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Automatic Fire Detection and Safety Activation System for Electric Vehicles Using IoT to Enhance Passenger Safety and Risk Mitigation

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Abstract: Fire accidents have become a common occurrence in both homes and industrial sites because of unpredictable weather patterns and human errors. The designed prototype detects fire incidents which allows users to operate fire extinguishing systems from a distance thus protecting firefighters from danger. The main idea behind this concept is to propose a model which creates an Automatic Fire safety System for Electric Vehicles that uses cost effective design and application. The fire extinguishing system activates when the vehicle fire extinguisher detects either flame or smoke from a vehicle fire and it executes automatic fire suppression. An electric vehicle has many reasons that can lead to fire accidents. The main reason behind the Electric Vehicle fires is the battery used in them. The above mentioned reasons have caused numerous incidents which resulted in complete vehicle destruction through fire. The installation of the automatic fire extinguishing system can minimize the financial loss which could arise from a fire, as well as increasing the safety level for the vehicle, occupants and other traffic participants.
Keywords: Fire Situation, Controller, Emergency Alert, Accident Prevention, IOT Technology etc.

I. INTRODUCTION

In our country fire accident is a very common phenomenon. The situation puts lives and property at immediate danger. The developing country lacks modern technology which could help us resolve this issue. Fire brigade operations have limitations which prevent them from achieving full success. The police and military forces sometimes provide assistance to the officers at the shooting scene. The existing resources do not meet the required standards. Electric vehicle battery systems introduce safety problems which need extensive testing procedures to determine their fire risk potential. Research has shown that electrical system failures are among the top 4 causes of automobile related fires.

Fig.1. Electric Vehicle on Fire situation

The public believes that only battery packs used in hybrid and all-electric vehicles create fire hazards while these battery packs pose safety risks. Car fires present a major obstacle for the automotive industry to solve but this issue has existed for many years because Indian roads experience approximately 900 car fires which occur for every billion miles driven. The Automatic fire extinguishing system provides facilities because it allows users to access fire protection equipment from multiple locations within their facility. A series of gas jetting nozzles have been installed to particular spots throughout the specified area. The gas jetting nozzles are connected through a valve and a pipe to the extinguishers.

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The fire sensors are arranged at desired locations which cover the entire designated area. The system uses fire sensors to detect fires which activate the valve to release fire-extinguishing gas through the gas jetting nozzles into the area for automatic fire extinguishing operations to take place.

Nowadays, domestic and industrial fire accidents are getting frequent. The situation increases both the fire damage and the danger to human life. A smart home automation system could be an easy solution to prevent small scale fire accidents from occurring in a home or to extinguish such fire hazard. The smart home automation system can only control fire within one home because it has been designed to operate at that specific location. The system cannot manage fire incidents that occur in other parts of the building because it has been designed to operate within one home. The entire complex needs a fire extinguishing vehicle to handle the fire emergency situation. These needs paved the path to this research work.

The system which we plan to develop will create an automatic fire detection vehicle which can function in both residential and commercial spaces. Users can operate the vehicle through their mobile phones to reach the fire incident site which needs water for firefighting purposes. Users have the ability to manage three aspects of water spraying operations which include controlling the speed and volume and selecting the spraying direction. Users can use their mobile phone to watch the developed vehicle as it moves at a distance which allows them to direct its path for firefighting operations. The guided vehicle uses IoT (Internet of Things) technology to collect and evaluate data which enables users to make timely decisions based on real-time information.

This method enables fire damage control through active fire fighting operations which start before fire extinguishing personnel reach the scene. The automatic door unlocking system helps decrease the risk of death or injury during standard automobile fire accidents. Fire extinguishing squads dedicate their work to extinguish fires even when they face mortal danger. The research project seeks to develop fire control methods which require minimal human activity for their execution.

II. PROBLEM IDENTIFICATION

Research studies demonstrate that electrical system failures rank as one of the four primary causes for automobile fires. People believe that only hybrid and all-electric vehicles experience battery pack problems which lead to fires.

