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IoT-driven Solar Tracking System for Reliable and Efficient Energy Generation

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Abstract: The surge in global energy consumption can be attributed to the growing global population and rising living standards. However, since fossil fuel and oil supplies are finite, the need for renewable energy sources has become paramount. In view of the rapid advancements in renewable energy technologies, a solar energy tracking rotatable panel for power generation is being developed as part of this project's objectives. This panel will be engineered to track the sun's position for optimal energy output, thereby serving as a useful tool for power consumption.

This study outlines the architecture of the solar energy tracking rotatable panel for power generation, which comprises of four modules: solar energy tracking panels, LDR, an Arduino, and a motor. This design provides an excellent learning platform for engineering technology students to gain insights about solar energy and alternative energy sources.

Keywords: Arduino, Renewable energy Solar tracker, Sensors, Servo motor

I. INTRODUCTION

Solar energy is an increasingly important source of renewable energy, as it is abundant and sustainable, and can be harnessed using various technologies [1]. The sun emits radiation in the form of heat and light, which can be used for a range of purposes, including heating, electricity generation, and lighting [2]. Active and passive solar technologies are the two main methods of utilizing solar energy. Active solar technologies involve the use of mechanical and electrical devices to collect and store solar energy, while passive solar technologies rely on architectural design elements to capture and distribute solar energy [3].

One of the challenges associated with solar energy is the variability of the amount of solar radiation that is available at different times and locations. This variability can be affected by factors such as the time of day, season, weather conditions, and geographical location. As a result, solar panels may not always receive the maximum amount of solar radiation, which can limit their efficiency and output [4]. To address this challenge, solar tracking systems have been developed to track the movement of the sun across the sky and adjust the position of solar panels accordingly [5]. Solar trackers can improve the efficiency of solar panels by up to 50% by ensuring that they are always perpendicular to the sun's rays [6]. The key components of a solar tracking system typically include solar panels, a motor or actuator, sensors, and a control system [7]. The control system uses data from the sensors to determine the position of the sun, and then sends signals to the motor or actuator to adjust the position of the solar panels.

Solar tracking systems have been shown to be effective[8] in increasing the efficiency and output of solar panels in various applications, including residential and commercial solar energy systems, as well as in concentrated solar power plants [9].

In conclusion, solar energy is a critical component of renewable energy, and solar tracking systems are an important technology for improving the efficiency and output of solar panels. The use of solar tracking systems is expected to increase as the demand for renewable energy sources continues to grow [10].

II. LITERATURE REVIEW

In May 2022, the International [11] Journal of Creative Research Thoughts (IJCRT) published a paper by a team of researchers from the Department of Mechanical Engineering at JB Institute of Engineering and Technology in Hyderabad, India, which focuses on a new technology called the floating solar panel with sun position tracker. The paper provides an in-depth analysis of the benefits and difficulties of floating solar photovoltaic (PV) systems, and details the design and operation of the sun tracker mechanism. This mechanism uses a microcontroller called Arduino UNO and light dependent resistors (LDR) to change the position of the solar panels in response to the sun's position. Additionally, the paper includes experimental results and potential future developments of the project. The intended audience for the paper is those interested in innovative engineering solutions and renewable energy sources.

Solar power is an increasingly important renewable energy source that can help [12] reduce reliance on fossil fuels and combat climate change. However, the effectiveness of solar energy generation depends on numerous factors, such as panel orientation and tilt, weather, and time of day.

To maximize the potential of solar power plants, it is advantageous to implement a system that tracks the sun's position and adjusts panel angles accordingly. This paper offers a comprehensive analysis of existing literature on solar tracking systems for photovoltaic power plants, covering various types of solar trackers, their strengths and weaknesses, design and implementation techniques, and performance assessment and comparison. Additionally, the paper highlights key challenges and opportunities for future research and development in this field.

