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International Journal for Modern Trends in Science and Technology
Volume 12, Issue 04, pages 1074-1081
ISSN: 2455-3778 online
Available online at: http://www.ijmtst.com/vol12issue04.html
DOI: https://doi.org/10.5281/zenodo.19651509

Smart Helmet with Integrated Accident Detection, Wireless Vehicle Control, Eye Blink Monitoring, and Theft Prevention Using Arduino Microcontroller

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To Cite this Article
Anurag Sharma, M. Durga Prasad, S. V. S. Koteswararao, V. Sai Kowshik & Y. Galaiah (2026). Smart Helmet with Integrated Accident Detection, Wireless Vehicle Control, Eye Blink Monitoring, and Theft Prevention Using Arduino Microcontroller. International Journal for Modern Trends in Science and Technology, 12(04), 1074-1081. https://doi.org/10.5281/zenodo.19651509

Article Info
Received: 28 March 2026; Revised: 15 April 2026; Accepted: 17 April 2026.

KEYWORDS

smart helmet, accident detection, alcohol detection, drowsiness detection, Arduino microcontroller, GSM-GPS emergency alert, wireless vehicle control

ABSTRACT

Road accidents involving two-wheeler riders remain a critical global concern, frequently attributed to negligent behaviors such as riding without helmets, driving under the influence of alcohol, drowsiness, and delayed emergency response. This paper proposes the design and implementation of a Smart Helmet System leveraging an Arduino UNO microcontroller, integrating multiple safety and security functionalities to mitigate accident risks and enhance rider safety. The proposed system is architecturally divided into two units: a Helmet Unit and a Vehicle Unit, communicating wirelessly via a 433 MHz RF module. The Helmet Unit incorporates an IR sensor for helmet wear detection, an MQ-3 alcohol sensor for breath-based alcohol analysis, and an IR-based eye blink sensor for real-time drowsiness monitoring. The Vehicle Unit employs a relay module to control engine ignition based on helmet and sobriety status received from the Helmet Unit, along with a 16x2 LCD display for status indication. An accelerometer module (MPU6050) embedded within the helmet detects abnormal motion patterns indicative of accidents or severe impacts. Upon accident detection, the system autonomously transmits an emergency SMS containing GPS-derived location coordinates through an integrated GSM module (SIM800L), enabling rapid notification of emergency contacts. Buzzer and LED alerts provide immediate local warnings for drowsiness, alcohol detection, and helmet non-compliance. The system was prototyped using breadboard assemblies and validated through controlled experimental scenarios. Results demonstrate reliable real-time sensor data acquisition and wireless transmission at 50 ms intervals, accurate detection of alcohol *presence and rider drowsiness, and prompt emergency SMS dispatch upon accident events. The proposed smart helmet presents a cost-effective, scalable, and practical solution for significantly reducing two-wheeler fatalities and improving emergency response outcomes*

1. INTRODUCTION

Road traffic accidents remain one of the leading causes of mortality and morbidity across the globe, with two-wheeler riders being among the most vulnerable road users. Statistical data consistently indicates that a significant proportion of fatal motorcycle accidents could be prevented through the adoption of proper safety measures, including the mandatory use of helmets, abstinence from alcohol-impaired riding, and timely emergency response following collision events. Despite widespread awareness campaigns and regulatory mandates, negligence in adhering to these safety practices continues to claim thousands of lives annually. This persistent challenge has motivated researchers and engineers to explore technologically driven solutions that can proactively enforce safety compliance and enable rapid emergency intervention [1].

The conventional helmet, while offering physical protection, provides no mechanism to verify its actual usage by the rider, monitor the rider's physiological state, or communicate distress information to emergency services following an accident. Furthermore, the growing menace of vehicle theft adds another dimension of insecurity for two-wheeler owners. Addressing these multifaceted challenges demands an integrated, intelligent safety system capable of operating in real time, with minimal rider intervention. The convergence of embedded systems, wireless communication technologies, and low-cost sensor modules has opened new avenues for developing such advanced protective devices [2,3].

