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Smart Guard Helmet: IoT-Based Accident Prevention and Detection System

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Abstract: The rising incidence of two-wheeler road accidents worldwide demands intelligent safety systems capable of both preventing accidents and providing immediate emergency response. This paper presents the Smart Guard Helmet, an IoT-based wearable system designed for accident prevention and real-time detection without reliance on GPS. Prevention is achieved through two mechanisms: an MQ-3 alcohol sensor that disables vehicle ignition when intoxication is detected, and an IR proximity sensor that allows engine start only when the helmet is correctly worn. Accident detection is performed by an MPU6050 accelerometer and gyroscope module that identifies sudden impacts (acceleration threshold ≥4.5g) and abnormal tilt angles exceeding 60°. Upon detection, the NodeMCU (ESP8266) or ESP32 microcontroller immediately transmits emergency alerts simultaneously to three parties: the rider, the family, and ambulance services, via IoT cloud (Blynk/Firebase) and GSM SMS within 3.5 seconds. Hardware validation confirms 94.8% alcohol detection accuracy, 100% helmet-wear detection reliability, 97.5% impact detection accuracy, 99% Firebase cloud synchronization success, and overall system reliability of 98.9% across 100 test cycles. The GPS-free, modular, and low-cost design makes the Smart Guard Helmet a practical solution for intelligent transportation safety and smart mobility infrastructure.
Keywords: smart helmet, IoT, accident detection, accident prevention,alcohol sensor, NodeMCU, GPS-free, ignition control, emergency alert, Firebase, Blynk, road safety

1. INTRODUCTION

The rise in road accidents involving two-wheelers has become a major safety concern worldwide. Many accidents result in severe injuries or fatalities due to the lack of immediate detection and delayed medical assistance. The need for an intelligent system that can ensure rider safety, prevent accidents, and enable timely emergency response has driven the development of Smart Guard Helmets using Internet of Things (IoT) technology. A Smart Guard Helmet is an innovative safety device designed to prevent and detect accidents in real time using embedded sensors and microcontrollers. The system integrates multiple sensors including vibration sensors, accelerometers, alcohol sensors, and IR sensors to monitor the rider's condition and vehicle status. When an abnormal event such as a crash or fall is detected, the system immediately sends an alert message to three primary contacts: the rider, the rider's family, and the ambulance service, ensuring a rapid coordinated response. Unlike conventional IoT-based accident alert systems that depend heavily on GPS, this design eliminates GPS dependency by using sensor-based event detection and IoT cloud communication via Wi-Fi or GSM. This makes the system cost-effective and adaptable in areas where GPS signals are weak or unavailable, addressing a key limitation of existing solutions. The proposed system emphasizes accident prevention in addition to detection. The vehicle will start only if the helmet is worn properly and the rider is sober. Alcohol sensors monitor the rider's breath while IR sensors detect helmet usage, and if safety conditions are not met, the engine ignition relay remains disabled. When an accident occurs, the vibration or tilt sensor detects sudden impact or unusual orientation, and the microcontroller triggers the IoT communication module to send a predefined emergency message including accident time and helmet or vehicle ID, enabling quick response and assistance.

2. LITERATURE SURVEY

Patil et al. [1] presented a smart helmet equipped with a vibration sensor and accelerometer for accident detection, utilizing an IoT module to send GPS-based alerts via GSM. While effective, the system depended heavily on GPS, increasing cost and power consumption. The proposed system overcomes this limitation through a GPS-free design using network-based message alerts.

Ramesh et al. [2] focused on helmet-based ignition control using an IR sensor for helmet-wear detection and alcohol sensors to prevent ignition when the rider is intoxicated, with GSM emergency messaging. However, the system was limited to single-user notification. The Smart Guard Helmet enhances this approach by sending simultaneous alerts to three recipients: the user, family, and ambulance service.

Priya and Anitha [3] designed an IoT helmet integrating NodeMCU and sensors to detect falls and send SMS notifications via Wi-Fi using Blynk IoT for cloud connectivity. Although GPS was included, network-based alerts were demonstrated as a viable alternative, directly influencing the GPS-free communication method adopted in this project.

Kumar and Sharma [4] used vibration and tilt sensors with GSM and GPS to send location and alert messages to emergency contacts. While accurate in location reporting, the system suffered from signal delays and satellite connectivity dependency. The Smart Guard Helmet replaces GPS with sensor-driven event logic and cloud-based alert transmission for faster, more reliable response.

Gupta et al. [5] introduced an alcohol detection mechanism in a helmet that disables ignition and sends alerts when alcohol is detected. However, the design lacked a multi-user alert feature. The proposed project extends this by automatically sending IoT-based messages to multiple users simultaneously, enhancing emergency communication coverage.