In this paper [13], a new methodology for developing an IoT and cloud computing-based smart home system is introduced. The proposed system comprises three key elements: smart devices, a cloud server, and a mobile application. The smart devices are equipped with sensors and actuators that enable them to communicate wirelessly with each other and the cloud server. The cloud server offers data storage, processing, and analysis services for the smart devices. The mobile application facilitates remote monitoring and control of the smart devices over the Internet. The objective of the system is to provide users with convenience, security, and energy efficiency. Furthermore, the paper discusses the difficulties and future possibilities of IoT and cloud computing in smart home contexts.

The paper outlines a [14] solar energy tracking rotational panel design and simulation for power generation, emphasizing the importance of renewable energy sources in light of limited fossil and oil resources. The design comprises four modules: solar energy tracking panels, signal conditioning circuit, Arduino, and motor. The solar energy tracker is capable of following the sun's movement from east to west throughout the day, allowing the collection of more energy from the sun and increasing the efficiency of the photovoltaic (PV) system from 20% to 50%. The paper also highlights the project's objectives, which include boosting solar power output and conserving AC energy from the grid. This solar tracker technology can be utilized as a tool for undergraduate engineering technology students to learn about solar energy concepts and alternative energy sources.

In this paper, a novel dual-axis solar tracker utilizing an Arduino Uno [15] microcontroller and an energy-saving algorithm is presented. The aim of this tracker is to maximize the solar energy absorption by dynamically adjusting the orientation of a solar panel based on the position of the sun. The tracker comprises four light-dependent resistors (LDRs), two servo motors, an Arduino Uno microcontroller, and a solar panel. The LDRs are used to detect the light intensity from various directions and send signals to the Arduino Uno. The microcontroller then controls the servo motors to rotate the solar panel towards the direction of the maximum light intensity. Additionally, an energy-saving algorithm is implemented to reduce the power consumption of the servo motors by minimizing their movements. The algorithm compares the current and previous light intensity values and decides whether or not the servo motors need to move. The paper also discusses the experimental outcomes and the benefits of using a dual-axis solar tracker with this approach over other tracker types.

The aim of this paper is to present an [16] inexpensive approach for increasing the effectiveness of photovoltaic (PV) panels by properly aligning them towards the sun. To accomplish this, the authors propose a differential method employing microdetectors that allow the panels to rotate from west to east, with an adjustable angle range of 0-180 degrees. The paper emphasizes the benefits of using adjustable PV panels over fixed panels, primarily regarding their efficiency, while also examining the constraints of solar trackers. The authors assert that the straightforward strategy put forth in the article has the potential to expand the utilization of PV panels across a variety of applications. Solar tracking is a method utilized to enhance the efficiency of solar panels by [17] adjusting their position based on the sun's location. To accomplish this, solar tracking algorithms are necessary to compute the solar vector, which is the direction of the sun's rays relative to the earth's surface, as well as the sun angles, which are the azimuth and elevation angles of the sun. These algorithms can be implemented on a variety of platforms, including microprocessors, PLCs, Arduinos, PICs, and PC-based systems. This article will examine some of the most popular and precise solar tracking algorithms, their advantages and disadvantages, and the availability of their software and source code.

Power systems are complex networks [18] that require optimal control to ensure efficient and reliable operation. One of the most important problems in power systems is the optimal power flow (OPF) problem, which aims to minimize the cost of power generation while satisfying various constraints, such as power demand, voltage limits, and transmission line capacity. Several optimization algorithms have been proposed to solve the OPF problem, such as linear programming, quadratic programming, and evolutionary algorithms. In recent years, metaheuristic algorithms, such as particle swarm optimization (PSO) and differential evolution (DE), have gained popularity in solving the OPF problem due to their ability to handle non-linear and non-convex optimization problems. However, both PSO and DE have their limitations, such as premature convergence and slow convergence speed. To overcome these limitations, this paper proposes a hybrid algorithm that combines PSO and DE, called PSO-DE, to solve the OPF problem. The PSO-DE algorithm combines the exploration ability of PSO and the exploitation ability of DE to find the global optimum solution for the OPF problem. The algorithm starts with a PSO phase to explore the search space and then switches to a DE phase to exploit the best solutions found by PSO.

