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IoT-Based Smart Helmet for Real-Time Crash Detection, Prevention and Rider Safety Monitoring

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Abstract

Motorcyclists remain among the most vulnerable road users, with high fatality rates often linked to delayed emergency response and unsafe riding practices. This project presents the design and development of an IoT-based smart helmet for real-time crash detection, accident prevention, and rider safety monitoring. The system integrates multiple sensors, including the MPU6050 accelerometer and gyroscope for crash detection, MQ- 3 alcohol sensor for intoxication monitoring, TCRT5000 IR sensor for drowsiness detection, ultrasonic sensor for obstacle awareness, and IR sensor for helmet- wearing verification. An ESP32 microcontroller serves as the central unit, coordinating sensor inputs and outputs, while GSM and GPS modules enable automatic emergency communication through SMS, calls, and location sharing. Testing results demonstrate that the helmet reliably detects unsafe conditions such as crashes exceeding a 2.5 g threshold, alcohol presence above set limits, prolonged eye closure, and nearby obstacles within one meter. The system initiates alerts via buzzer, Blynk mobile application, Gmail notifications, and GSM communication, with a 10- second countdown provided to cancel false crash triggers. Findings confirm that the smart helmet offers both preventive and responsive safety features, reducing accident risks and improving emergency response times. This work highlights the potential of IoT technology to enhance motorcycle safety by integrating real-time monitoring, rider condition assessment, and automated emergency alerts into a single wearable device. The prototype demonstrates a practical and scalable solution that can contribute to reducing motorcycle fatalities and advancing intelligent road safety systems.

1. Introduction

Road safety remains a critical global concern, particularly for motorcyclists who are highly vulnerable to severe injuries and fatalities during road accidents. Various traffic safety reports indicate that a significant proportion of road accident deaths involve two-wheeler riders [1]. Although helmet usage has been proven to significantly reduce the severity of head injuries [2], conventional helmets function only as passive protective equipment. They neither prevent accidents nor provide timely emergency response when accidents occur, especially in isolated locations. This limitation highlights the urgent need for smarter, technology-driven solutions that enhance rider safety beyond basic physical protection. Recent advancements in sensor technology, wireless communication, and the Internet of Things (IoT) have enabled the development of smart helmets with active safety capabilities. One major improvement in modern helmet systems is their ability to automatically detect accidents and respond rapidly. Riders involved in severe crashes may lose consciousness or be unable to call for help, resulting in delayed emergency assistance. Previous studies have demonstrated the use of pressure, vibration, or motion sensors to detect impacts and automatically transmit emergency alerts along with GPS location information via GSM networks [3]–[4]. In addition to crash detection, other important safety features include alcohol monitoring to prevent drunk riding, helmet-wearing verification to ensure compliance, and drowsiness detection through eye blink or facial movement analysis to reduce fatigue-related accidents [5–[6]. These developments reflect a shift from passive helmet protection toward active safety systems capable of real-time risk management. Despite these advancements, many existing smart helmets designs still suffer from significant limitations. Most systems primarily focus on post-accident detection and alert transmission [7], while several studies highlight limitations such as sensor accuracy, delayed response time, and limited real-time environmental awareness [8]–[9]. Furthermore, some designs rely on outdated communication methods or incomplete sensor integration, which can compromise reliability and user safety [10].

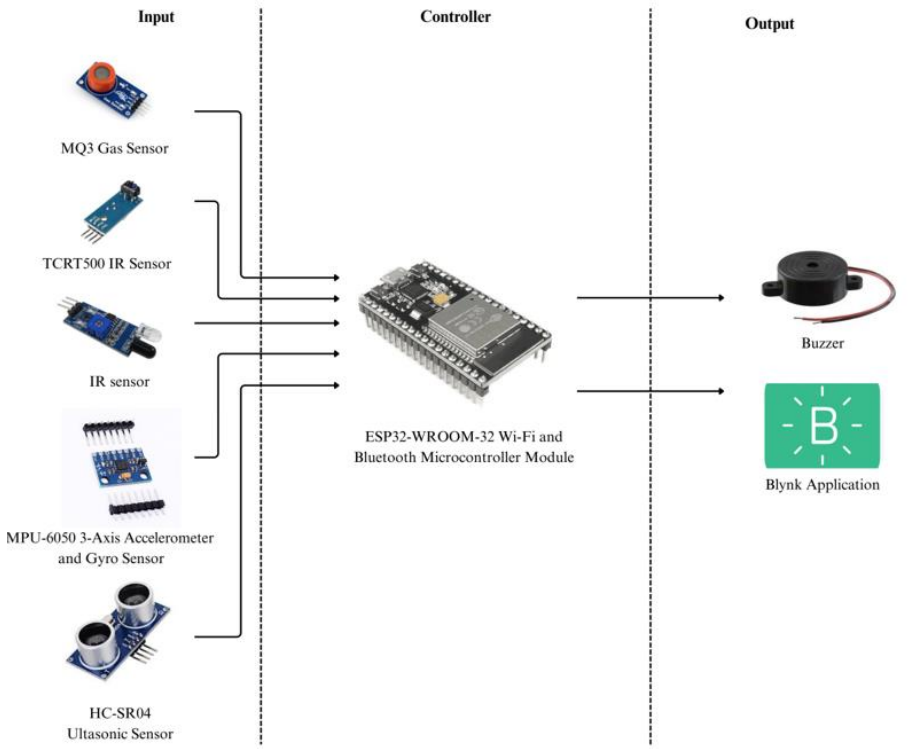
In order to address these challenges, this work proposes an IoT-based smart helmet system for real-time crash detection, accident prevention, and continuous rider safety monitoring. The proposed system integrates multiple sensors and communication modules into a single, cohesive platform. By combining preventive and responsive safety features within an IoT framework, the proposed smart helmet continuously monitors both rider condition and surrounding environment. This integrated approach aims to reduce accident risks, improve emergency response time, and enhance overall motorcyclist safety, offering a practical and scalable solution for real-world applications.

