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A Review of MQ135 Sensor-Based IoT Solutions for Real-Time Air Pollution Tracking

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Abstract: ***Abstract Air pollution has in fact become a daily issue of. Many in developing areas which see great urban. Growing, heavy traffic, and industry are present. Also. High quality air monitoring stations exist and put out reliable data. They are expensive, hard to maintain, and usually installed in only that which. A few places out of many. Thus people rarely get a full picture of. What they are living in their own streets, homes, or. workplaces. With the growth of cheap sensors and the Internet of Things. In IoT we have seen the design of small affordable devices which. That measures air quality in real time and shares data online. Of the common sensors which include the MQ135 gas sensor. Appears in many academic projects and prototypes which include it. This paper reports on a in depth review of what is out there in terms of IoT solutions which are based on the MQ135 sensor for real time air pollution tracking. We go over the MQ135 sensor's operation principle and we also look at its issues. Also covered are common IoT architecture models, communication protocols, cloud platforms, data processing techniques, and we also look at which are the typical system designs. We discuss a wide range of related research works which we then put under the microscope and do a comparison of which does what better. Also we look at which are the main issues of calibration, power use, data reliability and security which these systems have and then we look at what the future holds which is the combination of IoT with AI, edge computing and large scale distributed sensing. Our aim is to present a very practical and useful overview for students, hobbyists and researchers of how you may use MQ135 based IoT systems for air quality monitoring.***

Index Terms: ***MQ135, Internet of Things, ESP8266, Air Qual- ity Monitoring, Cloud Platforms, Real-Time Tracking, Wireless Sensor Networks.***

I. INTRODUCTION

Air pollution has evolved from a remote environmental issue of which we were mostly unaware. Issue of very personal health issues. Many people living. In urban areas we see thick air, dust on windows, and irrita. During the course of breathing at certain times of the year.

These everyday. Experiences usually result from a mix of. emissions, industrial smoke, biomass burning, construction Activities which include domestic fuel use. Pollutants like carbon. Dioxide (CO_2), nitrogen oxides (NO_x), ammonia (NH_3), ben. Music, volatile organic chemicals (VOCs) and fine particles. Issue may affect lungs, heart, and also overall.

Standard methods of monitoring air quality require large stations that have highly precise measuring instruments. Al- though these measurement devices can be trusted, they are only set up in a limited number of predetermined locations. For most citizens, measurement devices do not capture the air quality around their home, school, work, or place of study. There is a clearly expressed demand for monitoring devices that can be set up in greater number, and measure air quality in a small enough area to detect changes in air quality even within the same city block.

The Internet of Things puts forth a solution which is the deployment of very many small sensing nodes at low cost. We see that which are the IoT devices fitted with gas sensors, microcontrollers, and wireless technology which are constantly measuring pollution levels and putting out data to the web based dashboards, mobile apps, or cloud platforms. In various sensors which are available today the MQ135 has taken the lead in what we see in educational projects and prototype systems. It is a low price option which is easy to hook up to boards like the NodeMCU ESP8266 and also is able to detect a range of harmful gases.

This review paper reports on a study of MQ135 based IoT systems for air pollution monitoring. We do not present one single prototype in this work instead we seek to put forward a review and analysis of how this sensor is used in many designs, which architectures and communication methods are common, what cloud platforms are preferred and what issues are usually faced. By bringing these elements together we put forth a picture which is at once clear and practical which in turn should guide future research.

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II. FUNDAMENTALS OF AIR POLLUTION AND MONITORING

A. Pollutants In The Air

Air pollutants may also be categorized as gases and also to particulate matter. Common gaseous pollutants include: Fine and coarse particles. Also see also that which includes:.

1) Carbon out of which is CO and CO_2 from incomplete and complete combustion of fuels.
2) Nitrogen oxides (NO and NO2) from vehicles and Power plants.
3) Coal and heavy oil use in the process of combustion which is a source of sulfur dioxide (SO2).
4) Ammonia (NH_3) that comes out of farm practices and waste breakdown. Also we see volatile organic com- pounds (VOCs) which come from the use of fuel, paint, solvents, and industrial processes.

Particulate matter (PM) is a term for very small solid or liquid particles which are suspended in air. Very fine particles like PM2.5 are able to get deep into the lungs and present serious health issues.

