Smart Guard Helmet Module: A Next-Gen AI Helmet module For Rider Protection and Real Time Alert

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ABSTRACT

Two-wheeler riders are highly vulnerable to road accidents because of factors such as rider fatigue, improper helmet usage, and delays in emergency response. To improve rider safety, this paper proposes a Smart Guard Helmet Module, an advanced IoT-enabled safety system designed for continuous monitoring and real-time emergency assistance. The proposed system is built around an ESP32 microcontroller for data processing and communication. It integrates an MPU sensor for accident and sudden impact detection, an IR sensor for helmet-wearing detection, a microphone (mic) and speaker connected through the MAX98357 audio amplifier for voice alerts and warning notifications, and a SIM A7 communication module for transmitting emergency alerts and location details. In addition, buck and boost converters are used to provide stable power management for the entire system.

When unsafe riding conditions or an accident are detected, the helmet automatically triggers warning alerts and sends emergency messages to predefined contacts through the communication module, enabling quicker assistance. The developed prototype demonstrates reliable performance, rapid response time, and cost-effective implementation. These results indicate that the proposed Smart Guard Helmet Module has strong potential for practical deployment in real-world two-wheeler safety applications.

Keywords: Smart Helmet, Internet of Things, Rider Safety, Accident Detection, ESP32, MPU Sensor, SIM A7670C Module, Helmet Detection, Real-Time Alert System, MAX98357 Audio Module,1x4 keypad.

1. INTRODUCTION

Road safety has become a major global concern, especially for two-wheeler riders who are more exposed to severe injuries and fatalities during road accidents. In developing countries, motorcycles and scooters are widely used because they are affordable, fuel-efficient, and convenient for traveling through heavy traffic. However, compared to four-wheelers, two-wheelers offer limited built-in safety features. As a result, accidents involving two-wheelers continue to increase, often caused by factors such as rider fatigue, improper helmet usage, sudden collisions, and delayed emergency response after an accident [1][9][13].

Conventional helmets mainly provide passive protection by reducing the impact of head injuries during collisions. Although they are essential safety equipment, traditional helmets do not actively monitor rider condition or provide assistance during emergencies. Recent developments in the Internet of Things (IoT) have created opportunities to transform ordinary helmets into smart safety devices capable of real-time monitoring, accident detection, and emergency communication [2][7][15].

Several smart helmet systems have been proposed in recent years. Many of these systems focus on isolated features such as accident detection, alcohol sensing, or location tracking. However, many existing solutions rely on costly hardware, limited functionality, or lack practical emergency communication support, which reduces their effectiveness in real-world use. In particular, some systems do not provide direct communication between the rider and emergency contacts after an accident [3][6][11].

To address these limitations, this paper presents the Smart Guard Helmet Module, an IoT-based smart safety helmet designed to provide continuous rider monitoring, accident detection, and rapid emergency response. The proposed system is built around the ESP32 microcontroller, which acts as the central processing unit for coordinating sensor inputs and communication tasks. An MPU sensor is used to detect sudden impacts, abnormal motion, and accident conditions. An IR sensor is integrated to verify whether the rider is wearing the helmet properly before vehicle operation [4][8][10].

For emergency communication, the system uses a SIM A7670C module that enables automatic alert transmission when an accident is detected. In addition to sending emergency messages, the helmet also supports a calling feature. Through dedicated control buttons mounted on the helmet, the rider can receive incoming calls, answer calls, and end calls without needing to access a mobile phone directly. This feature improves rider convenience and safety, especially during urgent situations [5][12][14].

The proposed helmet further includes a microphone and a speaker, interfaced through the MAX98357 audio amplifier module, to provide clear voice communication and audio alert notifications. These components allow the rider to receive warning messages and communicate effectively during emergencies. To ensure stable operation of all electronic components, buck and boost converters are incorporated for efficient power management and voltage regulation [4][9][15].

Unlike conventional helmet systems that mainly focus on post-accident response, the Smart Guard Helmet Module combines both preventive and emergency safety functions in a single compact and cost-effective design. By continuously monitoring rider behavior, detecting accident conditions, ensuring helmet usage, and enabling immediate communication support, the proposed system aims to improve two-wheeler safety significantly. Its practical design, low implementation cost, and scalability make it suitable for real-world deployment and future enhancement in intelligent transportation safety systems [1][7][15].

