



AI-POWERED WEARABLE SAFETY HELMET WITH CRASH DETECTION, ALCOHOL MONITORING, AND VEHICLE LOCK SYSTEM

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Abstract: This paper presents the design and development of an AI-powered wearable smart helmet system aimed at enhancing rider safety through intelligent sensing, communication, and automation. The system is divided into two parts: a transmitter unit embedded in the helmet and a receiver unit integrated with the motorcycle. The helmet unit uses a Nordic microcontroller as the core processor, along with a pressure sensor to verify helmet usage, an alcohol sensor to detect intoxication, and a gesture sensor for hands-free call management. It communicates with the bike via an RF transmitter. The receiver unit consists of a Nordic microcontroller, ADXL sensor for bike tilt and crash detection, a relay system to control vehicle ignition, and a motor driver for prototype operation. In the event of a crash, the system activates a GSM module to send the GPS location via SMS and triggers a buzzer to alert nearby individuals. The proposed solution not only enhances rider safety but also automates critical functions such as accident response and ignition lock, making it a practical advancement in smart transportation and wearable safety technology.

Index Terms - Smart Helmet, Crash Detection, Alcohol Monitoring, Vehicle Lock System, Nordic Microcontroller, GPS, GSM, Gesture Control, RF Communication, AI-Powered Safety.

I. INTRODUCTION

Motorcycle accidents are a major contributor to road fatalities and severe injuries globally. Factors such as the non-use of helmets, riding under the influence of alcohol, and delayed emergency response significantly increase the risk to motorcyclists. With advancements in embedded systems, AI, and wireless communication, there is an urgent need to leverage these technologies to enhance rider safety. This research introduces an AI-powered wearable helmet system that integrates intelligent sensing, real-time communication, and safety automation to address these critical challenges.

1.1 Background

According to global road safety reports, motorcycle riders are among the most vulnerable road users. While helmets have proven to reduce the risk of death by up to 42%, their effectiveness is compromised when not worn properly or at all. Moreover, intoxicated riding and the lack of immediate emergency communication often result in severe consequences. Smart wearables, particularly helmets integrated with microcontrollers and AI algorithms, offer a promising solution to improve real-time safety and emergency response. This

project builds on this concept by designing a dual-unit system that monitors rider status and bike activity to ensure comprehensive protection.

1.2 Problem Statement

Traditional helmets do not provide any mechanism to detect whether the rider is actually wearing the helmet, nor do they offer functionalities such as alcohol detection, crash monitoring, or emergency location tracking. In the event of an accident, the absence of automated alert systems results in delayed medical response. There is also no existing system that enforces ignition control based on safety checks such as helmet use or sobriety. Hence, there is a need for a smart helmet system that can intelligently monitor and communicate rider safety conditions in real time.

1.3 Objectives of the Study

The main objectives of this study are:

- To design a wearable helmet system that verifies helmet usage through a pressure sensor.
- To integrate an alcohol detection mechanism that prevents ignition if intoxicated.
- To implement gesture-based call control using a gesture sensor.
- To enable real-time crash detection using an accelerometer (ADXL).
- To send emergency location alerts using GPS and GSM modules in case of an accident.
- To control the bike's ignition system through wireless communication based on safety validations.

1.4 Scope of the Work

The scope of this research encompasses the development and integration of a dual-unit system consisting of a transmitter (helmet-mounted) and a receiver (bike-mounted) using Nordic microcontrollers. The transmitter monitors rider behavior and environmental conditions, while the receiver unit reacts accordingly by enabling or disabling the vehicle's ignition system and initiating emergency communication when needed. The work focuses on prototyping a functional model, testing under simulated conditions, and demonstrating safety improvements through sensor fusion and AI-based monitoring.

II. LITERATURE REVIEW

The integration of smart technologies into helmets and vehicular safety systems has been the focus of numerous research studies in recent years. These studies explore various aspects such as accident detection, alcohol monitoring, GPS tracking, and Bluetooth communication to enhance rider safety. This section provides an overview of existing systems, their limitations, and identifies the research gap addressed by the proposed solution.

