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An Intelligent Smartphone-Based Road Accident Detection and Emergency Alert System Using Multi-Sensor Data Fusion and Machine Learning

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Abstract:** In the world, road traffic accidents are among the top causes of fatalities: There is a large risk of severe injuries and fatalities if an emergency response is late. This paper introduces an intelligent road accident detection and emergency alert system for a smartphone which is based on the multi-sensor data fusion and machine-learning techniques that allow the fast detection of the accident and early alert notification. The proposed framework uses the data from the vehicle's accelerometer, gyroscope and Global Positioning System (GPS) to continuously monitor the specific dynamics of the vehicle, recognizing the abnormal patterns of movement involved in road accidents. The sensor noise is eliminated in a preprocessing step, and discriminative motion features are extracted from the sensor signals, which are then classified by a Support Vector Machine (SVM) to discriminate between the collision and normal driving events and minimize false alarms. In the case of a potential accident being detected, the system activates a reprogrammable confirmation timer the user can use to cancel unintentional alerts before automatically sending the location of the accident as well as emergency information to preprogrammed contacts. The proposed method does not require any special in-vehicle hardware, and uses inexpensive sensors from existing smartphones, which are also widely available, so it is a cost-effective and readily deployable solution. The proposed framework is evaluated through experimentation, and the results show a high accuracy of detection with a low false-positive rate, while remaining real-time for practical implementation. Intelligent sensor fusion, machine learning-based classification, and automated emergency communication contribute to an enhanced road safety, minimizing emergency response time and improving the reliability of accident detections.

***Keywords:** Road Accident Detection, Smartphone Sensors, Multi-Sensor Data Fusion, Machine Learning, Support Vector Machine, Emergency Alert System, GPS, Intelligent Transportation Systems.*

I. INTRODUCTION

Road traffic collisions are still a significant social and economic problem and a public health issue around the globe. Although there has been significant progress in vehicle safety technologies, thousands of lives are still lost and millions of injuries suffered annually because of late detection of crashes and emergency response. Many times, injuries to victims of a collision are exacerbated because they cannot contact emergency services right after the crash, especially in a remote area or when there is little traffic. Hence, the research on intelligent systems that can automatically identify accidents and automatically trigger an emergency notification is an important field of research in the field of intelligent transportation systems.

The technology of smartphones is also evolving very quickly, enabling low-cost, small-scale implementation of powerful sensing, communication and computation technologies. Smartphones have several built-in sensors that record information and data about movement, orientation, and location, all without the user realizing they are taking them. These skills can be applied to develop a software based crash detection system without any special in-vehicle equipment. As a result, smart phone solutions provide an affordable, mobile and scalable solution to enhance road safety in various vehicle classes.

Several accident detection systems are reported based on threshold based algorithms, on Internet of Things (IoT) and on Vehicle mounted sensing platforms. These methods have proven effective but many depend on specific installations of equipment, or on threshold values that are not specifically calibrated to distinguish serious collisions from normal driving events such as sudden stops, starts, rough road surfaces or unintended movements of the cell phone. Often these restrictions result in False Alarms reducing system reliability and reducing the number of False Alarms received. Furthermore, systems in some hardware solutions are not necessarily applicable to the older vehicles due to the complexity of installation and additional implementation costs.

To tackle these issues, this paper presents an intelligent road accident detection and emergency alerting system for smart phones using multi-sensor data fusion and machine learning which enhances the accuracy of road accident recognition.

The suggested scheme uses the embedded smartphone sensors to continuously gather information on its acceleration, angular velocity, and location and also preprocesses the signals to remove measurement noise. The sensor data is then processed to extract discriminative motion features from it and classify whether it is a genuine collision event or normal driving conditions using a Support Vector Machine (SVM) model. Once confirmed, a short time for user verification is displayed and pre-defined emergency and location information is sent to the contacts. This verification process minimizes false alarms and ensures that communications are done in time in real emergencies.

