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A Decentralized Pollution Meter for Pollution Monitoring

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Abstract: ***Global increases in anthropogenic emissions of pollutants have resulted in sometimes hazardous fluctuations in air quality worldwide. This has led to a need for a publicly available, scalable, and tamper-proof pollution monitoring system for use by authorities, private citizens and researchers alike. In this paper, we investigate the applications of blockchain in such a system and propose a prototype that attempts to meet all of the above criteria. It is designed to be fully decentralized by using the Blockchain to store and retrieve the data recorded by IoT sensors. Thus, data integrity is provided without the need for a Trusted Third Party (TTP) and data is collected and captured automatically without any manual operations needed. Our prototype demonstrates that, despite the cost of storage and transactions on the blockchain, a cost-effective blockchain-based solution for a pollution monitoring system is possible, and such a solution could solve problems of data reliability that persist in pollution monitoring.***

Keywords: Internet of Things, Air Quality, Pollutants, Tamper proof, Trusted Third Party

I. INTRODUCTION

Air quality and pollution have been hot topics in science, technology, and social media, and is now making its way in the daily lives of people living in the metropolitan cities that range from minor respiratory ailments to something as big as the lung cancer, Ischemic Heart Disease (IHD) and stroke. The report released by the World Health Organization (WHO) on May 2, 2018 [1] indicates that "in 2016, Ambient (outdoor air pollution) in both cities and rural areas was estimated to cause 4.2 million premature deaths worldwide in 2016; this mortality is due to exposure to small particulate matter of 2.5 microns or less in diameter ($PM_{2.5}$), which cause cardiovascular and respiratory disease, and cancers." Particulate Matter (PM) is a common proxy indicator for air pollution. It affects more people than any other pollutant. The major components of PM are sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. It consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. Most of these particles are generated after the gases released from different sources undergo combustion. Particles with a diameter of 10 microns or less, ($\leq PM_{10}$) can penetrate and lodge deep inside the lungs. For instance, with regard to particle size, the epidemiological, physiological, and toxicological evidence suggests that fine particles with a diameter of 2.5 microns or less, ($\leq PM_{2.5}$), are even more health-damaging particles and play a substantial role in affecting human health. These fine particles can be breathed deeply into the lungs, penetrate into indoor environments, remain suspended in the air for long periods of time, and are transported over long distances, resulting in relatively ubiquitous exposures. Chronic exposure to particles contributes to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer [2].

It is very important to continuously monitor the air pollution levels, in order to make the real time data available to the public and making it useful to the residents, especially those living in the urban areas. However, the existing methods and models demand a high financial and technical support. Furthermore, these methods lack the power to convince the people who often doubts about the data being published by the government agencies that operate and maintain such systems that may be manipulated on purpose in order to benefit some specific organizations. This problem arises due to the centralized operation and management of the pollution monitoring systems by the government agencies. Hence, there is a growing need for a Decentralized and Tamper proof pollution monitoring system which is operated and maintained by a trusted third party. Beyond our own health and safety, this is more important to create a more sustainable future for our children. Unfortunately, the use of Trusted Third Party is limited only to a limited number of use cases, even in the most developed and wealthy countries like the United States, China, Japan, Germany and India. In this article, we present a low-cost smart sensor system for air quality monitoring. Our system is different from the existing works in the way that it utilizes the Blockchain Technology and Smart contracts for storing the data collected by the sensor unit and a data display. Adding this technology ensures a tamper proof way to store and use the data for use of common people as well as future environmental predictions as it eliminates the involvement of any centralized body for the storage and maintenance of the sensor data. Furthermore, the data display ensures the transparency of the system since the statistics can be viewed by people.

The remainder of this article is organized into following sections; Section 2 is based upon summarizing the existing approaches and also introduces our approach. Section 3 discusses the structure of our Decentralized Air quality Monitoring System. In Section 4 we provide the details about system requirements.

Section 5 and section 6 explain the proposed methodology and the proposed outcomes respectively. Section 7 presents the future work that can be done to enhance the proposed model. Finally we conclude this work in section 8.