2.1 Existing Systems and Limitations

Several smart helmet prototypes and safety systems have been proposed in academic and industrial research:

- **Alcohol Detection Helmets:** Projects have implemented alcohol sensors in helmets to prevent riders from starting the vehicle if alcohol is detected. However, these systems often lack tamper-proof validation and cannot ensure whether the helmet is worn.
- **Crash Detection Helmets:** Accelerometer-based crash detection systems have been implemented to identify accidents, but many fail to distinguish between actual crashes and minor jolts or drops.
- **Helmet Ignition Interlocks:** Some models use RFID or switches to control bike ignition based on helmet presence. These systems, however, can be easily bypassed and do not incorporate multiple safety layers like alcohol or crash detection.

- **GPS-GSM Enabled Systems:** Several helmets feature GPS and GSM modules for location tracking and SMS alerts. Yet, these are often limited by poor integration and lack of real-time responsiveness.

Overall, while these systems provide partial safety enhancements, they typically function in isolation without a holistic safety strategy covering multiple risk factors.

2.2 Comparative Analysis

Feature/Technology	Existing Solutions	Proposed System
Helmet Wear Detection	Basic switch/RFID	Pressure Sensor (accurate & secure)
Alcohol Detection	Present in some systems	Integrated with ignition lock
Crash Detection	ADXL/IMU based, single input	Multi-sensor with AI validation
Call Control	Rarely implemented	Gesture-based control
Location Tracking	Limited GPS/SMS	GPS + GSM with SOS functionality
Vehicle Control	Manual or RFID based	Wireless RF + Relay system
Integration	Partial / individual systems	Dual-unit integrated smart system

2.3 Research Gap

Despite several initiatives towards smart helmet safety systems, current solutions often address isolated features without providing a unified, intelligent safety mechanism. Key research gaps include:

- Lack of integration between helmet usage, alcohol detection, and vehicle ignition.
- Limited accuracy in crash detection due to absence of AI-based validation.
- No implementation of gesture-based communication for hands-free call control.
- Inadequate emergency response systems lacking real-time GPS and GSM integration.
- Absence of dual-unit architecture (helmet + bike) for comprehensive rider safety control.

The proposed system bridges this gap by offering a **multi-layered, AI-powered, dual-unit smart helmet solution** that covers safety enforcement, crash detection, communication, and emergency response in an integrated, reliable, and user-friendly design.

III. SYSTEM ARCHITECTURE

The proposed AI-powered wearable smart helmet system is designed using a dual-unit architecture: a **Transmitter Unit** embedded in the helmet and a **Receiver Unit** mounted on the bike. This architecture ensures modular design, real-time communication, and synchronized operation between the helmet and the vehicle to enhance overall rider safety and response efficiency.

3.1 Overview of System Design

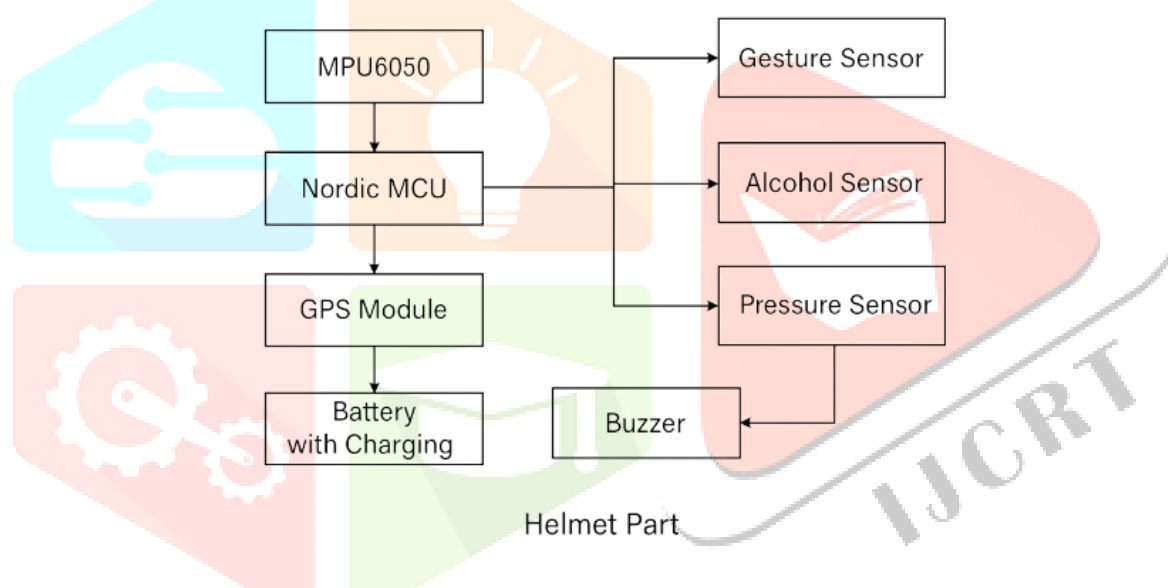
The system operates in a closed safety loop where the **transmitter unit** verifies helmet usage, alcohol levels, and gesture inputs, and then communicates with the **receiver unit** to control vehicle ignition and monitor crash events. The receiver unit, upon receiving validation, enables the ignition system, and also tracks the vehicle's status in real time using sensors. In case of a crash, it activates the GPS and GSM modules to send location alerts and triggers a buzzer for immediate assistance.