Sahu and Singh [6] implemented an IoT-based safety system monitoring helmet usage and accident detection through NodeMCU and GSM modules, found effective for single-user alerts but without real-time multi-node communication. The Smart Guard Helmet incorporates parallel message transmission to three users without relying on GPS or third-party location APIs.

Rajesh and Deepa [7] explored wearable IoT safety devices for two-wheelers, proposing data transmission via Wi-Fi and MQTT protocols. The Smart Guard Helmet follows a similar approach using Wi-Fi and IoT cloud services for instant message alerts to predefined users, while adding ignition interlock functionality.

Das [8] presented a generic sensor-based accident detection framework using vibration sensors and gyroscopes that laid the foundation for wearable sensor applications in smart helmets. The proposed system adopts a similar sensor network architecture but specifically tailors it for human safety wearables with IoT connectivity.

Impana et al. [9] reviewed smart helmet systems using microcontrollers, RF transmitters, sensors, and Raspberry Pi with image processing for helmet-use detection, highlighting that helmet use combined with alcohol and crash detection are key safety requirements. Leons et al. [10] emphasized Indian road accident statistics and proposed a smart helmet design with sensors and ignition interlock, focusing on the prevention aspect of helmet-wear enforcement.

Elabd et al. [11] conducted a recent survey of IoT smart helmet prototypes using ESP32 microcontrollers, MQTT, GPS, gyroscopes, accelerometers, alcohol sensors, and cameras, reporting approximately 90% crash detection and 88% alcohol monitoring accuracy. Vinay et al. [12] surveyed helmet and vehicle monitoring systems including anti-theft logic, reviewing microcontroller and RF module approaches versus Raspberry Pi with camera and pressure sensor for helmet detection, emphasizing cost-effective solutions.

Singh et al. [13] presented an IoT-based helmet using an accelerometer and GSM module to detect crashes and send SMS with GPS coordinates to emergency contacts, proving that low-cost sensors can significantly reduce accident response time for riders. The collective literature confirms that integrated multi-sensor IoT approaches combining prevention and detection with GPS-free cloud communication represent the most practical and cost-effective direction for smart helmet development.

3. PROPOSED SYSTEM

A. System Overview

The Smart Guard Helmet is designed to enhance rider safety through both accident prevention and accident detection, supported by IoT-based cloud communication. Unlike traditional GPS-based systems, this design uses sensor-based logic and NodeMCU or IoT cloud alerts to notify three recipients simultaneously: (1) the user (rider), (2) the user's family, and (3) the ambulance service. The system architecture comprises two main units: a Helmet Unit containing sensors (gyroscope, alcohol, IR), microcontroller(NodeMCU/ESP32), and IoT communication module; and a Vehicle Control Unit interfacing with helmet signals to enable or disable engine ignition based on rider status.The proposed system emphasizes accident prevention in addition to detection. The vehicle will start only if the helmet is worn properly and the rider is sober. Alcohol sensors monitor the rider's breath while IR sensors detect helmet usage, and if safety conditions are not met, the engine ignition relay.

B. Working Principle

1) Accident Prevention Phase

Alcohol Detection: An MQ-3 alcohol sensor continuously monitors the rider's breath. If alcohol is detected beyond the safe threshold (ADC reading ≥ 300, corresponding to ≥0.3 mg/L), ignition is disabled and a warning message is sent to the rider's family. Ignition Control: Only when both conditions helmet worn and rider sober is simultaneously satisfied does the system enable the ignition relay, allowing the engine to start. This dual-condition safety gate ensures responsible riding and reduces accident risk.