II. EXISTING WORK AND OUR APPROACH

As the environmental issue is getting more attention, many efforts have been taken to help address the problems. Pei-Lun Sun et al. [3] in their proposed model for air pollution monitoring, have made use of the Hybrid database converter technology for storing and processing the data. The Zigbee wireless sensor network technology is used to store and process environmental data in HBase. The environmental data collected by sensors will be stored and processed in the cloud using HBase, which supports storing large amounts of data, free to easily increase storage space. And can also can compute through Hadoop MapReduce for the HBase database to do distributed computing or cloud computing to process environmental records. But this can lead to tampering of the data by those who have been granted the rights in a database for accessing the records stored in it. Although, Suraj Dhnawe in his work [4] has stated that the tampering done in the database can be detected through the cryptographically hash functions and the forensic analysis can be made to detect when the data was tampered. But this will add on to the cost of the pollution monitoring system, as the number, frequency and amplitude of the attacks cannot be determined in prior. Somansh Kumar et al [5] in their proposed model as a solution for the same cause, deployed the prototype of their device in Delhi, India, which makes use of the cloud computing to store the data collected by the sensors. Another work by Swati Dhingra et al [6], consists of a portable kit that is integrated with an android application named Iot-Mobair, which helps its users in predicting the pollution levels of their entire route. This is helpful for the people suffering from respiratory ailments. But the proposed system faces with computational complexity particularly when dealing with big sensor data as it uses the cloud platform for storing the data. But the users must be extremely careful while selecting the cloud service provider as it may lead to tampering of data and involve the cloud forensics to detect any data breaches or tampering. Over the span of few years there has been immense growth in the technology giving rise to several technological products that aid in improving the quality of life of the common citizens. Probably there is a trend of developing the devices that are helpful for monitoring the pollution levels (e.g. creek watch, launched by IBM research platform, for monitoring water pollution) in ones locality. However, most of them make use of the cloud platforms or databases for storing the data collected by the sensor unit. In this article we present a decentralized, system for air quality monitoring and protecting the data from getting tampered with the help of blockchain technology. This air quality monitoring system helps in eradicating the issue of trust that exists in the current monitoring system. Author Yunyun Chen, in his article [7], describes the way in which the blockchain technology can help in monitoring the air pollution levels while guarding the data against tampering and states that the current centralized monitoring system faces critical problems: scalability and cost. Besides, another inevitable problem is the trust issue— *"What are the guarantees for the citizens that this data will not be abused, misused or just sold to the corporations that work with the government in this kind of initiatives?" — Federico Guerrini*, a statement that Chen uses in his article. Since, there is no centralization of the duties in blockchain, any human intervention for storing and managing of data in the block is eliminated. Furthermore this model can be used by the government to draw insights from the data and can impose a fine on the defaulters in a non-biased way.

III. SYSTEM STRUCTURE

The structure of the sensing unit and the flow of the data are shown in Fig. 1 which consists of three main units: pollution sensors, ethereum blockchain and government and law authority.

The sensor unit is responsible for sensing the different types of gases that are present in the air, in different areas where the sensor units are deployed. These sensor units then transmit there data through an embedded Wi-Fi, to the Wi-Fi devices setup at a particular distance from the sensors. These Wi-Fi devices help the different sensor units in communicating with each other, thus creating a *Things Network*. The things network refers to the network of the different sensor units and the Wi-Fi nodes that are deployed in the different parts of the city or any other area.

The data collected by the individual sensor units is transmitted with the help of the Wi-Fi devices is sent to a pollution monitoring web server and from there is stored in the Ethereum Blockchain with the help of smart contracts. This block helps in storing the data permanently into the block and thus it is protected against any tampering in the future in order to avoid favoring or biased behavior towards any individual or any organization.

The government and law authority are responsible for ensuring the proper enforcement of the laws that are set up to monitor the level of different pollutants present in the air and imposing appropriate fine on the defaulters according to the set guidelines that are set for the threshold value of different gases.

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IV. SYSTEM REQUIREMENTS

As described earlier, this system consists of the sensor unit and the Ethereum blockchain. This section describes the details of these units.

