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Strand beest Coal Mine Robot for Detection of Hazardous Objects and Gases

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Abstract: Worker safety in coal mines is of utmost significance, given the high likelihood of hazards in mining processes, ranging from harmful gases and unforeseen objects. Here, we report the design of an autonomous robot for detecting hazards such as gases and objects in coal mines. Based on state-of-the- art sensors, comprising gas sensors for detecting methane, carbon monoxide, and oxygen content, as well as infrared cameras to detect potential gas leaks and dangerous atmospheric pressure, temperature, and oxygen level conditions, and physical obstacles endangering worker lives, therobot can detect hazards automatically. With real-time data transmission capabilities for reporting its observations to centers in charge, it can respond instantly in emergency conditions. Its mobility system, capable of accessing tight and risky places, can detect hazards in difficult-to-reach and risky locations, improving the efficiency and effectiveness of hazard identification. This robot is expected to greatly increase worker protection through reduced exposure to risky scenarios and offer an active, sturdy approach to hazard identification and risk mitigation in coal mines[1].

Keywords: Autonomous Robot, Safety in Coal Mines, Detection of Hazardous Gas, Obstacle Detection, Real-time Monitoring

I. INTRODUCTION

Coal mining is still an essential part of energy production, yet one of the risk industries because of constant threats of toxic gas exposure, collapse of debris, and accidents caused by heavy equipment. Traditional safety measures, although necessary, are based mostly on human inspection and manual intervention, which are time-consuming, error-prone, and put workers in perilous situations. With the necessity for faster, better, and more dependable measures for safe operations, research has focused on improved technologies[2]. Advances in robotics and sensor systems in recent years have proven highly useful for improving coal mine safety. Autonomous robots mounts usually with specialized gas sensors, infrared cameras, and object identification features can continuously scan underground environments and detect hazards such as high carbon monoxide and methane concentrations or physical hazards causing potential accidents. A coal mine robot designed for real-time hazard and object detection is introduced in this paper. It is mounted with an intelligent sensor fusion system and AI-based data processing allowing for fast and accurate hazard identification. It has a rugged mobile system capable of traversing underground mines' narrow, bumpy, and at times treacherous paths, extending surveillance to inaccessible and unsafe zones for human workers. With its integration of real-time data transmission and smart data analysis, the robot facilitates timely interventions for accident prevention and saving lives. With its autonomous operation feature, dependency on manual labour becomes less, and human exposure to risky conditions is also minimized. With such an adoption of robotic technology, mining operations can greatly optimize their level of safety, minimize downtime due to unexpected hazards, and increase overall efficiency[3]. In this paper, we shall discuss the design and operation of this robot and its revolutionary impact in reconfiguring coal mining safety in terms of providing an updated, technology-based solution for one of the riskiest work environments.

II. EXISTING SYSTEM

The existing coal mine safety measures rely heavily on manual inspection and traditional gas monitoring devices, e.g., fixed sensors and handheld detectors, to regulate concentrations of methane (CH_4), carbon monoxide (CO). Although localized effectiveness is achieved through these mechanisms, they have poor coverage and rely on human intervention, further subjecting the system to risk of late hazard detection and human error. Detection of objects is equally limited, using manual inspection and fixed cameras, which are plagued by poor sight, limited range, and inability to detect buried hazards[4]. With existing robotic solutions gaining prominence through gas sensing and object identification, they remain weak in terms of mobility, ruggedness, real-time data realization, and integration in existing platforms. Most remain in prototype form and have limited autonomy and sensor fusion.

As such, existing measures remain limited in scalability and efficacy, highlighting the compelling need for an advanced, fully autonomous robotic system for integrating hazardous gas and object detection with real-time monitoring and astute analysis, optimized for harsh underground conditions[5].

III. DRAWBACKS OF EXISTING SYSTEM

Existing coal mine safety measures have key shortcomings. Gas detectors have poor coverage and depend upon human intervention, resulting in late hazard detection and human error.

Detection of objects is impaired by poor sight, limited scope, and inability to detect concealed threats. Novel robotic solutions have poor mobility, longevity, and real-time data handling, and in some cases, poor autonomy and fusion of sensors. Such devices also have poor integration capabilities and scalability. As a whole, existing measures lack adequate reliability and flexibility for use in harsh and complicated underground coal mines[6].