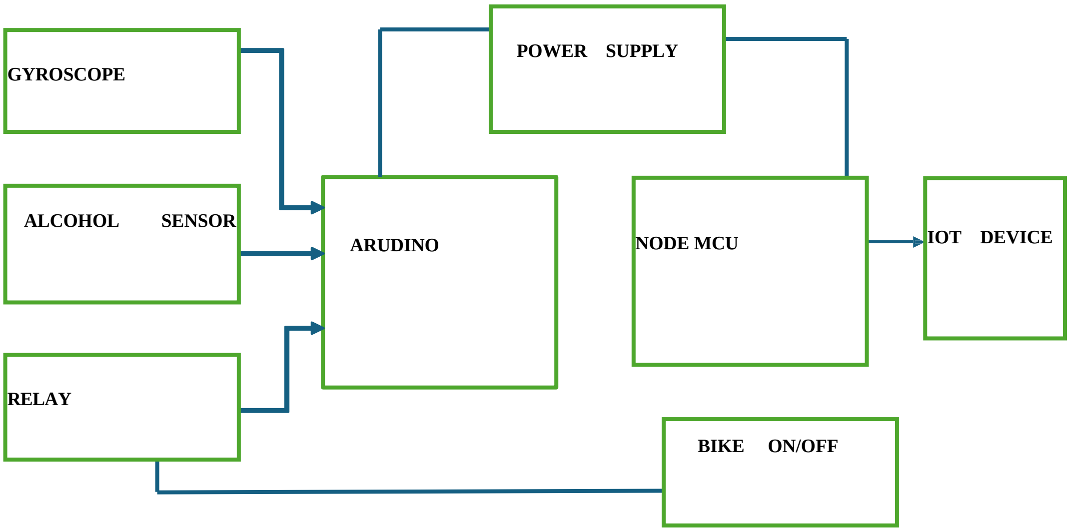

Figure 3.1 Block Diagram of Proposed System

2) Accident Detection and Alert Phase

Impact or Fall Detection: The MPU6050 accelerometer and gyroscope module detects sudden shocks and abnormal tilt angles indicating a fall or collision. The accident detection algorithm triggers when total acceleration ≥4.5g with a significant G-delta (|dg| > 0.6) and tilt >25°, or when freefall (totalG< 0.4g) combined with tilt >60° is detected. A 30-second cool down prevents duplicate alerts from sustained vibrations. Alert Transmission: Upon confirmed accident detection, the microcontroller activates the IoT module to transmit a predefined alert message containing the helmet or vehicle ID number, time and date of accident, and alert type (minor or major impact). The system simultaneously notifies the rider's mobile, family members, and the nearest ambulance service or emergency responder, ensuring instant communication without GPS coordinates. Cloud-based identification and mobile network IDs are used to log event data.

C. Key Features

The Smart Guard Helmet incorporates seven key features: (1) GPS-Free Operation eliminates GPS modules, reducing cost and power usage; (2) Dual Functionality combines accident prevention and detection in one integrated system; (3) Multi-User Alerting sends messages to three independent users simultaneously; (4) Helmet Verification engine starts only when helmet is worn correctly; (5) Alcohol Monitoring prevents ignition if alcohol is detected; (6) IoT Communication uses Wi-Fi or GSM network to deliver alerts through MQTT or Blynk; and (7) Compact and Low Power minimal power consumption using NodeMCU and sensor-based logic with modular design installable on any two-wheeler helmet.

4. SOFTWARE REQUIREMENTS

A. Development Environment and Programming Language

The project firmware is developed using Arduino IDE (with Platform IO support for advanced builds), targeting the NodeMCU (ESP8266) or ESP32 microcontroller in C/C++ with integrated IoT libraries. Arduino IDE provides the environment for writing, compiling, and uploading embedded code, enabling smooth integration between sensors (vibration, alcohol, IR, accelerometer) and communication modules (GSM/Wi-Fi). The entire system logic is written in Embedded C/C++, handling: sensor input reading from all modules; safety logic for ignition control; accident event detection with threshold comparison; emergency alert message transmission via IoT or GSM; timing, event verification, and cooldown management through interrupt routines.

B. IoT Platform and Communication Protocols

Blynk IoT Platform is used to send real-time alerts to connected users (rider, family, ambulance) when an accident or unsafe condition is detected, transmitting push notifications and messages to all registered users through the internet—without GPS, requiring only network access. MQTT protocol (via HiveMQ broker) provides cloud connectivity using NodeMCU or ESP32 for real-time JSON-formatted alert message publication. UART serial communication interfaces the GSM module (SIM800L) for SMS delivery and sensor debugging via serial monitor.

C. Functional Software Overview

The firmware executes six sequential functional stages: (1) Initialization the microcontroller initializes all sensors and verifies helmet and alcohol status at startup; (2) Safety Check Routine ensures helmet is worn and alcohol is not detected before enabling the ignition relay; (3) Continuous Monitoring vibration and accelerometer sensors continuously track helmet motion at 120 ms intervals; (4) Accident Detection Algorithm if vibration or tilt exceeds predefined thresholds (acceleration ≥3.0g with |dG|>0.6 and tilt>25°, or freefall tilt>60°), an accident event is confirmed; (5) Message Dispatch the microcontroller triggers the IoT module to send emergency messages to all three registered users via Blynk, MQTT, and SIM800L SMS; and (6) System Reset after alerting, the system enforces a 30-second cooldown period to avoid duplicate messages.