A. Sensor Unit

This unit consists of the Arduino development board, gas sensors and Ethereum blockchain.

1) *The Arduino Development Board:* Arduino development board [8] is an open source electronics platform based on easy to use hardware and software

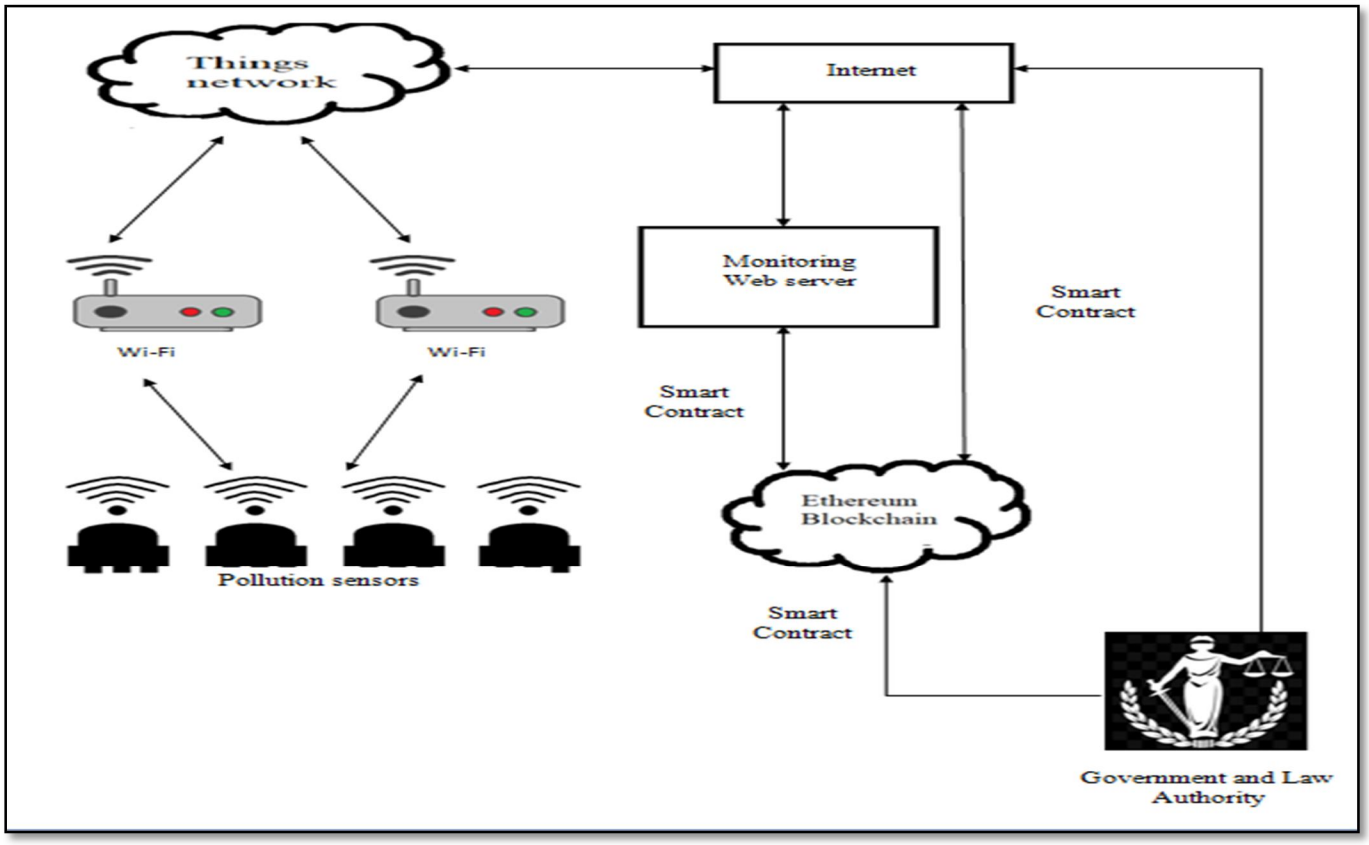

Fig. 1 Data Flow

The user can tell the board what to do by giving it instructions. The board is inexpensive, provides simple and clear programming environment, has open source and extensible hardware and software and can work on cross-platforms when most of the microcontrollers are limited to Windows.

