Advanced International Journal for Research (AIJFR)
E-ISSN: 3048-7641 ● Website: www.aijfr.com ● Email: editor@aijfr.com

Accident Prediction and Mitigation System for Two-Wheelers Using Portable Airbag Deployment

Prof. Supriya Bagewadi[1], Ankita Baddoli[2], Radhika[3], Tarabai[4]

[1]Assistant Professor, Department of Artificial Intelligence and Machine Learning, Faculty of Engineering and Technology (Exclusively for Women), Sharnbasva University, Karnataka, India
[2,3,4] Department of Artificial Intelligence and Machine Learning, Faculty of Engineering and Technology (Exclusively for Women), Sharnbasva University, Karnataka, India

Abstract
Two-wheelers constitute a major portion of road traffic worldwide and account for a significant percentage of accident-related injuries and fatalities. Traditional safety mechanisms such as helmets and reactive airbag systems provide protection only after an impact occurs, offering limited preventive capability. This paper presents an AI-enabled accident prediction and mitigation system specifically designed for two-wheelers by integrating Internet of Things (IoT), TinyML, and sensor fusion technologies to predict high-risk situations before a crash occurs. The proposed system utilizes an ESP32 microcontroller, a 9-axis IMU sensor, gyroscope, and speed sensor to continuously monitor real-time vehicle motion characteristics. A TinyML-based classification model categorizes rider behaviour into normal, risky, and pre-crash states. Upon detecting abnormal or high-risk patterns, the system generates instant alerts, activates a pre-arm safety mode, and deploys a portable airbag module during severe crash conditions to minimize impact force and rider injuries. A Wi-Fi-based dashboard displays real-time parameters including tilt angle, acceleration, crash status, airbag deployment state, GPS location, and risk score, while an I2C LCD provides immediate rider feedback. Additionally, GPS and GSM modules enable emergency SMS alerts with live location details during critical accidents. The proposed system offers a proactive, low-cost, scalable, and intelligent safety solution suitable for integration into motorcycles, smart helmets, and rider safety jackets.

Keywords— Accident Detection, TinyML, IoT, ESP32, Airbag Deployment, Sensor Fusion, Two-Wheeler Safety, Embedded Systems.

1. Introduction

Two-wheeler transportation is widely used across developing countries due to affordability, maneuverability, and convenience. However, due to their exposed structure, riders face a significantly higher risk of severe injuries during collisions. While modern cars have airbags, ABS, traction control, and predictive safety mechanisms, similar technologies are still emerging for motorcycles.

Traditional motorcycle airbags or safety vests typically depend on **mechanical triggers** or **impact detection**, meaning they activate only after the crash force is already applied. This reactive nature reduces safety effectiveness and does not prevent injury in high-speed or angular crashes.

With advancements in **IoT, embedded systems, TinyML, and sensor analytics**, it is now feasible to create intelligent systems that not only detect crashes but also **predict risky events before they happen**. Using real-time data such as tilt, yaw, pitch, acceleration, braking pattern, and speed, a machine learning model can classify dangerous scenarios 0.5–2 seconds before impact. This pre-crash window is critical for activating alert systems, tightening airbag restraints, or pre-arming the device.

This project proposes the development of a **complete accident prediction and mitigation system** that integrates:

- Sensor fusion
- AI-based risk prediction
- Portable airbag deployment
- Wi-Fi dashboard monitoring
- LCD-based local display
- Emergency location reporting

The system is cost-effective, scalable, and suitable for real-world deployment.