2. Methodology

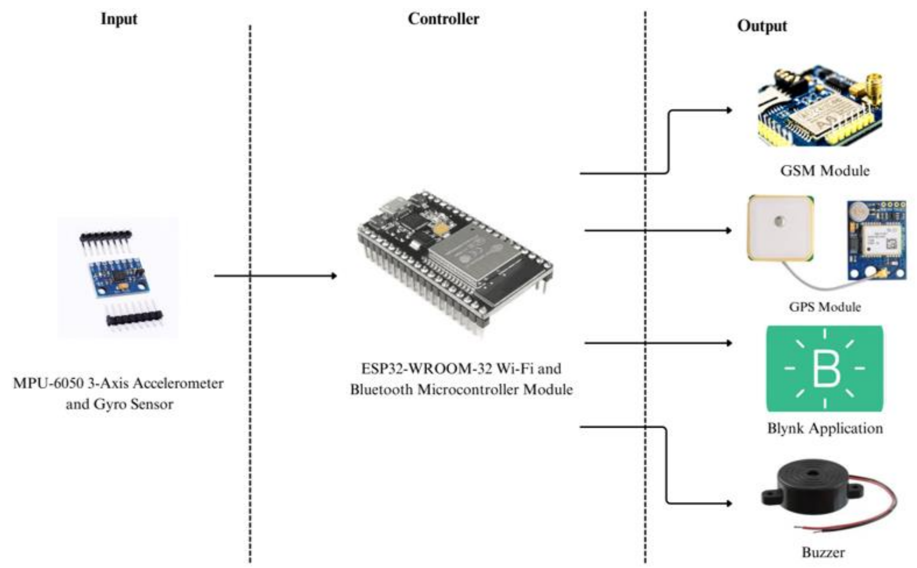
The proposed IoT-based smart helmet system is designed to enhance rider safety by combining real-time monitoring, accident detection, and emergency response within a single platform. Its architecture integrates multiple sensors, a microcontroller, and communication modules to detect unsafe conditions, prevent accidents, and alert both the rider and external contacts in critical situations. The system design is illustrated in Fig. 1, which highlights the structure and interaction of the input, control, and output units. Fig. 1(a) illustrates the overall architecture of the proposed IoT-based smart helmet system, which consists of three main units which are the input unit, control unit, and output unit. The input unit includes several sensors such as the MPU6050 accelerometer and gyroscope for crash detection, MQ-3 alcohol sensor for intoxication monitoring, TCRT5000 infrared sensor for drowsiness detection, an infrared sensor for helmet-wearing verification, and an HC-SR04 ultrasonic sensor for obstacle distance measurement. The collected sensor data are transmitted to the ESP32-WROOM-32 microcontroller, which acts as the control unit to process the data and identify unsafe conditions. When abnormal situations are detected, the system activates the output unit to alert the rider and emergency contacts through a buzzer, LEDs, GSM module for SMS and call notifications, GPS module for location tracking, and the Blynk mobile application for real-time monitoring. Fig. 1(b) presents the crash detection subsystem, where the MPU6050 sensor continuously measures the rider's acceleration and orientation during riding. The ESP32 calculates the total G-force and compares it with a predefined crash threshold [11]. If the value exceeds the threshold, the system identifies a potential crash and initiates a short countdown to prevent false alerts. If the alert is not cancelled, the system activates the emergency response by triggering the buzzer and sending the rider's GPS location to predefined contacts through the GSM module.

2.1 Block Diagram of The IoT-based Smart Helmet System

The methodology of the proposed IoT-based smart helmet system is illustrated in the block diagram shown in Fig. 1, which outlines the overall system architecture and data flow between the input, control, and output units. The design integrates multiple sensors, a microcontroller, and communication modules to enable real-time accident detection, prevention, and rider safety monitoring. From the figure, the input unit consists of several sensors that continuously collect data related to the rider's physical condition and surrounding environment. The MPU-6050 accelerometer and gyroscope sensor monitor sudden changes in acceleration and angular motion to detect potential crash events. The MQ-3 alcohol gas sensor measures the presence of ethanol in the rider's breath to identify intoxication levels that may impair riding ability. A TCRT5000 infrared sensor is used to monitor eye blink patterns, allowing detection of rider drowsiness or fatigue. In addition, an infrared (IR) sensor is employed to verify whether the helmet is properly worn, while an HC-SR04 ultrasonic sensor measures the distance to nearby obstacles to support accident prevention through early warning. All sensor data are transmitted to the control unit, which is centered on the ESP32-WROOM-32 microcontroller. An ESP32-WROOM-32 microcontroller serves as the main control unit, interfaced with an MPU-6050 accelerometer and gyroscope for crash detection, an MQ-3 alcohol gas sensor for intoxication monitoring, a TCRT5000 infrared sensor for drowsiness detection, an infrared sensor for helmet-wearing verification, and an HC-SR04 ultrasonic sensor for obstacle distance measurement.



(a)



(b)

Fig. 1 *Block diagram of the IoT-enabled Smart Helmet designed for real-time crash detection, rider safety monitoring through alcohol and drowsiness detection, and distance monitoring to enhance accident prevention (a) Overall system; (b) Crash detection system*

A GPS module is used for real-time location tracking, while a SIM900A GSM module enables automatic emergency SMS notifications and calls. Audible and visual alerts are provided through a piezoelectric buzzer and light-emitting diodes (LEDs). System programming and integration are carried out using the Arduino IDE, with real-time monitoring and alert visualization supported through the Blynk mobile application. The ESP32 processes the incoming signals in real time and compares them against predefined threshold values. When abnormal conditions such as a crash impact, alcohol detection, excessive drowsiness, or close obstacle proximity are identified, the microcontroller triggers appropriate system responses. The ESP32 is selected due to its high processing capability, low power consumption, and built-in support for wireless communication [12]– [13].

The output unit, as shown in the block diagram, is responsible for alerting the rider and external parties during critical situations. A piezoelectric buzzer and light-emitting diodes (LEDs) provide immediate audible and visual warnings to the rider when unsafe conditions are detected. For emergency situations, the SIM900A GSM module is activated to automatically send SMS notifications and initiate emergency calls to predefined contacts. Simultaneously, the GY-NEO-6M GPS module supplies real-time latitude and longitude data, ensuring accurate location tracking during accident reporting. The system software is developed using the Arduino IDE, where sensor data acquisition, decision logic, and communication protocols are implemented. The smart helmet is also integrated with the Blynk mobile application, enabling real-time visualization of sensor data and system status on a smartphone. This combination of hardware and software components forms a complete IoT-enabled safety system capable of both preventive monitoring and rapid emergency response.