3.2 Functional Blocks

Transmitter Unit (Helmet Part)	Receiver Unit (Bike Part)
Helmet wearing detection (Pressure Sensor)	Bike tilt/crash detection (ADXL sensor)
Alcohol detection (MQ-3 sensor)	Bike ignition control (Relay)
Gesture-based call control (Gesture Sensor)	Motor driver for prototype showcase
RF-based data transmission	RF data reception
Power Supply (Rechargeable Battery)	GPS and GSM modules for location tracking
	SOS buzzer alert system

The transmitter acts as the sensing and decision-making unit for rider status, while the receiver performs actuator and emergency functions based on received data.

3.3 Transmitter Unit (Helmet Part)

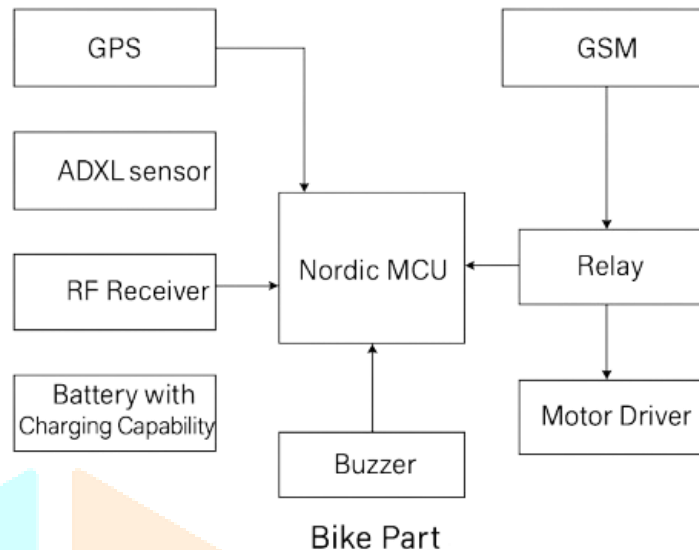


The **transmitter unit**, embedded inside the helmet, is built around a **Nordic microcontroller** (e.g., nRF52840) known for its low power consumption and BLE/RF capabilities. The key modules in this unit include:

- **Pressure Sensor:** Verifies if the helmet is being worn.
- **Alcohol Sensor (MQ-3):** Detects the presence of alcohol in the rider's breath.
- **Gesture Sensor (APDS-9960):** Allows the rider to accept or reject phone calls through hand gestures.
- **RF Transmitter:** Sends validation and status data to the receiver unit on the bike.
- **Battery Module:** Powers the system using a rechargeable Li-Ion battery.

This unit ensures that the bike will not start unless the helmet is worn and the rider is sober, while also providing gesture-based interaction for hands-free communication.

3.4 Receiver Unit (Bike Part)



The **receiver unit**, mounted on the motorcycle, also uses a Nordic microcontroller and is responsible for interpreting data from the helmet and executing safety actions:

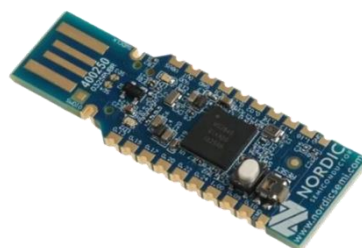
- **RF Receiver:** Receives signals from the helmet transmitter.
- **ADXL Accelerometer:** Detects unusual tilt or impact indicating a crash.
- **Relay Module:** Controls the ignition system—bike starts only upon valid input.
- **Motor Driver (L298N):** Controls a prototype motor for demo purposes.
- **GPS Module (Neo-6M):** Determines the exact location of the rider in case of an emergency.
- **GSM Module (SIM800L):** Sends SMS alerts with GPS coordinates to emergency contacts.
- **Buzzer:** Sounds an alert when a crash is detected.