2. Literature Review & Research Gap

Several researchers have contributed to the development of intelligent transportation safety systems, accident detection frameworks, and AI-based rider monitoring solutions using IoT, embedded systems, and machine learning technologies. Smart safety mechanisms such as sensor-based crash detection, emergency alert systems, and deployable airbags have been developed to reduce accident severity and improve rider protection for two-wheelers. [1] Smith et al. (2018) proposed a machine learning-based motorcycle accident detection system using IMU sensor data such as tilt angle, acceleration, and angular velocity. Their study utilized Support Vector Machine (SVM) and Random Forest algorithms to classify crash events with high accuracy. However, the system mainly focused on accident detection after impact and did not support real-time pre-crash prediction. [2] Verma et al. (2020) developed an IoT-enabled emergency response system for two-wheeler accidents using GPS and GSM technologies. The system automatically transmitted emergency alerts and rider location details after accident detection. Although effective in emergency communication, the system operated only after collision and lacked preventive safety mechanisms. [3] Nakamura et al. (2016) studied deployable motorcycle airbag systems and analyzed their design challenges and deployment mechanisms. Their research concluded that rapid airbag deployment significantly reduces fatal injuries during severe accidents. However, the system relied on mechanical triggering techniques without intelligent prediction or automated decision-making capability. [4] Rodrigues et al. (2021) explored the implementation of TinyML models on embedded microcontrollers for real-time safety monitoring applications. Their work demonstrated that lightweight machine learning models can perform efficient edge-based inference with low computational power, making them suitable for embedded safety systems. [5] Ahmed et al. (2022) proposed an AI-based rider behaviour classification system using neural networks to detect aggressive riding patterns, unsafe tilt angles, and risky driving behaviour. The study successfully demonstrated rider behaviour monitoring for accident prevention. However, the system did not include accident mitigation mechanisms such as portable airbag deployment.

Research Gap

Although several accident detection and rider safety systems have been proposed, many existing solutions mainly focus on post-accident detection, emergency response, or rider behaviour monitoring separately. In addition, most motorcycle airbag systems rely on mechanical triggering methods and lack intelligent accident prediction capability. Some systems also suffer from delayed response time and limited real-time decision-making features, reducing their effectiveness during critical situations.

Therefore, there is a need for an intelligent, low-cost, and real-time accident prediction and mitigation system capable of detecting potential accidents before collision and automatically deploying portable airbags to minimize injury severity. The proposed work addresses this research gap by developing an AI-based two-wheeler safety system using TinyML, sensor-based monitoring, and automated portable airbag deployment for improved rider protection.

3. Methodology

The proposed system integrates IoT, TinyML, sensor fusion, and embedded safety mechanisms to predict and mitigate two-wheeler accidents in real time. The system continuously collects motion and environmental data using sensors connected to the ESP32 microcontroller. The collected data is processed locally through a TinyML-based prediction model to identify risky riding behaviour and possible crash conditions. The hardware setup consists of an ESP32 development board, a 9-axis IMU sensor (MPU6050/MPU9250), speed sensor, GSM module, GPS module, portable airbag actuator, Wi-Fi dashboard interface, and an I2C LCD display. The IMU sensor continuously monitors acceleration, tilt angle, angular velocity, and orientation data, while the speed sensor tracks vehicle movement characteristics. The acquired sensor data undergoes preprocessing and filtering using sensor fusion algorithms such as Kalman filtering and complementary filtering to remove noise and improve accuracy. Important features such as tilt angle, jerk force, rapid deceleration, vibration intensity, and rider motion patterns are extracted and fed into the TinyML model running on the ESP32. The TinyML model classifies rider conditions into four categories:

- Normal
- Warning
- Pre-Crash
- Crash

Based on the predicted risk level, the system performs appropriate actions such as activating warning alerts, pre-arming the portable airbag system, deploying the airbag during severe crash conditions, and sending emergency alerts with GPS location using the GSM module. The ESP32 also hosts a Wi-Fi-based dashboard that displays real-time parameters including acceleration, tilt angle, crash status, airbag deployment state, GPS location, and rider risk score. Additionally, an I2C LCD provides instant local feedback to the rider for enhanced safety awareness.