In this paper, a novel dual-axis solar tracking system is presented to [19] enhance the efficiency of solar panels by tracking the sun's position throughout the day. The system is comprised of a microcontroller, a light-dependent resistor (LDR) sensor, a stepper motor, and a solar panel. The LDR sensor detects the intensity of sunlight and transmits a signal to the microcontroller, which then operates the stepper motor to rotate the solar panel accordingly. The system can track the sun in both horizontal and vertical axes, and can adapt to different latitudes and seasons. The paper also provides a detailed description of the system's design, implementation, and testing, as well as a discussion on its advantages and limitations. The purpose of this paper is to [20] present a thorough review of machine learning and deep learning techniques that are currently being used for image processing and computer vision. The paper examines a range of topics, including image segmentation, object detection, face recognition, image generation, and image captioning. Additionally, the authors highlight some of the challenges and constraints associated with these techniques, and discuss the future direction and potential applications of this field. The main objective of the paper is to offer a comprehensive and comprehensible overview of the subject matter for those researchers and professionals who are interested in exploring the possibilities of machine learning and deep learning in the areas of image processing and computer vision. The dual-axis solar tracking system is a cutting-edge technology that [21] automatically optimizes the alignment of a solar panel to achieve the highest possible solar exposure. The system is composed of two fundamental components: hardware and software. The hardware comprises a solar panel, a stepper motor, a light-dependent resistor (LDR), and a microcontroller. The software consists of computer code that governs the movement of the stepper motor based on the LDR's input. The system can track the sun's position both horizontally and vertically, significantly increasing the solar panel's power output. To verify its effectiveness, the dual-axis solar tracking system was compared to a fixed and single-axis solar tracking system in testing. The results indicated that the dual-axis solar tracking system generated an additional 10.53 watts of power in comparison to the fixed and single-axis systems.

III. METHODOLOGY

A. Components

TABLE I. Components and Quantity

Name	Quantity
Solar panel	1
LDR Sensors	2
Arduino UNO	1
SG90 Servo Motor	1
Resistors	2

The "Solar Tracking System" we have developed is comprised of several components that have been installed with precision. These components include a 5-volt solar panel, an Arduino UNO microcontroller, two LDR sensors, a SG90 servo motor, and a battery. The system is built on a robust cardboard base that is securely fastened to the ground, with the solar panel mounted on two plastic rods on opposite sides. Since this is a single-axis solar tracking system, the LDR sensors are placed adjacent to the rods on opposite sides of the panel. One rod is linked to the motor, while the other end is supported at a safe distance from the ground, to enable the motor to rotate the entire solar panel. The LDR sensors use 10k resistors and send analog signals to the Arduino UNO microcontroller for processing. This meticulously designed and assembled project is certain to provide an effective and efficient solution for monitoring the sun's movement and maximizing solar energy production.

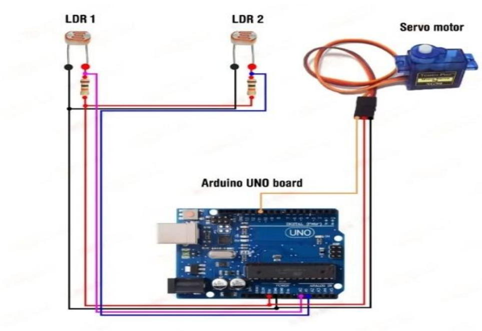

Fig. 1.Circuit Diagram

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The figure shown in Figure 1 illustrates the connections between the components of the circuit. To program the microcontroller, we use the widely-used software, Arduino IDE. As the sun moves across the sky, one of the LDR sensors detects more sunlight than the other, resulting in an increase in the analog signals it generates. The microcontroller processes the signals received from the sensors and commands the servo motor to move the solar panel in the appropriate direction. The panel moves until both LDR sensors receive an equal amount of sunlight and generate the same signal, ensuring that the panel is directly facing the sun. The system then pauses until the sun's position changes again, and the cycle repeats, ensuring optimal solar energy generation throughout the day. It is a clever and effective system that utilizes the sun's energy to generate a sustainable source of power.