B. Traditional Monitoring Systems

Traditional air pollution monitoring is of the professional Grade tools which include gas analyzers, optical particle coun- ters, and spectroscopy based systems. These sets of equipment report very precise measurements of individual pollutants but they also have a few drawbacks:.

1) High price point of equipment.
2) Also require regular calibration and maintenance.
3) Need of skilled operators.
4) May be installed only in specific locations.

While they do play an important role in large scale reporting we find that they do not work well for use in the community level. This is where low cost Internet of Things based solutions can support in what traditional systems do but may not be ready to take over fully.

III. OVERVIEW OF IOT IN AIR QUALITY MONITORING

A. Fundamental IoT Concepts

The Internet of Things is a network of physical sensors which process and report a typical IoT set up includes:

1) Sensing elements which record information from the environment.
2) Embedded processors which deal with reading, simple processing, and communication.
3) For communication we see use of Wi-Fi, Bluetooth, LoRa, or cell phone networks.
4) Cloud servers which store, display and analyze in coming data.
5) User interfaces include websites, dashboards, or mobile apps.

In environmental air quality monitoring sensor equipped de- vices which also function as IoT nodes. For example MQ135 and PM sensors which do continuous measurement of pollu- tion levels which also include live access to readings.

B. Advantages of IoT in Monitoring Pollution

A few advantages of pollution monitoring systems that utilize IoT technology are:

1) Cheaper deployment costs per sensor means more stations can be placed.
2) Ability to upload and visualize data in real-time
3) Simple remote access via web dashboards and mobile apps.
4) Opportunity to add more sensors such as temperature, humidity, and GPS.
5) Ability to use data for alerts, automation and analysis over time.

Due to these advantages, IoT solutions have been increasingly utilized by students, researchers, and members of the commu- nity studying the environment.

IV. MQ135 GAS SENSOR: PRINCIPLES AND CHARACTERISTICS

A. Internal Structure and Sensing Chemistry

The MQ135 is a type of semiconductor gas sensor and consists of a small ceramic tube with a coating of tin dioxide (SnO_2). Within the tube is a heating element, and the elec- trodes measure the change in resistance. There is a metal mesh cap over the sensor that protects it and allows gas to diffuse in.

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In pure air, oxygen molecules will attach to the SnO_2 layer. That trapped oxygen takes in free electrons thus raising the surface resistance. As for the reduction gases like ammonia, VOCs, or CO_2 that which come in to contact with that surface they react with the adsorbed oxygen. This in turn releases electrons into the conduction band and reduces the resistance. The sensor's output is based on this resistance change.

B. Electrical Behavior

The MQ135 sensor is usually powered by a heater voltage of approximately 5V. The sensor element is configured in a voltage divider arrangement along with a load resistor. The output voltage at the analog pin shifts with the change in gas concentration, which is sensed by a change in sensor resistance. An example of a microcontroller that does this is the NodeMCU, which reads this analog voltage through an ADC (analog to digital converter) and assigns a digital value to it. Some of the main characteristics include:

1) A broad range of gas detection, including NH3, CO2, benzene, and smoke and alcohol vapor.
2) It also includes the requirement of a preheating period (especially the first time around) and a reliance on the temperature and humidity.

C. Preheating and Conditioning

For reliable performance the MQ135 sensor requires a break in which it is conditioned. It is put forward that the sensor be run for a large time frame which may be from 24 to 48 hours before we take in serious data. This allows the internal elements to stabilize into a constant baseline resistance. Also during normal use it is typical to ignore data collected in the first few minutes after the device is turned on as the heater and sensing layer are still in the process of warming up. This sort of behavior will result in poor or false readings.

D. Calibration Challenges

Calibration Challenges A significant challenge when using the MQ135 sensor in real world situations is converting the raw ADC values to the appropriate units such as parts per million (ppm) or converting to the air quality index (AQI). Accurate calibration is typically done by:

1) Taking reference measurements with known gas concen- trations.
2) Accounting for the effects of temperature and humidity.
3) Repeated recalibration as the sensor undergoes aging. Academic projects tend to provide the sensor with relative indications rather than indicative absolute concentrations. In these situations, the sensor is used more as an indication to show an increase or decrease in pollution as opposed to providing an exact numerical answer.