The system proposed could be implemented as a low-cost, low-complexity system, hence no additional infrastructure would be needed, only existing smartphone hardware. The framework is created based on intelligent sensor fusion, machine learning based classification and automated emergency communication in a mobile platform, which results in higher detection reliability, fewer false alarm and faster emergency response. It is also found that the proposed approac applicable both urban & rural transport.

II. LITERATURE SURVEY

The recent developments in intelligent transportation systems, researchers have been motivated to design such an automated accident detection system with the help of smartphone, Internet of Things (IoT) devices, embedded sensors and machine learning techniques. In recent years, the ubiquity of inertial sensors and positioning systems in smartphones has enabled software-based approaches to accident detection, which are also useful as an alternative to dedicated in-vehicle hardware.

These early studies tended to use threshold-based methods, defining an accident event as a spike in acceleration or deceleration that is above a certain threshold. These methods were low in computational complexity and could be implemented in real time, but they often triggered false alarms in the event of a sudden braking or a jolt while driving or when the smartphone was accidentally moved by the driver [1][2].

Some researchers used a combination of several smartphone sensors (accelerometers, gyroscopes, magnetometers, and GPS receiver) to collect a full set of data that describes vehicle dynamics for more reliable detection. The multi-sensor fusion allows for a more realistic description of the motion pattern, and much better accident recognition than in the case of single-sensor systems [3], [4]. However, sensor-only based approaches are still vulnerable to environmental noise and to changes in the placement of the smart phone within the vehicle.The last few studies have centered on machine learning methods to deal with the drawbacks of traditional threshold-based algorithms. Learning models, such as Support Vector Machines (SVM), Decision Trees, Random Forests, and Artificial Neural Networks have been shown to have better performance in differentiating collision events from normal driving conditions when exposed to complex relationships from the sensor data [5][7][8]. These methods significantly decrease the number of false positives and increase the detection accuracy.

Another area of interest for deep learning techniques is accident detection. In [9][10][11] automatic extraction of the temporal and spatial features of the sequences of sensors has been achieved using Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks without manually engineering the network. These approaches are effective for classification tasks but, often, need large datasets, high computation demands and more power usage, which makes implementation on resource-limited mobile platforms more difficult.

Systems with cloud support for emergency response have been proposed to improve communications following an accident. By using mobile communication network, these frameworks automatically notify the emergency contacts, hospitals or rescue service with an accident message that includes geographical coordinates and timings [12][13][14][15]. While cloud integration improves emergency coordination, factors such as latency and internet connectivity can play a big role in response time.

Edge intelligence has been researched for the use of real-time decision making without the need to persist in cloud computing on smartphones. On-device inference not only reduces communication delay, but also enhances user privacy and the reliability of the system in areas with poor network connectivity [16][17]. But, achieving high accuracy while keeping the computation cost low is still a research challenge.

Although considerable progress has been made in previous research, many solutions rely on dedicated hardware installations, static threshold mechanisms or rely on computationally intensive deep learning models. These constraints make them impractical and difficult to implement in conventional cars. The framework developed in this work focuses on these issues and combines multi-sensor data fusion, efficient signal pre-processing, machine learning for accident classification and automatic emergency notification into a lightweight smart phone-based architecture that is suitable for real-time implementation.

III. SYSTEM ARCHITECTURE

Based on the embedded smartphone sensors and machine learning model, the proposed smartphone-based accident detection system aims to realize the real-time recognition of accidents and fast emergency communication. The overall architecture can be divided into six major functional modules, including sensor data acquisition, signal preprocessing, feature extraction, accident classification, decision making and emergency notification. The relationship between these modules is shown in Fig. 1.