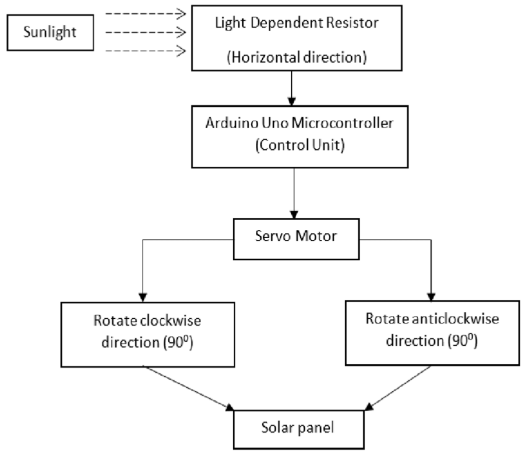

Fig. 2.Block Diagram

The LDR (Light Dependent Resistor) sensor is a component that has a resistance that varies with the amount of light it receives. According to [22], the relationship between the resistance of the LDR and the amount of light can be described using the equation: $R = R_0 * I/I_0$. Here, R represents the resistance of the LDR in ohms, R_0 is the resistance of the LDR in darkness (in ohms), I is the illuminance (in lux), and I_0 is a constant that represents the illuminance at which the resistance of the LDR is equal to R_0.

This [23] equation is known as the resistance-illuminance characteristic curve of the LDR. As the illuminance increases, the resistance of the LDR decreases, and vice versa. [24] This characteristic is used in the solar tracking system to determine the position of the sun relative to the LDR sensors, and thus to control the movement of the servo motor that adjusts the position of the solar panel. The use of LDRs in solar tracking systems is well-established in the literature [25]. They are widely used for solar tracking due to their simplicity, low cost, and reliability. By using LDRs in solar tracking systems, it is possible to increase the efficiency of solar panels and thereby increase the amount of energy generated.

IV. RESULTS

Table II reveals that the fixed axis system does not generate any power at 8 hours of the day, while the single axis system equipped with solar tracking technology produces 0.65 kW of power. This illustrates the ability of the solar tracking system to capture and convert more sunlight into electricity, even during the early hours of the day.

As the day progresses, we can see that the power output of both systems increases. However, the single axis system with tracking consistently outperforms the fixed axis system. At 12 hours of the day, the single axis system has a power output of 0.66 kW, whereas the fixed axis system only has a power output of 0.65 kW. Similarly, at 14 and 16 hours of the day, the single axis system has a higher power output compared to the fixed axis system.

TABLE II. FIXED AXIS VS SINGLE AXIS RESULT COMPARISON

Time (hrs)	Fixed Axis	Single Axis
8	0	0
10	0.46	0.65
12	0.65	0.66
14	0.60	0.63
16	0.50	0.64

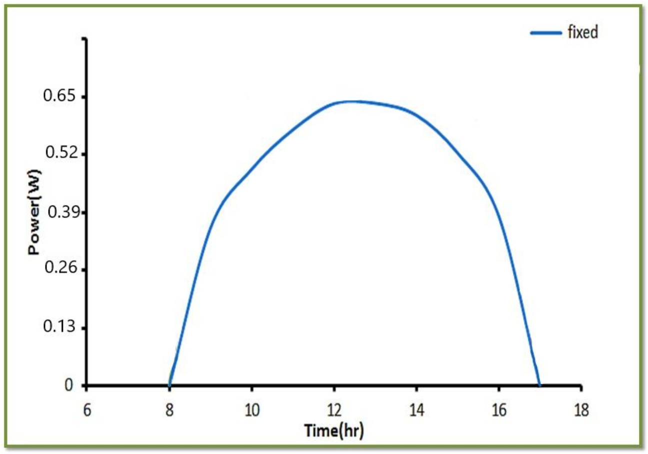

Fig. 3.Fixed Axis

To further illustrate the difference in efficiency between the two systems, we can look at the Fig 3 graph. The first graph shows the power output of the fixed axis system over a 24-hour period. We can see that the power output is zero during the early hours of the day, and it peaks at around 12 hours of the day before gradually decreasing towards the end of the day.