E. Strengths and Limitations

Main features of MQ135 include:

1) Low price and wide availability.
2) Easy to use analog interface.
3) Ability to detect a variety of pollutants. Its limitations include:
4) In comparison to professional grade sensors we see lower performance.
5) Also what we see is cross reactivity with many different gases which in turn makes it hard to identify specific pollutants.
6) Also there is high power use due to the heating element.
7) Over time we see drift in data which is a result of aging and environmental factors.

V. SYSTEM ARCHITECTURES FOR MQ135-BASED IOT MONITORING

A. Three Layer Architecture

A common approach for describing IoT systems is the three layer model:

1) Perception or Sensing Layer: Contains the MQ135 sensor and possibly other sensors like temperature and humidity. It deals with collecting raw data.
2) Network Layer: Handles communication between de- vices and the internet using Wi-Fi, LoRa, or cellular links.
3) Application Layer: Includes cloud servers, dashboards, and user applications that visualize and analyze the data.

B. Cloud Centric Architecture

Most cost-effective setups perform the majority of the processing work in the cloud. The microcontroller:

1) Reads the MQ135 analog voltage.

2) Implement simple filtering or scaling and send the data to cloud platforms such as ThingSpeak or Firebase.

The cloud side is responsible for:

1) Data storage of the cloud sensor readings, graphing, and rule based alerting.

C. Edge and Fog Based Architecture

More in complex designs we see some of the processing brought forward to the sensor. Edge or fog based architectures:

1) Filter out noise and remove outliers at the local level.

2) Do local AQI reporting or trend analysis.

3) Send to the cloud summarized or reduced data sets instead of full raw samples.

This reduces bandwidth use and also may see quick local action e.g. a buzzer going off or a warning light coming on when pollution hits a certain level.

D. Hybrid Architectures

Hybrid systems which combine both approaches. We see devices computing basic metrics on the go and also sending raw or semi processed data to the cloud for in depth analysis. In this way we see value in what they do when building out large scale air quality networks.

E. Representative Architecture Diagram

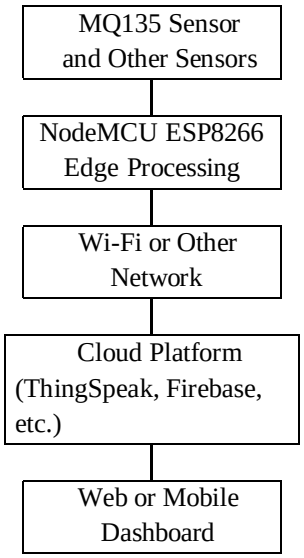


Figure 1. Generic architecture of an MQ135 based IoT air quality monitoring system.

VI. IOT COMMUNICATION TOOLS FOR AIR QUALITY SENSORS

A. Wireless

Wi-Fi is a very present feature in ESP8266 based proto- types. It includes:

1) Great bandwidth.

2) Easy integration with home routers.

3) Simple HTTP and MQTT communication.

It's that we see high power usage as a issue which may be a challenge for battery powered devices.

B. LoRa and LoRaWAN

LoRa which is used in systems does so well when sensors are spread out. In large scales and in which low power is a must. LoRaWAN networks report to cover several kilometers with a single gateway. This is attractive for city wide moni- toring even if the data rate is lower as compared to Wi-Fi.

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C. Cellular Technologies

Newer cellular technologies NB IoT, LTE M, 4G, and GSM, enable system deployment in remote areas without Wi-Fi. While cellular modules do tend to consume power more than Wi-Fi, they do provide better coverage and system independence from local routers.

D. Other Short Range Options

Systems using other technologies, like Zigbee, Bluetooth Low Energy, and Wi-Fi HaLow, are also used. These technolo- gies are better for localized or mesh networks, like monitoring in a building, campus, or industrial site.

VII. CLOUD AND DATA PLATFORMS

E. ThingSpeak

ThingSpeak is a popular platform which is used for aca- demic and hobby projects because it's:

1) Free for low to medium scale use.
2) Does simple HTTP based data uploads.
3) Includes charts and widgets.
4) Interfaces with MATLAB for analytics.

F. Blynk

Blynk is into mobile app based dashboards. We see them to provide easy interface for users to put in buttons, graphs, and labels which refresh in real time.