2.2 System Operation

The operational flow of the proposed IoT-based smart helmet system is designed to function continuously in real time, ensuring both preventive monitoring and rapid emergency response. Once the helmet is powered on, the ESP32-WROOM-32 microcontroller initializes all connected sensors and communication modules. The system begins by verifying helmet usage using the infrared sensor to ensure that the helmet is properly worn before enabling full operation. During normal riding conditions, the system continuously collects data from multiple sensors. The MPU-6050 accelerometer and gyroscope monitor motion patterns and orientation to identify abnormal acceleration or impact that may indicate a crash. At the same time, the MQ-3 alcohol sensor analyzes the rider's breath to detect the presence of alcohol, while the TCRT5000 infrared sensor tracks eye blink activity to identify signs of rider drowsiness. The ultrasonic sensor measures the distance between the rider and nearby obstacles to provide early warning of potential collisions. All sensor data are processed in real time by the ESP32 microcontroller, which compares the measured values against predefined threshold limits. If alcohol levels exceed the allowable limit, excessive drowsiness is detected, or an obstacle is detected within a critical distance, the system immediately triggers warning responses. These responses include activating the piezoelectric buzzer and visual indicators to alert the rider and prompt corrective action.

In the event of a crash, identified by a sudden and significant change in acceleration or orientation, the system enters an emergency mode. A short delay of 10-second is applied to prevent false triggering, after which the system automatically retrieves the rider's real-time location using the GPS module. The GSM module is then activated to send an emergency SMS containing the accident alert and GPS coordinates to predefined emergency contacts, followed by an automatic emergency call if required.

Simultaneously, system data and alerts are transmitted to the Blynk mobile application, allowing real-time monitoring of helmet status, sensor readings, and emergency notifications. This operational workflow ensures that the proposed smart helmet not only detects accidents after they occur but also actively monitors unsafe conditions to prevent accidents, providing a comprehensive rider safety solution.

3. Results and Discussion

This section discusses the results obtained from system testing and provides an analysis of the performance of the proposed smart helmet.

3.1 Final Product

The final prototype of the proposed IoT-based smart helmet system demonstrates the complete integration of hardware components while maintaining comfort and usability. Fig. 2 presented from multiple perspectives to illustrate the complete physical implementation and integration of hardware components. The prototype demonstrates successful embedding of sensing, control, and communication modules within a standard motorcycle helmet while maintaining usability and comfort. As shown in Fig. 2(a), the front view highlights the placement of the infrared sensor used for helmet-wearing detection, ensuring that the system activates only when the helmet is properly worn. The front-mounted ultrasonic sensor is also visible in this view, positioned to detect obstacles in the rider's forward path and provide early warning for accident prevention. The placement ensures unobstructed sensing while minimizing interference with the rider's vision. The top view of the prototype, illustrated in Fig. 2(b), shows the internal arrangement of the main control and communication modules. The ESP32-WROOM-32 microcontroller is centrally positioned to efficiently process data from all sensors. The MPU-6050 accelerometer and gyroscope sensor is mounted near the helmet's center to accurately capture motion and impact forces during riding and potential crash events. This placement improves crash detection reliability by reducing measurement distortion caused by helmet movement. Fig. 2(c) presents the left-side view of the

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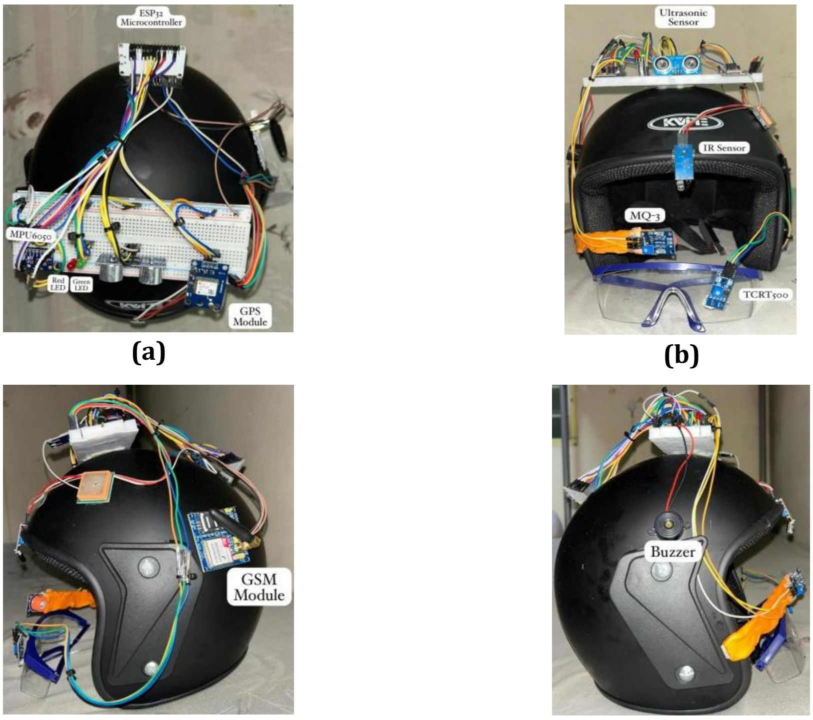
helmet, where the MQ-3 alcohol sensor is located near the rider's mouth region to effectively detect alcohol presence in exhaled breath. The TCRT5000 infrared sensor for drowsiness detection is also integrated in this area to monitor eye blink activity. This positioning allows continuous monitoring of rider condition without causing discomfort or obstruction. The right-side view, shown in Fig. 2(d), displays the GPS and GSM modules, along with the piezoelectric buzzer and visual indicator LEDs. The GPS module is positioned to maximize satellite signal reception, while the GSM module enables reliable communication for emergency alerts. The buzzer and LEDs provide immediate audible and visual feedback to the rider during unsafe conditions such as alcohol detection, drowsiness, obstacle proximity, or crash events.

Overall, the final prototype validates the practical feasibility of the proposed system. The integration of multiple sensors and communication modules within a wearable helmet demonstrates the system's ability to perform real-time monitoring, accident detection, and emergency response. The physical design, as shown in the multi-view images, confirms that the smart helmet can function as a complete IoT-enabled safety solution while remaining suitable for real-world motorcycle use.