2. LITERATURE REVIEW

Table 2.1 Comparative Summary research papers (2016-2025)

Originating information		**Result Outcomes**		
Author/s	Purpose/Aims	Results	Contribution	Limitation of research outcomes
. Prasad, A. Aryan, S. R. Swamy, A. Kishore, H. Deepanjali, and A. Karan [1]	The main aim was to develop a smart helmet using AI and IoT to enhance driver safety, reduce accidents, and ensure safer riding practices.	The helmet was able to monitor driving behavior and detect unsafe conditions effectively,	It contributed to the growing body of research on smart wearable safety devices, proposing a	The work is limited to a prototype stage and needs large-scale trials and real-world validations to prove effectiveness.

April 2025		showing promise as a preventive safety tool.	new AI–IoT integration for helmets.	
S. Sharma, S. Rai, and A. A. Ansari. [2] 2025.	The study aimed to design an IoT-enabled helmet that can detect accidents and send quick alerts to ensure timely medical help.	The system successfully detected simulated accidents and transmitted alerts, showing practical usefulness in reducing accident response time.	The paper adds value by demonstrating how IoT can directly contribute to accident prevention and emergency response for two-wheelers.	Scalability, power management, and real-world connectivity issues remain unresolved and were identified as future challenges.
V. Bangera, A. S. M., P. R. Betrabet, and K. R. N. S. [3] 2022	The primary goal was to build an automated helmet detection system that could support traffic enforcement and encourage compliance with safety rules.	The machine learning approach achieved good detection accuracy under normal conditions, making it a feasible solution for real-time traffic monitoring.	The research contributed an automated tool for identifying helmet violations, reducing reliance on manual monitoring by traffic police.	The solution struggles in challenging weather, poor lighting, and occlusion, limiting its effectiveness in uncontrolled environments.
P. C., R. C., P. N. M., R. P. S., and S. M. [4] 2022	To design a smart bike helmet equipped with vehicle tracking features using Arduino, ensuring both safety and location monitoring.	Successfully tracked vehicle location and integrated it with helmet-based safety systems.	Demonstrates how Arduino and GPS/GSM can be integrated into helmets for combined safety and tracking.	Does not address battery backup, scalability, or long-term durability in real-world conditions.
S. Nanda, H. Joshi, and S. Khairnar [5] 2018	To build an IoT-based smart system that prevents accidents by monitoring conditions	The system was able to detect abnormal situations and	Early attempt to combine IoT with helmets for accident	Prototype stage; reliability in diverse traffic conditions not proven.

	and detecting collisions.	provide timely alerts.	monitoring and prevention.	
Somantri and I. Yustiana [6] 2022	To design a smart helmet integrated with motorcycles to improve rider awareness and ensure safety using IoT.	Helmet successfully communicated with the motorcycle system to enhance safety.	Adds to research on vehicle–wearable integration for proactive safety.	Field trials and durability analysis missing.
F. Naz, S. Ghildiyal, H. Negi, and A. Shankar [7] 2023	To develop a multi-functional helmet that combines several safety features to protect riders.	Provided effective monitoring and safety alert functions.	Shows how multiple safety technologies can be combined into one helmet system.	Needs real-world trials and performance validation under different traffic conditions.
V. R. Ch., S. Murala, S. Chegondi, S. S. Myla, K. Myla, and D. R. Kalava [8] 2024	To create an IoT-based helmet system that improves bike rider safety.	Helmet provided effective safety alerts and monitoring.	Expands on how IoT can improve helmet design for everyday riders.	System requires real-world pilot deployment for reliability testing.
M. E. Alim, S. Ahmad, M. N. Dorabati, and I. Hassoun [9] 2020	To design and implement a smart helmet capable of detecting road accidents using IoT technology.	Helmet system detected impacts and communicated accident information effectively.	Demonstrates IoT's usefulness in accident reporting and helmet-based safety innovations.	Remains at prototype level; lacks performance testing under real traffic conditions.
S. J. Swathi, S. Raj, and D. Devaraj [10] 2019	To design a microcontroller and sensor-based system for enhancing rider safety.	Demonstrated ability to monitor riding conditions and enhance safety features.	Provides an example of sensor-based approaches to rider safety.	Requires field testing for reliability and user adaptability.
A. P. Akul, A. M. B. Abhijna,	To implement a camera sensor that detects helmets and	System successfully detected helmet	Bridges helmet detection with ECU, making	Performance may vary under low-visibility and