G. Firebase

Firebase is a real time database and also has strong integra- tion with Android and web apps. We use it for custom apps which require live data sync.

H. Enterprise IoT Platforms

Cloud services such as AWS IoT Core, Azure IoT Hub, and Google Cloud IoT are designed to support large mass deploy- ments. They provide enhanced security, device management, storage, and integration with analytics. While these platforms are more complex, they are ideal for industrial and urban use case deployments.

VIII. SIGNAL PROCESSING, CALIBRATION, AND AQI ESTIMATION

A. Noise and Fluctuation Management

Sensor outputs at times include noise which is due to:

1) Electrical noise.
2) Instability during warm up.
3) Rapid environmental changes.

For simple systems we apply moving average filters, exponen- tial smoothing, or median filters on the microcontroller before sending data to the cloud. In more complex systems we use Kalman filters or machine learning based denoising methods which improve stability.

B. Calibration Approaches

Calibration is a variable process which includes:

1) Using the sensor in what is known to be clean air to determine a baseline performance.
2) Comparing sensor outputs to that of standard instruments and fitting curves out.
3) Applying temperature and humidity corrections.

In in many of student projects calibration is approximate and focuses more on trends than exact ppm values.

C. Air Quality Index Mapping

Some projects which use the MQ135 sensor report out on a rough air quality index. A common approach is to:.

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1) Define sets of sensor readings which correspond to dif- ferent qualitative scale which includes good, moderate, or poor.
2) Use interpolation formulas to map measurements into an index which goes by as a scale.

Public AQI scales which environmental agencies put out put air quality into categories like good, satisfactory, moderate, poor, very poor, and severe. While MQ135 by itself may not present a government grade AQI it can be used to put forth a basic index for alertness.

IX. COMPARATIVE ANALYSIS OF SENSORS AND SYSTEMS

A. *Sensor Review*

Table I presents a broad look at the most common sensors used in air quality monitoring projects.

Table I
COMMONLY USED AIR QUALITY SENSORS

Sensor	Target	Output	Cost	Power
MQ135	NH_3, CO_2, VOCs, smoke	Analog	Low	High
MQ7	CO	Analog	Low	High
MQ2	Smoke, LPG	Analog	Low	High
SDS011	$PM_{2.5}$	Digital	Medium	Medium
PMS5003	PM2.5, PM10	Digital	Medium	Medium
BME680	VOC, temperature, humidity	Digital	Higher	Low

B. *System Level Tradeoffs*

Different sensors are chosen by different projects. Micro- controllers, and communication modules based on peripherals which include:.

1) Budget issues.
2) Component availability.
3) Power requirements.
4) Accuracy and reliability.

MQ135 is in most cases not enough by itself for professional. Applications that is which may serve as a good base for low cost awareness systems.

X. LITERATURE REVIEW OF MQ135-BASED IOT SOLUTIONS

A large body of research has looked at the application of MQ135 in the field of IoT based air quality monitoring. Some studies look at indoor settings. For example we see that which which is reported in a number of papers – they designed out systems to put in classrooms, offices and home settings which used the MQ135 in association with NodeMCU. Also they made available dashboards for the public to see how air quality changed during events like cooking or when the ventilation was poor. What is put forth is the sensors' value in terms of detecting overall pollution trends although very precise ppm values were not produced.

Outdoor study has also been a focus. We have reported on projects which put MQ135 based nodes by roads, at inter- sections, and in industrial zones. In some cases we deployed multiple nodes across a campus or small town which we then collected data from into a central server. Even with basic sensors we saw how pollution peaks during traffic times and drops during the night or in green areas. Also we reported on research which combined MQ135 with particulate matter sensors and which used machine learning techniques to build prediction models. For example a few stud- ies used neural networks or long short term memory (LSTM) models to forecast pollution levels based on historical data from low cost sensors. Also we saw research which focused on calibration algorithms that compensation for temperature, humidity and sensor drift. The utilization of various communication technologies rep- resents another trend of significance. Although several papers focus on the implementation of Wi-Fi and ESP8266 boards, there are also papers integrating communications via LoRa, GSM, NB IoT, and custom mesh networks. These methods target area coverage in the rural, highway, or Wi-Fi infras- tructure absent zones.

