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Real-Time Biogas Monitoring Using Gas Sensors

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Abstract: Biogas digesters are sustainable solutions for managing organic waste, but most monitoring systems focus mainly on methane and ignore toxic gases produced during anaerobic digestion. This proposed system introduces a low-cost multi-gas monitoring framework that detects both combustible and harmful gases in real time using sensor-based microcontroller technology. The system enables early detection of toxic gas buildup, improves worker safety, and helps optimise the digestion process. By using affordable and easily available sensors, the system supports safer, more efficient, and environmentally friendly biogas production while allowing users to take early preventive actions.
Keywords: Embedded System, Biogas, Substrate, Decomposition, Renewable Energy, Monitoring System.

I. INTRODUCTION

The importance of renewable energy is increasing, and this has increased research and utilisation of the biogas concept as a key formula for managing waste and generating energy. Biogas digesters basically use anaerobic digestion to convert organic matter like agricultural waste, animal manure, and vegetable waste into a gas combination that mainly has methane. This proposed process provides a renewable energy source that helps reduce greenhouse gas, maintain sanitation, and reduce pollution [1]. As biogas systems are widely used, safety precautions, gas quality, and concentration monitoring become a big challenge. Traditional methods for monitoring gases are focused on methane concentration to get energy output and combustion efficiency. But anaerobic digester also creates some amount of toxic and corrosive gases, because the decomposition is done without the presence of oxygen, so some gases such as carbon dioxide is created, and mostly this gas is created in the early phases of digestion [13]. The above-mentioned gas are highly risky, and they create serious health risks to workers. It also causes corrosion in storage tanks, damages engines, and it also reduces the efficiency of combustion. It can cause respiratory poisoning, and ammonia can create eye irritation in the workers [21]. So, from the proposed work, I would help the worker to monitor the gas concentration and maintain the quality of the gas created from the digester. I would use multiple sensors to monitor the gas concentration by integrating an embedded system with them. The proposed system will use MQ-4 to detect Methane, and MQ-135 to detect CO2. So this proposed system will use an embedded system to integrate the sensors and give the concentration of the gas mixture created from the digester. Recent updates have made sensors more affordable and have created new possibilities for real-time monitoring of multiple gases by integrating them with the embedded system. So this proposed system becomes more affordable more cheap so it would be easy to install in small or medium-level biogas plants.

II. METHODOLOGY

A. Preparation of the digester container:

Fig. 1 explains the construction of the container. After obtaining a suitable container, a hole is drilled at the top to create a gas outlet for the biogas produced during anaerobic digestion. A PVC pipe is inserted into the hole and sealed using M-seal to prevent gas leakage. Once the digester container is prepared, slurry is prepared for decomposition [7]. Slurry is a mixture of organic waste and water, commonly prepared using cow dung, vegetable waste, and water.

It can also be made using pig manure, kitchen waste, food waste, bamboo shoots, and other organic materials. Cow dung and manure are preferred because they contain natural microbes that accelerate decomposition. For a mini biogas digester, only a small quantity of organic material is required [8].

From Fig. 1, we can understand that how the prepared slurry, known as input slurry, is poured into the digester, and the container is tightly sealed to prevent air entry and gas leakage. The digester is then left undisturbed for about 5–7 days. During this period, microbes decompose the slurry in the absence of oxygen, producing biogas [10] [5]. After gas production, the remaining material is called digested slurry, which is nutrient-rich and can be used as fertiliser in agriculture. The proposed system is designed to monitor gas production, including methane (CH_4) and carbon dioxide (CO_2) levels, during the biogas generation process.