IV. PROPOSED SYSTEM

The Strandbeest system, as suggested, is an independent robotic platform for detecting dangerous gases and physical hazards in underground coal mines so as to ensure better worker safety and monitoring of the environment. The robot utilizes an uncommon leg-based locomotion system based on the Strandbeest structure to move in difficult terrain where wheeled robots can fail. It is equipped with multiple sensors for observing environments, such as gas sensors for measuring methane (CH_4), carbon monoxide (CO), and levels.

The sensors carry out continuous monitoring of the atmosphere in mines and give real-time notifications in the event of gas leakage or unsafe environments[7].

Additionally, the robot contains ultrasonic sensors, camera module, and infrared imaging to identify physical hazards like rocks that have fallen, weaknesses in structures, and blockages. All data gathered is sent wireless to a remote operation station through Wi-Fi or LoRaWAN, ensuring operators receive information immediately[8]. Robust in autonomous modules, yet optional through manual takeover, the robot can reach inaccessible locations and react quickly to emergency cases, making hazard detection and risk minimization in coal mining operations scalable and astute.

WORKING:

The Strandbeest robot is capable of operating autonomously in risky coal mining environments by continuously monitoring and measuring surrounding conditions for hazards. Its unusual mechanical body allows for walking over uneven and unstable terrain, suitable for underground environments in which wheeled robots would have difficulties navigating. When switched on, the robot initiates operation by creating an onboard map of its environment using LiDAR and ultrasonic sensors to detect physical obstacles and drive safely[3].

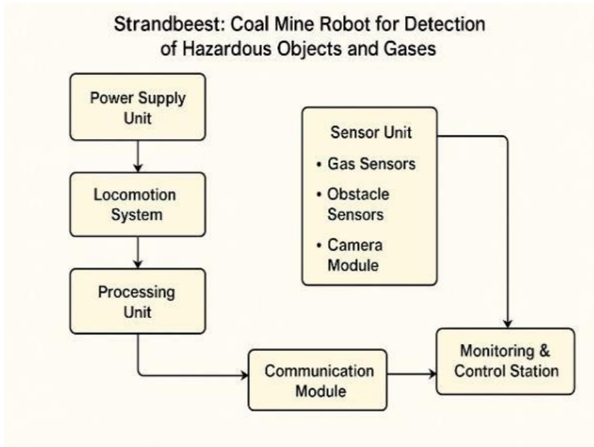
When in transit, gas sensors actively analyze gas in the air in an attempt to detect toxic and flammable gases like methane, carbon monoxide, and hydrogen sulfide and ensure oxygen remains at safe proportions. Visual data from onboard cameras, such as infrared for low-contrast environments, is analyzed to detect structural abnormalities or debris on the ground. All information is analyzed using an onboard system interpreting sensor data and making capable decisions concerning route correction, speed, and threat responses.

When in dangerous situations, the robot can trigger alert devices and send instantaneous messages to a command center in terms of wireless communication. This setup provides real- time knowledge of the surroundings and takes prompt actions against unsafe environments, minimizing human interaction and increasing overall reliability and security in coal mining operations.

In addition, Strandbeest can survive harsh underground environments in its rugged, dust-resistant, and moisture-proof casing, ready for long-term operation without regular maintenance[6]. A modular structure facilitates quick upgrades or swaps of modules, enabling flexibility in adapting to different mine configurations and changing requirements for safety. Its battery system enables long-duration missions, while its optimized power consumption maximizes energy efficiency.

Connection to remote monitoring platforms enables visualization of data in real-time, allowing for predictive maintenance and quick decision making. With its robust and smart design, not only is Strandbeest enhancing safety, but its use also drives automation and digitization in mining activities.

V. ARCHITECTURE



VI. COMPONENTS USED AND DESCRIPTION

1) ARDUINO UNO:

The Arduino Uno serves as the Strandbeest robot's controlling hub, managing disparate elements for dangerous gas and object detection. Arduino processes MQ-series gas sensors' data for detecting gases such as carbon monoxide and methane, while using ultrasonic sensors for detecting obstacles. Arduino also connects to ESP32-CAM module for real-time visual captures of surroundings. Arduino manages the robotic movement through L298N motor driver and interacts with GPS and GSM modules for real-time location tracking and emergency notifications. This integration assures automatic functioning of the robot in dangerous coal mine surroundings, improving overall safety and minimizing manual intervention. .