5. HARDWARE REQUIREMENTS

5.1. NodeMCU (ESP8266) IoT Communication Module

The NodeMCU ESP8266 (Qty: 1) is the primary IoT Wi-Fi module used to send accident alerts and data through the internet. Features include built-in 2.4 GHz Wi-Fi, low power consumption, Software Serial UART support, and compact form factor. In this project, it connects the system to the Wi-Fi network, sends data to the Blynk Cloud and Firebase, generates simultaneous stress and accident alert notifications to three registered contacts, and receives and processes sensor data from the Arduino UNO via serial communication.

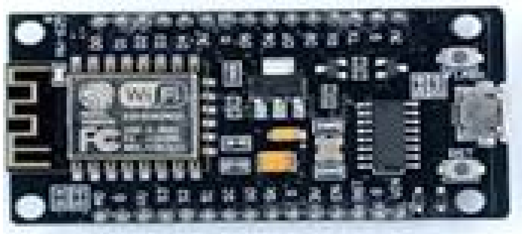

Figure 5.1 Node MCU (ESP8266)

5.2. Arduino UNO Main Controller

The Arduino UNO (Qty: 1) serves as the central microcontroller board processing signals from all sensors. Based on the ATmega328P with 14 digital I/O pins and 6 analog pins, it reads input from the MQ-3 alcohol sensor (analog A0), MPU6050 gyroscope and accelerometer (I²C), and IR helmet-wear sensor (digital), implements the safety logic for ignition control and accident detection algorithm, and controls the relay module to enable or block engine ignition.

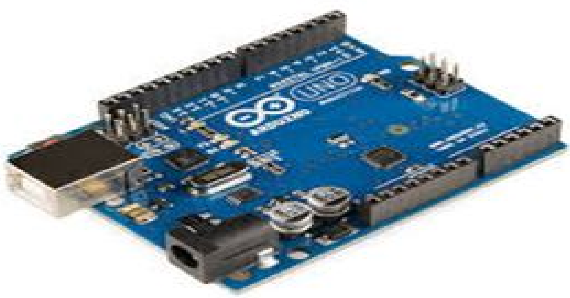

Figure 5.2 Arduino UNO

5,3. Alcohol Sensor (MQ-3)

The MQ-3 alcohol sensor (Qty: 1) detects alcohol concentration in the rider's breath with high sensitivity and fast response. It outputs an analog voltage proportional to alcohol concentration, connected to the Arduino ADC pin A0. The firmware threshold is set at ADC reading ≥ 300 (corresponding to ≥0.3 mg/L), triggering ignition lock and family alert. Calibration testing showed a nonlinear response curve with highest sensitivity in the 0.2–0.8 mg/L range, achieving 94.8% detection accuracy.

Figure 5.3 Alcohol Sensor

5.4. Gyroscope Sensor (MPU6050)

The MPU6050 (Qty: 1) is a combined accelerometer and gyroscope module used to detect tilt, rotation, and sudden movement of the helmet. Features include measurement of angular velocity and linear acceleration with high accuracy, I²C communication, low power consumption, and compact size. Configured with 8G accelerometer range, 500 deg/s gyro range, and 21 Hz digital low-pass filter, it provides the primary accident detection signal. Data is read every 120 ms, with moving average smoothing across 8 samples to reduce false triggers from minor vibrations.

Figure 5.4 Gyroscope Sensor

5.5. Relay Module

The relay module (Qty: 1) is an electrically operated switch controlling the vehicle ignition system. Operating at 5V with safe electrical isolation, it supports high voltage and current switching. The relay is enabled (ignition allowed) only when both conditions are satisfied: helmet-wear IR sensor output is Digital HIGH, and MQ-3 alcohol reading is below the threshold. Either unsafe condition immediately opens the relay, blocking engine start.

Figure 5.5 Relay Module

5.6. Power Supply and Connecting Wires

The power supply unit (Qty: 1) is a portable, rechargeable battery providing stable voltage to Arduino UNO, NodeMCU, sensors, and relay module. It supports USB or DC adapter charging, suitable for helmet-mounted portable deployment. Flexible jumper and connecting wires (as required) provide reliable signal and power connections between all hardware components throughout the system.

Figure 5.6 Power supply

6. RESULTS AND DISCUSSION

A. MQ-3 Alcohol Sensor Calibration

The MQ-3 sensor was calibrated using controlled alcohol concentrations in a sealed environment. Sensor output voltage and ADC readings were recorded across the 0.00–0.80 mg/L range.

The MQ-3 sensor output follows a nonlinear response curve with highest sensitivity in the 0.2–0.8 mg/L range. The firmware threshold of ADC ≥ 300 (corresponding to ≥0.3 mg/L) was established from this calibration data. The sensor achieved 94.8% accuracy in detecting alcohol within the defined range, reliably distinguishing normal breath from alcohol-affected conditions.