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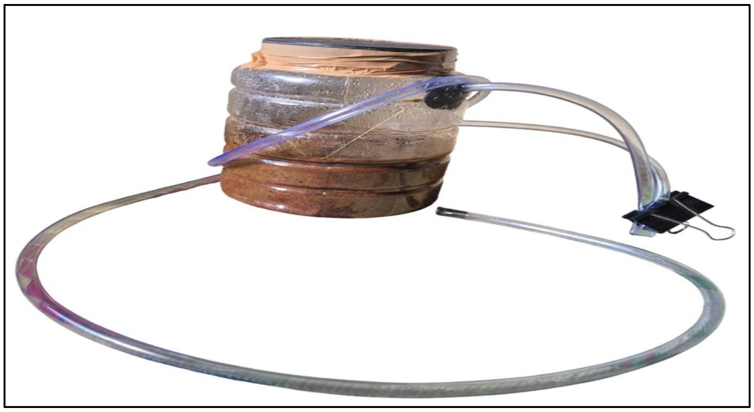


Fig. 1 : Experimental setup of the developed anaerobic digestion unit for biogas generation.

B. Block Diagram

Fig. 2 below is the block diagram of the proposed system, and we are getting output in the Blynk Web. The Blynk is a console basically used for interfacing, but it can also be used for integration in some situations. Figure 1 explains the whole concept of the proposed system.

Fig. 2 shows all the components used in the proposed system and how the connections are made.

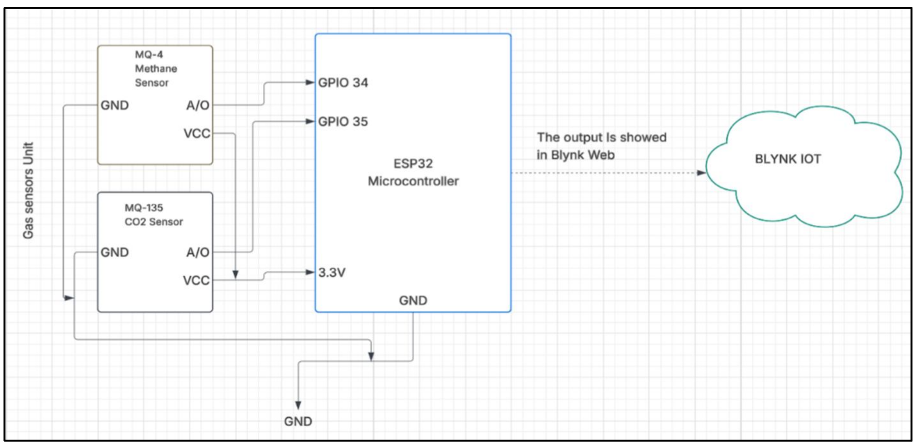


Fig. 2 : System architecture illustrating MQ-4 and MQ-135 sensor interfacing with the ESP32.

C. Components used in Block Diagram

About ESP32 Microcontroller:

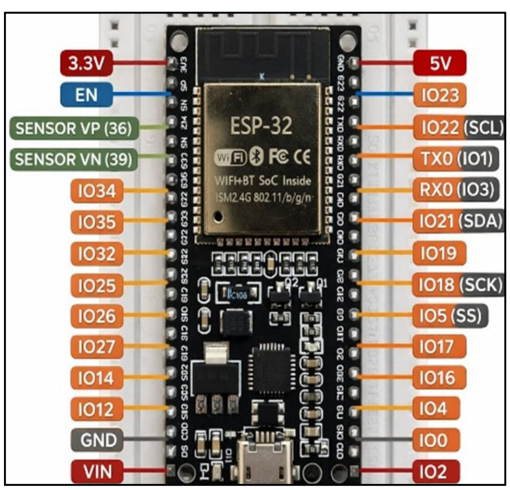


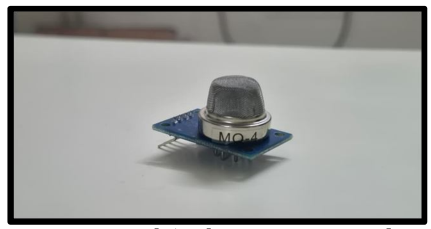
Fig. 3 : Pin configuration and hardware overview of the ESP32 microcontroller.