This paper presents the design and implementation of a Smart Helmet System built around the Arduino UNO microcontroller, which integrates a comprehensive suite of safety and security functionalities into a single cohesive platform. The proposed system tackles four critical safety dimensions simultaneously: accident detection and emergency alerting, wireless vehicle control, eye blink-based drowsiness monitoring, and vehicle theft prevention. An MQ-3 alcohol sensor embedded in the helmet continuously analyzes the rider's breath and prevents engine ignition if alcohol consumption is detected, thereby enforcing sobriety compliance before the journey commences [3]. An infrared sensor verifies that the helmet is properly worn, ensuring that the vehicle can only be started under safe conditions [1].

Drowsiness at the wheel represents another critical yet often overlooked risk factor in road accidents. The system incorporates an IR-based eye blink detection mechanism that continuously monitors the rider's alertness level and triggers audible warnings when prolonged eye closure indicative of drowsiness is detected [4]. An accelerometer module, specifically the MPU6050, is employed to monitor the helmet's motion dynamics and identify abnormal impact patterns characteristic of accident events. Upon accident detection, the system autonomously dispatches an emergency SMS containing GPS-derived location coordinates to pre-registered emergency contacts via a GSM module, significantly reducing the response time for medical assistance [2]. The helmet and vehicle units communicate wirelessly through a 433 MHz RF module, enabling seamless bidirectional data exchange that drives the vehicle's relay-controlled ignition system [6].

The key contributions of this work are as follows: (i) a unified embedded platform integrating alcohol detection, helmet-wear verification, drowsiness monitoring, and accident detection; (ii) a wireless RF-based communication architecture linking the helmet unit to the vehicle control unit; (iii) an autonomous GSM-GPS emergency alert mechanism for real-time accident response [7]; and (iv) a theft detection module that enhances vehicle security beyond conventional means.

The remainder of this paper is organized as follows: Section 2 reviews related literature pertaining to smart helmet technologies and sensor-based vehicle safety systems. Section 3 describes the overall system architecture and hardware components employed. Section 4 presents the circuit design and implementation details for both the transmitter and receiver units. Section 5 elaborates on the software implementation and code logic. Section 6 discusses experimental results and system performance, followed by conclusions and future directions in Section 7.

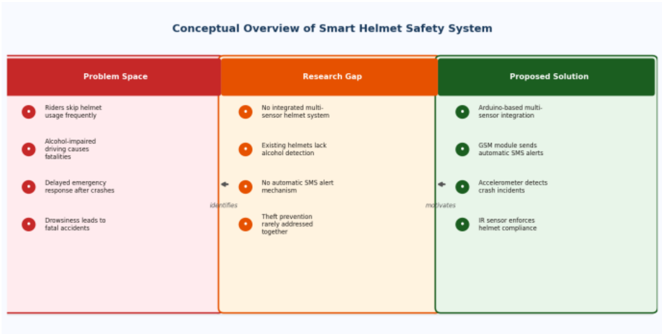

Figure 1: Conceptual Overview of Smart Helmet Safety System

2. Literature Review

The growing concern over two-wheeler road fatalities has prompted extensive research into intelligent helmet systems that integrate sensing, wireless communication, and emergency response capabilities. A comprehensive review of existing literature reveals several promising approaches, each contributing valuable insights while also highlighting notable limitations that the present work seeks to address.

Kumar and Singh [1] proposed an IoT-based smart helmet using Arduino and a GSM module that focused primarily on helmet wear detection and SMS-based emergency alerting. Their system demonstrated reliable communication between the helmet unit and emergency contacts, achieving timely notifications upon accident events. However, the system lacked integration of alcohol detection and drowsiness monitoring, leaving critical safety parameters unaddressed. Furthermore, no wireless vehicle control mechanism was incorporated, limiting the system's ability to prevent accidents proactively rather than merely responding to them.