Arduino UNO [9] is a microcontroller board based on ATmega328P. It operates at 5V. The input voltage limit is 6V to 20V and the recommended input voltage is 7V to 12V. It has 14 digital I/O pins out of which 6 provide PWM output. It consists of 6 PWM digital I/O pins and 6 analog input pins. The DC current per I/O pin is 20mA and 50mA for 3.3V DC current pin. The sizes of the flash memory, SRAM and EEPROM are 32KB (out of which 0.5KB is used by bootloader), 2KB and 1KB respectively. It has 13 (or D13) as the LED_BUILTIN value.

2) *Air Quality Sensors:* The air quality sensors that we used for this unit include MQ-2 sensor for methane (CH_4), butane (C_4H_{10}), LPG and smoke, one MQ-9 for carbon monoxide (CO) and a combined sensor for temperature and humidity. Since this is just a prototype of our model, more number of sensors can be added in it in order to get a more precise outcome. These sensors are connected to the Arduino board through its analog and digital I/O pins. Below we briefly summarize these sensors.

a) *MQ-2 gas sensor:* This sensor is used for sensing methane (CH_4), butane (C_4H_{10}), LPG and smoke. Methane is one of the well known green house gas which is able to trap heat in the atmosphere and contributes to climate change. It gets produced during the natural gas production. On the other hand butane, when burnt, is responsible for the production of water vapors and carbon dioxide (CO_2) which is a principle green house gas. LPG, though produces less pollutants compared to other gases but is highly flammable and its leakage must be detected in places where it is used the most. A contributor to the same cause is smoke, which is released in huge amounts by the various industries operating in the different parts of the country and world. Moreover, smoke combines with the fog during winter season and brings down harmful pollutants like ozone near the earth surface which lead to many short term health problems like irritation in respiratory system etc. This sensor can detect these gases anywhere between 200 ppm to 10000 ppm.

b) *MQ-9 gas sensor:* According to the National pollutant Inventory of Australia [10], the industrial processes where the carbon monoxide (CO) may be produced include metal manufacturing, electricity supply, food manufacturing, production of chemicals, cement lime, plaster and concrete manufacturing etc. Industrial plants emit carbon monoxide through combustion of natural gas, coal and coke too. Also CO is a major component of the motor vehicle exhaust fumes. When it is emitted into the atmosphere it affects the amount of greenhouse gases, which are linked to climate change and global warming. This means that the temperature of the land and sea increases leading to changing ecosystems, increased storm activities and other extreme weather events. This sensor is also capable of sensing flammable gases. It is capable of detecting the concentration of CO from 10ppm to 1000ppm and 100 to 10000ppm of combustible gas.

c) *Temperature and Humidity sensor DHT-22:* This sensor is also known as RHT-03 and is fully calibrated which means it does not require any other components for measuring temperature and relative humidity. The range of temperature measurement is from -40°C to +80°C with an accuracy of ±5°C and humidity measurement range is from 0 to 100% with accuracy of ±2%.

d) *ESP8266 Wi-Fi module:* We selected the ESP8266 Wi-Fi module for our prototype. This module enables a single sensor unit to communicate with other sensor units through Wi-Fi which results in a network formation. It delivers up to 7 Mbps data rate for distance up to 479 meters.

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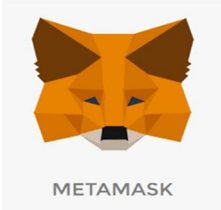
B. Ethereum Blockchain

The blockchain is a database that is not governed by any centralized party rather it is distributed in nature and is public i.e. everyone participating in the chain can see the blocks as well as the transactions that are stored in them. Transaction refers to all the actions that are taking place within a block. Block refers to the single unit of the chain that stores all the transactions and make sure that the order of transactions is maintained and is free from any tampering. This technology provides an extremely good solution and acts as the bridge to solve the problem of reliability and privacy issues that exist in the IoT. It can be used to track the devices present in the network as well as setting up co-ordination and processing the transactions between devices [11].