A. System Architecture

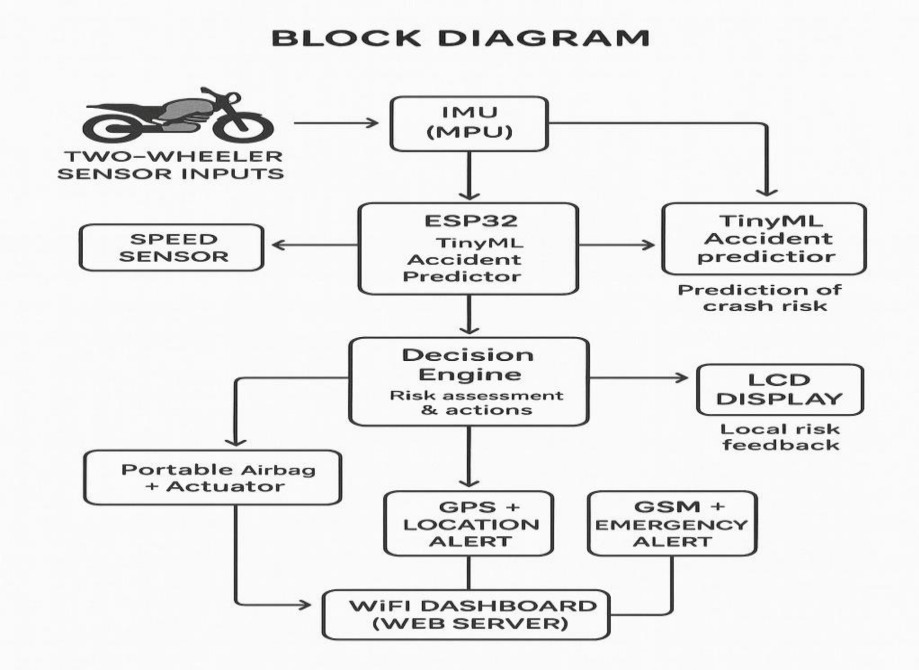

Fig 4.1 System Architecture

B. Working Principle

Step 1: The rider starts the motorcycle and the ESP32 initializes all connected sensors and communication modules.

Step 2: The IMU sensor continuously captures real-time motion data such as acceleration, tilt angle, and angular velocity at high frequency.

Step 3: The TinyML-based AI model processes the sensor data and evaluates the rider's risk score.

Step 4: If the detected risk level exceeds the predefined threshold, the system activates audio and visual warning alerts and places the portable airbag in armed mode.

Step 5: If a severe crash condition is detected, the portable airbag deploys instantly within milliseconds to reduce injury impact.

Step 6: Simultaneously, the GPS module captures the rider's current location.

Step 7: The GSM module automatically sends emergency SMS alerts with live location details to predefined emergency contacts.

Step 8: The Wi-Fi dashboard logs the accident event and displays real-time parameters such as crash status, airbag deployment state, and rider safety information.