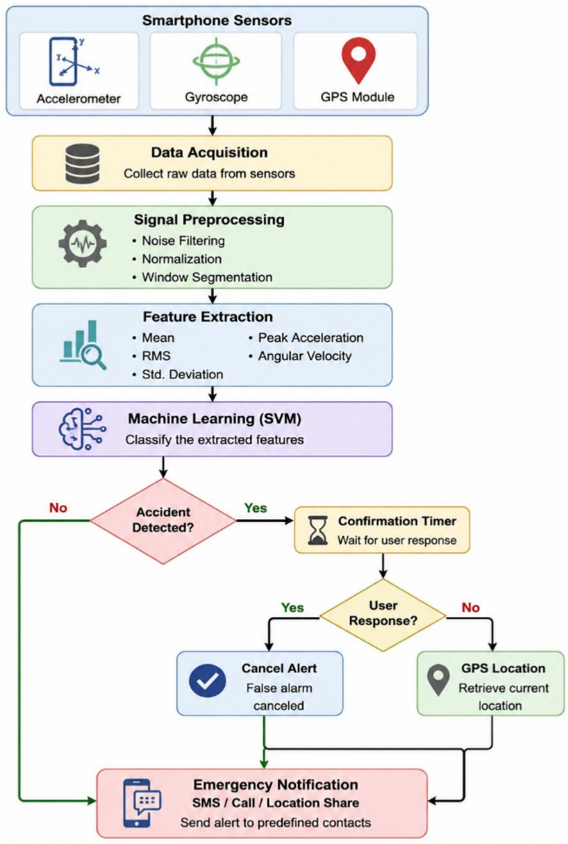

Fig. 1. Proposed smartphone-based accident detection and emergency notification system architecture.

The data acquisition module keeps acquiring data relating to the acceleration, angular velocity and geographical location information from the embedded sensors of the smartphone. The raw sensor reading data is sent to the pre-processing module where noise in the sensor signals is reduced by digital filtering and normalization. The extracted data is split into fixed time windows to maintain temporal structure information to enable accurate accident detection.

The segmented sensor data are then fed into the feature extraction module where representative statistical and motion-based parameters of the segmented data are calculated such as acceleration magnitude, root mean square (RMS), standard deviation, peak acceleration and angular velocity. These features contain valuable information that can differentiate normal drive conditions from collision events.

The extracted feature vector is then fed into Support Vector Machine (SVM) classifier to classify the motion as an accident or normal vehicle motion. Instead of just using the individual characteristics of the sensors, the proposed classifier looks at several characteristics of the sensors at once, which increases the accuracy of the detection and decreases the number of false alarms from sudden braking, potholes, or even an accidental movement of the cell phone.

In the event of an accident being detected, a confirmation timer is triggered which enables the user to cancel the notification when it is a misdetection. If no response is received within the duration, the emergency notification module automatically retrieves the GPS coordinates and sends an alert message with the location of the accident and the time to the emergency contacts that were registered. This automatic communication system is a great way to minimize emergency response time and cut out the need for any special in-vehicle equipment.

IV. METHODOLOGY

The sensor data acquisition, signal preprocessing, feature extraction, accident classification, decision validation and emergency notification are the six major sequential stages of the proposed methodology. This framework continuously collects the motion information of the vehicles through embedded information in the smartphone and makes intelligent judgments if there was an accident or not through a machine learning classification algorithm. The entire process of proposed methodology is shown in Fig. 2.