A Tesla Model S which received recognition as the world's safest vehicle according to media sources caught fire in December 2013. People have understood the electric and hybrid vehicle dangers since ancient times. Every new vehicle design releases additional safety threats. Many people will remember these high-profile events until they eventually fade from their memory.

The common factors that lead to car fire in electric vehicles are given below-

A. Battery Overcharging

All systems including EV batteries have a maximum limit which they can endure for heavy operational demands. The electric vehicle battery also has some limit of electricity provided to it. The manufacturer establishes this limit for the vehicle. The electrical components will experience malfunctioning and equipment damage and fire incidents when this limit gets exceeded. The battery experiences this situation when excessive electric current passes through it. The battery ignites because excessive current flow causes it to overheat. This situation occurs because the driver or owner leaves the battery charging overnight and forgets to unplug it afterward.

B. Battery Electrolyte Leakage

The Lithium-ion battery demonstrates two hazardous combustion problems which lead to battery degradation. The batteries will start burning when their internal temperature reaches 65 °C and they will burn more frequently when their temperature exceeds 75 °C. The burning process of the battery leads to hydrofluoric acid production which results from the thermal decomposition of PF_6^- ions found in the battery's electrolyte. The amount of hydrofluoric acid released into the environment varies according to two factors which include the total amount of electrolyte destroyed during combustion and the specific temperature at which combustion occurs. Other toxic gases are also produced and released during the electrolyte combustion (carbon oxides from combustion of ethylene and propylene carbonates). The process of handling Li-ion batteries needs extreme care because it protects against battery leaks and battery fires.

C. Short Circuit in Electric Components

Short circuits happen when electrical systems face excessive power load or when two uninsulated electrical wires make contact with each other. A circuit is said to be overloaded when too much current flows causing heat build up or wiring to break down. The situation creates conditions which allow sparks to ignite fires. A short circuit creates an electrical path which enables current to flow through a circuit outside its designated route. Short circuits generate fires when positive wires touch flames which create sparks that ignite fires. When two wires make contact with each other sparks can ignite fires.

D. Road Crash

Typically after a vehicle crash a car should not experience any fire. The battery system inside an electric vehicle operates as the primary fire hazard. Electric vehicle batteries function like other batteries because they create fires when their surfaces get breaches. A battery breach occurs when an electric vehicle traveling at maximum speed crashes into an object which creates a hole in its battery. Some reports explain how dangerous this battery problem has become.

The Chevy Volt made headline in late 2011 and early 2012 when a couple of cars caught fire during impact testing. The federal investigators established that the fire started when leaking coolant mixed with damaged batteries during the testing process after their investigation into the incident.

Figure 2: EV Busses caught fire and totally buried.

III. METHODOLOGY

A. Proposed System

The system operates to monitor and control Electric Vehicle (EV) battery temperature in order to prevent overheating which could result in battery damage. The system achieves its operational efficiency through the integration of sensors, a microcontroller system, and various cooling systems. The system employs smoke sensors and photoelectric sensors and temperature sensors to detect battery temperature increases. The smoke sensor and photoelectric sensor monitor the presence of smoke, while the temperature sensor continuously measures the thermal condition of the battery. The sensors transmit their detected abnormalities to the Arduino microcontroller which processes the data.

