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Low Cost Decentralized Smart Air Purification and Monitoring System

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Abstract: Air pollution has become a serious threat to human health, especially in densely populated urban regions such as Delhi NCR. The increasing number of vehicles, industries, and construction activities has resulted in high levels of harmful gases and airborne particles. To overcome this challenge, this work presents a low- cost decentralized smart air purification and monitoring system based on Internet of Things (IoT) and blockchain technology. The proposed system uses DHT11, MQ-7, and MQ-135 sensors to continuously measure temperature, humidity, carbon monoxide, and overall air quality. The sensed data is transmitted to a cloud platform and securely recorded using blockchain to ensure data integrity and transparency. When pollution levels exceed safe limits, a low-cost air purification unit is automatically activated to reduce contaminants. The system is affordable, scalable, and suitable for deployment in smart city environments, providing both real-time monitoring and localized pollution control.
Keywords: Air Quality Monitoring, Smart Air Purification, Low-Cost Sensors, Internet of Things (IoT), Decentralized Systems, Embedded Systems, Environmental Monitoring, Block chain.

I. INTRODUCTION

Air pollution is one of the most serious environmental problems affecting modern society, particularly in rapidly growing urban regions such as Delhi NCR. The rapid expansion of transportation systems, industries, and construction activities has significantly increased the concentration of harmful pollutants such as carbon monoxide, toxic gases, and fine particulate matter in the atmosphere. Continuous exposure to such pollutants can lead to respiratory disorders, heart diseases, and a decline in overall quality of life.

Conventional air quality monitoring systems mainly rely on expensive and centralized monitoring stations installed at a limited number of locations. Although these stations provide accurate data, they are unable to represent the actual pollution levels experienced at streets, homes, and workplaces. This creates a gap between reported air quality and real-world exposure. In addition, the high installation and maintenance cost makes it difficult to deploy these systems on a large scale.

Recent advances in IoT technology have enabled the development of compact and affordable air quality monitoring devices using low-cost sensors and microcontrollers. These devices can continuously collect environmental data and transmit it to cloud platforms, allowing users to access pollution information in real time. However, ensuring the security and reliability of this data is still a major concern, as environmental data plays an important role in public awareness and policy decisions.

Blockchain technology offers a solution to this problem by providing a decentralized and tamper- proof data storage mechanism. When used with IoT- based monitoring systems, blockchain ensures that sensor data cannot be altered or manipulated. In addition to monitoring, local air purification is equally important to reduce pollution at the source. Integrating air purifiers with monitoring units enables automatic and timely pollution control.

Therefore, this work proposes a low-cost decentralized smart air purification and monitoring system that combines IoT-based sensing, blockchain-based secure data storage, and automated air purification to improve air quality in highly polluted environments.

The proposed system is designed with simplicity, affordability, and scalability in mind so that it can be easily adopted in homes, offices, schools, and small public spaces. By using widely available low-cost sensors and microcontrollers, the overall implementation cost is kept minimal without compromising functionality. At the same time, the decentralized architecture allows multiple units to operate independently while still contributing to a shared data network. This makes the system suitable for large-scale deployment in urban areas, where localized air quality control is essential for protecting public health and improving living conditions.

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II. LITERATURE REVIEW

Low- Several studies have investigated the use of low-cost sensors for air quality monitoring in urban environments. Devarakonda et al. demonstrated that deploying a large number of inexpensive sensors can provide better spatial coverage than traditional monitoring stations, enabling the identification of localized pollution zones. Their work highlighted the importance of dense sensor networks in understanding real-world air quality variations.

IoT-based air monitoring systems have also been widely explored. Kumar et al. developed a cloud- connected pollution monitoring system that allowed real-time visualization of gas and particulate levels. Although their system improved accessibility to pollution data, it did not include any mechanism to actively reduce air pollution.

The performance of low-cost sensors was evaluated by Castell et al., who showed that proper calibration techniques can significantly improve measurement accuracy. Their results confirmed that low-cost sensors can be effectively used for environmental monitoring when supported by suitable data processing methods.