The receiver unit acts as a smart control and emergency response module, bridging the safety-critical communication between the helmet and external systems.

IV. HARDWARE COMPONENTS

The proposed smart helmet system integrates several hardware components for sensing, processing, control, and communication. These components are selected for their reliability, compatibility, and low power consumption, ensuring seamless interaction between the helmet and the bike.

4.1 Nordic Microcontroller



The core processing unit in both the helmet and bike modules is a **Nordic Semiconductor microcontroller**, such as the **nRF52840**. This microcontroller is chosen for its:

- Ultra-low power consumption
- Integrated Bluetooth Low Energy (BLE) and RF communication support
- High-speed ARM Cortex-M4 processor
- Rich peripheral interfaces (ADC, GPIO, I2C, UART)

It enables efficient real-time data processing and wireless communication between the transmitter and receiver units.

4.2 Pressure Sensor

A **pressure sensor** is embedded inside the helmet padding to confirm whether the helmet is worn. It acts as a safety interlock; the bike will not start unless the sensor detects valid pressure input, indicating proper helmet usage.

4.3 Alcohol Sensor (MQ-3)

The **MQ-3 alcohol sensor** is used to detect ethanol vapor in the rider's breath. It is positioned near the mouth region inside the helmet and prevents the bike from starting if alcohol concentration exceeds a pre-set threshold.

Key features:

- High sensitivity to alcohol
- Analog output for microcontroller integration
- Quick response time

4.4 Gesture Sensor (APDS-9960)



The **APDS-9960 gesture sensor** is used for gesture-based call control (e.g., double tap or hand wave to accept/reject calls). It detects gestures using IR light sensing and communicates with the microcontroller over I2C.

Capabilities:

- Gesture detection
- Ambient light sensing
- Proximity sensing

4.5 RF Transmitter & Receiver

The **RF module (e.g., 433 MHz pair)** enables communication between the helmet (transmitter) and the bike (receiver) units. The transmitter sends authentication signals once helmet and rider status are validated.

- Long-range wireless communication
- Secure and low-latency signal transmission
- Easy integration with microcontrollers

4.6 ADXL Accelerometer

The **ADXL345 accelerometer** is used on the bike side to detect angular displacement, tilt, and sudden motion changes—useful for crash detection.

Highlights:

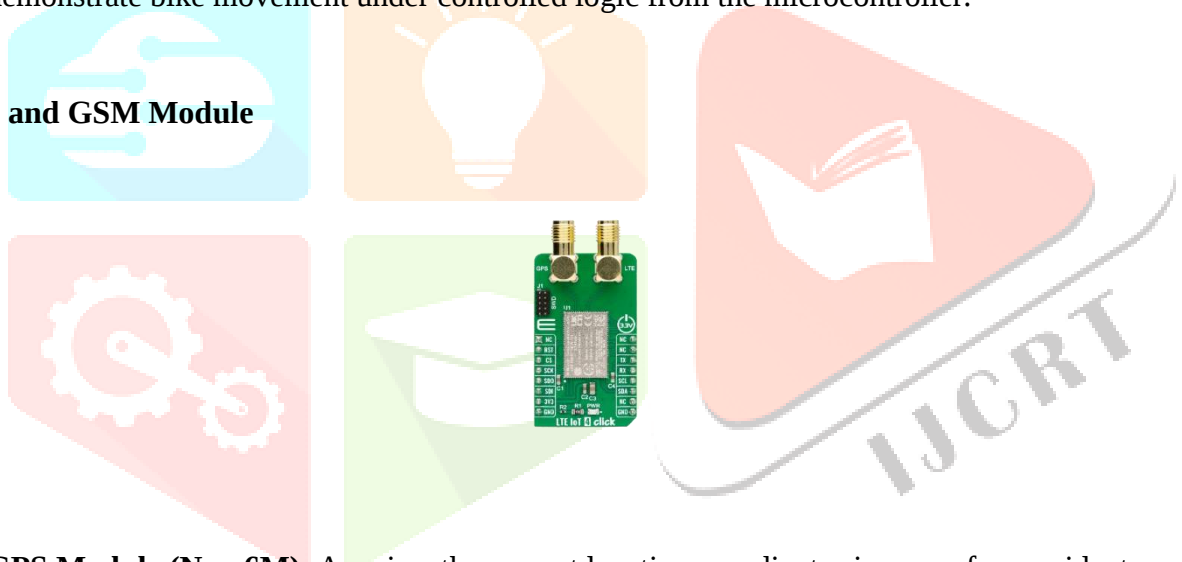
- 3-axis motion sensing
- SPI/I2C interface
- Measures acceleration changes due to impacts