and D. T. Avlani [11] 2024	integrates with ECU for two-wheeler safety.	usage and communicated with the ECU.	safety enforcement automated at vehicle level.	diverse environmental conditions.
A. P. Akul, A. M. B. Abhijna, and D. T. Avlani [12] 2024	To integrate camera-based helmet detection with ECU to automate safety features in two-wheelers.	Proved that ECU integration is feasible for helmet enforcement.	Strengthens the case for merging rider detection systems with vehicle electronics.	Performance may vary under low-visibility and diverse environmental conditions.
N. Manjunathan, P. Rajesh, and A. Suresh [13] March 2019	To detect drunk driving using IoT-based sensors for road safety.	Successfully detected alcohol consumption and communicated warnings.	Expands IoT use from helmets to broader driver safety applications.	Prototype only; needs ethical approval and real-world validation with drivers.
C. J. Behr, A. Kumar, and G. P. Hancke [14] 2016	To design a helmet for miners that monitors air quality and detects hazardous events.	Helmet successfully detected air quality levels and hazardous events.	Extends smart helmet applications beyond traffic to industrial safety.	Limited to experimental testing; not deployed in real mining operations.
I. Campero-Jurado, S. Márquez-Sánchez, S. Rodríguez, J. M. Corchado, and J. Quintanar-Gómez [15] November 2020	To develop Smart Helmet 5.0 for industrial IoT applications using artificial intelligence.	Helmet provided effective AI-driven monitoring for worker safety.	Pushes smart helmet concept into industrial IoT and AI domains.	Limited trials; requires long-term validation across multiple industries.

3. OUR FINDING FROM THE STUDIED LITERATURE

N. Prasad, A. Aryan, S. R. Swamy, A. Kishore, H. Deepanjali, and A. Karan presented an AI and IoT based smart helmet aimed at enhancing rider safety through real-time monitoring. Their system integrated accident detection, alcohol sensing, helmet usage verification, and emergency alert mechanisms using GPS and GSM. The study demonstrated that AI-assisted decision making improves the accuracy of

accident identification and reduces emergency response time, although increased system complexity was noted as a limitation.[1]
S. Sharma, S. Rai, and A. A. Ansari proposed an IoT-enabled smart helmet focusing on accident detection and automated emergency alerting. The system used sensor-based impact detection combined with real-time location sharing. Experimental results showed reliable accident recognition and faster notification to emergency contacts; however, the solution primarily addressed post-accident response rather than preventive safety measures.[2]
V. Bangera, A. S. M., P. R. Betrabet, and K. R. N. S. developed an automated helmet detection system using machine learning and computer vision techniques. The camera-based approach achieved high accuracy in identifying helmet compliance under controlled conditions. The study highlighted that vision-based methods significantly enhance enforcement but require high computational resources and consistent lighting conditions. [3]
P. C., R. C., P. N. M., R. P. S., and S. M. designed a smart bike helmet integrated with Arduino for vehicle tracking. The system utilized GPS and GSM modules to transmit real-time location data during accidents. The findings confirmed that low-cost microcontroller-based solutions can effectively support emergency tracking, though they lack advanced intelligence and preventive analytics.[4]
S. Nanda, H. Joshi, and S. Khairnar proposed an IoT-based smart helmet for accident prevention and detection using multiple sensors. Their study emphasized the importance of combining accident detection with preventive alerts such as speed and alcohol monitoring. The work concluded that early-warning mechanisms can significantly reduce accident severity but require user compliance. [5]
Somantri and I. Yustiana presented an IoT-based smart helmet integrated with the motorcycle system to improve rider safety. The helmet communicated directly with the vehicle to enforce helmet usage before ignition. Results showed improved compliance and reduced risk behavior, although system integration with different vehicle models posed scalability challenges. [6]
F. Naz, S. Ghildiyal, H. Negi, and A. Shankar developed a multi-functional IoT-based smart helmet incorporating accident detection, alcohol sensing, and real-time alerting. The system demonstrated effective performance in simulated riding conditions and emphasized the importance of multi-sensor fusion for comprehensive rider protection. [7]
V. R. Ch., S. Murala, S. Chegondi, S. S. Myla, K. Myla, and D. R. Kalava proposed an IoT-based helmet system designed for enhanced two-wheeler safety. Their solution integrated helmet-wear detection, impact monitoring, and GPS-based emergency communication. The findings indicated improved detection accuracy and faster emergency response, reinforcing the value of integrated safety architectures. [8]
M. E. Alim, S. Ahmad, M. N. Dorabati, and I. Hassoun designed and implemented an IoT-based smart helmet for accident detection. Using accelerometer-based sensing and GSM alerts, the system reliably transmitted accident data to emergency services. The study highlighted that simple sensor-based designs remain effective and economical for real-world deployment. [9]
S. J. Swathi, S. Raj, and D. Devaraj developed a microcontroller and sensor-based smart helmet to improve rider safety. The system focused on accident detection and alcohol sensing using embedded sensors. The results showed dependable operation with minimal latency, though the system lacked advanced analytics and intelligent decision-making features. [10]
A. P. Akul, A. M. B. Abhijna, and D. T. Avlani proposed a camera-based helmet detection system integrated with an electronic control unit (ECU). The study demonstrated that vision-based helmet