2) CAMERA OV2640 OF ESP3
MODULE.

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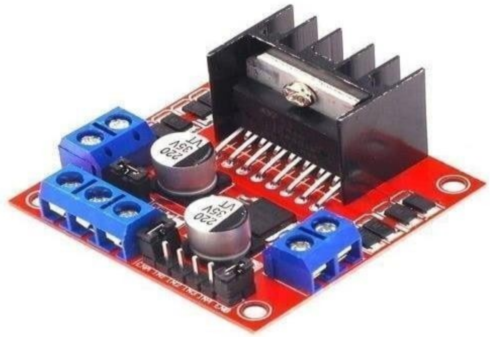
The ESP32-CAM module, equipped with a 2MP OV2640 camera, is a compact solution for capturing images and video, often used in face recognition systems. Measuring only 40 x 27 mm, it supports deep sleep current as low as 6mA, making it highly efficient for IoT applications. It's commonly used in smart home devices, wireless monitoring, and industrial control. This module integrates Wi-Fi, Bluetooth, and BLE Beacon with dual-core 32-bit LX6 CPUs, supporting frequencies between 80MHz and 240MHz. It includes built-in sensors like a Hall sensor and a temperature sensor, making it highly versatile for embedded systems.

3) L298N MOTOR DRIVER



The L298N is a dual H-Bridge motor driver IC that controls the speed and direction of two DC motors or one stepper motor. It supports up to 2A current per channel and operates with motor voltages from 5V to 35V. Featuring onboard heat sinks and power supply terminals, it easily interfaces with microcontrollers like Arduino or ESP32. It enables pins to allow for PWM control of motor speed. It's a popular component in DIY robotics and automation systems.

4) DUAL SHARPED DC MOTOR

This motor features output shafts on both ends of the rotor, enabling it to drive different components simultaneously. It's especially useful in robotics and automation, where one shaft can drive wheels while the other handles feedback mechanisms like encoders. Operating between 3V and 12V, it offers high torque in a compact design, making it suitable for mobile robots, line-followers, and mini conveyor systems. It integrates well with motor drivers like the L298N for PWM- based speed and direction control.

5) MQ9 GAS SENSOR

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The MQ9 sensor detects gases like carbon monoxide (CO), methane (CH_4), and LPG. It uses a tin dioxide (SnO_2) layer that changes conductivity with varying gas concentrations, offering both analog and digital outputs. Operating at 5V, it has an internal heater for accurate readings. It's widely used in gas leak detectors, industrial safety systems, and mine-monitoring robots. Calibration enhances accuracy, and with a typical lifespan of two years, it's a cost-effective and reliable solution for toxic gas detection.

6) SERVO MOTOR SG50

The SG50 is a lightweight micro servo motor known for its precision. It operates between 4.8V and 6.0V and offers around 0.8 kg/cm torque with up to 180° rotation using PWM. Weighing just 9 grams, it's great for applications like robotic arms, camera mounts, or RC models. With its easy 3-pin connector, it's commonly used in Arduino and ESP32 projects due to its fast response and affordability.

7) ULTRA SONIC SENSOR

Ultrasonic sensors measure distance by emitting 40kHz sound waves and detecting their reflection. The HC-SR04 is a popular module that provides accurate distance readings between 2 cm and 400 cm. It has four pins: VCC, Trigger, Echo, and GND, and operates at 5V. It's frequently used in robotics for obstacle detection, autonomous navigation, and industrial automation. Its reliability, small size, and affordability make it ideal for non-contact distance measurement.