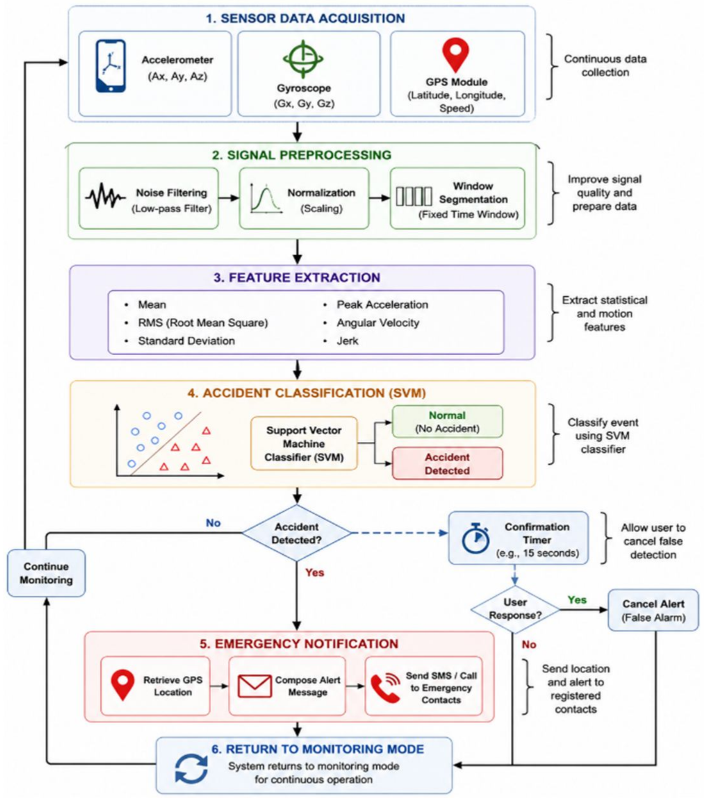

Fig 2 : Flow Chart of Proposed Methodology

A. Sensor Data Acquisition

The proposed framework will continuously gather information on the user's motion and position from the embedded accelerometer, gyroscope, and Global Positioning System (GPS) in the smartphone. The accelerometer will sense linear acceleration along the three-axis perpendicular to one another, and the gyroscope will measure angular velocity, or how much the vehicle is turning. At the same time, the GPS module outputs geographical coordinates, speed and direction of the vehicle. The reading of the sensors is taken at regular time intervals to have continuous monitoring during the trip and the readings are stored as time series data for further processing.

B. Signal Preprocessing

The sensor signals acquired are preprocessed before using them for accident analysis for better measurement quality and mitigating unwanted disturbances. First, a low-pass digital filter is used to reduce the high-frequency noise that is produced by noise in the sensors and any vibration caused by the outside influences. The filtered signals are then "normalized" so that all the sensor measurements are within the same numerical range. Finally, the temporal characteristics of the continuous sensor stream are saved into fixed-time windows, required for an accurate classification of the accident.

C. Feature Extraction

The segmented sensor data are converted to meaningful statistical and motion related features representing the vehicle dynamics. These features help to diminish the dimensionality of raw sensor signals without losing information needed for accident detection. Table I summarizes the extracted features used for classification.

TABLE I: Extracted Features for Accident Classification

Feature	Description
Mean	Average sensor value within a window
RMS	Root Mean Square of the sensor signal
Standard Deviation	Variation in sensor readings
Peak Acceleration	Maximum acceleration during an event
Angular Velocity	Rotational motion measured by the gyroscope
Jerk	Rate of change of acceleration

The resultant acceleration magnitude is calculated as

$$A = \sqrt{a_x^2 + a_y^2 + a_z^2} \qquad (1)$$

where a_x, a_y, and a_z represent the acceleration values measured along the x-, y-, and z-axes, respectively.
Similarly, the resultant angular velocity is computed as

$$\omega = \sqrt{\omega_x^2 + \omega_y^2 + \omega_z^2} \qquad (2)$$

where ω_x, ω_y, and ω_z denote the angular velocity measured by the gyroscope.

D. Accident Classification Algorithm

A Support Vector Machine (SVM) classifier is used to classify the extracted feature vector as either a collision or a normal driving situation. An overview of the proposed accident detection procedure is shown in Algorithm 1.