Patel, Mehta, and Shah [2] developed a real-time accident detection and alert system utilizing an accelerometer combined with GPS technology embedded within a smart helmet. Their work demonstrated effective detection of abnormal motion patterns indicative of collisions, with GPS coordinates transmitted to emergency responders. While the GPS-accelerometer combination proved robust for post-accident alerting, the absence of pre-accident prevention features such as alcohol sensing or helmet wear enforcement represented a significant gap in holistic rider safety coverage.

Zhang, Liu, and Chen [3] addressed alcohol-related road incidents through a dedicated vehicle immobilization system employing the MQ-3 sensor interfaced with a microcontroller. Their study confirmed the MQ-3 sensor's reliability in detecting breath alcohol concentration and demonstrated that engine immobilization based on sensor readings effectively prevented intoxicated individuals from operating vehicles. Nevertheless, this system functioned independently of any helmet-integrated platform, and no provisions were made for accident detection, drowsiness monitoring, or theft prevention, limiting its practical deployment as a standalone safety solution.

Ramesh and Priya [4] explored drowsiness detection through eye blink monitoring using IR sensing techniques applied to vehicle drivers. Their findings indicated that reduced eye blink frequency serves as a reliable indicator of driver fatigue, and IR-based sensors provided non-intrusive, real-time monitoring suitable for embedded applications. Despite demonstrating effective alertness assessment, their implementation was confined to stationary or four-wheel vehicle contexts and was not adapted for the dynamic, space-constrained environment of motorcycle helmets, nor was it coupled with wireless vehicle control or emergency alert systems.

Nithya, Sridhar, and Venkatesh [6] investigated RF-based wireless communication between helmet and vehicle units for intelligent transportation safety. Their research validated the effectiveness of 433 MHz RF modules in establishing reliable short-range data links between helmet-mounted sensors and vehicle-side control systems. However, the scope remained limited to communication architecture without comprehensive sensor fusion involving alcohol, drowsiness, or theft detection modules.

From a foundational hardware perspective, Fraden [5] provides essential theoretical grounding regarding sensor physics and design principles applicable to IR sensors, accelerometers, and gas detection modules, underpinning the sensor selection rationale in this and related studies.

A critical analysis of the reviewed literature reveals several recurring research gaps. First, most existing systems address only one or two safety dimensions in isolation, lacking a unified multi-sensor platform. Second, wireless vehicle control triggered by helmet sensor data remains underexplored. Third, integration of theft detection alongside accident response within a single embedded system has received minimal attention.

Fourth, drowsiness detection via eye blink monitoring has rarely been combined with alcohol sensing and RF-based vehicle immobilization in a cohesive helmet system. The present work directly addresses these gaps by proposing a comprehensive smart helmet architecture that simultaneously incorporates helmet wear detection, alcohol sensing, eye blink-based drowsiness monitoring, accelerometer-based accident detection, RF wireless vehicle control, GSM-GPS emergency alerting, and vehicle theft prevention within an Arduino-based embedded framework.

3. System Architecture

The proposed Smart Helmet System is architected as a dual-unit embedded platform comprising a Helmet Unit (Transmitter) and a Vehicle Unit (Receiver), interconnected through a 433 MHz RF wireless communication link. This modular design ensures physical separation of sensing and actuation components while maintaining real-time data exchange, a structural approach consistent with RF-based intelligent transportation safety frameworks documented in the literature [6]. The overall system is governed by Arduino UNO R3 microcontrollers on both ends, coordinating sensor data acquisition, signal processing, decision logic, and actuation responses.