Centralized monitoring approaches were analyzed by Snyder et al., who pointed out that high- cost installations and limited station density reduce their effectiveness in capturing localized pollution levels. This study emphasized the need for decentralized and community-level monitoring systems. Recent research has also focused on air purification technologies. Zhang et al. proposed sensor-controlled purification units that automatically activate when pollution levels rise. Although their system improved indoor air quality, it was not designed for cost-effective large-scale deployment. Sharma et al. introduced a microcontroller-based purifier using HEPA and activated carbon filters, but their design lacked cloud connectivity and data logging features.

From a global health perspective, the World Health Organization reported that cities such as Delhi frequently experience particulate matter levels far above safe limits, indicating an urgent need for affordable and scalable air quality solutions. Based on these studies, it is clear that very few systems combine low-cost monitoring, secure data storage, and real-time purification in a decentralized architecture, which motivates the proposed work. Recent developments in blockchain-enabled IoT systems have further strengthened the reliability of environmental monitoring platforms. Researchers have shown that integrating blockchain with sensor networks can prevent data tampering, improve transparency, and build trust among users and regulatory bodies. Such secure data frameworks are particularly important for air quality monitoring, where accurate and historical data are essential for environmental analysis, public reporting, and policy making. However, only a limited number of studies have combined blockchain technology with low-cost air quality sensing and purification, highlighting a clear research gap that the proposed system aims to address.

Furthermore, recent studies emphasize the importance of integrating monitoring systems with automated response mechanisms to improve environmental control. Instead of only observing pollution levels, smart systems that can react in real time by activating purification or ventilation units provide more effective protection against harmful pollutants. Such closed-loop systems reduce human dependency and ensure quicker mitigation of poor air quality conditions. This approach aligns with the growing demand for intelligent and self-regulating environmental management solutions in smart homes and smart cities.

III. METHODOLOGY

1) Air Quality Sensing: Low-cost environmental sensors are used to continuously measure parameters such as harmful gas concentration, temperature, humidity, and overall air quality in the surrounding environment.
2) Data Processing: The sensor readings are processed by an IoT-enabled microcontroller, which evaluates the measured values against predefined safe limits to determine the level of air pollution.
3) Purification Control: When the detected pollution exceeds the allowable threshold, the control unit automatically activates the air purification system to remove harmful particles and gases from the air.
4) Cloud Monitoring: The processed data is transmitted to a cloud platform, allowing users to monitor air quality in real time and analyze historical trends remotely.

IV. EXISTING SYSTEM

The existing IoT-based air pollution monitoring system focuses on tracking environmental conditions to address the growing problem of air and noise pollution. Due to rapid urbanization, industrial growth, and increased vehicle usage, harmful pollutants have reached alarming levels, posing serious risks to human health and the natural environment. These systems aim to provide continuous environmental data that can support pollution awareness and regulatory control. In conventional IoT monitoring models, several sensor nodes are installed at different locations to measure parameters such as carbon monoxide, carbon dioxide, nitrogen oxides, particulate matter, temperature, humidity, and noise levels. These sensors are connected to microcontrollers and wireless communication modules that send the collected data to cloud servers for further processing.

The received data is analyzed and presented through web or mobile-based dashboards, enabling authorities, researchers, and the public to observe pollution levels remotely. This real-time monitoring helps in identifying pollution trends, detecting hazardous conditions, and supporting environmental management decisions.

Although the existing system is useful for monitoring environmental conditions, it only provides information about pollution levels and does not actively improve air quality. It depends on users or authorities to take action after observing the data, which may lead to delays in pollution control. Moreover, centralized data storage can be vulnerable to data loss or manipulation, reducing the reliability of long-term environmental records. These limitations highlight the need for an intelligent system that not only monitors air quality but also automatically performs purification while ensuring secure and reliable data handling.

V. PROPOSED SYSTEM

The proposed system introduces an intelligent IoT-based air purification and monitoring unit designed for indoor environments such as homes, offices, and small public spaces. Unlike traditional solutions that only display pollution levels, this system combines continuous sensing with automatic purification, thereby ensuring both detection and control of indoor air pollution.

