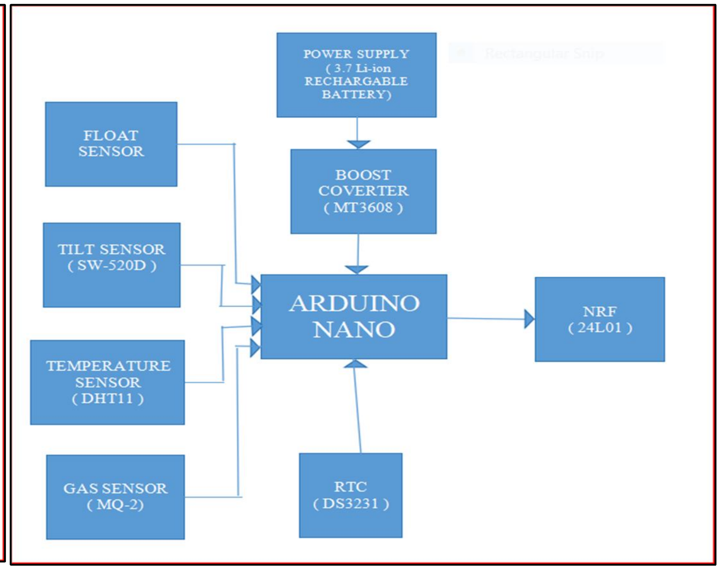
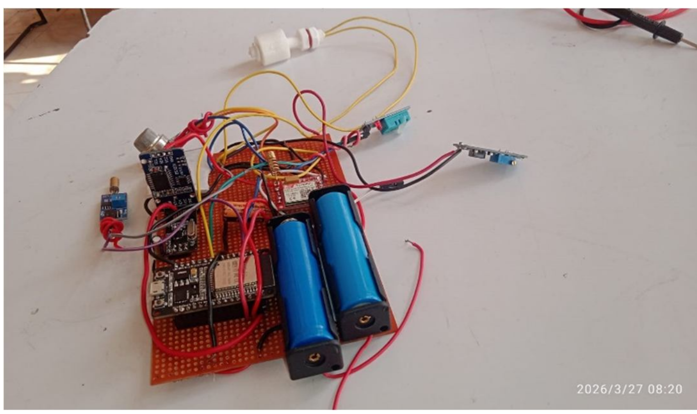
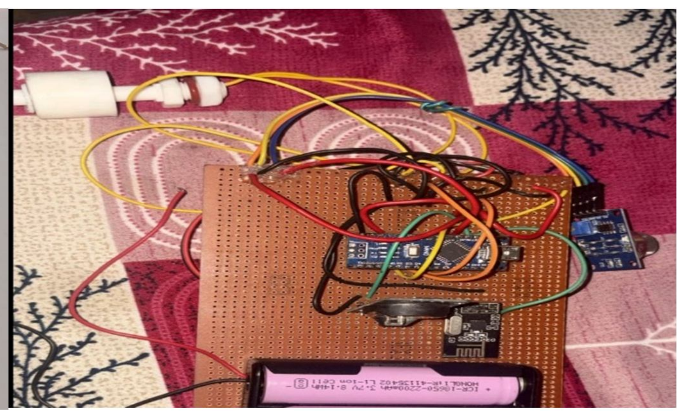


Fig.b (SLAVE)