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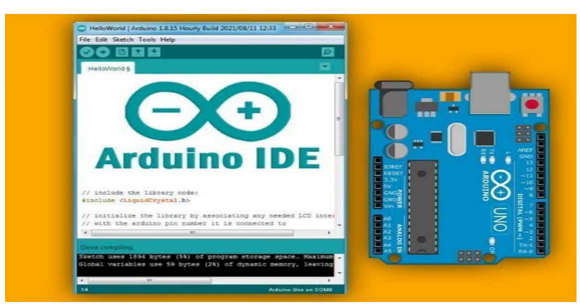
8) BATTERY 3.7V

A 3.7V Li-ion or Li-Po battery is a compact, rechargeable power source often used in embedded systems. Known for high energy density and light weight, it provides stable power for microcontrollers, sensors, and motors. With capacities from 300mAh to over 5000mAh, they're suitable for both low- and moderate-power devices. Proper charging and protection circuits are essential for safe use and longevity.

9) JUMPER WIRES

Jumper wires are used to connect electronic components on a breadboard or between modules and microcontrollers like Arduino or ESP32. Available as male-to-male, male- to-female, and female-to-female, these flexible, insulated wires come in various lengths and colours for easy identification. They're reusable and ideal for temporary circuit setups during prototyping, commonly used in robotics, IoT, and hobby projects.

10) SOFTWARE(ARDUINO IDE)



The Arduino IDE is the core software used to program and upload code to the Arduino Uno. It offers an easy-to-use interface for riting, compiling, and managing code for all system components—like the MQ-9, servo motor, camera module, ultrasonic sensor, L289N motor driver, and display. It supports real-time monitoring and response in your IoT-based system.

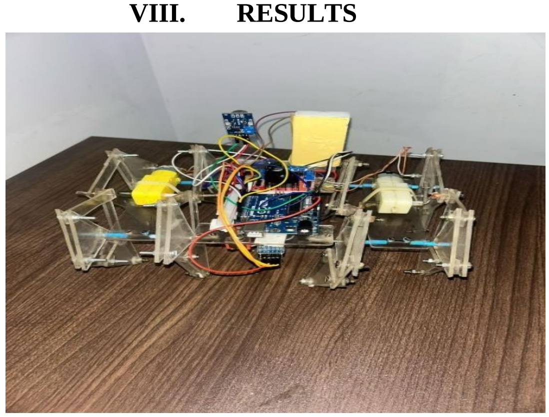
11) POWER SUPPLY

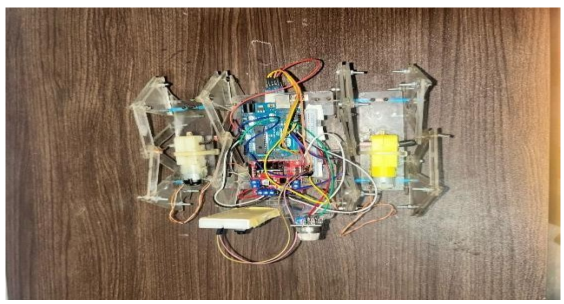
9V HW battery (also known as a 9V battery) is crucial in supplying power to the whole system. As the devices in the system, including the Arduino Uno, GSM module, GPS module, and sensors (such as the MQ- 3alcohol sensor and MEMS accelerometer), need a constant power supply, the 9V battery is utilized to supply the required power.

