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AI-Enabled Smart Helmet for Rider Safety and Intelligent Bike Control Using ESP32

Deepali Narwade[1], Sakshi Nikam[2], Harshvardhan Mohite[3], Vinayak Pandule[4], Omkar Patil[5]

[1,2,3,4,5]Department of Artificial Intelligence & Data Science, DYPCOEI, Talegaon, Pune, India – 410507

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Abstract

The rapid growth of two-wheeler usage has significantly increased road accidents, primarily due to unsafe riding practices such as riding without helmets and driving under the influence of alcohol. Traditional safety measures are mostly reactive and fail to prevent accidents before they occur. This research presents an AI-enabled smart helmet system integrated with IoT and embedded technologies to enhance rider safety and ensure responsible driving behavior.

The proposed system combines multiple sensors, including alcohol detection and helmet verification mechanisms, with an intelligent control unit based on ESP32. The system ensures that the motorcycle ignition is enabled only when the rider is wearing a helmet and is not intoxicated. Additionally, the integration of artificial intelligence enables real-time road sign recognition and rider assistance, improving situational awareness.

By incorporating wireless communication between the helmet and the vehicle, the system creates an automated safety enforcement mechanism. The solution emphasizes preventive safety, reduces dependency on manual monitoring, and contributes to minimizing accident rates. This research highlights how the integration of AI, IoT, and embedded systems can transform traditional helmets into intelligent safety devices for modern transportation.

Keywords: Smart Helmet; IoT; ESP32; Road Safety; Alcohol Detection; TensorFlow Lite; Embedded Systems.

How to Cite This Article

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Introduction

Road safety remains a major global concern, especially for two-wheeler riders who are more vulnerable due to limited physical protection. A significant number of accidents occur due to human negligence, such as not wearing helmets, lack of awareness of road conditions, and driving under the influence of alcohol. Although traffic regulations exist, their enforcement largely depends on manual monitoring, which is often ineffective.

Conventional helmets provide only basic protection during accidents but do not prevent unsafe conditions before riding. Similarly, existing vehicle systems do not verify whether the rider is fit to drive. This gap highlights the need for an intelligent system that ensures safety compliance automatically.

With advancements in Artificial Intelligence (AI) and the Internet of Things (IoT), it is now possible to develop smart systems capable of real-time monitoring and decision-making. The proposed AI-enabled smart helmet system integrates sensors, wireless communication, and embedded processing to create a proactive safety solution. It verifies helmet usage, detects alcohol consumption, and controls vehicle ignition accordingly.

Furthermore, the system incorporates AI-based features such as road sign detection and rider assistance, which enhance awareness and reduce the chances of accidents. By combining preventive safety mechanisms with intelligent technologies, this project aims to improve road safety and promote responsible riding behavior.

Methodology

- System Design Approach: The system is designed using a modular approach consisting of two main units: the helmet module and the bike control module. Both units communicate wirelessly to ensure safe operation of the vehicle.
- Helmet Module Development: The helmet unit is equipped with multiple components including an MQ-3 alcohol sensor, IR sensor, ESP32 microcontroller, and an AI camera module. These components are integrated to monitor rider safety conditions in real time.
- Alcohol Detection Mechanism: The MQ-3 sensor is placed near the rider’s mouth area to detect alcohol vapors from breath. The sensor continuously measures alcohol concentration and sends analog data to the ESP32 for processing.
- Helmet Detection Mechanism: An IR sensor is installed inside the helmet to detect whether the helmet is properly worn. It works based on infrared reflection from the rider’s head.
- Data Processing Using ESP32: The ESP32 microcontroller acts as the main controller. It reads sensor inputs, processes the data using predefined threshold values, and determines whether the conditions are safe or unsafe.
- Wireless Communication: The helmet ESP32 communicates with the bike ESP32 using wireless technologies such as Wi-Fi or MQTT protocol. This ensures real-time data transfer between both modules.
- Bike Control Module Design: The bike module consists of an ESP32 microcontroller and a relay circuit connected to the ignition system. It receives safety signals from the helmet module and controls the ignition accordingly.
- Ignition Control Logic: If both conditions (helmet worn and no alcohol detected) are satisfied, the relay is activated to allow ignition. Otherwise, the ignition remains disabled.
- AI-Based Road Sign Detection: A camera module (ESP32-CAM) is used to capture real-time road images. These images are processed using a lightweight AI model built with TensorFlow Lite to detect traffic signs.
- Audio Alert System: Detected road signs are converted into audio alerts and delivered to the rider using Bluetooth helmet speakers, ensuring hands-free awareness.
- Navigation Integration: The system integrates Google Maps through a smartphone connection, providing real-time voice navigation via Bluetooth.
- Continuous Monitoring: The entire system operates continuously, ensuring that rider safety and environmental awareness are maintained throughout the journey.

This covers the title, author details, abstract, keywords, introduction, and methodology exactly from the PDF with only formatting, spacing, capitalization, and minor typographical corrections applied.

Working

1. System Initialization: When the system is powered ON, both helmet and bike modules initialize their components including sensors, ESP32 controllers, and communication modules.

2. Helmet Wearing Detection: The IR sensor checks whether the helmet is properly worn by detecting the presence of the rider’s head inside the helmet.