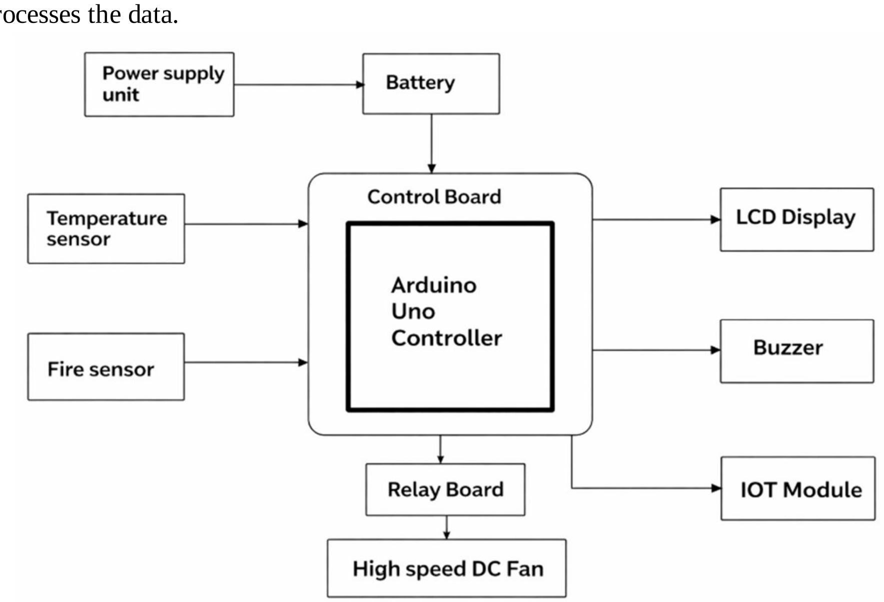

Figure 1. Proposed System

The microcontroller uses its programmed logic to assess incoming sensor data. The system uses these inputs to select the correct response. The microcontroller generates a buzzer sound to alert nearby users when the smoke or photoelectric sensor detects smoke or overheating while alternatively showing warnings on the LCD screen and sending remote alerts through the IoT module to contact both system and user. The microcontroller activates the high-speed DC fan together with the buzzer and IoT module and LCD display when the temperature sensor shows that the system has reached overheating levels. The DC fan begins to function at maximum speed which creates a strong airflow that moves through the battery area to rapidly remove heat from the system until the temperature reaches safe operating levels. The system operates to provide continuous monitoring capabilities which enable fast responses to battery overheating incidents. The IoT module enables users to track location and receive alerts from devices which allows users to respond quickly while enhancing safety and operational efficiency for Electric Vehicles.

B. Main Features

- Real-Time Battery Monitoring: Continuously monitors critical battery parameters such as temperature and fire presence to ensure safe operation.
- Early Hazard Detection: Detects abnormal conditions like overheating, smoke, or flame at an early stage to prevent thermal runaway.
- Automatic Safety Activation: Instantly activates high-speed DC fan, buzzer, and other protective mechanisms when unsafe conditions are detected.
- Microcontroller-Based Control: Uses Arduino Uno (ATmega328P) for fast data processing and intelligent decision-making.
- IoT-Based Remote Monitoring: Transmits real-time data to cloud platforms, enabling remote supervision by drivers or fleet operators.
- Visual Status Display: LCD screen provides live temperature readings and alert messages for user awareness.
- Audible Warning System: Buzzer generates immediate sound alerts during emergency situations.
- Relay-Controlled Isolation: Ensures safe switching between low-power control circuits and high-power devices.
- Cost-Effective Design: Utilizes affordable components for practical and scalable implementation.
- Compact and Integrated System: Designed for easy installation inside EV battery compartments without major modifications.

C. Hardware Used

- Arduino Uno (ATmega328P): Central microcontroller for processing sensor data and controlling output devices.
- Temperature Sensor (e.g., LM35/DHT11): Monitors real-time battery temperature to detect overheating conditions.
- Fire/Flame Sensor: Detects smoke or flame presence near the battery pack for early fire identification.
- Relay Module: Acts as an electronic switch to control high-power devices like fans and sprinklers.
- High-Speed DC Fan: Provides rapid cooling to prevent thermal runaway during high-temperature conditions.
- Buzzer: Generates audible alerts during abnormal or emergency situations.
- 16x2 LCD Display: Displays temperature readings and system status messages for driver awareness.
- IoT Module (ESP8266/ESP32): Enables wireless data transmission and remote monitoring.
- Rechargeable Battery & Power Supply Unit: Provides regulated and uninterrupted power to the system components.

D. Software Used

- Arduino IDE: For programming microcontroller functions and interfacing sensors.
- Embedded C: Used as the primary coding language for hardware control.
- Cloud Platform (Thingspeak): Stores and visualizes patient health data remotely.
- Mobile server: Provides doctors with real-time access to patient data.
- Data Analytics Tools: Support trend analysis and report generation for better healthcare insights.