The proposed system is built around the ESP32-WROOM-32, we can see the microcontroller from Fig. 3, a microcontroller that features a 32-bit processor capable of handling sensor integration and performing multiple operations simultaneously [7] [8]. This module is widely used in embedded and IoT applications because it includes an inbuilt Wi-Fi capability, enabling wireless communication and real-time data transmission without the need for additional networking hardware. The ESP32-WROOM-32 consists of a total of 34 pins, among which 28 can function as input/output pins and 6 are dedicated input pins, allowing flexible interfacing with different sensors and peripheral components required for the project [17] [3]. The ESP32 platform supports programming in languages such as C/C++ and MicroPython, giving developers the freedom to choose an appropriate development environment based on application requirements. For this project, C/C++ is selected due to its efficiency, reliability, and strong compatibility with embedded system design. The development and programming process is carried out using the Arduino IDE, which provides a user-friendly interface, extensive library support, and simplified code uploading to the ESP32 board [5] [6]. By combining the ESP32-WROOM-32 with suitable sensors and programming tools, the system is designed to continuously monitor gas concentrations and enable effective data acquisition for further analysis and safety monitoring [9].
The sensors we are going to use are:

MQ-135

a.) This sensor is used to detect CO_2

MQ-4



b.) This sensor is used to detect CH_4

Fig. 4 : The above are the sensors used in this proposed system.

From Fig. 4, we get to know that the proposed system utilises two primary gas sensors, namely the MQ-135 and MQ-4, to effectively monitor the composition of gases produced during the biogas generation process. These sensors are selected because of their suitability for detecting key gases that influence both safety and fuel efficiency. The MQ-135 sensor is mainly employed for the detection of carbon dioxide (CO_2) [6] [9].
During the decomposition of slurry inside the digester, a mixture of gases is released, and carbon dioxide forms a significant portion of this mixture.
Continuous monitoring of CO_2 presence is important because excessive exposure can be harmful to users and workers operating near the system. By integrating the MQ-135 sensor into the proposed setup, the system can track CO_2 levels in real time and help maintain a safer working environment [4] [24]. The MQ-4 sensor is designed to sense methane (CH_4), which is the principal combustible component of biogas. Measuring methane presence is essential because higher methane content indicates better fuel quality and improved energy efficiency. Incorporating the MQ-4 sensor in the system enables accurate detection of methane presence within the generated biogas, thereby assisting in evaluating the effectiveness of the digestion process and the usability of the produced biofuel.
Together, these sensors play a crucial role in the proposed monitoring system by providing continuous information about gas composition, ensuring safety, and supporting efficient biogas production.

D. Blynk Web

The Blynk Web Dashboard is an Internet of Things (IoT) control and monitoring environment, which is built upon a cloud platform and is aimed at making it easier to communicate between embedded devices and user interfaces. It makes the interconnection of microcontrollers, sensors and actuators to the internet and shows real-time data through customizable dashboards to the developers, researchers and students.
Blynk has become popular in the current research of embedded and industrial automation since it does not require any complex server programming, database handling, or mobile app development. Rather, the platform includes ready-made tools like providing devices, cloud storage, analytics and remote control widgets, which are available in a web browser [32] [6].

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III. MODELING AND ANALYSIS

A. Schematic Representation of the Designed System

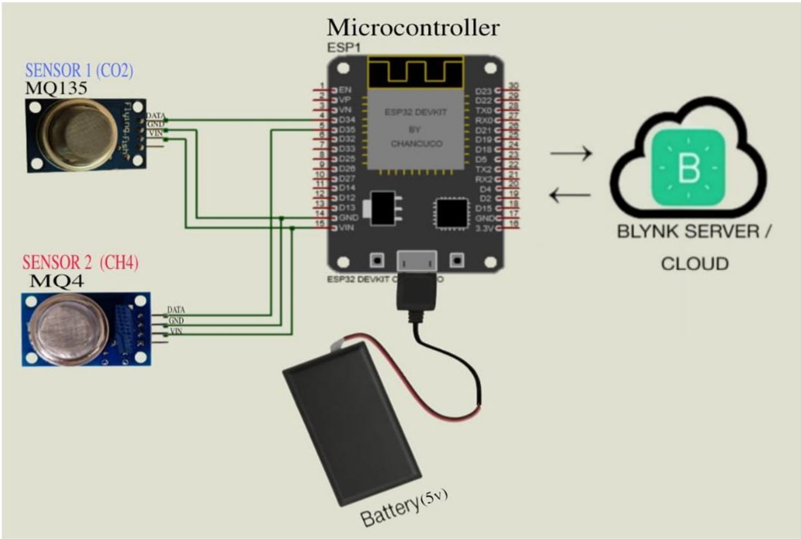

Fig. 5 : Schematic circuit setup of the ESP32-based gas sensing system.