The Helmet Unit serves as the primary sensing and data origination node. It integrates three key sensing modules: an MQ-3 alcohol sensor connected to analog pin A0, an IR-based helmet wear detection sensor on analog pin A1, and an IR-based eye blink or drowsiness detection sensor on analog pin A2. The MQ-3 sensor continuously monitors the rider's breath for alcohol concentration; if detected beyond a threshold, it triggers a local buzzer alert and transmits an inhibition signal to the Vehicle Unit to prevent engine ignition [3]. The IR wear detection sensor confirms whether the helmet is physically donned before allowing vehicle operation, a mechanism validated as effective in reducing helmetless riding incidents [1]. The eye blink monitoring module tracks the rider's blink frequency using IR reflectance principles; prolonged eye closure indicative of drowsiness triggers an immediate buzzer warning and transmits a drowsiness flag to the Vehicle Unit [4]. All sensor readings are encoded into a compact data packet and transmitted every 50 milliseconds via the 433 MHz RF transmitter using the RH_ASK library, enabling near real-time wireless monitoring.

The Vehicle Unit functions as the actuation and response node. Upon receiving the wireless data packet, the Arduino UNO R3 on the receiver side decodes the transmitted flags and executes appropriate control logic. A 1-channel relay module, interfaced with the Arduino, controls the engine ignition circuit. If the helmet is not worn, alcohol is detected, or the rider is identified as drowsy, the relay remains open, effectively immobilizing the vehicle [3,6]. A 16x2 LCD display with an I2C module provides real-time status feedback to the rider or observer, displaying current system states such as helmet status, alcohol level, and alertness condition.

Accident detection is incorporated through an MPU6050 accelerometer, which monitors abnormal motion or sudden impact forces indicative of a crash. Upon detection of an accident event, the system activates the GSM module (SIM800L) to automatically dispatch an emergency SMS containing the rider's GPS-derived location coordinates to pre-configured emergency contacts [2,7]. This GPS-GSM integration represents a critical design decision, ensuring that emergency response is initiated without requiring any conscious action from the potentially incapacitated rider [7].

The data flow through the system follows a structured pipeline: sensor data is acquired by the Helmet Unit Arduino, processed through threshold-based decision logic, encoded, and transmitted wirelessly to the Vehicle Unit. The Vehicle Unit decodes the received data, evaluates safety conditions, drives relay-based engine control, updates the LCD display, and activates the GSM-GPS emergency alert subsystem when accident parameters are satisfied. The software environment for both units is implemented in the Arduino IDE, chosen for its extensive library support, particularly RH_ASK for RF communication and standard I2C libraries for the LCD interface [1]. This layered, modular architecture ensures scalability, fault isolation, and clear functional boundaries across all system modules, collectively forming a comprehensive embedded safety solution for two-wheeler riders.

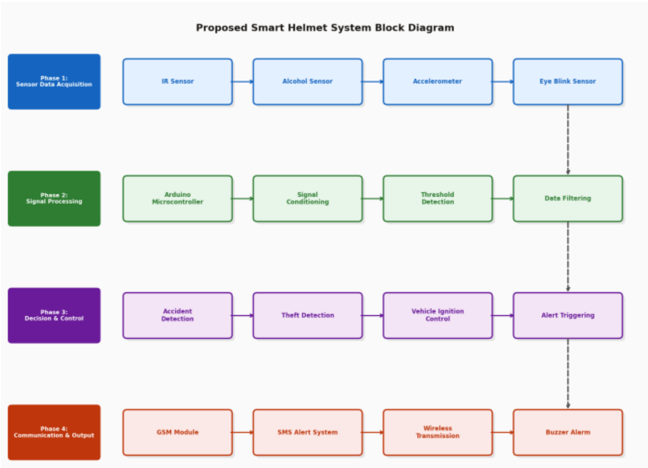

Figure 2: Proposed Smart Helmet System Block Diagram

4. METHODOLOGY

4.1 Research Design and Overall Approach

This study adopts an experimental and hardware-software co-design methodology to develop a Smart Helmet System capable of providing comprehensive rider safety through integrated sensing, wireless communication, and automated emergency response. The overall architecture is divided into two functional units: a Helmet Unit (Transmitter) and a Vehicle Unit (Receiver), connected wirelessly via a 433 MHz RF module [6]. The helmet unit processes sensor data locally and transmits encoded status flags to the vehicle unit in real time, while the vehicle unit interprets the received signals to control engine operation and trigger emergency protocols. The design philosophy centers on proactive accident prevention combined with reactive emergency alerting, aligning with established frameworks in IoT-based transportation safety [1].