The core of the system is an Arduino UNO microcontroller interfaced with gas, temperature, and humidity sensors. These sensors continuously capture environmental data, including air quality levels, temperature, and relative humidity. The collected information is processed in real time and displayed on an LCD screen, allowing users to easily understand the condition of the indoor environment. The purification unit is constructed using a transparent enclosure that houses multiple filtration stages. A HEPA filter is used to trap fine particles such as dust, smoke, and allergens, while an activated carbon filter absorbs harmful gases, unpleasant odors, and volatile organic compounds. In addition, a UV-C lamp is integrated into the system to disinfect the air by deactivating bacteria and viruses, thereby improving the overall hygienic quality of the purified air.

During operation, polluted air is drawn into the system by a fan and passed through the filtration layers and UV-C treatment chamber. The purified air is then released back into the room, creating a continuous cycle of air cleaning. Due to its compact and lightweight design, the system can be easily installed in various indoor locations, including bedrooms, offices, clinics, kitchens, and classrooms. One of the key advantages of the proposed system is its ability to operate automatically without human intervention. When the sensors detect a rise in pollution beyond safe limits, the microcontroller immediately activates the purification components. This real-time response ensures that harmful pollutants are removed as soon as they appear, reducing health risks and maintaining a safer indoor environment. Furthermore, the use of low- cost components makes the system affordable and accessible to a wide range of users. Unlike expensive commercial air purifiers, this model provides an economical alternative while still offering effective monitoring and filtration. Its modular design also allows future upgrades such as wireless connectivity, mobile app integration, and cloud-based data analysis, making it suitable for smart home and smart building applications.

Block Diagram

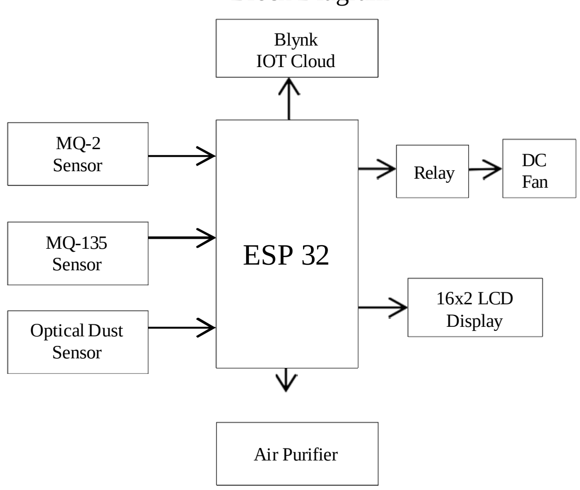

Fig 1- Block Diagram

VI. SYSTEM DESIGN

The proposed IoT-based Smart Air Purification and Monitoring System is developed to continuously track and improve indoor air quality in residential areas and small public spaces. The overall structure of the system consists of four main components: a sensing unit, a control and processing unit, a display module, and a purification unit. These components work together to detect air quality conditions, analyze sensor data, and perform suitable purification actions.

The sensing unit includes gas sensors, temperature sensors, and humidity sensors that measure the presence of harmful gases, environmental temperature, and relative humidity. These sensors provide real-time data to the Arduino UNO microcontroller, which functions as the central controller of the system. The controller evaluates the sensor inputs and compares them with predefined safe limits to determine whether the air quality is acceptable or hazardous.

The calculated values are displayed on anLCD panel in the form of air quality, temperature, and humidity readings. This allows users to easily observe the indoor environmental condition. In addition, the microcontroller uses this information to automatically control the air purification process, ensuring that the air remains clean and safe.

The purification unit is composed of a fan, HEPA filter, activated carbon filter, and a UV-C light source. When poor air quality is detected, the fan draws polluted air into the device. The HEPA filter captures fine dust particles and allergens, while the activated carbon filter absorbs toxic gases and unpleasant odors. The UV-C lamp further disinfects the air by neutralizing harmful microorganisms before clean air is released back into the room.

To enhance system accuracy, the sensor readings are continuously sampled and processed using simple filtering techniques to reduce noise and sudden fluctuations. This ensures that the controller receives stable and reliable data, leading to better decision-making and more efficient activation of the purification components. Proper calibration of the sensors further improves the overall performance of the system.