VII. WORKING

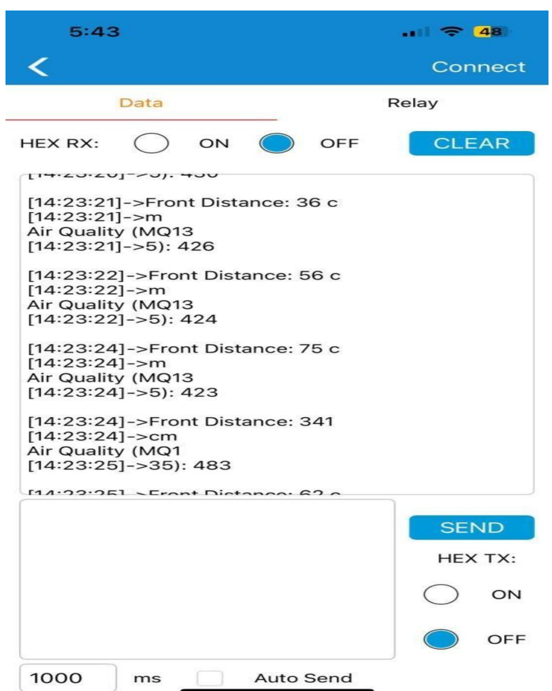
1) The system is powered using a 3.7V or 9V battery, which activates the Arduino Uno and initializes all connected components.
2) The alcohol sensor checks the driver's breath for alcohol levels continuously in real-time.
3) If alcohol concentration is higher than allowed, the Arduino triggers a relay to block engine startup.
4) An SMS alert is immediately sent through the GSM module to a registered phone number.
5) The MQ9 gas sensor detects the presence of dangerous gases like CO, methane, and LPG.
6) When harmful gas levels are detected, alerts are activated, and notifications may be sent via GSM.
7) The GPS module fetches and shares the real-time location of the robot or vehicle.
8) If an accident or impact is detected, the Arduino sends the current GPS location via SMS.
9) The ultrasonic sensor measures distance to nearby objects to detect obstacles.
10) If an obstacle is too close, the Arduino redirects or stops the motors to avoid collision.
11) The L298N motor driver receives commands from the Arduino to control motor speed and direction.
12) Dual shaft DC motors enable the robot to move efficiently and handle extra attachments like encoders.
13) The SG50 servo motor performs precise 180° angular movements for tasks like rotating a camera or lock.
14) The ESP32-CAM module captures images or live video, used for surveillance or face recognition.
15) Jumper wires connect all components securely on a breadboard or PCB for smooth communication.
16) All logic and sensor handling is programmed in Arduino IDE and uploaded to the Arduino board.
17) The system operates continuously, monitoring conditions and taking automatic actions based on sensor data.

VIII. RESULTS



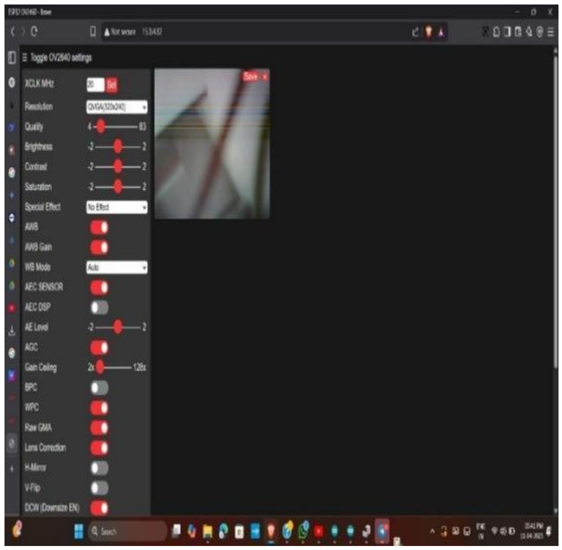


GAS DETCTION OUTPUT



The robot is integrated with gas sensors capable of detecting hazardous gases such as methane (CH_4), carbon monoxide (CO), which are prevalent in coal mine environments. These sensors generate analog outputs that are interfaced with the Arduino Uno microcontroller. The Arduino processes the incoming data and initiates exceed predefined safety thresholds. This real-time monitoring system enables early detection of toxic gases, significantly enhancing operational safety for personnel working in underground conditions[11].

CAMERA MODULE OUTPUT



The camera module provides a continuous real-time video feed of the coal mine environment, assisting in the identification of hazardous objects and potential obstacles along the robot's path. This live footage is transmitted to a remote monitoring system, enabling operators to track the robot's movement and assess its surroundings from a safe location. By offering enhanced situational awareness, the camera significantly improves operational safety in low-visibility or high-risk zones where direct human access is either unsafe or impractical.

IX. CONCLUSION

In this project, Theo Jansen's mechanical walking structure has been used to design a Strandbeest robot. It uses Arduino Uno, gas sensors (such as MQ series), and a camera module for identifying harmful gases and obstacles in coal mines. With its legged movement, which is inspired by Theo Jansen's mechanical walking structure, the robot can walk over rugged and uneven coal mining surfaces within which wheeled robots can get stuck. The gas sensors detect harmful gases such as carbon monoxide and methane in the surroundings, while a camera module offers real-time visual feedback for navigating and detecting obstacles. It is compact in size, economical in cost, and meant for remote use within harsh and risky underground environments. This shows the viability of using biogeometry -based mechanical structures integrated with embedded systems for industry-level safety purposes.
Autonomous path planning, wireless data transmission using IoT, and machine learning-based algorithms for better object and gas identification can be further included in future improvements for better system robustness and efficacy[12].