Fig. 5 explains the Schematic representation of the proposed system. The pin configuration of the sensor 1 and sensor 2 are mentioned above.

B. Real-time Implemented circuit for the Proposed System

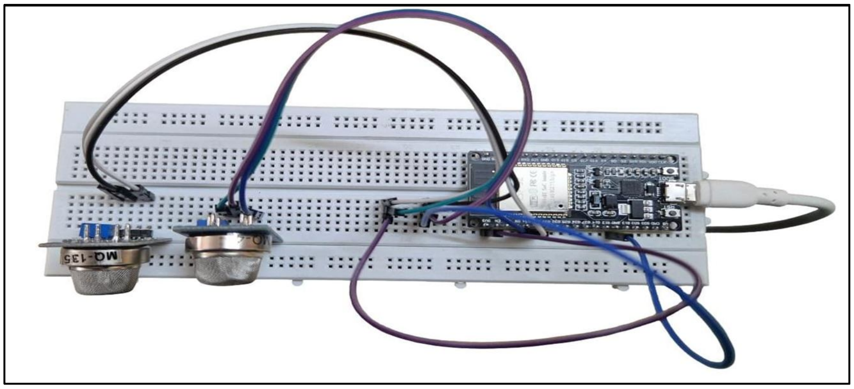

Fig. 6 Real-time circuit setup of the ESP32-based gas sensing system.

From Fig. 6, the illustrated circuit diagram represents the proposed gas monitoring system designed using an ESP32 microcontroller along with MQ-135 and MQ-4 gas sensors. In this setup, the ESP32 acts as the central processing unit that receives analogue signals from both sensors and processes them for further monitoring.

The MQ-135 sensor is connected to detect carbon dioxide levels produced during the decomposition of slurry, while the MQ-4 sensor is used to sense methane concentration present in the generated biogas. Each sensor is powered through the appropriate voltage supply and shares a common ground with the ESP32 to ensure stable operation and accurate signal transmission. Overall, the circuit demonstrates how sensor outputs are interfaced with the ESP32 to enable continuous observation of gas composition, supporting safe handling and effective evaluation of biogas production.

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IV. RESULTS AND DISCUSSION

The developed gas monitoring prototype based on the ESP32 microcontroller and MQ-series sensors was experimentally evaluated to observe methane and carbon dioxide generation inside the biogas container. The raw analog values obtained from the ESP32 were converted into concentration values expressed in parts per million

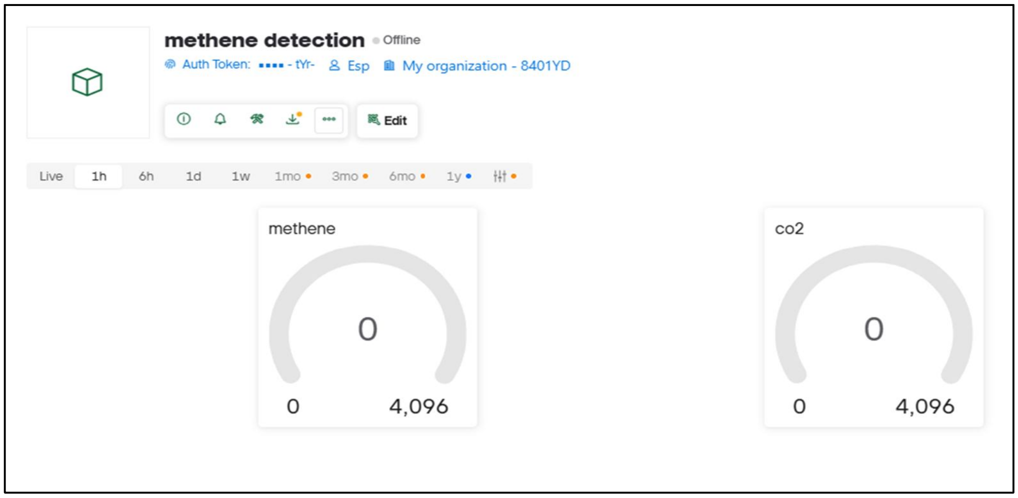

Fig. 7 : Initial dashboard showing zero methane and CO_2.