The modular design of the system allows easy expansion and future upgrades. Additional sensors or wireless communication modules can be integrated without modifying the basic structure. This flexibility makes the system suitable for smart home and smart building applications, where real-time monitoring, remote access, and long-term data analysis are increasingly important for maintaining healthy indoor environments.

To enhance the accuracy and stability of the system, sensor outputs are sampled at regular intervals and processed to reduce unwanted noise and sudden variations. Calibration methods are applied so that the sensors provide dependable measurements of air quality parameters. Based on these readings, the microcontroller runs programmed decision-making logic to determine when the purification unit should be activated, allowing the system to operate in an automatic and intelligent manner.

The system is also designed to be scalable and energy efficient. Its modular structure makes it possible to add new sensors or communication devices in the future for expanded monitoring and data collection. Since the Arduino UNO and the sensing devices consume very little power, the system can operate continuously without excessive energy usage, making it suitable for long-term indoor deployment.

In addition, the architecture supports future integration with IoT platforms. This allows air quality data to be transmitted to cloud servers for storage, visualization, and long-term analysis. Remote access to this information enables users and administrators to monitor indoor air conditions from anywhere and identify pollution patterns over time, which is especially useful for smart homes and smart building environments.

Cost efficiency and ease of installation are also important design goals of the proposed system. By using commonly available and low-cost electronic components, the overall system cost is kept low while maintaining reliable performance. This makes the solution practical for use in homes, classrooms, clinics, and small offices where expensive commercial air purifiers may not be affordable.

Overall, the Smart Air Purification and Monitoring System supports the creation of healthier indoor environments through continuous sensing and automatic purification. The combination of low power consumption, decentralized operation, and future connectivity options makes the system suitable for integration into modern smart homes, smart buildings, and wider smart city frameworks.

The operation of the proposed Smart Air Purification and Monitoring System is based on a set of fundamental mathematical calculations for sensor signal conversion, air quality evaluation, and control decision making.

The analog output voltage of each sensor is first obtained from the digital value of the Arduino analog-to-digital converter using

$$Vout=ADC\times Vref\backslash 2\char`^n-1$$

where ADC is the digital reading, Vref is the reference voltage, and nnn is the ADC resolution.

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The temperature in degree Celsius is calculated from the sensor voltage as

$$T(C)=Vout\backslash 10\ mV/C$$

The gas concentration is estimated using a linear mapping relation

$$Cgas=Vout\backslash Vmax\times Cmax$$

The Air Quality Index (AQI) is computed using the standard breakpoint equation
$AQI=Ihigh-Ilow\backslash Chigh-Clow\times(C-Clow)+Ilow$ To reduce measurement noise, a moving average filter is applied as
$Cavg(k)=1N\sum i=0N-1C(k-i)$
Finally, the purifier control decision is based on threshold comparison:
If $AQI>AQIth\Rightarrow$Purifier ON If $AQI\leq AQIth\Rightarrow$Purifier OFF
These calculations ensure accurate sensing, reliable air quality assessment, and automatic operation of the purification system.

VII. MATLAB/SIMULINK MODEL

A MATLAB Simulink model was created to examine the working behavior of the proposed IoT-based Smart Air Purification and Monitoring System prior to hardware implementation. The simulation platform enables the system to be tested under different air quality conditions in a controlled and flexible environment. The model consists of functional blocks that represent sensor inputs, control logic, data processing, and air purification components.