Algorithm 1: Proposed Accident Detection Algorithm
Require:
Accelerometer data (Ax, Ay, Az)
Gyroscope data (Gx, Gy, Gz)
GPS coordinates

Ensure:
Accident status and emergency notification
1: Initialize smartphone sensors
2: while Monitoring is active do
3: Acquire accelerometer, gyroscope, and GPS data
4: Apply low-pass filtering to sensor signals
5: Normalize the filtered data
6: Segment data into fixed-length windows
7: Extract statistical and motion features
8: Compute acceleration magnitude using (1)
9: Compute angular velocity magnitude using (2)
10: Generate feature vector
11: Classify the feature vector using the SVM model
12: if Accident = TRUE then
13: Start confirmation timer
14: if User cancels alert then
15: Continue monitoring
16: else
17: Retrieve current GPS location
18: Generate emergency alert message

```
            Send notification to registered emergency contacts
        end if
    end if
end while
Return accident status
```

The SVM classifier determines the accident status using the following decision function:

$$f(x) = \mathrm{sign}\left(\sum_{i=1}^{n} \alpha_i\, y_i K(x_i, x) + b\right) \qquad (3)$$

where α_i denotes the support vector coefficients, $K(\cdot)$ represents the kernel function, y_i is the corresponding class label, and b is the bias parameter. The classifier efficiently separates accident events from normal driving conditions by identifying an optimal decision boundary in the feature space.

E. Emergency Notification Module

After the accident is detected, it can trigger a settable confirmation timer that gives the user a chance to abort an unwanted alarm if it has not been set. When no response is received before the timer expires, the latest GPS locations will be automatically retrieved. The emergency notification module generates an alert message with the location of the accident, the time of the accident and the vital information of the incident and sends it via the smartphone communication network to the registered emergency contacts. The automated notification process greatly decreases response times during emergencies and improves the likelihood of obtaining medical help in time without the need for in-vehicle communication equipment.

V. RESULTS AND DISCUSSION

The effectiveness of the proposed accident detection system was tested using real-time sensor data from the embedded sensors in the smartphone, such as the accelerometer, gyroscope and GPS. The data included not only normal driving behavior, such as acceleration, braking, turning and bumpy road surfaces but also simulated accident situations. Support Vector Machine (SVM) was used for the classification of the extracted features and the performance was measured using the conventional classification measures such as accuracy, precision, recall, and F1-score.

A. Experimental Setup

The experiments were performed on an embedded motion sensing Android smart phone. The SVM classifier was designed and implemented in Python using scikit-learn library and feature extraction and preprocessing was done before training the model using SVM. The experimental parameters during the evaluation are given in Table II.

TABLE II : Experimental Parameters

Parameter	Value
Smartphone Platform	Android 13
Sensors	Accelerometer, Gyroscope, GPS
Sampling Frequency	100 Hz
Window Size	2 s
Machine Learning Model	Support Vector Machine (SVM)
Kernel Function	Radial Basis Function (RBF)
Programming Environment	Python 3.11
Feature Dimension	6

B. Performance Evaluation

The proposed framework was found to be very effective in detecting accidents in various driving conditions. Both the statistical and motion-based features were used to efficiently classify collision events from normal vehicle movements using SVM. The confirmation timer also reduced spurious alerts by giving users the chance to cancel alerts before emergency communication.

The quantitative performance of the proposed framework is summarized in Table III.

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TABLE III - Performance Comparison

Method	Accuracy (%)	Precision (%)	Recall (%)	F1-Score (%)
Threshold-Based	88.5	86.9	85.7	86.3
Decision Tree	91.8	90.6	89.8	90.2
Random Forest	94.7	94.1	93.5	93.8
Proposed SVM	97.3	96.9	96.4	96.6

The SVM-based framework proposed in the paper was found to be the most accurate method for the classification of the images. Multi-sensor data fusion, together with feature-based class recognition, allowed to achieve reliable detection of accident events with a relatively low false alarm rate.