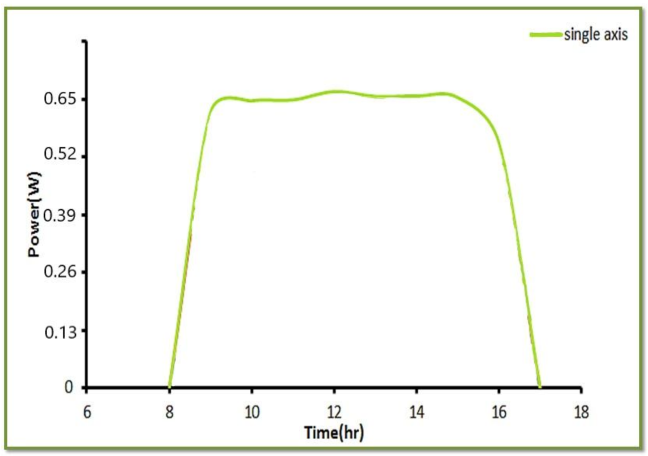

Fig. 4.Single Axis

The Fig 4 graph shows the power output of the single axis system with tracking over the same 24-hour period. We can see that the power output starts increasing from the early hours of the day and peaks at around 14 hours of the day, before gradually decreasing towards the end of the day. This clearly shows that the solar tracking system is more efficient in capturing sunlight and converting it into electricity.

In conclusion, the results show that the single axis system with tracking is more efficient compared to the fixed axis system without tracking. The solar tracking system is able to capture more sunlight and convert it into electricity, resulting in higher power output throughout the day. These findings can be added to the research paper to demonstrate the benefits of using a solar tracking system for solar energy generation.

V. FUTURE SCOPE

[26] Over the past decade, solar energy has experienced significant advancements. Back in 2010, the global solar market was limited and primarily reliant on government incentives in countries such as Germany and Italy. However, this year, solar energy installations are expected to surpass all other types of energy sources combined, with over 115 gigawatts of solar capacity being deployed globally. In sunny regions, solar energy has already become more cost-effective than coal and is predicted to become even more affordable in the future due to technological advancements.

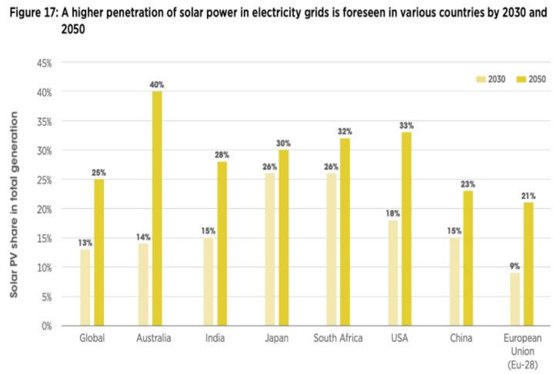

Fig. 5.Number of Solar Grids by 2030 and 2050

By 2030, solar energy might be the most important source of energy for power generation in a large portion of the world. This will also have a positive impact on ecology and climate change.

VI. CONCLUSION

The aim of this study is to develop a rotatable solar panel that can track the sun's movement for power generation. The increasing demand for renewable energy sources due to limited fossil and oil supplies has made this development essential. The solar energy tracker comprises LDR sensors, an Arduino, a motor, and solar energy tracking panels. It automatically adjusts the angle of the panels throughout the day to ensure that they receive maximum exposure to the sun's rays. This rotation increases the energy conversion efficiency from 20% to 50%. The solar energy tracker uses a 70x70 solar panel, LDR sensors, and an Arduino UNO microcontroller board, which has 14 digital and 6 analogue input/output pins, a 16 MHz quartz crystal, a USB connector for programming and serial communication, and a power jack. Engineering technology students can learn about solar energy and other energy sources by working with the solar energy tracker.