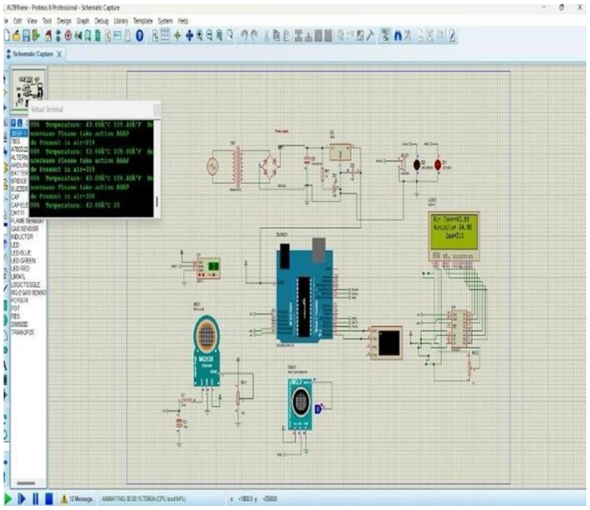

Fig 2- MATLAB Simulation Model

In the simulation model, air quality, temperature, and humidity are represented as input signal sources that generate different environmental conditions. These input signals are fed into a control block that simulates the operation of the Arduino UNO microcontroller. The controller evaluates the sensor data by comparing it with preset threshold values and produces suitable control signals to operate the fan, HEPA filter, activated carbon filter, and UV-C lamp.
The simulation clearly indicates that when the pollution level exceeds the defined limit, the purification system is activated automatically, resulting in improved air quality. This confirms the correct and reliable functioning of the proposed system.

VIII. SIMULATION RESULTS

The Simulink model was evaluated under different environmental conditions by varying pollution levels, temperature, and humidity. The results demonstrate that when air quality falls below safe limits, the control system activates the HEPA and activated carbon filters to remove airborne particles and toxic gases, while the UV-C lamp helps eliminate harmful microorganisms.
After the purification process, the Air Quality Index shows a noticeable improvement, and temperature and humidity remain within comfortable ranges. These results verify that the system is capable of continuously monitoring indoor air conditions and maintaining a healthier environment in real time. Therefore, the simulation confirms the suitability of the proposed system for use in residential buildings, offices, and small public spaces.

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IX. HARDWARE MODEL

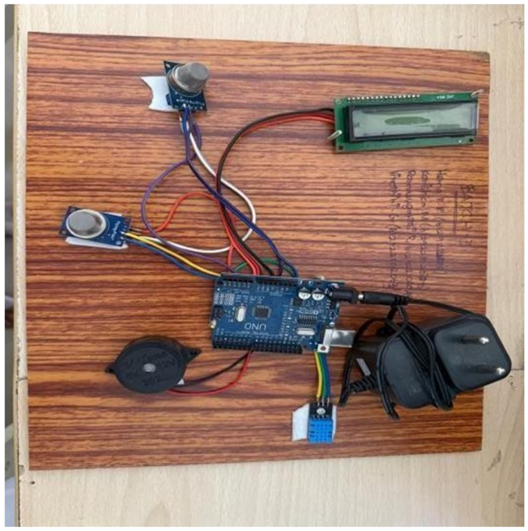

Fig 3 -Prototype

X. CONCLUSIONS

The IoT-based Smart Air Purification and Monitoring System presented in this work offers a practical and sustainable solution for maintaining healthy indoor air quality. By combining HEPA filtration, activated carbon adsorption, and UV-C disinfection, the system is capable of removing fine particles, toxic gases, and harmful microorganisms from the air. The use of environmental sensors together with an Arduino UNO controller enables continuous monitoring and automatic regulation of air quality within safe limits.

The proposed design is economical, easy to maintain, and well suited for use in homes, offices, and small public spaces. Its modular structure allows future improvements such as cloud connectivity, artificial intelligence–based air quality forecasting, and enhanced filtration techniques. Simulation results obtained through MATLAB Simulink validate the accuracy.

Overall, this project provides a compact, energy-efficient, and intelligent approach to indoor air purification, supporting healthier living environments and sustainable smart-technology applications.

XI. FUTURE SCOPE

1) The proposed Smart Air Purification and Monitoring System can be further enhanced in several ways to increase its functionality and effectiveness. One major improvement is the integration of IoT connectivity, which would allow users to remotely monitor and control the system through mobile applications or cloud-based platforms. This would provide real-time access to air quality data from anywhere.
2) The use of artificial intelligence and machine learning techniques can also be incorporated to analyze air quality patterns and predict future pollution levels. This would help the system to automatically optimize purification cycles, improving energy efficiency and overall performance.
3) A multi-sensor network can be developed to extend monitoring across multiple rooms or larger buildings. By connecting several sensor units, the system could provide a more complete view of indoor air conditions and enable coordinated purification across different areas.
4) Further improvements in filtration technology, such as electrostatic or photocatalytic filters, can be added to remove even finer particles and chemical pollutants. In addition, renewable energy sources like solar power could be used to operate the system, making it more environmentally friendly and reducing electricity consumption.
5) Finally, the system can be integrated with smart building and home automation platforms, allowing ventilation and air purification to be automatically controlled based on real-time air quality data. These enhancements will make the system more intelligent, scalable, and suitable for a wide range of indoor environments, supporting healthier and more sustainable living spaces.