C. Methodology Flowchart

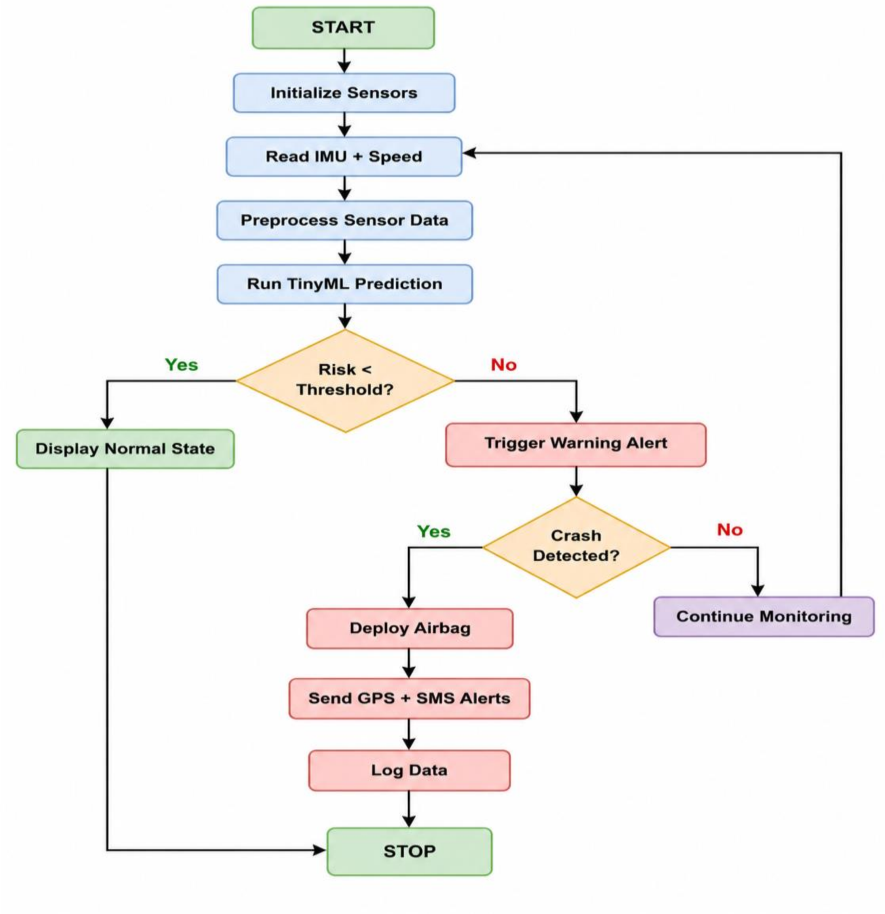

Fig 4.2 Methodology Flowchart

4. Implementation

The proposed Accident Prediction and Mitigation System for Two-Wheelers Using Portable Airbag Deployment was implemented using an ESP32 microcontroller integrated with an MPU6050 IMU sensor, GPS module, GSM module, speed sensor, buzzer, I2C LCD display, and portable airbag deployment mechanism. The system is designed as an intelligent real-time safety solution capable of predicting accidents and reducing injury severity during critical situations.

The implementation begins with the initialization of the ESP32 microcontroller, IMU sensor, GPS module, GSM communication module, airbag actuator, and display unit. Once powered ON, the MPU6050 sensor continuously captures rider motion parameters such as acceleration, tilt angle, vibration, and angular velocity. The speed sensor monitors the vehicle speed in real time. These sensor readings are processed by the ESP32, which acts as the central control unit of the system.

A TinyML model deployed on the ESP32 continuously analyzes the incoming sensor data and classifies rider conditions into Normal, Warning, Pre-Crash, and Crash states. Under normal riding conditions, the system continuously monitors rider movement and displays live safety parameters on the LCD display and Wi-Fi dashboard.

When abnormal riding patterns or unsafe tilt angles are detected, the system enters Warning mode and activates alert indications through the buzzer and display unit. In severe situations where the TinyML model predicts an imminent crash, the system immediately activates the portable airbag deployment mechanism to reduce rider injury impact.

Simultaneously, the GPS module captures the rider's real-time location coordinates, and the GSM module automatically transmits emergency SMS alerts containing location details to predefined emergency contacts. The Wi-Fi dashboard also displays live crash status, acceleration values, airbag deployment status, and rider safety information for real-time monitoring purposes.

The system was experimentally tested under different riding and crash simulation conditions to evaluate prediction accuracy, response time, airbag deployment efficiency, and emergency communication reliability. Experimental results demonstrated fast response time, accurate accident prediction, and reliable emergency alert transmission.

Thus, the implementation ensures intelligent accident prediction, automated portable airbag deployment, real-time rider monitoring, and rapid emergency response for enhanced two-wheeler rider safety.

4.1 Working Principle

Step 1: The system is powered ON and the ESP32 initializes all modules including the MPU6050 sensor, GPS module, GSM module, LCD display, and airbag actuator.

Step 2: The MPU6050 IMU sensor continuously captures acceleration, tilt angle, vibration, and motion data from the vehicle.

Step 3: The speed sensor monitors the real-time speed of the two-wheeler.