(ppm) using a proportional conversion approach. Continuous monitoring demonstrated that both methane and carbon dioxide were successfully detected, confirming the proper functioning of the sensing elements, signal acquisition circuitry, and data processing algorithm. The successful connection between the ESP32 hardware and the Blynk IoT platform was first verified through the initialization interface, which displayed stable communication and sensor readiness before gas detection began. Fig. 7 explains the initial stage of the blynk web where the values are zero. After initialisation, real-time sensing data became visible on the Blynk dashboard, where methane and carbon dioxide concentrations were continuously updated. This confirmed that the system was capable of transmitting environmental data wirelessly and presenting it in a user-friendly monitoring format suitable for safety supervision and remote observation.

a.) First CH_4 and CO_2 sample reading. b.) Second CH_4 and CO_2 sample reading.

Fig. 8 : Dashboard displaying methane and CO_2 levels.

From Fig. 8, it is the combination of the two different readings that we got from the Blynk web. During observation, methane concentration values remained within a moderate range and showed gradual variation across sequential samples. This behaviour indicates stable anaerobic digestion activity rather than abrupt gas leakage or irregular production. In comparison, carbon dioxide values appeared relatively higher and displayed noticeable fluctuations at certain sampling points. Such variation is expected in compact digesters because microbial activity, temperature distribution, and substrate decomposition do not remain perfectly constant over time. The converted ppm readings obtained from the ESP32 provide a clearer quantitative understanding of gas evolution inside the container. These measured values are summarised in the following Table 1 for reference and comparison across samples.

Table 1: Methane and CO_2 Concentration

Sample No.	Methane ADC Value	Methane (ppm)	CO_2 ADC Value	CO_2 (ppm)
1	2644	3456.65	2992	5306.47
2	2634	4432.23	2988	6296.74
3	2634	5432.23	2945	6191.71
4	2688	5564.11	2512	6134.31
5	2468	6126.86	2784	6798.53
6	2544	6812.45	2974	7262.52
7	2571	6478.39	2948	7199.02
8	2586	6915.02	3018	7369.96
9	2410	6885.23	2952	4308.79

Formula Used:

$$ppm = \frac{\text{ADC reading}}{4095} \times 10000$$

The sensor results in the Blynk cloud dashboard are displayed in the 0 to 4096 scale range of 12-bit resolution of ESP32 analog-to-digital converter. This is a graphical scaling which is only used in the representation of the user interface and doesn't have any effect on the proportional ppm conversion or the trends in the observed gas concentrations.

To further interpret the sensing behavior, the ppm values were plotted graphically to visualize concentration trends over time. The methane curve shows a relatively smooth pattern with minor increases and decreases, suggesting consistent gas formation. In contrast, the carbon dioxide curve exhibits sharper deviations, which may be influenced by temporary environmental variations, sensor sensitivity differences, or localized gas accumulation within the container. Despite these fluctuations, the overall trend confirms that the monitoring system can effectively capture real-time changes in gas concentration.