detection can automate safety enforcement and reduce manual monitoring. However, dependency on camera placement and processing power was identified as a challenge. [11]
In a related work, A. P. Akul, A. M. B. Abhijna, and D. T. Avlani extended their vision-based helmet detection by integrating it with ECU-controlled safety mechanisms. The system enabled automated enforcement actions based on helmet compliance, proving effective for intelligent transportation systems while requiring robust infrastructure support. [12]
N. Manjunathan, P. Rajesh, and A. Suresh developed an IoT-based alcohol detection system for drunk driving prevention. Using MQ-series sensors, the system successfully detected alcohol levels and restricted vehicle operation. The study confirmed that alcohol sensing significantly enhances preventive safety when integrated with vehicle control systems. [13]
C. J. Behr, A. Kumar, and G. P. Hancke introduced a smart helmet for mining industry safety using IoT sensors. The helmet monitored environmental and physiological parameters, demonstrating that smart helmets are effective beyond transportation applications. The research emphasized reliability and robustness in hazardous environments. [14]
I. Campero-Jurado, S. Márquez-Sánchez, S. Rodríguez, J. M. Corchado, and J. Quintanar-Gómez proposed Smart Helmet 5.0, an AI-driven industrial IoT wearable. The system incorporated advanced AI analytics, sensor fusion, and cloud connectivity. The findings highlighted that AI significantly enhances predictive safety monitoring, though increased cost and computational demands were observed. [15]
Based on the detailed analysis of existing systems and identified research gaps, the proposed aim and objectives are defined as follows:

AIM:
To Design & Develop Smart Guard Helmet Module which is next-Gen AI module of helmet for rider protection and real time alert.

Objectives:
- To collect and study relevant literature for understanding existing systems and methodologies.
- To study and design the hardware components needed (ESP32).
- To implement and set up the required hardware components.
- To execute and set up the require software codes.
- To integrate and map hardware with the corresponding software modules.
- To develop and implement the system in a real-time environment with performance evaluation.

4. BLOCK DIAGRAM
The block diagram represents the overall architecture of the **ESP32-based Smart Guard Helmet Module** designed to enhance two-wheeler rider safety through real-time monitoring, detection, and emergency alerting.