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VIII. WORKING PRINCIPLE

1) Sensor Data Acquisition: Each manhole is equipped with a slave node installed inside a hollow and lockable manhole cover, while sensors are mounted externally for direct exposure to sewage conditions. The float sensor measures water level, the MQ2 gas sensor detects harmful gases, the DHT11 monitors temperature, and the tilt sensor identifies manhole cover displacement or tampering.
2) Signal Processing at Slave Node: The Arduino Nano continuously receives signals from all sensors. Using predefined threshold values, it processes the raw data to determine whether conditions are normal or hazardous. During normal operation, the slave node remains in low-power sleep mode and wakes periodically using the RTC-based timing.
3) Emergency Wake-Up Mechanism: If the tilt sensor detects sudden cover opening or if gas, temperature, or water level exceeds safe limits, the slave node immediately wakes up (without waiting for the scheduled interval) and prepares emergency data for transmission.
4) Wireless Communication (Slave to Master): Processed sensor data is transmitted wirelessly from the slave node to the ESP32 WROOM-32 master node using NRF24L01 modules. This enables reliable short-range communication between multiple manholes and the central controller.
5) Master Node Processing: The ESP32 master also contains its own set of sensors and continuously listens for incoming data from slave nodes. Upon receiving abnormal readings—or detecting hazards locally—the ESP32 wakes from sleep, aggregates all information, and evaluates system status.
6) Alert Generation via GSM: When critical conditions such as overflow, toxic gas presence, temperature rise, or cover displacement are detected, the ESP32 activates the GSM module to send instant SMS alerts to municipal authorities, enabling rapid response.
7) Power Management and Sleep Cycle: After data transmission and alert generation, both master and slave nodes return to sleep mode to conserve battery power. The RTC maintains timing for periodic wake-up, ensuring long-term low-power operation.
8) Continuous Feedback Operation: This sensing–processing–communication–alert cycle repeats continuously, forming a closed-loop monitoring system that provides reliable real-time manhole surveillance with minimal human intervention.

IX. CONCLUSION

The proposed smart manhole monitoring system presents an efficient and reliable solution for enhancing urban sewage management and public safety. By integrating multiple sensors for detecting water level, temperature, toxic gas concentration, and manhole cover displacement, the system enables continuous and automated monitoring of underground manholes. The use of hollow and lockable manhole covers protects the main circuitry while allowing sensors to directly interact with the environment, improving durability and sensing accuracy. The master–slave architecture using Arduino Nano slave nodes and an ESP32 WROOM-32 master ensures scalable monitoring of multiple manholes. Wireless communication through NRF modules allows rapid data transfer, while GSM-based alerting provides immediate notification to municipal authorities during hazardous conditions. The emergency wake-up mechanism triggered by tilt or abnormal sensor readings further enhances system responsiveness. Low-power operation achieved through RTC-based sleep cycles significantly reduces energy consumption, making the system suitable for long-term outdoor deployment. Overall, the proposed system minimizes manual inspection, improves worker safety, and enables proactive sewage maintenance. By combining low-power IoT technology, wireless communication, and intelligent alerting, this project demonstrates a practical and scalable approach toward safer, cleaner, and smarter urban infrastructure management.

X. FUTURE SCOPE

The proposed smart manhole monitoring system offers a strong foundation for intelligent urban sewage management; however, several enhancements can further improve its performance and scalability.

1) Enhanced Accuracy: Although the system currently monitors water level, temperature, gas concentration, and manhole cover displacement with reliable accuracy, future improvements in sensor technology, calibration techniques, and data processing algorithms can reduce false alerts and increase detection precision.
2) Miniaturization and Robust Design: Advancements in microelectronics can enable more compact slave nodes, making installation inside hollow manhole covers easier while improving resistance to moisture, corrosion, and harsh underground environments.
3) Integration with Smart City Platforms: Future versions can be connected to centralized smart city dashboards, allowing authorities to monitor multiple manholes simultaneously, analyze historical data, and implement predictive maintenance strategies.

4) Extended Sensor Capabilities: Additional sensors such as humidity, pH, or chemical pollutant detectors may be incorporated to provide deeper insight into sewage conditions and environmental impact.
5) Energy Optimization: Further optimization using ultra-low-power components and energy harvesting techniques such as solar or vibration-based charging can enable long-term autonomous operation with minimal battery maintenance.
6) Automated Response Mechanisms: Future development may include local automated actions such as activating drainage pumps or warning alarms when hazardous conditions are detected, reducing dependence on manual intervention.

XI. ACKNOWLEDGEMENT

I take this opportunity to express my sincere appreciation for the cooperation given by Prof.S. G. GIRAM, Principal of AISSMS'S POLYTECHNIC, Pune and need a special mention for all the help extended by him, constant inspiration and encouragement to make my project a memorable experience. I am thankful to our H. O. D. of E&TC Department, Prof. V.S.Gaikwadfor her time to time support and valuable guidance. I am deeply indebted to my internal guide Mrs. R.V.Nilajagi, for completion of this project for which she/he has guided and helped me going out of the way.. I am thankful to all teachers and professors of our department for sharing with me, valuable knowledge on their respective fields. I would also thank my fellow classmates and friends for their support and timely suggestions. I would also like to thank library staff and laboratory staff for providing me cordial support and necessary facilities, which were of great help for preparing the project report. Thanks to all!!!