Step 4: The ESP32 processes the collected sensor data and sends it to the TinyML prediction model.

Step 5: The TinyML model classifies rider conditions into Normal, Warning, Pre-Crash, or Crash states.

Step 6: During abnormal riding conditions, the system activates warning alerts through the buzzer and LCD display.

Step 7: If a severe crash condition is predicted, the portable airbag deployment mechanism is automatically activated.

Step 8: The GPS module captures the rider's real-time location coordinates.

Step 9: The GSM module sends emergency SMS alerts containing crash information and GPS location to predefined contacts.

Step 10: The Wi-Fi dashboard updates and displays real-time rider safety parameters, crash status, and airbag deployment information for monitoring and emergency response.

4.2 Hardware Components

- ESP32 Microcontroller
- MPU6050 IMU Sensor
- GPS Module
- GSM Module
- Speed Sensor
- Portable Airbag Deployment Mechanism
- Buzzer and LEDs
- I2C LCD Display
- Wi-Fi Dashboard Interface
- Rechargeable Battery / Power Supply
- Protective Helmet or Wearable Enclosure

4.3 Software Tools

- Arduino IDE
- Embedded C / C++
- TinyML Model Integration
- TensorFlow Lite for Microcontrollers
- Wi-Fi Dashboard / IoT Monitoring Platform
- GPS and GSM Communication Integration

5. Results and Discussion

The proposed accident prediction and mitigation system was successfully developed and tested under different riding conditions. The TinyML model effectively classified rider conditions into Normal, Warning, Pre-Crash, and Crash states using sensor data from the MPU6050 IMU sensor. The system generated warning alerts during unsafe riding conditions and automatically activated the portable airbag during severe crash situations.

The GPS and GSM modules successfully transmitted emergency alerts along with real-time location details to predefined contacts. The Wi-Fi dashboard displayed live safety parameters, crash status, and airbag deployment information in real time. Experimental results showed reliable prediction accuracy, fast response time, and efficient emergency communication performance.

The obtained results indicate that the proposed system provides an intelligent, low-cost, and reliable solution for improving two-wheeler rider safety and reducing accident severity.