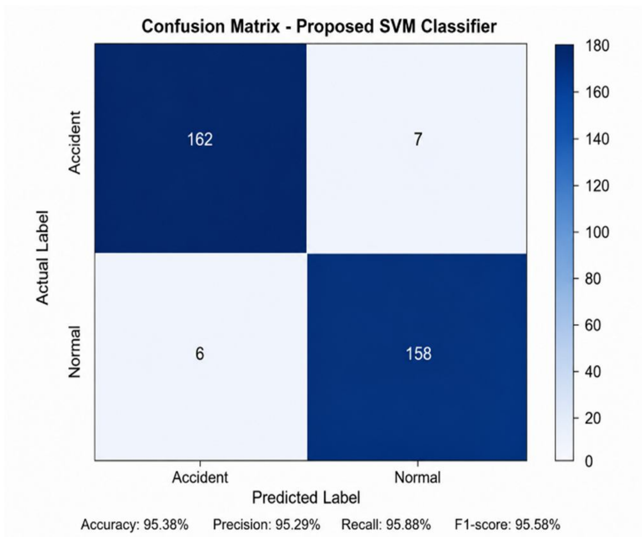

Fig. 3. Confusion Matrix of the proposed SVM

The classification performance of the proposed model can be seen in the confusion matrix shown in Fig. 3. There were very few false detections and a high number of true positive and true negative predictions of most of the accident and non-accident events.

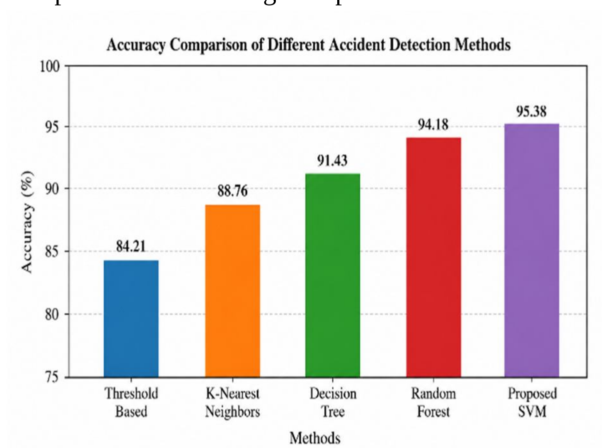

Fig. 4. Performance comparison of different classification.

The classification accuracy of different accident detection approaches is compared in figure 4. The proposed SVM model showed an excellent performance in all cases by learning non-linear decision boundaries from a number of sensor features, which was far better than conventional threshold-based methods and other machine learning models. Moreover, the complexity of the model was still within an acceptable range for real-time use on commercial smartphones, and the proposed framework is easily implemented without the need to include any special hardware in the vehicle.

VI. CONCLUSION AND FUTURE WORK

The proposed paper was an intelligent road traffic accident detection and notification system using embedded sensors for the detection, signal processing and machine learning approach to enhance the accuracy of accident detection and emergency notification. The proposed framework exploits data obtained by the accelerometer, gyroscope, and GPS sensors onboard the smartphone to continuously monitor the vehicle dynamics and detect collision events in real-time. The use of signal preprocessing and statistical feature extraction enhances the quality of the sensor data obtained, and the Support Vector Machine (SVM) classification is used to better separate genuine accidents from normal driving conditions, thus minimizing false-positive classifications. Moreover, the provision of user confirmation prior to sending out emergency alerts creates greater reliability in the system, as it avoids sending unnecessary messages. The proposed framework is made possible in a commercially available smartphone, thereby not requiring any special vehicle equipment and also making it both cost effective, portable and scalable to enhance safety on roadways. The results shows the high detection accuracy, good classification performance and rapid emergency communication of the proposed method, and it has potential application practice value in the construction of intelligent transportation systems.

Further study is planned to strengthen and make the proposed accident detecting system more intelligent by incorporating more sensors for smartphones and developing more intelligent deep learning model for the better recognition of accidents. The combination of Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) networks can be used to further improve the classification performance, as they can be trained on complex temporal patterns of sensor data. The framework can also be linked to the emergency response system that is cloud based for the hospitals, ambulance services and traffic management centers in the area, enabling earlier response and rescue. In addition, future iterations of the system might include additional features like driver behavior analysis, road conditions monitoring, and fatigue detection, providing comprehensive support for road safety. Fifth generation (5G) communication networks and Internet of Things (IoT) technologies can also further shorten emergency response time and bolster trust in real-time accident reporting in smart transportation system environments.