(a) (b) (c) (d)

Fig. 2 *Final product of the IoT-based smart helmet for real-time crash detection, accident prevention, and rider safety monitoring shown from multiple perspectives: (a) Top view, (b) Front view, (c) Left view and (d) Right view*

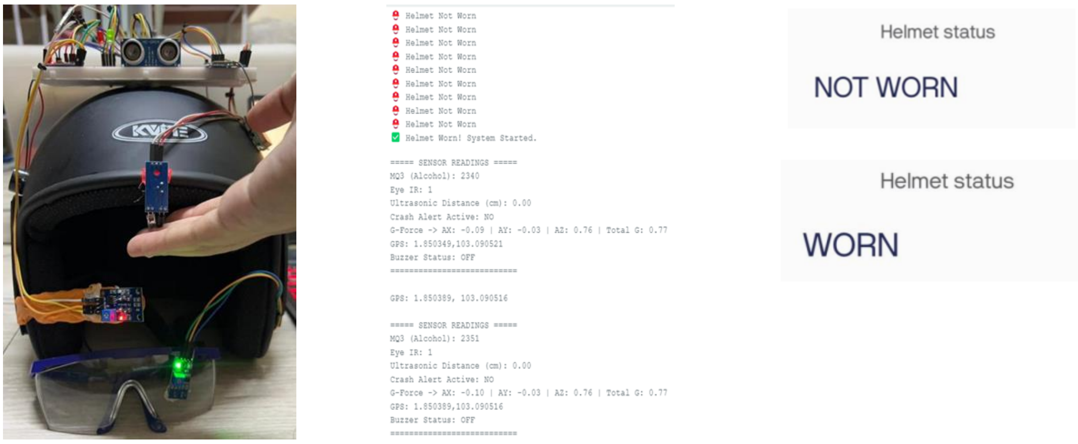
3.2 System Operation Analysis

The operation of the IoT-based smart helmet can be divided into three distinct phases: before riding, during riding, and after a crash. Each phase integrates multiple sensors and modules under the control of the ESP32 microcontroller, ensuring both preventive and responsive safety measures.

3.2.1 Before Riding - Helmet Wearing Detection

The helmet wearing detection system utilizes an infrared (IR) sensor positioned inside the helmet to verify whether the rider is wearing it. The sensor operates by detecting the presence of the rider's head through reflected infrared signals. If the helmet is not worn, the system remains inactive, thereby preventing activation of other safety features. This ensures compliance with basic protective measures and enforces rider discipline before the motorcycle can be operated. Fig. 3 illustrates the helmet-wearing verification process before system activation. In Fig. 3(a), an IR sensor inside the helmet detects the presence of the rider's head. If the helmet is not worn, the system remains off and all sensors are inactive, preventing false alerts. Fig. 3(b) shows the serial monitor output, where the status displays "Helmet Not Worn" when the helmet is off. Once the helmet is worn, the status changes to "Helmet Worn!" and the message "System Started" indicates that all sensors are activated. Fig. 3(c) shows the helmet status in the Blynk application, which changes from "NOT WORN" to "WORN" when the helmet is properly worn. This confirms that the system only operates when the helmet is correctly worn.

Validation was conducted under two conditions which are helmet worn and helmet not worn. The IR sensor output was monitored through the Arduino Serial Monitor, Blynk application, and the alert system consisting of buzzer and LED indicators. When the helmet was not worn, the Serial Monitor displayed repeated messages stating "Helmet Not Worn," and the Blynk application interface showed "Helmet status NOT WORN." In this state, the buzzer remained active and the system prevented further operation. Once the helmet was worn, the Serial Monitor updated to "Helmet Worn System Started," and the Blynk application reflected "Helmet status WORN." The buzzer was deactivated, and the system proceeded to activate other modules such as alcohol detection, obstacle awareness, and crash monitoring.



(a) **(b)** **(c)**

Fig. 3 *Helmet wearing detection using IR sensor: (a) Circuit assembly of IR sensor with ESP32 microcontroller; (b) Serial Monitor output showing detection status; (c) Blynk application interface displaying helmet-wearing verification*

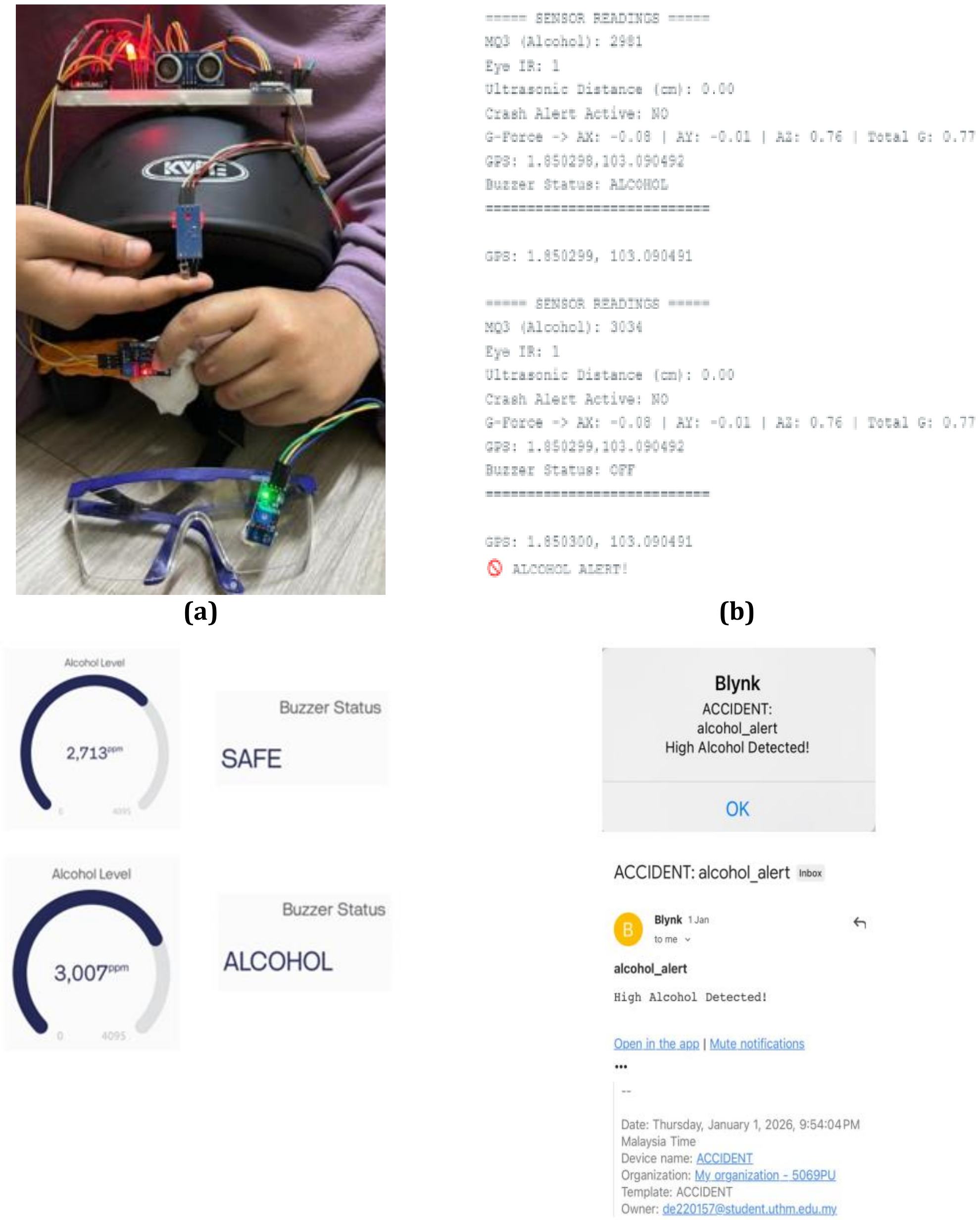
3.2.2 During Riding - Real-Time Monitoring