Ethereum is a public and blockchain based, distributed computing platform that also supports smart contract functionality. It is an open source and a public platform that allows developers to develop and deploy decentralized applications (dApps).

1) *Ethereum Metamask:* It is a very important tool that allows the users and developers to enter into the world of blockchain. It not only helps to create an Ethereum wallet but also helps the users to test their smart contracts on the test networks. There are four networks that are mainly used namely- Main Ethereum network, Ropsten test network, Kovan test network, Rinkeby test network. The main network requires to use real computing power and gas to carry out transactions on the network. Whereas the other three networks are test networks where the Ropsten test network is based on POW (proof of work) algorithm and the other are based on POA (proof of authority) algorithm. For our prototype we have used the Kovan test network. The user can request the ethers on the test network that gets stored in the wallet that they have created on metamask. These ethers are used at the time of testing the smart contract on the test network.



2) *Smart Contracts:* The smart contracts refer to the programs that are written to encode an agreement between the non-trusting parties. If the conditions specified in the smart contract are met, then it gets executed without the need or help of any trusted third party. The language used to write these contracts is Solidity. It is an object oriented programming language and is used on various blockchain platforms. Several integrated development environments (IDE) e.g. remix etc., can be used to write and compile the smart contracts. The smart contract must be designed in such a way that it does not need to be renewed repeatedly as it will add on to the overall cost.

V. PROPOSED METHODOLOGY

The level of different pollutants due to various factors like pollutants generated from the vehicles, different types of factories and industries and various other businesses contribute to the fluctuating and alarming levels of pollutants in the air and therefore motivate us to maintain a tamper proof way to maintain a record of all the gases and their quantity that are generated in different areas.

In order to maintain the principle of decentralization of the entire system, while also keeping the system tamper proof, we propose the following methodology as shown in Figure 2:

1) *Making Sensor Units:* the sensor units are made by connecting the different types of sensors that are interfaced with an arduino board to read the sensor values and also a Wi-Fi module to let every sensor unit communicate with every other individual unit, thus forming a network of things. For achieving the same we made use of a circuit simulator to create the environment of a sensor unit and the data sensed by them as shown in Figure 3. The circuit simulator used here is *Tinkercad.* This simulator allows us to add the components from a pre-existing list of components and then write the corresponding source code for each device to run them. The language used by us to write the source code is C language.