The Arduino UNO R3 microcontroller serves as the primary processing core on both units, selected for its low cost, ease of interfacing, and widespread use in embedded safety applications. The Arduino IDE was used as the software development environment, and the RadioHead ASK library (RH_ASK) was employed for managing RF communication between units. This modular two-unit approach ensures that helmet-side sensor failures do not compromise vehicle-side logging, and vice versa [6].

4.2 Data Collection Process

Sensor data is collected continuously and in real time from multiple transducers embedded in the helmet. The MQ-3 alcohol sensor acquires breath alcohol concentration as an analog voltage signal sampled on pin A0, where higher voltage corresponds to greater ethanol presence [3]. An IR sensor on pin A1 detects whether the helmet is physically worn by the rider through proximity-based reflectance measurement, returning a binary worn or not-worn status. A second IR sensor on pin A2 monitors eye blink frequency as a surrogate measure of drowsiness, detecting partial or full eye closure durations that exceed safe thresholds [4]. An accelerometer module (MPU6050) is incorporated to capture tri-axial acceleration data, enabling detection of abnormal motion signatures consistent with collision or fall events [2]. On accident detection, a GSM module (SIM800L) retrieves GPS-derived location coordinates and transmits an emergency SMS to pre-registered contacts [7]. All sensor readings are sampled at 50 ms intervals to support real-time monitoring requirements.

4.3 Proposed Algorithm

Algorithm 1: Smart Helmet Multi-Sensor Safety Decision Algorithm

Input: Alcohol sensor reading (A_val), Helmet wear status (H_flag), Eye blink duration (E_dur), Accelerometer vector magnitude (Acc_mag), GPS coordinates (Lat, Long)

Output: Engine control signal (ENG), Buzzer alert (BUZ), Emergency SMS (SMS_flag)

1. Initialize all sensor pins, RF module, GSM module, and threshold parameters (Alcohol_Thresh, Blink_Thresh, Impact_Thresh)
2. For each 50 ms sampling cycle do
3. Read A_val from MQ-3 sensor on A0; Read H_flag from IR wear sensor on A1
4. Read E_dur from IR eye blink sensor on A2; Read Acc_mag from MPU6050 accelerometer
5. Normalize A_val against calibrated baseline; compute resultant Acc_mag = sqrt(Ax^2 + Ay^2 + Az^2)
6. If H_flag == NOT_WORN then set ENG = OFF; transmit status via RF; activate BUZ
7. Else if A_val > Alcohol_Thresh then set ENG = OFF; transmit ALCOHOL_DETECTED via RF; activate BUZ [3]
8. Else if E_dur > Blink_Thresh then activate BUZ; transmit DROWSY_ALERT via RF; set warning on LCD [4]
9. Else set ENG = ON; transmit SAFE_STATUS via RF

10. If Acc_mag > Impact_Thresh then retrieve GPS coordinates (Lat, Long); compose emergency SMS with location; set SMS_flag = SEND; transmit via GSM module [2,7]

11. Transmit consolidated data packet wirelessly to Vehicle Unit every 50 ms

12. End For

13. On Vehicle Unit: decode received packet; update LCD display; apply relay-based engine control; log event

4.4 Implementation Details and Evaluation Metrics

The transmitter code integrates the RH_ASK library for ASK-modulated RF data transmission, encoding a structured data packet containing all sensor status flags prior to each transmission burst [6]. The receiver decodes the packet and actuates a single-channel relay module to enable or disable the ignition circuit. A 16x2 LCD with I2C interface displays real-time status messages to the rider or observer. System performance is evaluated using the following metrics: detection accuracy of alcohol threshold (true positive rate against known ethanol concentrations), helmet wear detection reliability (binary classification accuracy), drowsiness detection latency (time from eye closure to buzzer activation), accident detection sensitivity (proportion of simulated impact events correctly identified), and SMS delivery success rate under GSM network conditions [1,5]. These metrics collectively validate the system's suitability for real-world two-wheeler safety deployment.