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Generally speaking, MQ135-based IoT systems appear to be primarily utilized in educational and experimental purposes. They are great for teaching and raising awareness and for ini- tial research, and they also create an opportunity to prototype architectures and algorithms that can later be integrated with more accurate sensors.

XI. CHALLENGES AND OPEN ISSUES

A. Accuracy and Reliability

The most reported issue with MQ135 based systems is that of accuracy. We see that the sensor responds to a number of different gases at once and also is affected by environmental factors which in turn makes it hard to get exact pollutant levels without careful calibration. Thus it is best used for relative monitoring as a tool rather than for precise regulatory compliance.

B. Sensor Drift and Aging

Over time what we see is that the sensor's internal compo- nents break down and also become contaminated. This in turn affects baseline resistance and sensitivity which in large part causes drift in results. Out of which to correct for this issue either recalibration or replacement of the sensors is required, otherwise long term data sets may become undependable.

C. Power Consumption

A significant amount of power is consumed by the heating component of MQ sensors. This is a considerable design constraint for the type of devices that are intended to operate using batteries or solar panels. Although there are techniques that can help to improve the longevity of the battery, such as duty cycling the heater or putting the microcontroller into deep sleep modes, these techniques can adversely affect response time and accuracy.

D. Network and Cloud Constraints

While many devices are sending data to cloud services, network congestion and cloud services' rate limits become a problem. Some services impose restrictions on the number of data uploads allowed within a minute or a day. Designers will have to make trade-offs between detail and resource constraints for sampling and upload rate.

E. Security and Protection

Although we see that air quality data may not in itself be a sensitive issue, IoT networks can still be present to issues such as:

1) Access to devices and dashboards without permission.
2) Data tampering in transit.
3) Malicious firmware replacement.

Using encrypted communication, proper authentication and secure update protocols is a must in large scale deployments.

F. Ethical and Social Issues

Wide range of pollution issues is reported by large scale monitoring which presents social issues. For instance if low cost sensors report high. In some areas around certain facilities and in some neighborhoods there is debate regarding respon- sibility, transparency and data ownership. This is to a degree a non technical issue but very much a part of the real world adoption.

XII. FUTURE RESEARCH DIRECTIONS

A. Multi Sensor Integration

Future systems will use MQ135 in conjunction with other sensors which include PM2.5, CO specific sensors, and envi- ronmental sensors for temperature and humidity. By combin- ing these inputs we see the opportunity for more in depth and accurate reports of air quality.

B. Machine Learning Integration

Machine learning algorithms can do:

1) Determine pollutant levels from poor quality data.
2) Predict future pollution trends based on past patterns.
3) Improve calibration over time as it learns.

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C. Edge and Federated Learning

Edge and federated learning techniques are different from traditional methods since they do not send all the data to a central server. Rather, they provide the means to train the models locally on devices or gateways. This method keeps bandwidth and privacy concerns at a minimum, since only the model updates are shared.

D. Energy Optimized Designs

The research can focus on the following aspects to reduce power usage:

1) Better optimization of the control of heaters.
2) Intelligent use of sleep modes.
3) The implementation of energy harvesting, e.g., small solar panels.

E. Mobile and Pivoting Nodes

Mount we are putting air quality sensors on vehicles and drones which is opening up the possibility for dynamic pol- lution maps. These mobile nodes will cover larger areas as compared to static ones and also report on the spatial variation of pollutants.

F. Standardization and Calibration Frameworks

The development of common frameworks, shared calibra- tion protocols, and open data sets for low cost air quality sensors which will help students and researchers to align their work better and in turn make results more comparable.

XIII. CONCLUSION

MQ135 sensors which we see in the IoT systems are a great entry point for real time air quality analysis. They are very much a part of what we see in the field in terms of educational platforms, small scale research and as prototypes in both indoor and outdoor settings. Although the sensor does come with issues related to accuracy and selectivity, it still is a very good base from which to study air quality, sensing, and the Internet of Things. This review covers what the MQ135 sensor does in terms of its operation, we also look at typical IoT structures, commu- nication protocols, cloud platforms, what is out there in terms of signal processing methods and a large range of research that applies the above. Also we looked at what are the issues at hand like sensor drift, calibration, power issues, network constraints, and security which also included what the future holds for this field in terms of multi sensor fusion, machine learning, energy efficiency and advanced architectural designs. For students and new researchers MQ135 based IoT systems are a good base platform. For community and hobbyist groups they put out info on local air quality. With care in design and what is realistic to expect in terms of accuracy these systems may play a role in environmental monitoring and education.