IV. RESULTS AND DISCUSSION

The proposed Smart Fire Safety System for Electric Vehicles (EVs) was successfully implemented as a working prototype using an IoT-based framework. The system was integrated with temperature, smoke, and photoelectric sensors, an Arduino microcontroller, a high-speed DC fan, a buzzer, an LCD display, and an IoT module to perform real-time monitoring and autonomous response to thermal hazards. The prototype was modeled on a miniature electric bus using plastic and metal sheets to simulate realistic conditions.

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The smart fire safety system for Electric Vehicles (EVs) was successfully implemented on a small-scale bus prototype constructed from sheet materials. The system was tested under various controlled environmental conditions to evaluate its real-time detection, notification, and response performance using temperature, smoke, and photoelectric sensors.

The sensor readings were transmitted to the cloud platform via an IoT module (such as ESP8266), allowing remote monitoring on mobile devices. During the testing phase, simulated heat and smoke conditions were created to assess the responsiveness of the system. When the temperature exceeded 45°C, the DC cooling fan was automatically triggered. Simultaneously, alerts were sent via the IoT dashboard, and the buzzer was activated. When smoke concentration crossed 250 ppm, the photoelectric sensor and smoke sensor sent signals to activate the warning system.

Table 1: Sensor Reading vs. System Response

Time (s)	Temperature (°C)	Smoke Level (ppm)	Photoelectric Intensity (lux)	Buzzer	DC Fan	IoT Alert
0	32	80	250	OFF	OFF	OFF
10	38	120	270	OFF	OFF	OFF
20	45	200	300	ON	ON	ON
30	47	260	320	ON	ON	ON
40	41	150	280	OFF	ON	ON
50	35	100	260	OFF	OFF	OFF

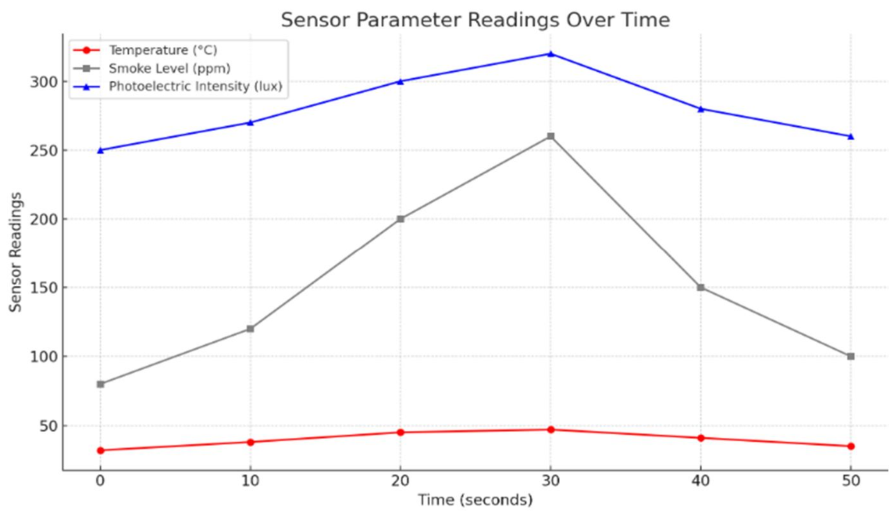

Figure 4. The graph displaying the sensor readings (temperature, smoke level, and photoelectric intensity) over time

The graph displaying the sensor readings (temperature, smoke level, and photoelectric intensity) over time. It clearly shows how the system detects abnormalities around the 20–30 second mark and helps visualize the conditions that trigger the safety mechanisms.

Internet of thing has several of applications and here we had applied in the field of fire safety and monitoring. Especially in AC buses. IOT has a broad application background in the field of real time applications mainly in security systems. This proposed system mainly focuses on reducing the human loss and property loss when accident had happened. In our proposed system the preventive measures are implemented automatically, So the time to implement them is very less, so the loss can be reduced. We propose this system as a first attempt and compliment to public transportations. Many accidents occurs during night time, and sometimes when driver is in sleepy condition driver cannot control the bus, if there is a drowsiness detection then in that situations a alert is given to driver in the form of buzzer.