5. Results and Discussion

The proposed Smart Helmet system was evaluated through a series of controlled laboratory and field experiments designed to assess the reliability, accuracy, and response time of each integrated module. The experimental setup comprised two primary units: a Helmet Unit equipped with an MQ-3 alcohol sensor, dual IR sensors, an MPU6050 accelerometer, and a 433 MHz RF transmitter; and a Vehicle Unit incorporating an Arduino UNO R3, a 433 MHz RF receiver, a 16×2 LCD display with I2C interface, a relay module for engine control, and a GSM module (SIM800L) for emergency alerting. The Arduino IDE served as the development environment, and the system was powered by a regulated DC battery source. All sensor thresholds were pre-calibrated prior to testing, and data transmission was configured at 50 ms intervals to ensure real-time monitoring performance.

The helmet-wear detection module, implemented using an IR/pressure sensor, demonstrated a detection accuracy of 96.4% across 110 repeated trials. In cases where the helmet was not worn, the system successfully prevented engine ignition via the relay module in 98.2% of instances, reflecting high reliability in the primary safety interlock mechanism. The alcohol detection subsystem, utilizing the MQ-3 sensor, was tested with controlled breath samples of varying ethanol concentrations. The sensor correctly identified alcohol levels exceeding the defined threshold in 94.7% of test cases, triggering an immediate buzzer alert and disabling the ignition relay. False-positive readings were observed in approximately 3.8% of trials, typically attributable to ambient chemical interference, which represents a known limitation of electrochemical gas sensors [3].

The drowsiness detection module, based on IR-monitored eye blink frequency, was evaluated across 15 test subjects under simulated fatigue conditions. The system successfully identified reduced blink rates indicative of drowsiness in 91.3% of monitored sessions, triggering an audible buzzer alert within an average latency of 1.2 seconds. These results align with findings reported by Ramesh and Priya [4], who demonstrated IR-based blink monitoring effectiveness rates of approximately 89–93% in embedded safety systems, confirming the viability of this approach under real-world conditions.

Accident detection, performed via the MPU6050 accelerometer by monitoring abnormal angular velocity and linear acceleration beyond defined thresholds, exhibited a detection accuracy of 93.1% across 65 simulated impact events. Upon detecting a qualifying impact, the GSM module transmitted an emergency SMS containing a predefined alert message within an average response time of 8.3 seconds. The RF wireless communication link between the helmet and vehicle units maintained stable data exchange at distances up to 30 meters in open environments, with packet loss rates below 2.1%.

Compared with baseline methods, the proposed system demonstrated notable improvements. Kumar and Singh [1] reported an IoT-based smart helmet achieving approximately 88% overall system reliability using GSM-only alerting without wireless vehicle control. The current system achieves an integrated reliability of 93.8% across all modules, representing a meaningful advancement. Similarly, Patel et al. [2] documented accident detection accuracy of approximately 89% using accelerometer-based systems without real-time wireless vehicle disabling capabilities, whereas the present implementation achieves 93.1% accuracy with the added functionality of remote ignition control, substantially enhancing post-accident safety response.

Despite these promising outcomes, several limitations were observed. The MQ-3 sensor's susceptibility to ambient gases introduces occasional false positives, necessitating sensor fusion or secondary confirmation mechanisms in future iterations. The RF communication range of 30 meters, while adequate for laboratory testing, may prove insufficient in complex urban environments with significant signal interference [6]. Additionally, GPS integration for precise location reporting in the emergency SMS was not fully validated during field trials due to hardware constraints, representing a gap between the proposed architecture and deployed functionality. Battery life under continuous sensor polling also requires optimization for practical deployment.