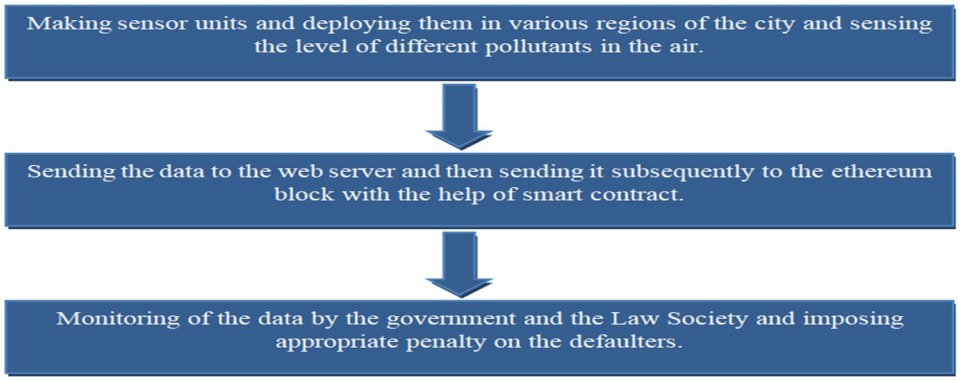


Fig. 2 Proposed Methodology

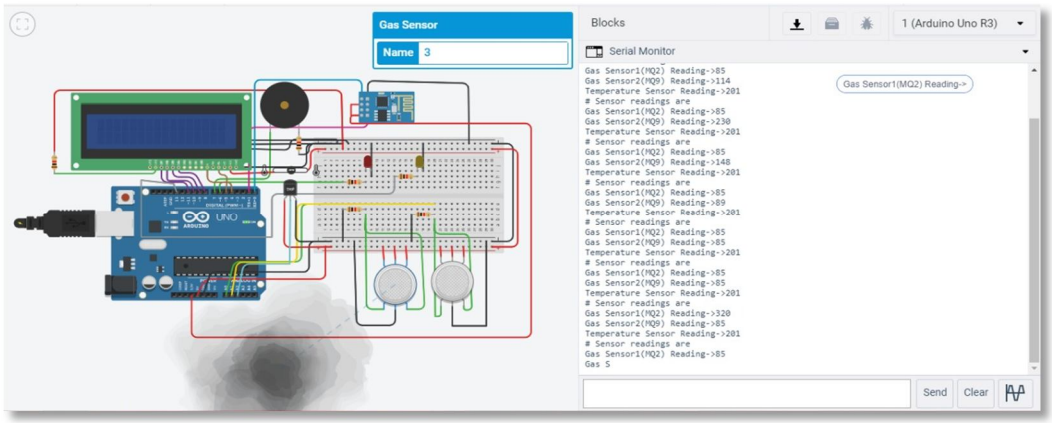


Fig. 3 Data sensed by the sensor

2) *Sending The Data To The Web Server:* The data recorded by the sensors is sent to the web server with the help of help of internet and Wi-Fi where it is monitored continuously. This web server helps in creating the logs of all the data that comes. The sensors record the data automatically onto the web server, thus removing the need for any third party to do the same.
3) *Designing and deploying a Smart Contract:* A smart contract is then designed and deployed on the blockchain network. The contract is designed to take the data from the web server to be stored into the ethereum block. Moreover, the contract must be designed to serve for a longer period of time as the renewal or redesigning increases the cost of the entire system compromising its feasibility.
4) *Checking for the Threshold levels of Different Pollutants:* The smart contract compares and checks each and every value coming from the web server with the threshold that has been set in the smart contract and stores the values which indicate the violated levels of the pollutants into the ethereum block. The threshold value for different pollutants can be decided based upon the regional standards.

The government is the highest authority in a country and its various regions and along with the Law Society is responsible for ensuring the enforcement of the various laws that are set up. For the methodology proposed in this article the government and Law society can device suitable guidelines and laws in order to monitor the level of different pollutants present in the air and imposing appropriate penalty on the defaulters according to the set guidelines that are set for the threshold value of different gases.

VI. PROPOSED OUTCOMES

The resulting outcome will mainly help in retaining the authenticity of the data collected by the sensors and the statistics that are drawn from them and hence will help in achieving the following:

A. The elimination of the third parties for storing and maintaining the data collected by the sensors, thus leading to decentralization of the system as the power doesn't lie in the hands of any centralized party.
B. Ease in maintaining the authenticity and trust with regards to the sensor data and the statistics drawn from them because the data remains tamper proof.
C. Helps in achieving transparency in the system as the transactions done in the block are visible to all the participants of the chain.
D. More accurate statistics are drawn since the data remains the same from the time it has been recorded to when it is being analyzed, thus the environmental changes can be predicted more accurately and suitable actions can be taken to minimize the level of pollutants in different regions.

VII. FUTURE WORK

The prototype proposed focuses on highlighting the use of blockchain technology for monitoring the air pollution. The following future work can be done in order to make the proposed work more useful and precise.

A. The numbers of sensors that are used are limited. However according to the need more number of sensors can be added to the sensor unit in order to get precise values of the pollution level.
B. A website and a mobile application can be developed to display the real time statistics and air quality forecasts, so that it is helpful for common citizens especially people suffering from respiratory ailments to keep their health in check.
C. In order to solve the problem related to the storage of large amounts of data collected by the sensors, a potential solution for this issue is to integrate fog computing with blockchain so that the data collected can be stored on fog and safeguarded through blockchain [12].

VIII. CONCLUSION

In this article, we present a Decentralized Pollution Monitoring System based on IoT and blockchain technologies, which combines the unique nature of the blockchain technology by making the system tamper resistant, decentralized and trusted distributed system. This approach allows the sensors to automatically sense and store the data directly into the blockchain without the need of a trusted third party to carry out these tasks. This system combines the aspects of both, the unique quality of being tamper proof of the blockchain as well as the sensors that can be made to work smartly individually and as a network of devices.