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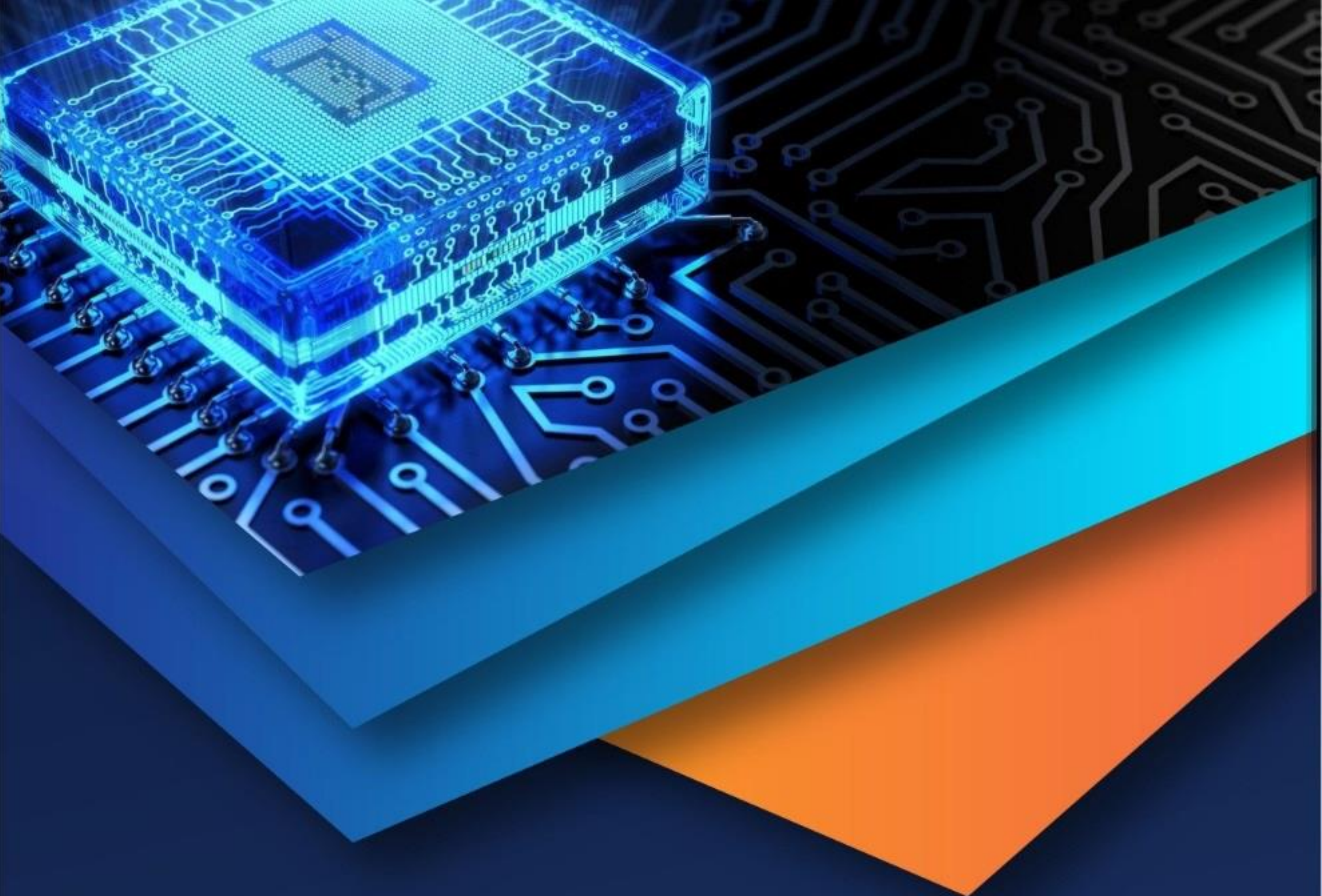

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