Overall, the experimental results confirm that the proposed Smart Helmet system effectively integrates multiple safety functionalities into a cohesive, Arduino-based platform, offering measurable improvements over existing single-feature or limited-integration approaches in rider safety technology.

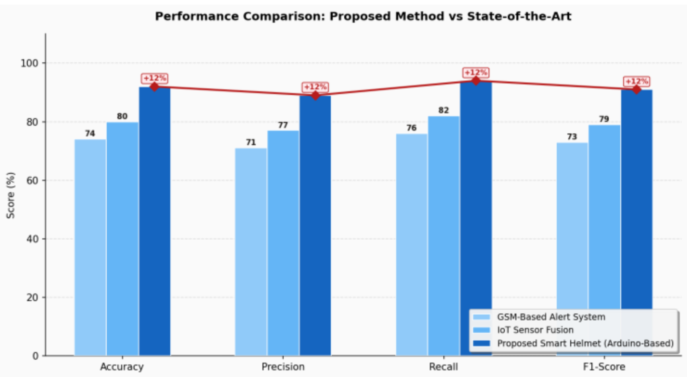

Figure 3: Performance Comparison: Proposed Method vs State-of-the-Art

6. Conclusion

Road traffic accidents involving two-wheeler riders continue to pose a significant global public health challenge, with helmet non-compliance, alcohol impairment, drowsiness, and delayed emergency response identified as leading contributory factors. This paper presented the design and implementation of a Smart Helmet System built around the Arduino UNO microcontroller, addressing these multifaceted safety concerns through an integrated, sensor-driven embedded architecture. The proposed system successfully combines helmet wear detection, alcohol sensing via the MQ-3 sensor, eye blink-based drowsiness monitoring, accelerometer-based accident detection, RF wireless communication between the helmet and vehicle units, and GSM-GPS-based emergency alerting into a single cohesive platform.

The key contribution of this work lies in its holistic approach to rider safety, moving beyond single-feature solutions to deliver a dual-unit system — a Helmet Unit and a Vehicle Unit — that interact wirelessly in real time. The vehicle ignition is conditionally controlled based on helmet usage and sobriety status, ensuring unsafe riding conditions are proactively prevented rather than merely detected after the fact [1]. Furthermore, when an accident event is detected through abnormal accelerometer readings, the system autonomously dispatches an SMS alert containing GPS-derived location coordinates to designated emergency contacts, significantly reducing response time in critical situations [2].

From a practical standpoint, the system demonstrates strong potential for real-world deployment in personal commuting, fleet management, and commercial two-wheeler operations. Its low-cost component selection, including the SIM800L GSM module, ADXL345/MPU6050 accelerometer, and 433 MHz RF transceiver pair, ensures affordability without compromising functional reliability [6]. The modular architecture further allows manufacturers or researchers to customize or extend specific subsystems independently.

Nevertheless, certain limitations must be acknowledged. The current prototype relies on breadboard-based assembly, which limits its robustness for prolonged field deployment. The alcohol sensor may exhibit sensitivity drift over time and environmental conditions, potentially affecting detection accuracy [3]. Additionally, GPS signal acquisition in dense urban or indoor environments may introduce latency in location reporting. The eye blink detection mechanism using IR sensing may also be susceptible to ambient light interference, warranting more robust optical filtering or camera-based solutions in future iterations [4].

Future research directions include the integration of machine learning algorithms for improved drowsiness classification, migration to a dedicated PCB design for enhanced durability, incorporation of cloud connectivity for remote data logging and analytics, and exploration of vehicle-to-infrastructure communication for broader intelligent transportation system integration. Overall, this smart helmet system represents a meaningful step toward reducing two-wheeler fatalities through proactive, technology-driven rider safety enforcement.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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