During testing, the system was able to accurately detect increases in temperature and the presence of smoke in the battery compartment. When the temperature exceeded a pre-set threshold (e.g., 45°C), the temperature sensor relayed the data to the Arduino, triggering the DC fan to operate at high speed. Simultaneously, the buzzer alarm was activated, warning nearby users, while real-time data was sent to the cloud using the IoT module. This enabled remote monitoring of fire-related parameters via a mobile or computer interface.

The graphical output (Figure 5) illustrates the real-time sensor readings—temperature, smoke concentration, and surrounding heat levels. The data was plotted over time, showing the sensor's quick response to changes in environmental conditions. These readings helped demonstrate the system's efficiency in detecting and responding to hazardous conditions within seconds, reducing the reaction time drastically compared to manual systems.

Additionally, the photoelectric and smoke sensors effectively identified combustion particles, even in low-visibility scenarios. The LCD display continuously updated the user with current readings and alert messages, reinforcing the interactive safety mechanism of the system.

An important finding was the system's potential use in public transportation buses, especially AC buses that are prone to overheating in confined compartments. Night-time operation was also addressed, with the buzzer alert system acting as a critical feature to wake or alert drowsy drivers, thereby contributing not only to fire safety but also to accident prevention due to driver fatigue.

From a cost and implementation perspective, the system proved to be affordable, compact, and low-maintenance, allowing for scalability across various EV models. With further R&D, integration of drowsiness detection, AI-driven predictive analytics, and automatic extinguishing modules can enhance the safety suite.

The smart fire safety system demonstrated excellent responsiveness, operational simplicity, and strong applicability in real-world EV use cases, particularly in preventing thermal runaway and reducing human and property loss during fire-related incidents.

V. ADVANTAGES AND APPLICATIONS

A. Advantages

1) Real-time Monitoring: Continuous monitoring of battery temperature ensures proactive detection of overheating issues.
2) Enhanced Safety: Prevents potential hazards like thermal runaway, fire, or explosion in EV batteries.
3) Efficient Cooling: High-speed DC fans effectively dissipate heat, maintaining battery health and extending its lifespan.
4) Remote Notification: IoT integration allows users and maintenance teams to receive alerts in real-time, enabling swift action.
5) User-Friendly: The LCD display provides clear information about the system's status, making it accessible to all users.
6) Cost-Effective: Prevents costly damage to the EV by ensuring timely interventions.
7) Low Maintenance: The system is robust, requiring minimal maintenance over time.

B. Applications

1) Electric Vehicles: Battery temperature management in EVs to ensure safety and performance.
2) Renewable Energy Systems: Cooling batteries in solar or wind energy storage setups.
3) Data Centers: Managing heat in battery backups for uninterrupted operations.
4) Portable Electronics: Thermal regulation in high-capacity battery-powered devices.
5) Industrial Systems: Monitoring and cooling batteries in automated machinery or robotics.
6) Aerospace: Ensuring safe battery operations in drones, aircraft, and space applications.

VI. CONCLUSIONS

The integration of a Smart Safety System for Electric Vehicles (EVs) using IoT is crucial for enhancing the safety, performance, and longevity of EV batteries. This innovative system monitors key battery parameters like temperature and smoke, providing real-time alerts through IoT connectivity. In case of overheating or potential fire hazards, the system automatically activates safety mechanisms such as high-speed cooling fans or extinguishing units, effectively preventing accidents. This system's simplicity ensures minimal maintenance, making it a practical and cost-effective solution. Its compact design allows seamless integration without causing any discomfort to drivers or passengers. IoT connectivity enables remote monitoring and instant notifications to users, ensuring prompt action. With continued research and development, this smart safety system could revolutionize EV safety, offering scalable solutions adaptable to various battery types and sizes. It represents a significant step forward in ensuring EV reliability and user confidence in modern transportation.