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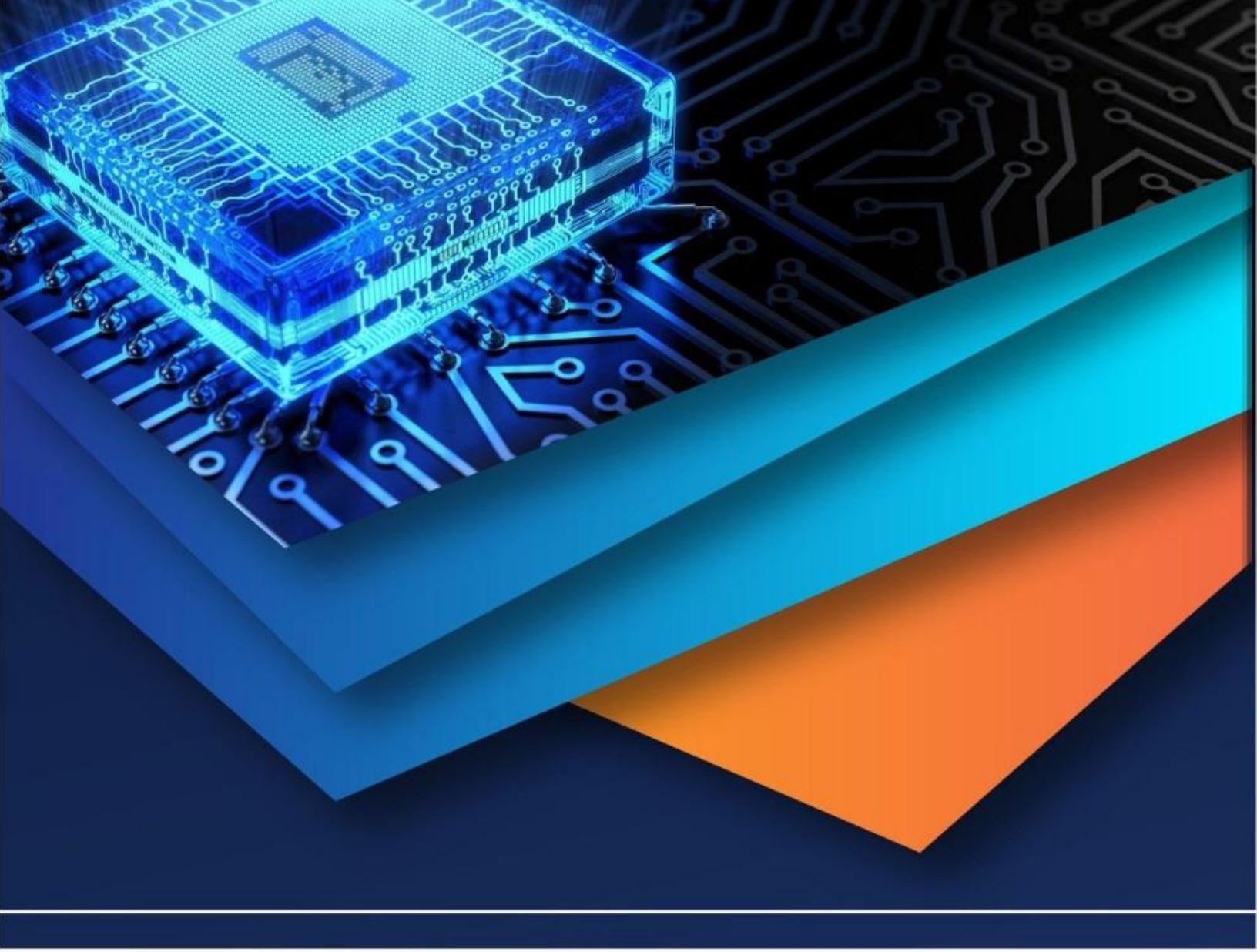

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