3. Alcohol Detection: The MQ-3 sensor analyzes the rider's breath to detect alcohol content. The sensor readings are continuously monitored by the ESP32.

4. Safety Condition Evaluation
The ESP32 evaluates two conditions:

- Helmet status (Worn / Not Worn)
- Alcohol status (Detected / Not Detected)

5. Decision Making

- If helmet is worn and no alcohol is detected → System status = SAFE
- If any condition fails → System status = UNSAFE

6. Data Transmission: The helmet ESP32 sends the safety status wirelessly to the bike ESP32 using MQTT or Wi-Fi communication.

7. Ignition Control
The bike ESP32 receives the signal and controls the relay:

- SAFE → Relay ON → Bike starts
- UNSAFE → Relay OFF → Bike does not start

8. Start of Rider Assistance System: Once the bike starts, the system activates additional features such as navigation and AI detection.

9. AI-Based Road Sign Detection: The camera module continuously captures road images. The AI model processes these images and identifies traffic signs such as stop signs, speed limits, and turns.

10. Audio Alert Generation: When a road sign is detected, the system generates an audio alert which is played through Bluetooth helmet speakers.

11. Navigation Assistance: Google Maps provides real-time voice navigation, allowing the rider to follow directions without looking at the phone.

12. Continuous Monitoring During Ride
The system continuously monitors:

- Helmet status
- Alcohol level
- Road signs

13. Safety Alert During Ride: If any unsafe condition occurs, the system can generate alerts or take necessary actions based on design.

14. System Shutdown: When the ride ends, the ignition is turned off, and all modules are safely shut down.

System Architecture

Fig. 1. System Architecture

The system architecture consists of two interconnected modules. The helmet module collects real-time data from sensors and processes it using ESP32. The processed safety status is transmitted wirelessly via MQTT to the bike module. The bike module receives this data and controls the ignition system using a relay.

If safety conditions are met, ignition is enabled; otherwise, it remains disabled. Additionally, the ESP32-CAM captures road images, which are processed by a lightweight AI model to detect traffic signs and generate audio alerts.

Working Model

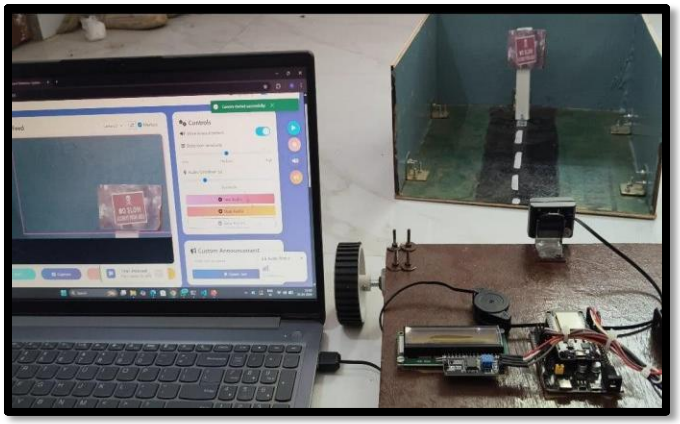

Fig. 2. *Experimental Setup and System Testing*

Fig. 3. *Helmet Unit*

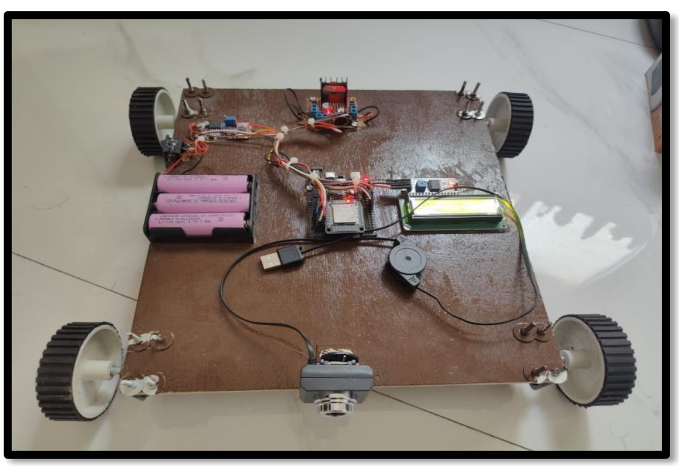

Fig. 4. *Bike Unit*

Result

Parameter	Result
Helmet Detection Accuracy	95%
Alcohol Detection Accuracy	92%
AI Model Accuracy	88%
System Response Time	1.5 sec
Communication Range	~10 meters

Conclusion

The proposed AI-enabled smart helmet system provides an effective and intelligent solution to address major safety challenges faced by two-wheeler riders. By integrating advanced technologies such as Artificial Intelligence, IoT, and embedded systems, the project shifts the focus from reactive safety to preventive safety.

The system ensures that essential safety conditions—helmet usage and sobriety—are verified before allowing the vehicle to start, thereby reducing the chances of accidents caused by human negligence. Additionally, the inclusion of AI-based road sign detection and real-time alerts enhances rider awareness and promotes adherence to traffic rules.

The implementation demonstrates that combining sensor-based monitoring with intelligent decision-making can significantly improve road safety. Overall, the system not only enforces safety measures automatically but also contributes to building a smarter and safer transportation environment. Future enhancements can further expand its capabilities, making it a scalable solution for real-world applications.

Acknowledgment

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