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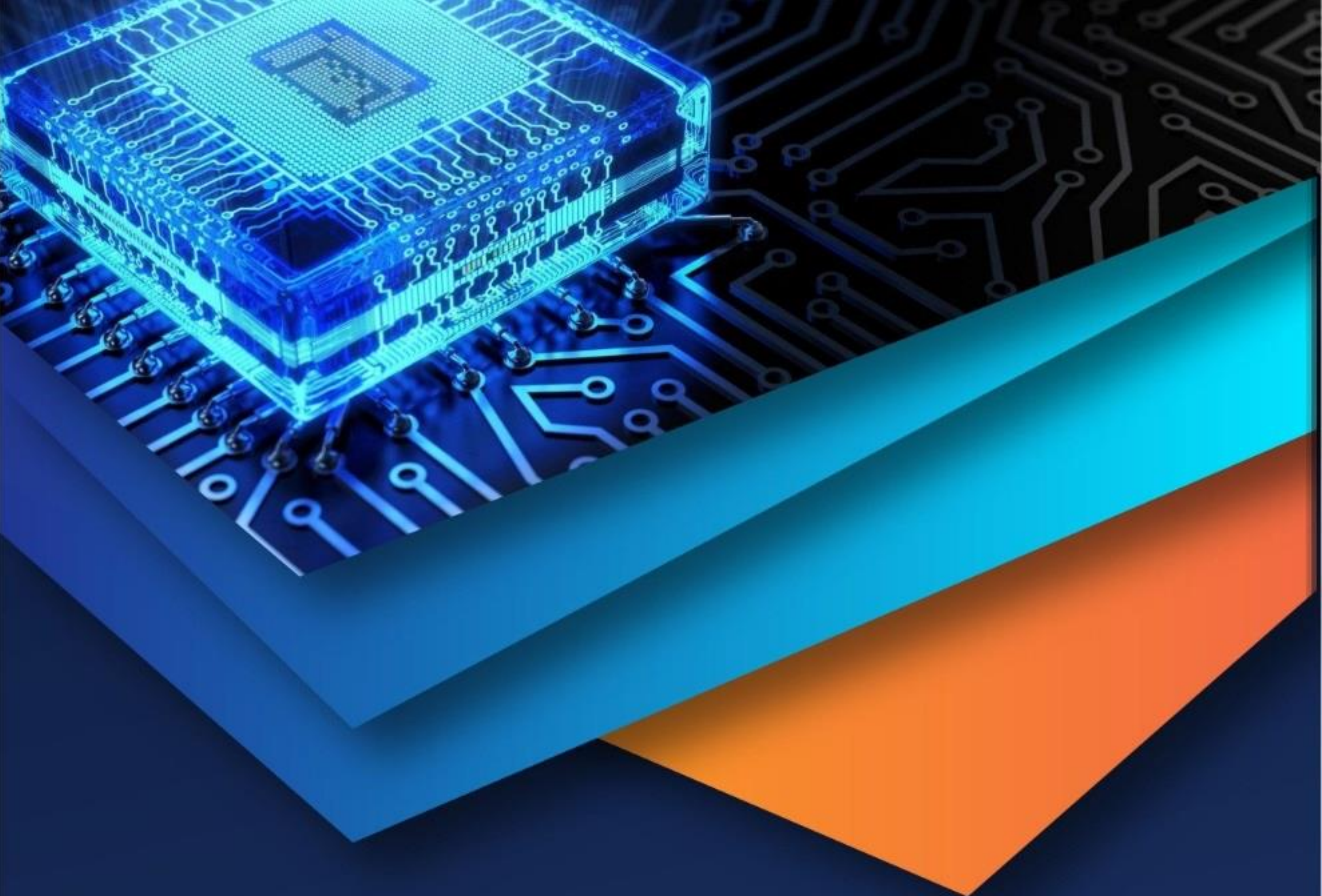

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