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AI and IoT-Enabled Smart Helmets for Accident Detection, Health Monitoring, and Automatic Emergency Alert Systems

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Abstract. Motorcycle accidents remain a leading cause of death on the roads, particularly in developing countries where two-wheelers are the primary means of transportation. The delayed emergency medical response and lack of information about the victim's health status increases the risk of death during the crucial first hour following the incident. WHO estimates that Powered two-wheelers (PTWs) account for nearly 25% of global road deaths, with some Asian countries witnessing even higher rates due to intense traffic and insufficient protective infrastructure. Researchers have proposed various Internet of Things (IoT) and sensor enabled smart helmets to address these issues. Previous works use a combination of motion sensor and communication modules coupled with micro-controllers to identify accidents and relay user location information. However, a deeper inspection of the recent literature suggests pertinent limitations with the proposed solutions. While most works demonstrate successful crash identification using accelerometers and force sensors, there was an apparent lack of integration of biometric monitoring (heart rate and SpOn), intelligent AI driven severity assessment tool, cloud assisted medical record retrieval and robust false alarm mitigation mechanisms. This paper presents a detailed analysis of five IEEE research papers published in 2023-2025 that explore smart helmet design. The papers examined various existing works related to smart helmet based accident detection systems, user health monitoring and emergency alert relaying mechanisms. The review highlights potential research opportunities based on the gaps identified in the surveyed works. Leveraging the lessons learned from the review and the opportunities highlighted, this work also proposes an original AI driven smart helmet system design. The proposed model uses a combination of sensors for accident detection, biometric health monitoring and alcohol content estimation. The model also implements an AI based impact assessment algorithm and intelligent dual mode emergency message relaying system. The observations made in this review can form a robust foundation for the development of next generation smart helmet systems that canreduce post-crash mortality rates due to timely emergency response

Keywords: Smart Helmet, Accident Detection, Health Monitoring, Internet of Things (IoT), Artificial Intelligence (AI), Emergency Alert System, Motorcycle Safety, ESP32, Biometric Sensors, Golden Hour, Edge Computing, False Alarm Mitigation

I. Introduction

Road traffic accidents involving motorcycles remain one of the most serious public safety concerns worldwide. The World Health Organization estimates that powered two-wheelers contribute to nearly one-quarter of all road fatalities globally. In developing nations such as India, Pakistan, Bangladesh, and several Southeast Asian countries, motorcycles are widely preferred because of their low cost, fuel efficiency, and ability to navigate congested urban traffic. Unfortunately, this popularity

comes at a high human cost. Riders of two-wheelers face a disproportionately high risk of severe head injury and death compared to occupants of four-wheeled vehicles. Conventional helmets have been proven to reduce the risk of fatal head injuries by more than 40%. However, they remain purely passive devices. They provide physical protection during impact but offer no mechanism for detecting that an accident has occurred, assessing the rider's physiological condition, or notifying emergency services. As a result, many accident victims lie unattended for critical minutes or even hours, especially on highways, rural roads, or during night-time incidents when bystander assistance is limited. Medical literature consistently emphasizes the importance of the "Golden Hour" — the first sixty minutes after a traumatic injury. Rapid medical intervention during this period dramatically improves survival rates and reduces long-term disability. Traditional emergency response systems largely depend on the presence of witnesses who must notice the accident, locate the victim, and then contact emergency services. This human-dependent chain frequently introduces unacceptable delays. Furthermore, when emergency medical teams finally arrive, they usually have no prior information about the victim's vital signs, blood group, or pre-existing medical conditions, which further complicates triage and treatment decisions.

To overcome these limitations, the research community has actively explored the concept of the "smart helmet." By embedding sensors, microcontrollers, wireless communication modules, and, more recently, Artificial Intelligence algorithms into a standard helmet form factor, it becomes possible to automatically detect crashes, monitor the rider's health parameters in real time, and transmit precise location along with physiological data to family members, hospitals, and cloud-based emergency platforms. Over the past few years, numerous prototypes and research prototypes have been reported in IEEE conferences and journals.