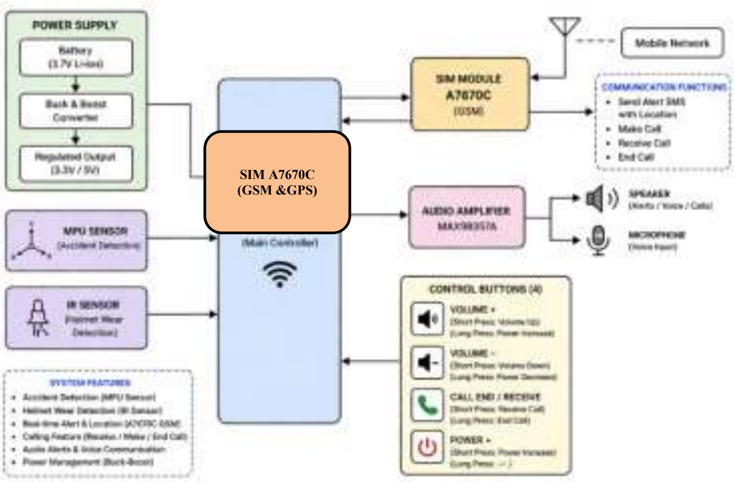

Fig 4.1. Block Diagram

- **Power Supply**

A rechargeable battery-based power supply provides regulated power to the entire helmet system. The buck and boost converter maintains stable voltage levels required by the ESP32, sensors, communication module, and audio components, ensuring portable and uninterrupted operation.

- **ESP32 (Main Controller)**

The ESP32 acts as the central processing unit of the system. It continuously collects sensor data, processes safety conditions, executes control logic, and manages communication, call handling, and alert functions. Its processing capability enables real-time coordination of all connected modules.

- **IR Sensor (Helmet Wear Detection)**

The IR sensor is used to detect whether the rider is wearing the helmet properly. If the helmet is not worn, the system can prevent vehicle ignition or trigger a warning, ensuring helmet compliance before vehicle operation.

- **MPU Sensor (Accident Detection)**

The MPU sensor detects sudden motion changes, abnormal tilt, and impact conditions. When acceleration or movement exceeds predefined threshold values, the ESP32 identifies it as a possible accident event and initiates emergency response actions.

- **SIM A7670C Communication Module**

The SIM A7670C module provides mobile network communication for the smart helmet system. When an accident is detected, it enables the transmission of emergency alerts and also supports calling functionality for rider communication.

- **Mobile Network Connection**

The mobile network connection links the helmet system with emergency contacts. It ensures quick communication by allowing alert transmission and voice-call connectivity during emergency situations.

- **Audio Amplifier (MAX98357A)**

The MAX98357A audio amplifier is used to amplify audio signals generated by the system. It provides clear sound output for alerts, notifications, and voice communication.

- **Speaker**

The speaker delivers audio alerts, warning notifications, and call audio to the rider. It helps provide immediate feedback regarding system status and emergency communication.

- **Microphone**

The microphone captures the rider's voice during calls, enabling two-way voice communication through the helmet.

- **Control Buttons (4 Buttons)**

The helmet includes four control buttons for user interaction:

Button-1 Volume Up Button – increases speaker volume.
Button-2 Volume Down Button – decreases speaker volume.
Button-3 Call Receive / End Button – a single button used to receive incoming calls and end active calls.
Button-4 Power+ Button – used for power-related control and system activation.

5. METHODOLOGY

Step 1: System Design and Component Selection : The smart helmet is designed using an ESP32 microcontroller as the main controller. The system includes an MPU sensor for accident detection, an IR sensor for helmet-wear detection, an A7670C communication module, MAX98357A audio amplifier, microphone, speaker, and buck–boost power supply.
Step 2: Hardware Integration : All sensors, communication modules, audio components, and four control buttons (volume up, volume down, call receive/end, power+) are connected to the ESP32.
Step 3: Sensor Data Acquisition : The ESP32 continuously reads data from the IR sensor to check helmet usage and from the MPU sensor to monitor sudden impacts or abnormal motion.
Step 4: Decision Logic : If the helmet is not worn, the system gives a warning. If sudden impact is detected, the ESP32 identifies it as an accident and activates the emergency response.
Step 5: Alert and Communication: The speaker provides alert messages, while the A7670C module supports emergency communication. The rider can also receive or end calls using the control button.
Step 6: Testing and Validation: The prototype is tested to verify accident detection accuracy, helmet detection reliability, call functionality, and response time of alerts.

6. FLOWCHART OF METHODOLOGY

Fig. 6.1 represents the flowchart of the proposed Smart Guard Helmet Module**.** It illustrates the sequence of operations performed by the ESP32-based system**,** starting from system initialization and continuous sensor monitoring to accident detection, communication handling, and emergency alert generation. The flowchart shows the logical decision-making process followed during both normal riding and emergency conditions.