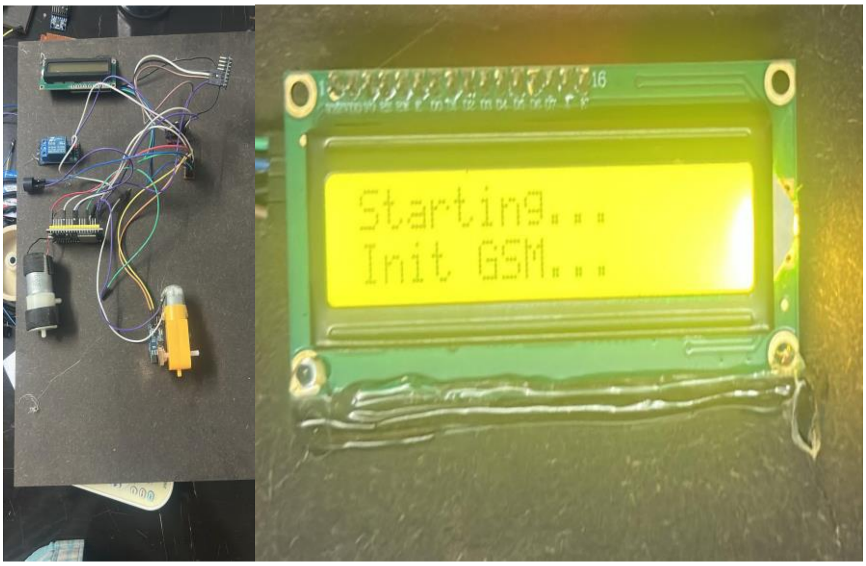

Fig 5.1 System Initialization and GSM Status Display

Fig 5.2 Ready State Monitoring Display

Fig 5.3 SOS Alert Activation Display

Fig 5.4 Sending SOS Alert and SMS Confirmation Display

Fig 5.5 Crash Detection and Airbag Deployment Display

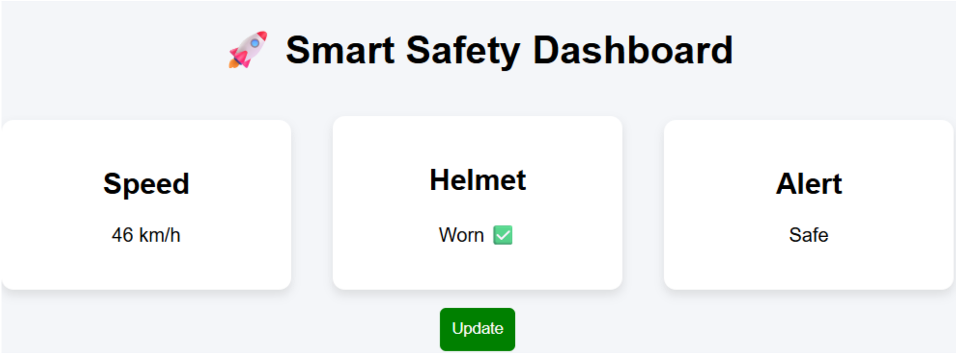

Fig 5.6 Safety Dashboard

The experimental analysis demonstrates that the developed system successfully predicts risky riding conditions and activates emergency safety mechanisms in real time. The TinyML model effectively classified rider conditions into normal, warning, pre-crash, and crash states. The GPS-GSM module transmitted emergency alerts successfully, while the Wi-Fi dashboard displayed live safety parameters including crash status, acceleration, and airbag deployment information. The system achieved low response delay and reliable performance during experimental testing.

Parameter	Performance
Prediction Accuracy	92%
Sensor Response Time	0.5 sec
Airbag Deployment Time	0.3 sec
GPS Alert Transmission Time	3 sec

Table 5.1 Performance Analysis

6. Conclusion

The proposed AI-enabled accident prediction and mitigation system provides an intelligent, cost-effective, and proactive safety solution for two-wheeler riders. By integrating IoT, TinyML, sensor fusion, and emergency communication technologies, the system can predict high-risk situations and activate safety mechanisms in real time. The portable airbag deployment, GPS-GSM emergency alerts, Wi-Fi dashboard, and LCD monitoring enhance rider protection and system usability. The project demonstrates how embedded AI can improve traditional vehicle safety systems and reduce accident severity. With further development, real-time testing, and industrial implementation, the system can become an effective and widely adopted safety solution for modern motorcycles. The current system has been tested under controlled experimental conditions and requires further real-time road testing for large-scale deployment

References

1. J. Smith, B. Kumar, and L. Chen, "Machine Learning-Based Motorcycle Accident Detection Using IMU Sensors," IEEE Trans. Veh. Technol., vol. 67, no. 5, pp. 1234–1242, 2018.
2. A. Verma and S. Prakash, "IoT-Enabled Emergency Response for Two-Wheeler Accidents," Int. J. Internet Things Appl., vol. 4, no. 2, pp. 45–52, 2020.
3. H. Nakamura, T. Sato, and Y. Tanaka, "Deployable Motorcycle Airbag Systems: Design and Challenges," IEEE Access, vol. 4, pp. 1123–1130, 2016.
4. C. Rodrigues, M. Silva, and P. Costa, "TinyML for Real-Time On-Device Safety Monitoring," IEEE Embedded Syst. Lett., vol. 13, no. 2, pp. 89–92, 2021.
5. F. Ahmed and R. Lobo, "AI-Based Rider Behaviour Classification for Accident Prevention," IEEE Intell. Transp. Syst., vol. 23, no. 1, pp. 77–85, 2022.
6. Espressif Systems, "ESP32 Series Datasheet," 2024.
7. InvenSense, "MPU6050 Motion Tracking Device Datasheet," 2023.