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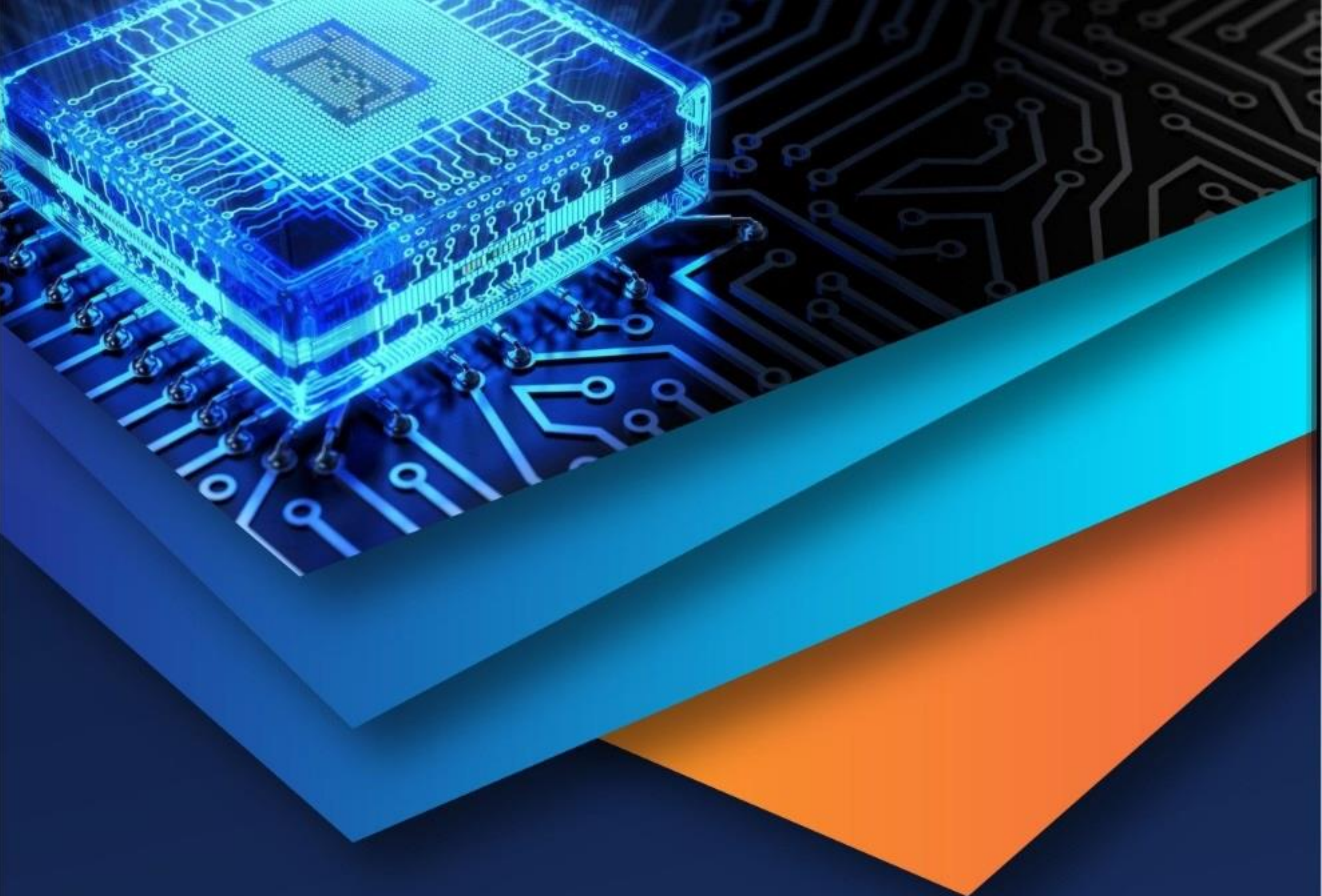

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