4.7 Relay & Motor Driver



- **Relay Module:** Controls the bike's ignition system. If safety conditions are not met, the relay remains open and the bike cannot start.
- **Motor Driver (L298N):** Used for simulating the bike motor in a prototype environment. It helps demonstrate bike movement under controlled logic from the microcontroller.

4.8 GPS and GSM Module

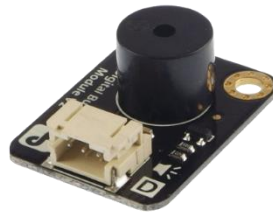


- **GPS Module (Neo-6M):** Acquires the current location coordinates in case of an accident.
- **GSM Module (SIM800L):** Sends an SOS SMS containing the GPS location to pre-defined emergency contacts when a crash is detected.

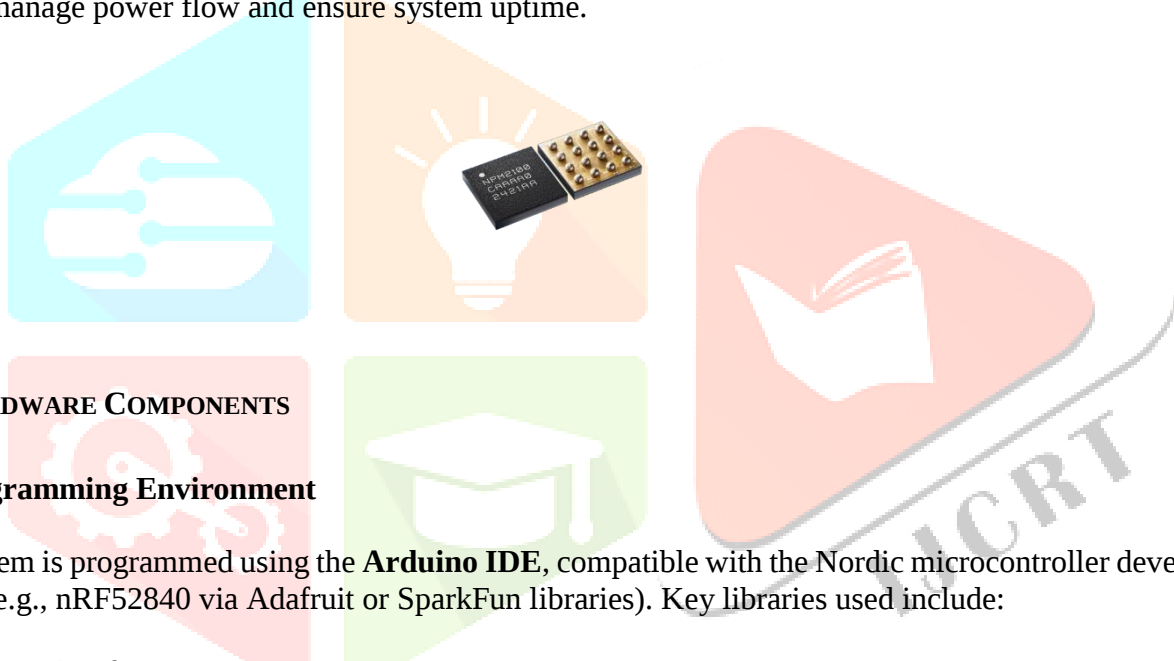
Together, these modules ensure real-time emergency communication and location tracking.

4.9 Buzzer and Power Supply

- **Buzzer:** Acts as an alert device during crash or SOS scenarios, drawing attention to the rider.