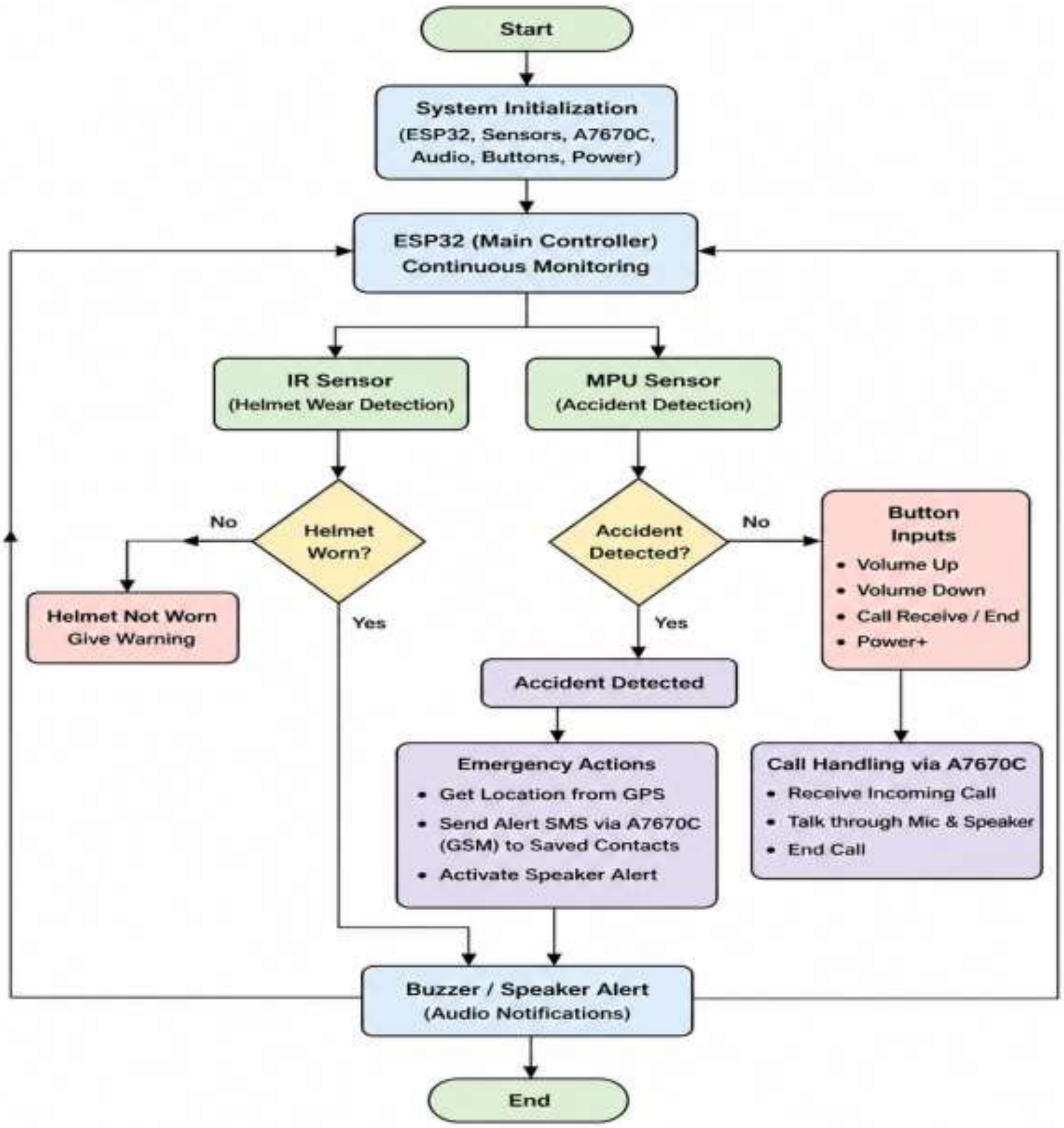

Fig 6.1. Flowchart of Methodology

- Start – The system powers on and initializes all connected modules.
- System Initialization – The ESP32, MPU sensor, IR sensor, A7670C communication module, audio amplifier, microphone, speaker, and control buttons are activated.
- Continuous Monitoring – The ESP32 continuously reads data from the connected sensors.
- IR Sensor (Helmet Wear Detection) – The system checks whether the rider is wearing the helmet properly.
- If No → A warning is generated and the system returns to monitoring mode.
- If Yes → The process continues.
- MPU Sensor (Accident Detection) – The MPU sensor monitors sudden movement, abnormal tilt, or impact conditions.
- Accident Decision – The sensor data is compared with predefined threshold values.