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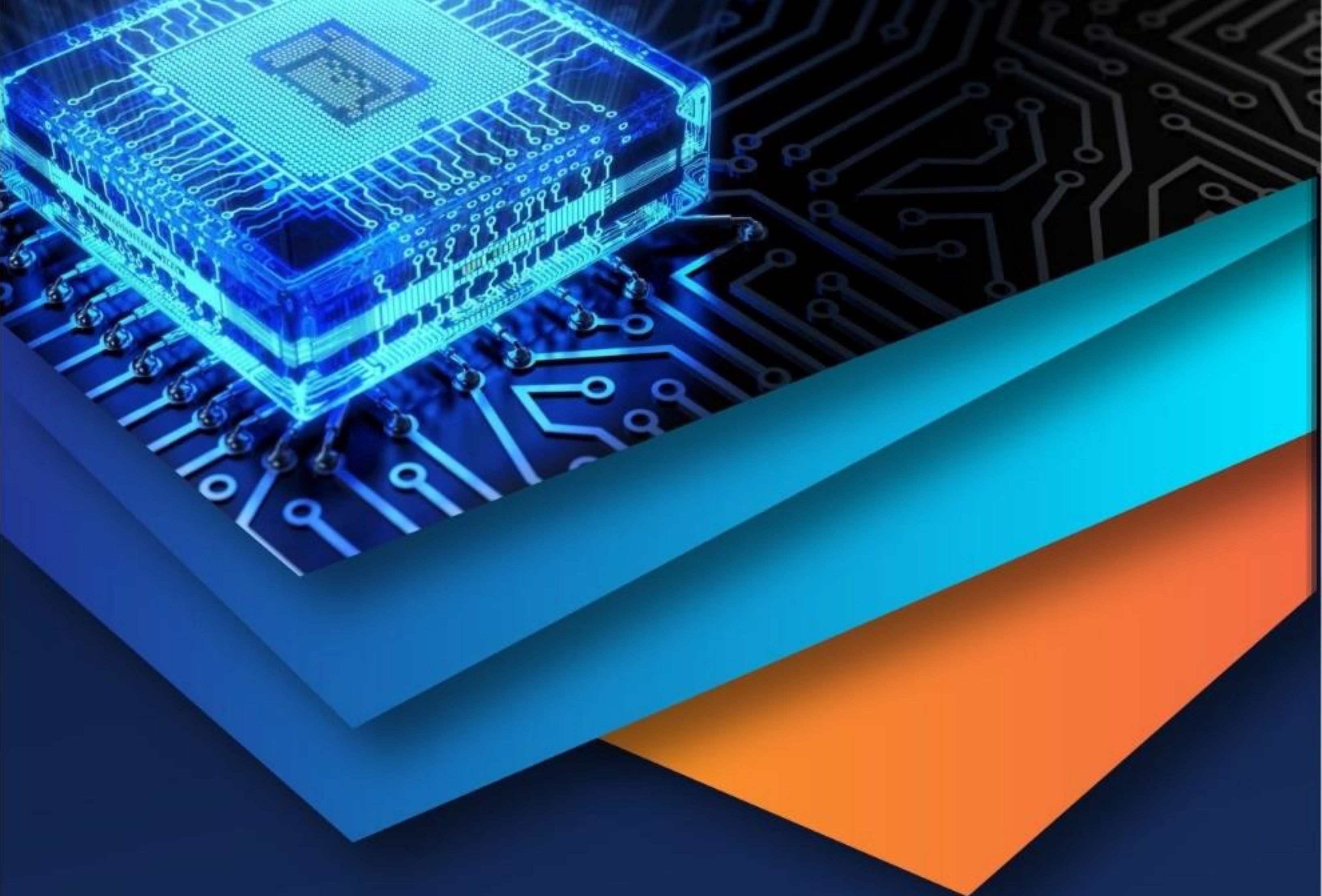

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