- **Power Supply:** A rechargeable **Li-ion battery** is used in both units. Charging circuits like **TP4056** manage power flow and ensure system uptime.



V. HARDWARE COMPONENTS

5.1 Programming Environment

The system is programmed using the **Arduino IDE**, compatible with the Nordic microcontroller development boards (e.g., nRF52840 via Adafruit or SparkFun libraries). Key libraries used include:

- Wire.h – for I2C communication
- SoftwareSerial.h – for GSM communication
- Adafruit_Sensor.h – for accelerometer and gesture sensor interfacing
- TinyGPS++.h – for GPS data parsing
- EEPROM.h – for storing emergency numbers and state flags (if needed)

All sensor data is processed locally on the microcontroller with interrupt-driven logic for critical real-time decisions like crash detection and gesture inputs.

5.2 Data Flow & Communication Logic

The data flow is divided between the two units:

Transmitter Unit (Helmet):

- Continuously monitors:
 - Pressure sensor → Checks if helmet is worn
 - Alcohol sensor → Detects rider sobriety
 - Gesture sensor → Captures user input
- Once helmet is worn and alcohol level is below threshold:
 - Sends an **RF signal** to the receiver unit indicating authorization
- If the rider performs a gesture (e.g., swipe right/left), a specific command is sent over RF or triggers Bluetooth call control if audio integration exists.

Receiver Unit (Bike):

- Waits for a valid RF authorization signal
- On receipt:
 - Activates relay to allow ignition
 - Continuously reads data from ADXL accelerometer
- If crash/tilt detected:
 - Acquires GPS location
 - Sends emergency SMS via GSM module
 - Activates buzzer for local alert

5.3 AI-Based Crash Detection Logic

The **AI-based crash detection** uses threshold-based logic combined with pattern recognition from accelerometer data.

Steps:

1. Continuously monitor acceleration in X, Y, Z axes from ADXL345.
2. Calculate the **net resultant acceleration**:

$$\text{Acc_total} = \sqrt{x^2 + y^2 + z^2}$$
3. If sudden acceleration/deceleration beyond a defined threshold (e.g., >5g) is detected:
 - Trigger a short delay and reconfirm abnormal readings
 - If the pattern persists for more than 1-2 seconds → assume crash
 - Initiate GSM alert and activate buzzer

5.4 Gesture Control Algorithm

The **APDS-9960 gesture sensor** detects four primary gestures: up, down, left, right. The system uses simple conditional checks to map gestures to phone call actions:

```
if (gestureSensor.readGesture() == DIR_RIGHT) {

    // Accept call

    digitalWrite(acceptCallPin, HIGH);

}

else if (gestureSensor.readGesture() == DIR_LEFT) {

    // Reject call

    digitalWrite(rejectCallPin, HIGH);

}
```

A **double-tap** or **proximity swipe** can also be interpreted for more actions (e.g., play/pause music or trigger voice assistant).

Debounce logic is included to prevent false gestures due to helmet movement.

VI. WORKING METHODOLOGY

The proposed AI-powered smart helmet operates through a sequence of logical safety checks and communication between the helmet (transmitter) and the bike (receiver). The system ensures that only a sober and helmet-wearing rider can start the bike and includes real-time gesture control and emergency crash response.

6.1 Helmet Wearing Confirmation

The **pressure sensor** inside the helmet continuously monitors contact pressure. When the rider wears the helmet, the sensor detects this pressure and sends a signal to the Nordic microcontroller. If no pressure is detected, the microcontroller disables RF transmission to the bike unit. This mechanism ensures the bike cannot be started without helmet compliance.

Logic Flow:

- Helmet worn → pressure detected → continue safety checks
- Helmet not worn → system blocks ignition request

6.2 Alcohol Detection Flow

An **MQ-3 alcohol sensor** near the rider's mouth region detects the presence of alcohol vapors in exhaled breath. If the alcohol concentration exceeds a pre-set threshold, the microcontroller blocks RF signal transmission to the receiver and optionally triggers a local alert (e.g., buzzer or LED).

Logic Flow:

- Alcohol level below limit → safe to proceed
- Alcohol level high → ignition blocked, warning generated

This feature ensures the rider is sober before ignition is permitted.