During riding, the smart helmet continuously monitors the rider's condition and surroundings using four key sensors: the MQ-3 alcohol sensor, TCRT5000 infrared sensor, HC-SR04 ultrasonic sensor, and MPU6050 accelerometer and gyroscope. These sensors are coordinated by the ESP32 microcontroller, which processes the inputs and triggers alerts through buzzer, LEDs, Blynk application, and Gmail notifications.

(i) MQ-3 Alcohol Sensor

In the smart helmet system, the MQ-3 sensor is positioned near the rider's mouth area to measure breath alcohol concentration (BAC) [5]. The sensor output is continuously monitored, and if the readings exceed a predefined threshold, the system interprets this as intoxication. Alerts are then triggered through buzzer, LEDs, the Blynk mobile application, and Gmail notifications. This ensures that riders are warned immediately and prevents unsafe riding conditions. Fig. 4 demonstrates how the MQ-3 sensor detects intoxication and activates safety protocols in real time. This alert is triggered immediately when the alcohol level exceeds the set threshold, preventing riding under intoxication. In Fig. 4(a), the alcohol sensor is installed inside the helmet to monitor the rider's breath and send readings to the ESP32. Fig. 4(b) shows the serial monitor output, where normal operation occurs below a reading of 3000. When the value exceeds this threshold, the system displays "ALCOHOL ALERT!" and activates the buzzer. Fig. 4(c) shows the Blynk application, which displays the alcohol level and changes the buzzer status from "SAFE" to "ALCOHOL." Fig. 4(d) shows notification alerts from Blynk and Gmail, informing the rider that a high alcohol level has been detected. These results confirm that the system responds quickly and helps prevent riding under the influence.

Validation was conducted by exposing the MQ-3 alcohol sensor to simulated alcohol vapours during riding conditions. The Arduino Serial Monitor displayed elevated sensor readings, indicating the presence of alcohol. Simultaneously, the Blynk application interface updated the alcohol level in parts per million (ppm), changing the buzzer status from "SAFE" to "ALCOHOL." The system triggered an alert response, including buzzer activation and Blynk notifications. A Gmail alert titled "ACCIDENT: alcohol_alert" was also sent, confirming high alcohol detection. These results demonstrate that the MQ-3 sensor reliably detects alcohol presence and initiates multi-channel alerts, thereby preventing intoxicated riding and enhancing rider safety [14]– [15].



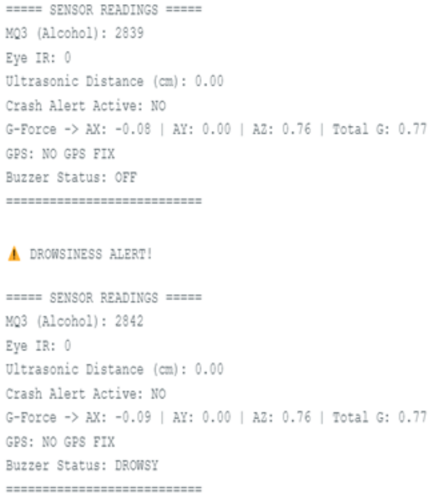
(c) (d)

Fig. 4 *Real-time monitoring during riding: (a) Smart helmet prototype with integrated MQ-3 sensors; (b) Serial Monitor output displaying sensor readings; (c) Blynk application interface showing alcohol status; (d) Alert system response triggered by unsafe riding conditions*

(ii) TCRT500 Eye Blink (Drowsiness) Sensor

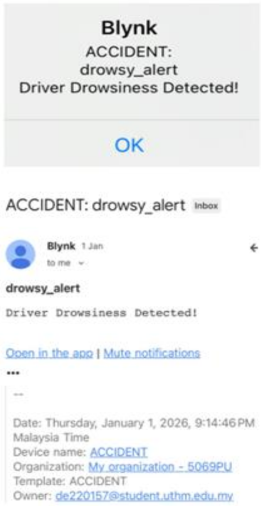
The TCRT5000 is used to monitor eye blinks [16]. Normal blinking produces short reflection interruptions, while prolonged closure which are 2 seconds indicates drowsiness [17]. The system then triggers alerts via buzzer, LEDs, and Blynk notifications to warn the rider. Fig. 5 illustrates the drowsiness detection system using the TCRT5000 IR sensor to monitor eye blinks. It shows how normal blinking produces short interruptions. Fig. 5 demonstrates the drowsiness detection function of the system. In Fig. 5(a), the IR sensor monitors the rider's eyes and detects drowsiness when the eyes remain closed for more than two seconds. Fig. 5(b) shows the serial monitor output, where the status changes from "SAFE" to "DROWSY" and the buzzer is activated. Fig. 5(c) shows the Blynk application, which updates the eye status from "OPEN" to "CLOSED" and turns on the buzzer. Fig. 5(d) shows notification alerts from Blynk and Gmail warning that the rider is drowsy. These results confirm that the system can detect fatigue and respond quickly to help prevent accidents.

(a)



(b)

(c)



(d)

Fig. 5 *Drowsiness detection system using TCRT5000 infrared sensor: (a) Smart helmet setup with eye-monitoring sensor; (b) Serial Monitor output showing eye status and drowsiness alert; (c) Blynk application interface displaying eye status and buzzer response; (d) Blynk notification and Gmail alert confirming drowsiness detection*

Observation was made by simulating eye closure using the TCRT5000 infrared sensor positioned near the rider's eye. The Arduino Serial Monitor displayed "Eye: 0" when the eyes were closed, triggering a "DROWSINESS ALERT" and activating the buzzer. The Blynk application interface updated the eye status from "OPEN" to "CLOSED" and changed the buzzer status from "SAFE" to "DROWSY." A Blynk notification and Gmail alert titled "ACCIDENT: drowsy_alert" were sent, confirming that the system successfully detected prolonged eye closure and initiated emergency warnings. These results demonstrate that the TCRT5000 sensor reliably monitors blink patterns and identifies drowsiness, enhancing rider safety during long or fatigued rides.