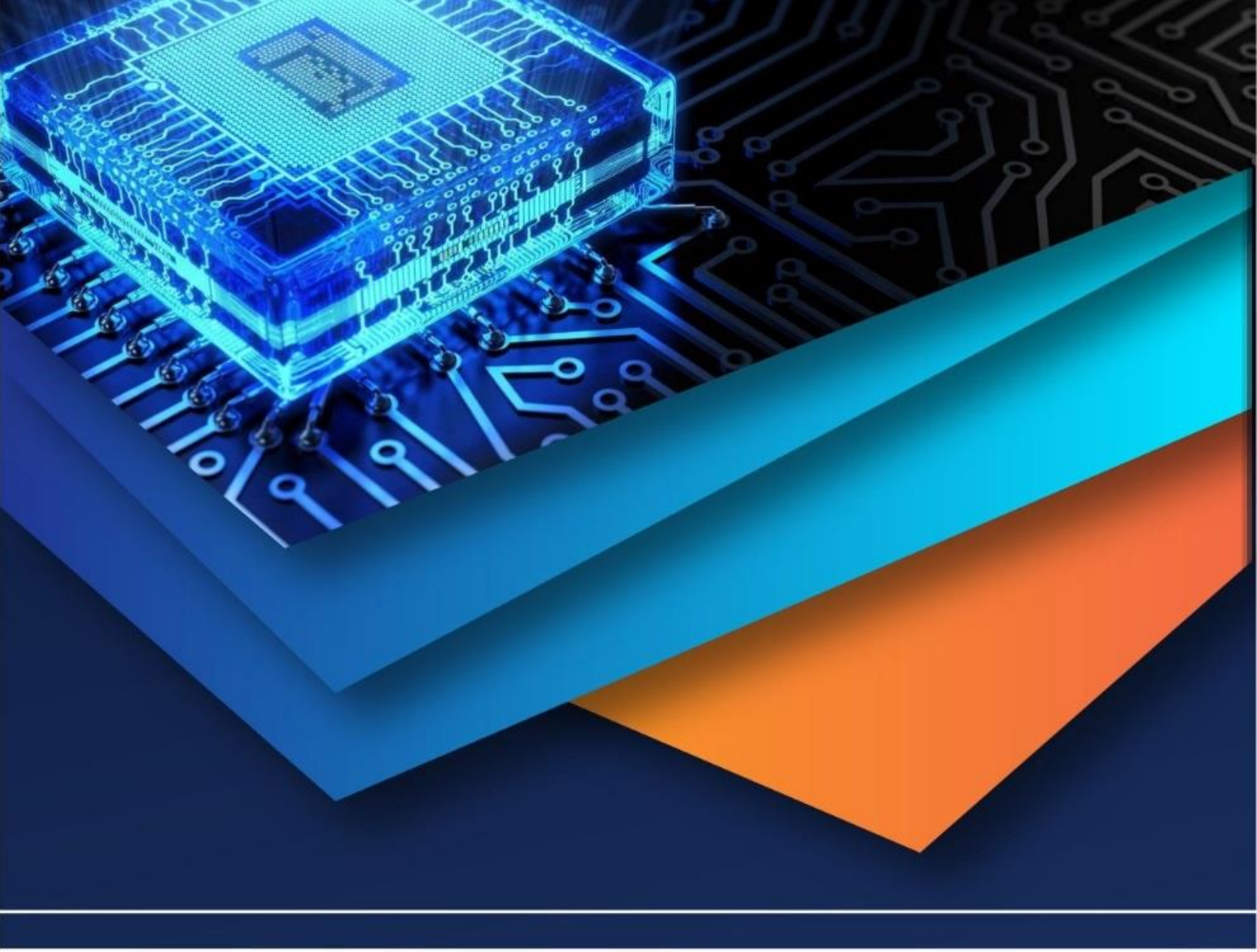
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