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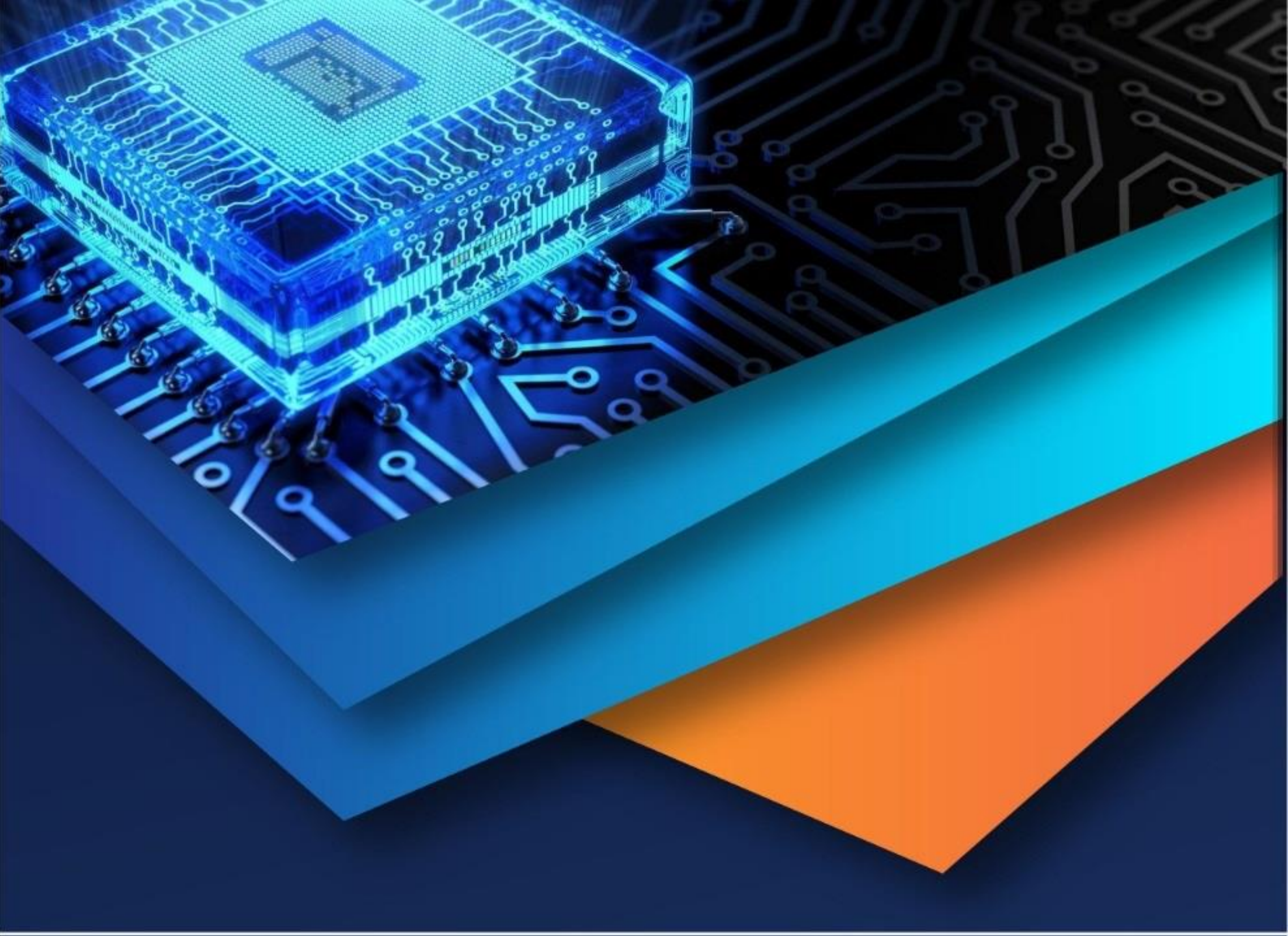

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