(iii) Ultrasonic Sensor (Obstacle Detection)

The HC-SR04 is mounted on the helmet to detect nearby vehicles or objects. If an obstacle is detected within a critical distance which are 1 m, the system triggers buzzer and LED alerts. Sensor readings are displayed on the Arduino Serial Monitor and updated in the Blynk app, ensuring the rider receives immediate warnings. Fig. 6 demonstrates the obstacle detection system using the HC-SR04 ultrasonic sensor mounted on the helmet. In Fig. 6(a), the ultrasonic sensor is mounted on the helmet to measure the distance to nearby objects. When no object is detected within the set range, the system remains in a safe state. Fig. 6(b) shows the serial monitor output, where

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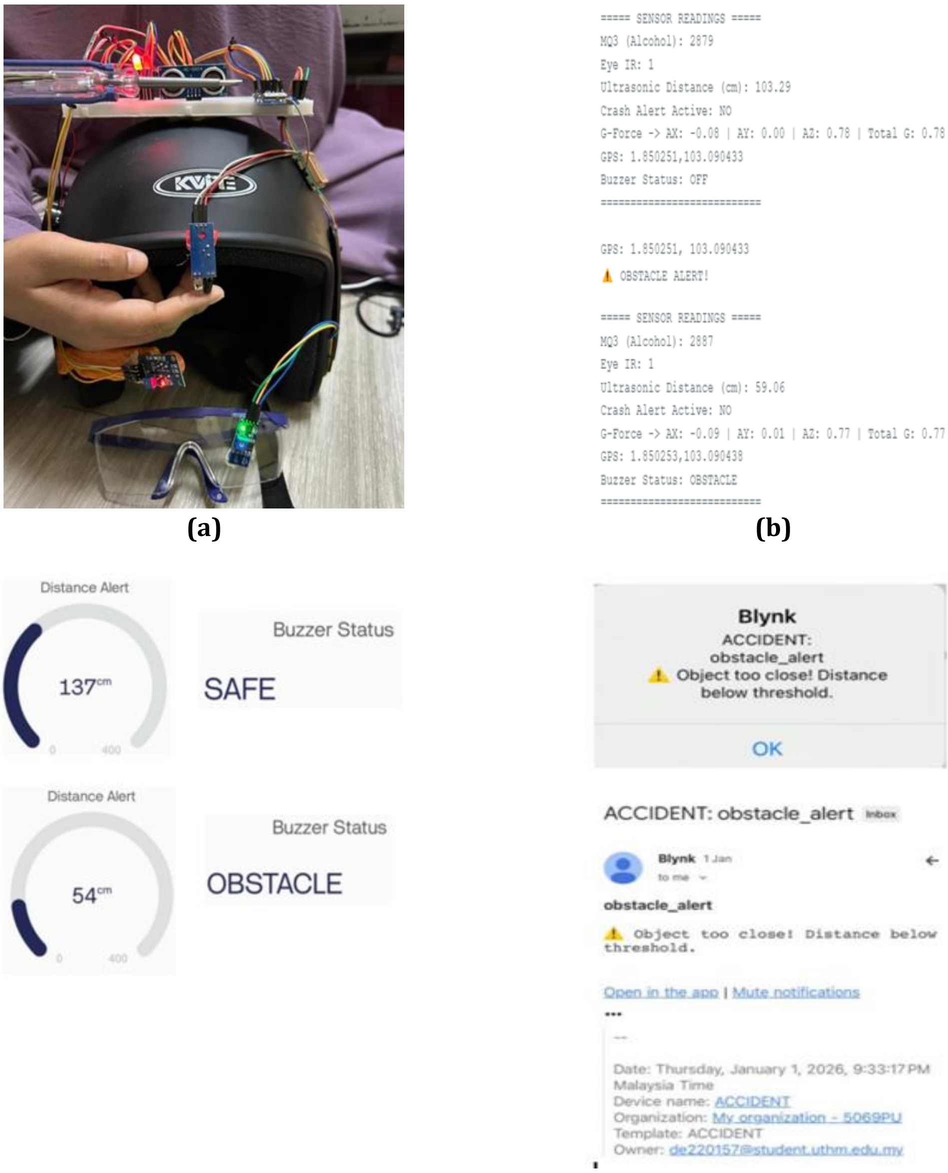
an "OBSTACLE ALERT!" is displayed and the buzzer is activated when an object is detected within 1 m. Fig. 6(c) shows the Blynk application, which displays the measured distance and changes the buzzer status from "SAFE" to "OBSTACLE." Fig. 6(d) shows notification alerts from Blynk and Gmail, warning the rider of a nearby object. These results confirm that the system can detect obstacles and provide timely alerts to help prevent collisions.



(a) (b) (c) (d)

Fig. 6 *Obstacle detection system using HC-SR04 ultrasonic sensor: (a) Smart helmet setup with ultrasonic sensor module; (b) Serial Monitor output showing distance readings and obstacle alert status; (c) Blynk application interface displaying distance gauge and buzzer response; (d) Blynk and Gmail notification confirming proximity alert activation*

Testing was carried out by placing objects at varying distances in front of the HC-SR04 ultrasonic sensor mounted on the helmet. The Arduino Serial Monitor displayed real-time distance measurements as the object approached. When the measured distance fell below the predefined threshold, the system triggered an "OBSTACLE ALERT," and the buzzer status changed from "OFF" to "OBSTACLE." The Blynk application interface updated the "Distance Alert" gauge and activated a mobile notification labeled "ACCIDENT:obstacle_alert," warning that an object was too close. These results confirm that the ultrasonic sensor accurately detects nearby obstacles and initiates timely alerts, enhancing rider awareness and safety during navigation.

(iv) MPU6050 Accelerometer and Gyroscope (Crash Detection)

The system continuously tracks the rider's total G-force, and when the measured value exceeds the crash threshold of 2.5 g, it is classified as an accident. A 10-second countdown is then initiated to allow cancellation of false triggers. If the alert is not canceled, the emergency protocol is activated, which automatically sends GPS coordinates via SMS, triggers buzzer and LED alerts, and delivers Blynk and Gmail notifications to designated emergency contacts. Fig. 7 illustrates the crash detection system using the MPU6050 sensor, which continuously tracks the rider's total G-force. In Fig. 7(a), the MPU6050 accelerometer and gyroscope detect sudden changes in acceleration along the x, y, and z axes. When the total acceleration exceeds the crash threshold of 2.5 g, the system identifies a potential crash. Fig. 7(b) shows the serial monitor output before and after the threshold is exceeded, including acceleration values, total g, and a 10-second countdown timer that allows the rider to cancel the alert in case of a false trigger, while the buzzer is activated. Fig. 7(c) shows the Blynk application, which displays real-time crash status through graphical gauges updated via virtual pins V4–V7. Fig. 7(d) shows emergency notifications sent through Blynk and Gmail with the GPS location when a crash is confirmed. These results confirm that the system can accurately detect crashes and provide timely emergency alerts.