A. *Graph of CH_4 and CO_2*

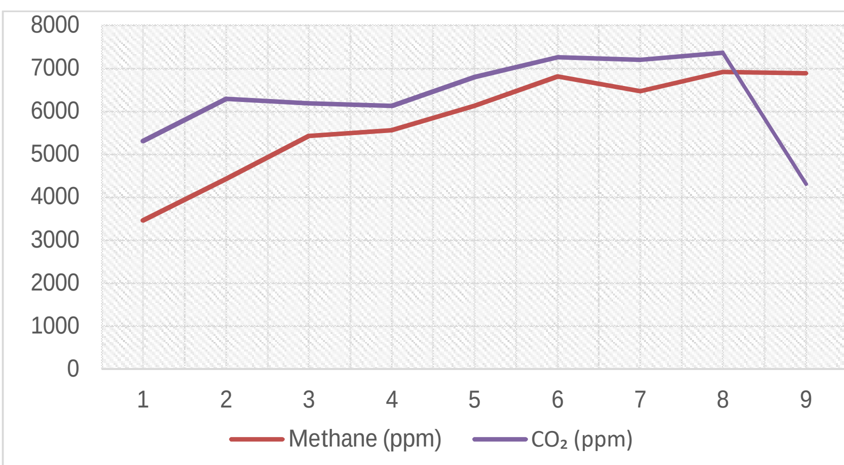

Fig. 9 : Graph showing variation of methane and carbon dioxide concentration across sampling intervals

From the Fig. 9, we compare the methane and carbon di oxide value. Overall, the experimental results validate that the proposed ESP32-based monitoring system can successfully detect methane and carbon dioxide generation in a small-scale biogas setup while enabling wireless visualisation through the Blynk IoT platform. Although the ppm estimation in this prototype is based on proportional conversion rather than full sensor calibration, the system clearly demonstrates real-time sensing capability, remote monitoring functionality, and meaningful trend analysis. With proper calibration and environmental compensation, the same architecture can be extended for accurate quantitative gas measurement in practical biogas monitoring applications.

V. CONCLUSION

The current work has been able to illustrate how a multi-gas monitoring system can be designed by a low-cost ESP32-based microcontroller and implemented in anaerobic biogas digesters. The proposed system is also a better alternative to the traditional methods of monitoring since it can identify both the generation of energy and safety, unlike the traditional method that is principally oriented on methane production. The results of the experiments indicated that it was possible to ascertain the presence of gas in the digester with a high degree of certainty, starting with a zero-gas state and onward to quantifiable levels of methane and CO 2 as decomposition took place. This does not only confirm the adequate operation of sensing hardware but the overall monitoring scheme is also effective in real digestion scenarios. The proposed solution to the implementation of continuous real time monitoring consists of the integration of MQ-series gas sensors with the ESP32 microcontroller and wireless dashboard, which is practical and easy to use. This kind of accessibility is especially useful with small-scale and rural biogas installations where costly analytical equipment is not an option. The system enhances the safety of the workers by allowing them to detect the harmful or excessive gases in time, offering them an opportunity to control the digester better, and ensuring the efficient production of bio-gas. The constant and unique sensor responses are also an indication that the system can be applied to measure the performance of digestion and fuel quality in a significant manner. To sum up, the monitoring system developed presents a cost-effective, efficient, and the green-friendly solution to the contemporary biogas facilities. Through the integration of safety consciousness and the use of renewable energy surveillance, this piece of work has been put into contribution of more sustainable and well-managed biogas production systems. This can be enhanced in future with the addition of gas sensing, field deployment and the mechanism of automatic control to ensure further enhancements in the efficiency of the operation and environmental safety.

VI. FUTURE WORKS

Though the created ESP32-based system of monitoring successfully allows tracking the levels of methane and carbon dioxide in real-time, it has evident potential to be improved, and its capacity to be utilized in the actual biogas facilities can be extended. Executive addition of specific sensors to detect dangerous gases like hydrogen sulfide (H_2S) and ammonia (NH_3), which are often produced in the process of anaerobic digestion and may present a safety threat, corrosion issue, and diminished fuel quality, may be identified as one of such enhancements. More sophisticated sensing devices, e.g. electrochemical sensors, NDIR sensors, can offer superior selectivity, higher accuracy and more stable long-term measurements to conventional MQ-series sensors. The additional progress may also be aimed at the enhancement of the comprehensive monitoring ecosystem. The ability to record the data in the clouds, issue the warning messages in real-time when the amount of gas in the digester is too high, as well as the possibility to add the environmental parameters like temperature, humidity, pH, etc., would enable the users to gain a better insight into the digester behavior. Besides that, the next generation of the system can be equipped with automatic control measures where the monitored data can be employed to control the state of digestion and ensure safe and productive gas production without having to monitor it manually. Through these empirical improvements, the prototype at hand can be developed into a stable smart monitoring and safety platform that can be used in real-world biogas facilities, especially in small-scale and rural energy systems and applications.