6.3 Gesture-Based Call Management

The **gesture sensor (APDS-9960)** detects simple hand gestures like left swipe (reject call) and right swipe (accept call). This allows the rider to interact with incoming calls without physically handling the phone or helmet buttons.

Working:

- Call rings on connected phone via Bluetooth
- Rider swipes hand near sensor:
 - Right swipe → Accepts call
 - Left swipe → Rejects call

Gesture inputs are processed and sent to a Bluetooth module (if connected), or routed via the microcontroller to interface with voice assistant or call controls.

6.4 Crash Detection & SOS Alert

The **ADXL345 accelerometer** mounted on the bike constantly monitors acceleration values on all three axes. A sudden spike in acceleration (simulating a crash or fall) triggers an interrupt in the microcontroller. The GPS module is immediately activated to fetch location coordinates, and the GSM module sends an **SOS SMS** containing the rider's live location to pre-stored emergency contacts. Simultaneously, a **buzzer** is activated for on-site alerting.

Crash Detection Algorithm:

- Monitor net acceleration: $\sqrt{X^2 + Y^2 + Z^2}$
- If threshold exceeded (e.g., $>5g$) for more than a preset time $\rightarrow$ confirm crash
- Trigger emergency SMS + buzzer alert

6.5 Vehicle Ignition Control

The bike-side receiver unit uses an **RF module** to receive a validated signal from the helmet only if:

- Helmet is worn
- Alcohol level is below threshold

Once both conditions are met, the Nordic microcontroller activates a **relay module** to complete the bike's ignition circuit. If any condition fails, the relay remains open, preventing the engine from starting.

Logic Flow:

- Valid RF signal received $\rightarrow$ Relay ON $\rightarrow$ Bike can start
- No RF / invalid RF signal $\rightarrow$ Relay OFF $\rightarrow$ Bike ignition disabled

This logic guarantees that only a safe and compliant rider is allowed to start the vehicle.

VII. RESULTS & DISCUSSION

The AI-powered smart helmet system was developed and tested in a controlled prototype environment to validate its functionality across all critical features: safety compliance, communication between helmet and bike, gesture response, and emergency location tracking. Each subsystem was tested individually and in integration to ensure accuracy and reliability.

7.1 System Testing

Testing Environment:

- Helmet unit with pressure, alcohol, and gesture sensors powered by a Li-Ion battery
- Bike unit with ADXL345, GPS, GSM, relay, and motor driver on a breadboard/prototype frame
- Communication between units via 433 MHz RF module
- Nordic microcontrollers (e.g., nRF52840) programmed using Arduino IDE

Tests Conducted:

Test Case	Expected Output	Result
Helmet not worn	Ignition disabled	✓ Passed
Helmet worn	Ignition enabled	✓ Passed
Alcohol detected	Ignition blocked	✓ Passed
Gesture swipe right	Call accepted	✓ Passed
Gesture swipe left	Call rejected	✓ Passed
Crash simulated	SMS sent + buzzer ON	✓ Passed
Normal bumps	No alert triggered	✓ Passed
GPS location	Accurate coordinates sent	✓ Passed

All components performed accurately with minimal delay in sensor response and communication (<1 second delay in RF and GSM triggers). The gesture sensor showed ~90–95% recognition accuracy under moderate lighting.

7.2 Observations

- **Pressure Sensor:** Reliable detection of helmet wear with minimal false negatives
- **Alcohol Sensor:** Sensitive to environmental alcohol; works best in a sealed area around the mouth
- **Gesture Sensor:** Requires clear, unobstructed hand gestures; performs better in well-lit conditions
- **Crash Detection:** Accurately triggers on high-impact shocks, with minimal false alerts due to normal riding movements
- **GSM Alerts:** SMS delivery success depends on signal quality; GPS lock takes 10–15 seconds after bootup

7.3 Limitations

- **Environmental Sensitivity:** Alcohol sensor may give false positives if exposed to perfumes or hand sanitizers
- **Gesture Recognition:** May misread in poor lighting or shaky riding conditions
- **GPS Delay:** Initial GPS lock can take time depending on location and weather
- **RF Communication Range:** Limited to short distances (~15 m); not suitable if bike and helmet get separated too far
- **Power Management:** Battery optimization needed for long-duration usage; pressure sensor can drain power if always active

Despite these limitations, the system demonstrates a robust proof-of-concept with potential for real-world deployment with minor improvements.