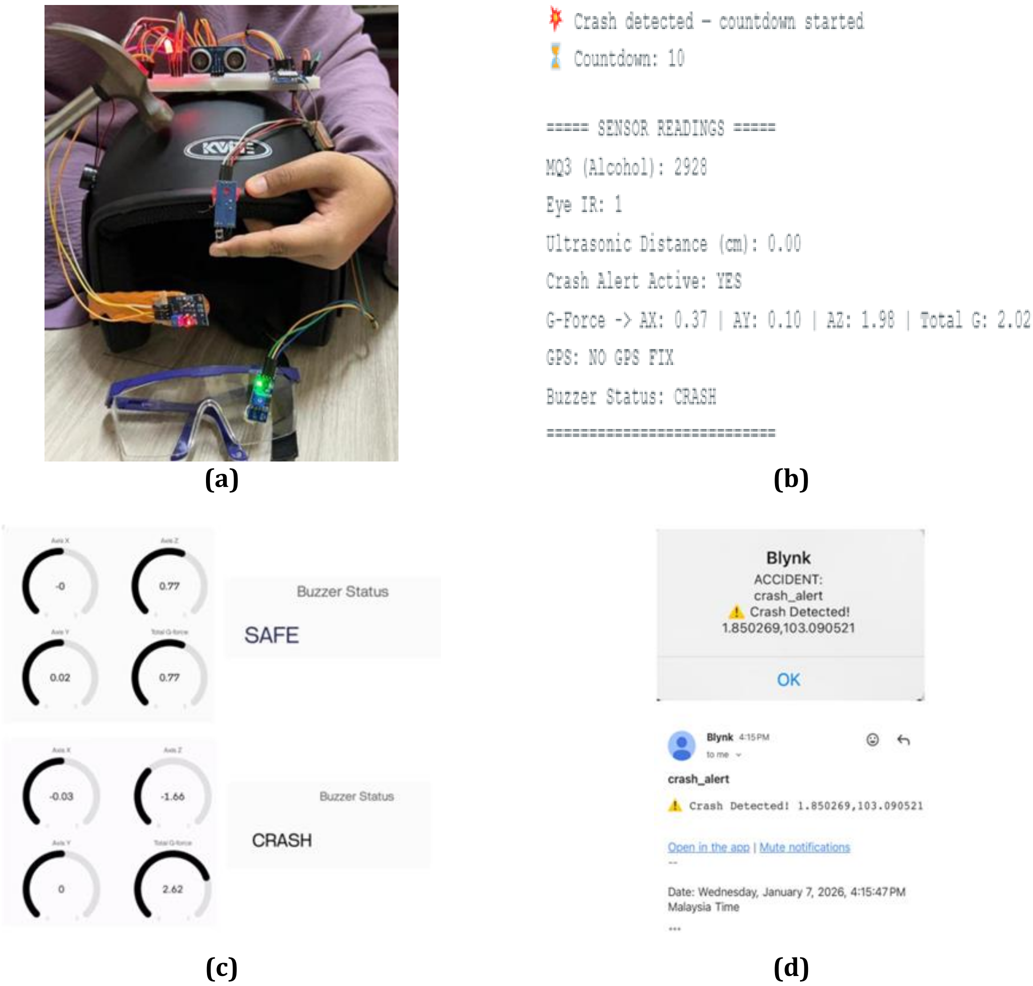


Fig. 7 *Crash detection system using MPU6050 sensor: (a) Experimental setup simulating crash impact; (b) Serial Monitor output showing G-force readings, crash alert status, and initiation of the 10-second countdown for rider confirmation. (c) Blynk application interface displaying crash status and buzzer response; (d) Blynk and Gmail notification confirming crash detection*

Crash detection was tested by simulating impact forces that exceeded the 2.5 g threshold using the MPU6050 accelerometer and gyroscope. The Arduino Serial Monitor displayed "Crash Alert Active: YES" along with real-time G-force readings across all axes. Upon detection, a 10-second countdown was initiated to allow cancellation of false alerts. If not canceled, the buzzer status changed to "CRASH," and the system activated the emergency protocol. The Blynk application interface updated the crash status and issued a mobile notification labeled "ACCIDENT: crash_alert," including GPS coordinates for emergency response. These results confirm that the MPU6050 sensor accurately detects crash events and reliably triggers the helmet's emergency safety system.

3.2.3 After a Crash – Emergency Response System

After the rider has finished riding or in the event of a crash, the GPS and GSM modules continue to play a crucial role in post-ride monitoring and emergency response.

(i) GPS Module (Location Tracking)

The GPS module acts as the location backbone of the emergency response system. When a crash is detected, it ensures that accurate coordinates are sent to emergency contacts, enabling rapid assistance. Without GPS integration, the helmet could detect accidents but would not be able to guide rescuers to the rider's exact position. Fig. 8 supports this functionality by showing how the GPS module captures and transmits precise location data during riding and emergency conditions, enabling accurate tracking and rapid response. In Fig. 8(a), the serial monitor displays live GPS coordinates from the GY-NEO 6M module, confirming successful satellite connection. Fig. 8(b) shows the same coordinates updated in the Blynk application for remote monitoring. Fig. 8(c) displays the location on Google Maps using these coordinates. These results confirm that the GPS system provides accurate real-time location tracking to support rapid emergency response.

System performance was tested by capturing GPS coordinates during normal riding. The GPS module accurately displayed latitude and longitude on the Arduino Serial Monitor as "GPS: 1.850239, 103.090545." These coordinates were consistently shown in the Blynk application and on a map, indicating the rider's location near Jalan Putra 3 and Kak Mah Corner. The GPS maintained stable tracking throughout, confirming its reliability for real-time location monitoring. This ensures that accurate coordinates can be sent after a crash for rapid emergency response.