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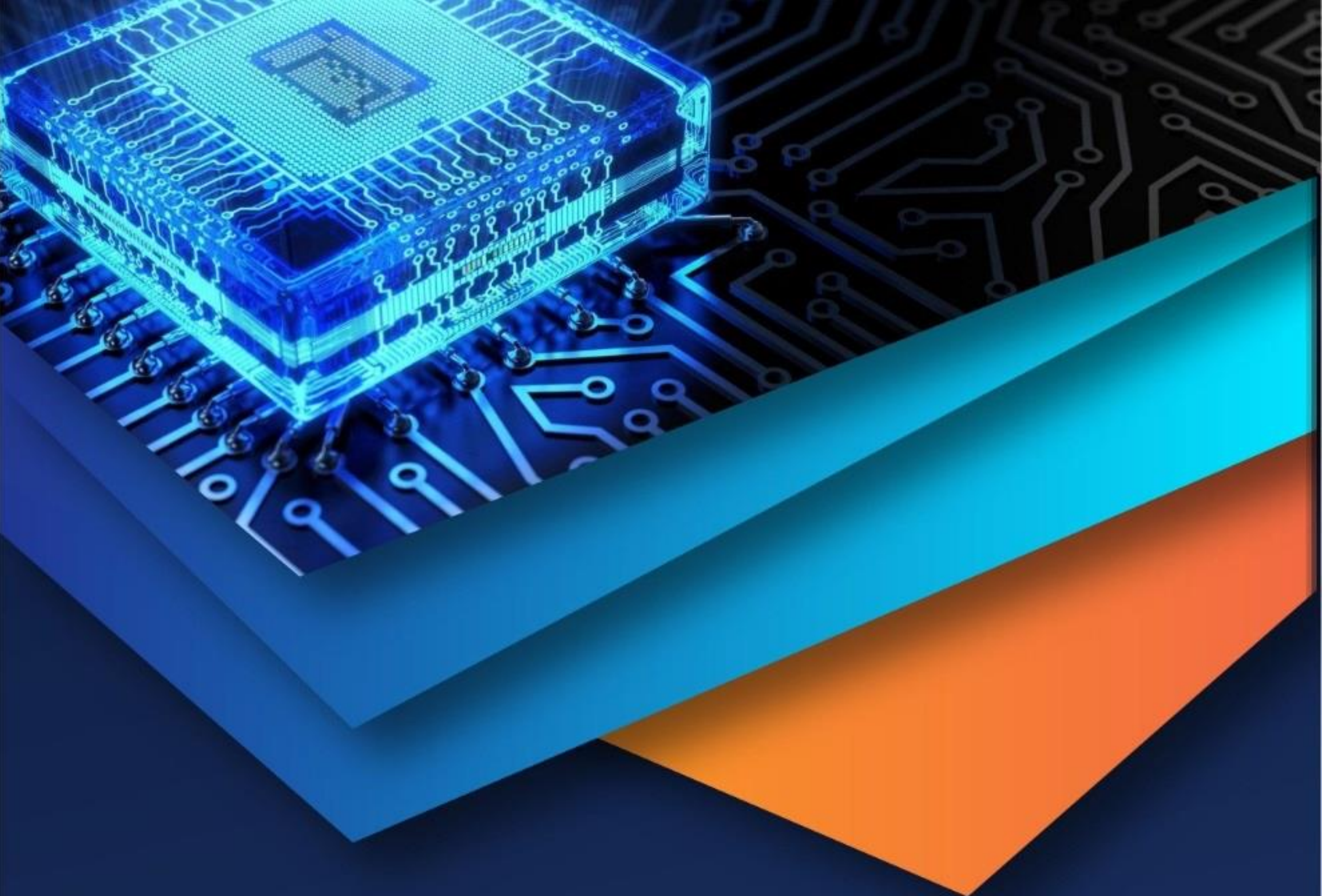

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