7.4 Implementations



VIII. APPLICATION

The proposed smart helmet system is designed to enhance rider safety using intelligent sensing, communication, and control technologies. Its real-world applications extend across various domains:

8.1 Personal Motorcycle Safety

- Ensures the rider is wearing a helmet and is sober before allowing ignition.
- Automatically detects accidents and notifies emergency contacts with location.
- Prevents unauthorized or unsafe vehicle operation, especially for young or impaired riders.

8.2 Fleet Management Systems

- Can be integrated into delivery, logistics, or rental bike fleets to enforce rider compliance.
- Real-time monitoring of crashes and rider behavior ensures fleet safety.
- Centralized emergency alert system for quicker dispatch and recovery in case of accidents.

8.3 Law Enforcement and Insurance

- Useful for verifying helmet usage and rider sobriety data for legal or insurance purposes.
- Can support accident investigation through logged sensor data.
- Helps reduce fraudulent claims by providing verified accident records and location history.

8.4 Emergency Response Automation

- GPS-GSM-based SOS alert system assists in automatic alerting of rescue services.
- Reduces emergency response time, potentially saving lives in critical situations.

8.5 Educational and Training Institutions

- Can be used in driving schools to train and monitor new riders.
- Demonstrates integration of electronics, IoT, and safety automation—ideal for academic projects.

IX. ADVANTAGES

The proposed AI-powered smart helmet offers a comprehensive and intelligent approach to enhancing rider safety through real-time monitoring and automated control. Key advantages include:

Helmet-Wearing Enforcement

- The integrated pressure sensor ensures the bike only starts when the helmet is properly worn, promoting safety compliance.

Alcohol Detection and Vehicle Lock

- Prevents ignition if alcohol is detected, thereby minimizing risks of drunk driving accidents.

Gesture-Based Call Control

- Enables hands-free operation of phone calls via gesture sensor, reducing distractions while riding.

Crash Detection with Auto SOS

- Uses an ADXL accelerometer and AI logic to detect accidents and immediately sends location-based alerts via GSM-GPS, ensuring faster emergency response.

Dual Unit Safety Integration

- Divides the system into a transmitter (helmet) and receiver (bike), ensuring robust two-way communication and safety checks.

Vehicle Ignition Control

- Relay-based control prevents bike ignition unless all safety conditions are met, reducing unauthorized or unsafe starts.

Compact, Wearable, and Wireless

- Designed to be lightweight and wirelessly connected, making it comfortable for the rider without compromising functionality.

Low Power Consumption

- Nordic microcontrollers provide energy-efficient performance, supporting longer battery life for both helmet and bike modules.

X. FUTURE SCOPE

The current prototype demonstrates a reliable, real-time safety system for motorcycle riders; however, several enhancements can be explored in future iterations to improve functionality, usability, and scalability:

1. Integration with Mobile Apps

- Development of a companion mobile app to monitor live helmet status, trip history, crash alerts, and sensor data logs.
- Allows riders and family members to receive real-time updates and manage emergency contacts directly from a smartphone.

2. AI-Based Crash Pattern Recognition

- Implementation of machine learning models trained on real-world crash datasets to reduce false positives and improve crash detection accuracy.
- Differentiates between actual accidents and sudden movements like speed bumps or potholes.

3. Upgraded Communication Protocols

- Replacement of basic RF modules with **Bluetooth Low Energy (BLE)** or **LoRa** for extended range and secure data transmission.
- Enables encrypted and reliable communication even in noisy environments.

4. Enhanced Power Management

- Solar charging or wireless charging options can be added to improve energy efficiency.
- Integration of battery health monitoring to alert users about charging needs.

5. Voice Command and Audio Integration

- Adding voice assistant support for answering calls, navigation, or emergency help without touching the helmet.
- Integration with bone-conduction speakers for safe, ear-free audio feedback.

6. Integration with Law Enforcement & Traffic Systems

- Future versions can directly alert nearby police stations or hospitals with crash data.
- Useful in developing smart city infrastructure for traffic safety monitoring.

7. Wider Two-Wheeler Compatibility

- Can be adapted for **electric scooters, delivery bikes, school transport vehicles, and rental fleets** with IoT-based dashboards for fleet management.

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