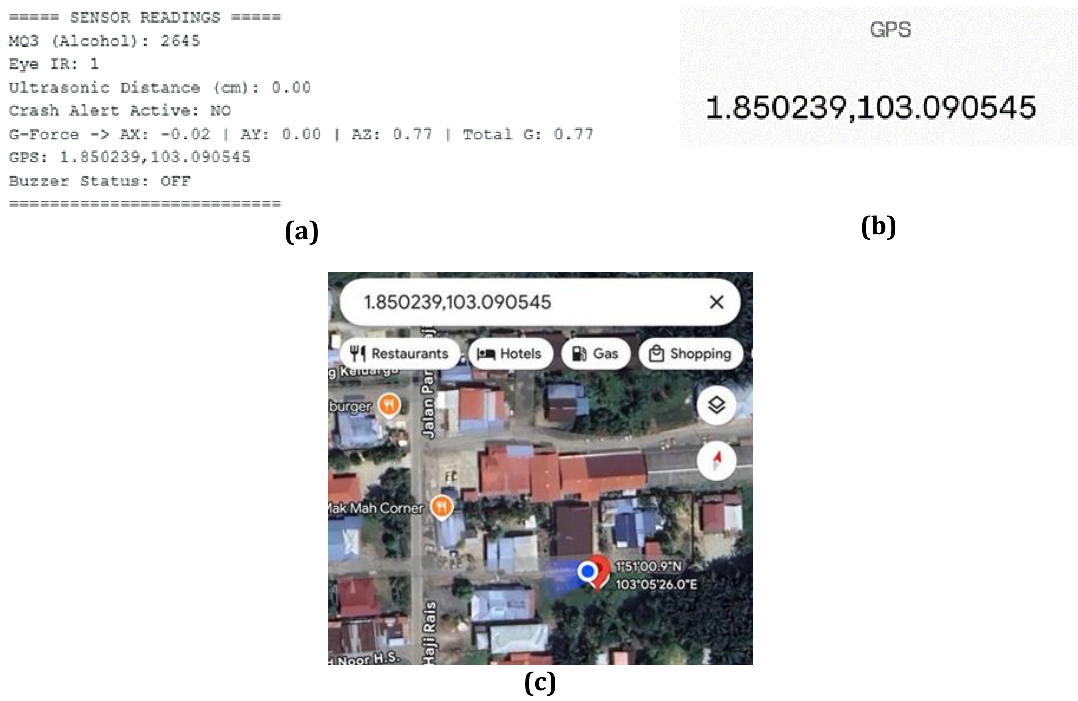
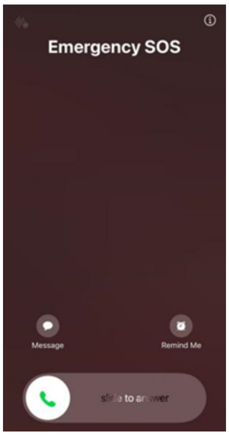


Fig. 8 *GPS module integration for location tracking: (a) Serial Monitor output displaying live GPS coordinates; (b) Blynk interface showing extracted location data; (c) Map showing the rider's position based on GPS data*

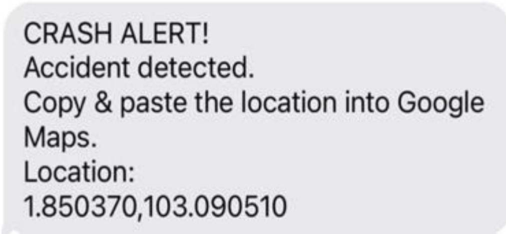
(ii) SIM900A GSM Module (Emergency SMS/Call)

In this smart helmet system, the SIM900A acts as the lifeline that bridges sensor detection with human response. It ensures that once a crash is confirmed, help can be summoned instantly. Fig. 9 supports this function by showing how the SIM900A GSM module transmits emergency SMS alerts with GPS coordinates immediately after a crash is confirmed, enabling rapid contact with responders. In Fig. 9(a), the GSM module automatically places an "Emergency SOS" call to a predefined contact. Fig. 9(b) shows an SMS alert containing the crash notification and GPS location. The alert can be cancelled during the countdown using the Blynk application. These results confirm that the SIM900A module provides reliable emergency communication and enables rapid assistance with accurate location information.

System performance was tested by simulating a crash. After the 10-second countdown, the SIM900A GSM module successfully sent an SMS alert with the rider's GPS coordinates ("1.850370, 103.090510") to a predefined contact. The message included "CRASH ALERT! Accident detected" and instructions to locate the rider on Google Maps. This confirms that the GSM module reliably delivers real-time crash alerts and location data for rapid emergency response.



(a)



(b)

Fig. 9 *Emergency SMS alert using SIM900A GSM module: (a) Mobile interface showing crash alert and call options; (b) SMS message containing GPS coordinates and instructions for locating the rider*

4. Conclusion

This project successfully developed an IoT-based smart helmet that integrates crash detection, accident prevention, and rider safety monitoring into a single system. The prototype combines multiple sensors MPU6050 accelerometer and gyroscope for crash detection, MQ-3 alcohol sensor for intoxication monitoring, TCRT5000 IR sensor for drowsiness detection, ultrasonic sensor for obstacle awareness, and an IR sensor for helmet-wearing verification, all controlled by an ESP32 microcontroller. GSM and GPS modules enhance the system by providing real-time emergency alerts and accurate location tracking, while the Blynk mobile application offers a user-friendly interface for monitoring and canceling alerts.

Key findings show that the MPU6050 sensor reliably detected crashes when total G-force exceeded 2.5 g, triggering a 10-second countdown for rider confirmation. The MQ-3 sensor detected alcohol levels above the set threshold, preventing unsafe riding. The TCRT5000 IR sensor effectively monitored eye closure exceeding two seconds, providing drowsiness alerts. The ultrasonic sensor accurately measured distances to obstacles and issued alerts when objects were within one meter. The GSM and GPS modules worked seamlessly to send SMS, make emergency calls, and share precise location coordinates, ensuring timely communication during emergencies. Integration with Blynk enabled real-time visualization of sensor data and allowed riders to cancel false crash alerts, improving system reliability.

Overall, the project achieved its objectives by showing that IoT technology can enhance motorcycle safety through both preventive and responsive measures. The smart helmet reduces accident risks by monitoring rider condition and surroundings while improving emergency response times through automatic notifications with location details. These results highlight the potential of IoT-enabled safety systems to reduce motorcycle fatalities and promote safer road environments.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nur Mellyna Mohd Nor;* ***data collection:*** *Nur Mellyna Mohd Nor;* ***analysis and interpretation of results:*** *Nur Mellyna Mohd Nor, Shaharil Mohd Shah;* ***draft manuscript preparation:*** *Nur Mellyna Mohd Nor, Shaharil Mohd Shah. All authors reviewed the results and approved the final version of the manuscript.*

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