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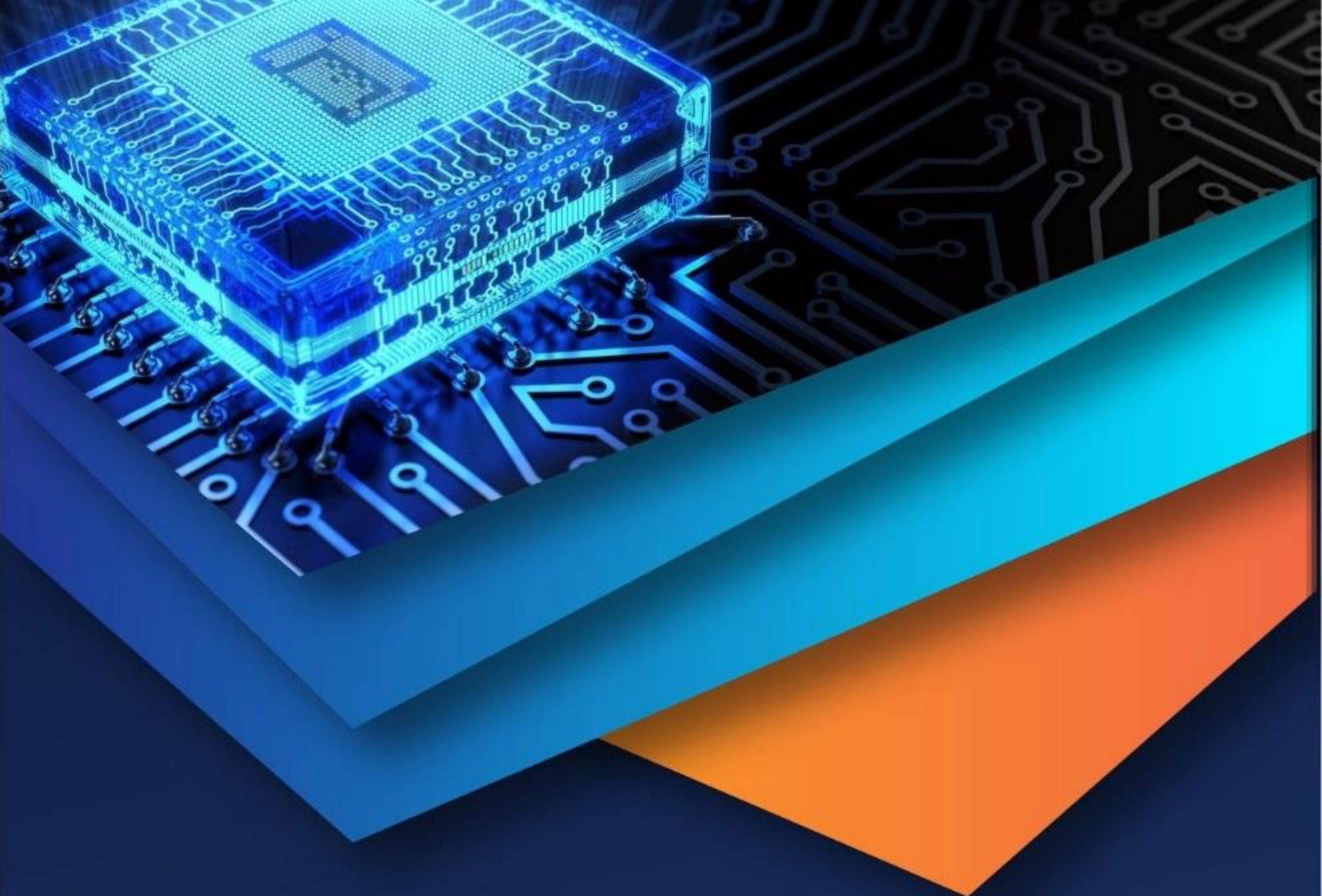

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