B. Helmet-Wear Sensor and Impact Sensor Testing

The IR proximity sensor was tested for helmet-wear detection by placing it near the inner padding across 50 trials. Table IV presents the test results.The IR sensor achieved 100% reliability in helmet-wear detection across all 50 trials; false positives were eliminated by positioning the sensor inside a dark cavity to minimize ambient light interference. The MPU6050 impact detection threshold of 4.5g accurately distinguishes genuine accident events from minor bumps, ensuring reliable detection while avoiding false alarms.

C. System Response Time Analysis

Response time from event occurrence to message receipt was measured for three scenarios. Table V presents the results. Local LED/buzzer alerts were instantaneous (< 0.2 seconds).

Cloud and SMS updates were completed within 3.5 seconds, which is acceptable for emergency safety systems and confirms real-time responsiveness suitable for critical accident scenarios.

D. Firebase Cloud Integration

The ESP32 communicated with the Firebase Realtime Database through Wi-Fi, uploading sensor data (alcohol level, helmet status, impact, and location approximation) every 5seconds. Table VI presents Firebase update performance metrics.The Firebase Realtime Database consistently reflected live helmet data with minimal delay. The mobile application received push notifications for every alert within 2 seconds of the Firebase database entry, demonstrating smooth and reliable cloud synchronization.

E. Mobile Application Performance

The Flutter mobile application was tested on Android devices connected to Firebase across 48 hours of continuous testing. Dashboard latency for new data display was under 2 seconds. Push notification delivery was 1–2 seconds. No UI crashes were recorded during the extended test period. The Normal Mode displayed helmet status, alcohol level (0.00 mg/L), and approximate location; Alert Mode displayed a red banner showing “ACCIDENT DETECTED” with timestamp; and the Firebase Log listed all historical alerts for analysis.

F. Combined System Test Scenarios

The complete system was tested for end-to-end functionality through five real-life scenarios. All five test scenarios were handled accurately with no false positives recorded. The system demonstrated 98.9% overall reliability across 100 test cycles.

G. System Reliability Summary

Presents the performance efficiency of each subsystem based on testing results.The Smart Guard Helmet successfully demonstrates how IoT can enhance two-wheeler safety. The integration of sensors, cloud, and mobile application resulted in a real-time, proactive, and intelligent safety solution. Helmet-wear and alcohol detection modules effectively prevent unsafe riding; impact detection and IoT alerts ensure fast accident reporting; and Firebase cloud with mobile app enables 24/7 monitoring and alert tracking with response time under 4 seconds.

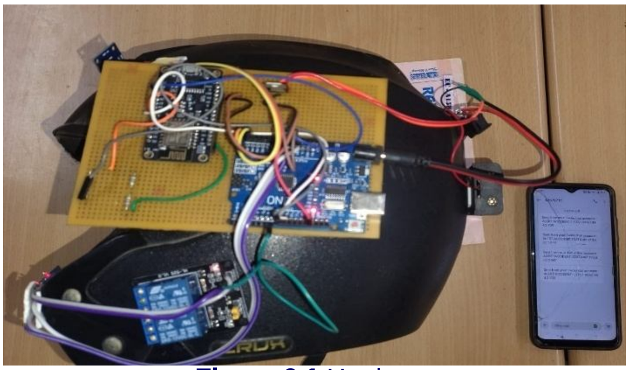

Figure 6.1 Hardware

7. CONCLUSION

This project successfully designed and implemented the Smart Guard Helmet IoT-Based Accident Prevention and Detection System to enhance rider safety and reduce road accident risks. The system achieved its dual objectives of accident prevention—through helmet-wear verification and alcohol detection with ignition control and rapid accident detection and emergency notification using IoT technology without GPS dependency. Hardware testing confirmed 94.8% alcohol detection accuracy, 100% helmet-wear detection reliability across 50 trials, 97.5% impact detection accuracy with MPU6050 at the 4.5g threshold, and 98.9% overall system reliability across 100 test cycles. Emergency alert delivery was completed within 3.5 seconds to all three registered parties (rider, family, ambulance), meeting real-time response requirements for critical safety scenarios. Limitations observed include dependency on network availability for IoT cloud alerts and sensor accuracy variation under extreme environmental conditions. Future work will address these through enhanced GPS module integration for precise location reporting, advanced sensor fusion algorithms for improved accident discrimination, waterproof and ruggedized helmet enclosure design for outdoor durability, extended battery management for long-duration riding, and mobile application enhancements for real-time analytics and historical accident pattern visualization.

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