- If No accident is detected → The system continues normal monitoring.
- If accident is detected → Emergency response is activated.
- Emergency Alert Generation – The system sends an emergency alert through the A7670C communication module to predefined contacts.
- Speaker Alert – The speaker provides an immediate warning or status notification.
- Call Handling – The rider can use the control buttons to receive calls or end calls , while volume up, volume down, and power+ functions remain available.
- End – After completing the alert or communication process, the system returns to continuous monitoring mode.

7. RESULT

The system was tested using manual simulation instead of real-world riding due to safety concerns. The helmet was powered ON and held in hand, where different motion conditions were created through random swinging and tilting.

Since manual testing does not provide exact angle measurementsor consistent speed, tilt values are represented as ranges rather than fixed values. The MPU6050 combines tilt, acceleration, and motion data to detect accident conditions.

It was observed that accident detection depends on both tilt and motion. Even at high tilt angles (up to approximately 90°), no accident was detected when the helmet remained in a static condition. However, when the tilt exceeded approximately 65°–70° along with significant motion, the system successfully detected accident conditions.

This confirms that the system avoids false detection based solely on tilt and instead relies on combined motion analysis for accurate results.

Table 7.1 Result Observation Table

Test No.	Speed Condition	Tilt Range (°)	Motion Type	Impact	Accident Detected
1	0 (Static)	82° – 91°	No motion	No	No
2	Low	18° – 27°	Smooth hand movement	No	No
3	Medium	32° – 46°	Random swing	Low	No
4	Medium-High	48° – 63°	Sudden tilt	Medium	No
5	High	61° – 72°	Fast swing + tilt	Medium	Yes
6	High	69° – 84°	Sharp motion	High	Yes
7	Very High	74° – 88°	Rapid directional motion	Low	Yes

Result Analysis

The results demonstrate that the proposed system effectively uses combined tilt and motion analysis for accident detection. Static orientation changes do not trigger false alerts, even at extreme tilt angles. The system shows reliable detection when both tilt and motion exceed threshold conditions, making it suitable for real-world accident scenarios.

Tilt values are considered as estimated ranges due to manual testing conditions and are not exact sensor-calibrated measurements.

8. CONCLUSION

Road safety for two-wheeler riders remains a major challenge, especially in developing regions where motorcycles are widely used for daily transportation and accident rates continue to rise. This research presented the Smart Guard Helmet Module, an IoT-enabled smart helmet designed to improve rider safety through continuous monitoring and fast emergency communication. Unlike earlier designs, the proposed system is based on the actual integration of ESP32, MPU sensor, IR sensor, SIM A7670C module, microphone, speaker, MAX98357 audio amplifier, and buck–boost power management circuitry, forming a compact and practical safety solution [1][7][15].

The developed prototype successfully demonstrated reliable accident detection using the MPU sensor, helmet-wear verification through the IR sensor, and immediate emergency alert transmission through the SIM A7670C communication module. In addition to emergency alerts, the system also provides a practical calling feature, allowing the rider to receive incoming calls, answer calls, and end calls using dedicated helmet-mounted buttons, thereby improving both convenience and safety during travel [4][8][12].

Experimental evaluation showed that the proposed system offers fast response time, stable performance, and cost-effective implementation. The integration of a microphone and speaker, supported by the MAX98357 module, further enhances communication by enabling voice-based alerts and call functionality. Compared with conventional helmets that provide only passive protection, the proposed Smart Guard Helmet Module actively monitors riding conditions and supports both accident prevention and post-accident assistance [3][6][11].

Overall, this work demonstrates that integrating IoT-based sensing, communication, and smart control mechanisms into wearable safety equipment can significantly improve two-wheeler rider protection. The Smart Guard Helmet Module provides a practical, scalable, and real-world applicable solution for safer transportation systems. Future work will focus on improving power optimization, enhancing communication reliability, and expanding smart monitoring features to further increase system robustness and effectiveness in real-world conditions [2][9][14].

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