Despite this progress, a careful review of existing systems reveals several recurring shortcomings: high false-positive rates caused by simple threshold-based detection, limited or completely absent continuous health monitoring after the crash, lack of intelligent severity assessment, incomplete emergency messages that contain only GPS coordinates, and insufficient attention to battery life when multiple sensors operate continuously. These limitations motivate the present review and the subsequent proposal of a more comprehensive AI-powered architecture. The primary objectives of this review paper are: (1) to systematically examine recent IEEE research on smart helmets focusing on accident detection, health monitoring, and emergency alerting; (2) to identify technological trends, strengths, and limitations across existing designs; (3) to highlight critical research gaps; and (4) to present a structured multi-stage architecture for an AI-Powered Smart Helmet that addresses the identified shortcomings

II. Review Methodology

1. Selection Criteria

The following inclusion criteria were applied during the literature search and screening process• The research must focus on smart helmets specifically designed for motorcycle or two-wheeler rider safety.

Preference was given to systems that incorporate Internet of Things (IoT) connectivity, embedded microcontrollers, wireless communication modules, or Artificial Intelligence / Machine Learning techniques.

- Both complete hardware prototype implementations and detailed system architecture proposals were considered eligible.
- Only peer-reviewed papers published in IEEE conferences or IEEE-sponsored venues between the years 2023 and 2025 were selected, ensuring technical relevance and recency.
- Papers that focused exclusively on industrial safety helmets, bicycle helmets without accident detection, or purely theoretical studies without system design were excluded.

1. Selected Literature

After applying the above criteria, five research papers were shortlisted for detailed critical review. These papers represent a balanced mix of energy-efficient designs, multi-sensor health monitoring approaches, machine-learning-enhanced systems, and computer-vision-based solutions

- Rahman et al. (2025) – Battery-Efficient IoT-Enabled Smart Helmet for Real-Time Motorcycle Accident Detection and Notification (IEEE HONET 2025).
- Venkateswara Rao et al. (2023) – IoT based Smart Helmet for Bike Rider Safety (IEEE ICECA 2023).
- Sumon et al. (2024) – Development of a Multi-Functional Smart Helmet for Enhanced Rider Safety and Health Monitoring (IEEE ISAECT 2024).
- Hasan et al. (2025) – SafeRide: A Real-Time IoT-Based Smart Helmet with Road-Condition Intelligence(IEEE RAAICON 2025).
- Hemalatha et al. (2025) – Smart Helmet for Safety Driving using YOLOv8 (IEEE ICESC 2025).

III. Literature Review

1. Battery-Efficient IoT-Enabled Smart Helmet (Rahman et al., 2025)

Rahman and colleagues present a carefully engineered, cost-effective smart helmet whose primary design goals are reliable accident detection and extended battery life. The sensing subsystem employs a dual-sensor strategy: the MPU-6050 six-axis Motion Processing Unit captures abrupt changes in acceleration and orientation, while the FSR-402 force-sensitive resistor measures direct impact pressure on the helmet shell. An anomaly is declared when the MPU-6050 reading exceeds 20,000 raw units or the FSR resistance drops below 120 W, indicating a significant impact. Upon detection, a piezoelectric buzzer is activated for a configurable 10-second window, giving the rider an opportunity to cancel a false alarm by pressing a miniature push-button. If the override is not exercised, the ESP32 microcontroller first attempts to establish a WiFi connection and transmit the GPS coordinates (previously acquired by a NEO-6M module operating in Power Saving Mode).

Should WiFi be unavailable within a 5-second timeout, the system automatically falls back to the Sim800L GSM module and sends an SMS. Experimental results report average transmission times of approximately 4 seconds over WiFi and 11 seconds via GSM. Through selective activation of high-power modules and GPS power-saving techniques, the prototype achieves 9–10 hours of continuous operation on a single 18650 lithium-ion cell. The total added weight of the electronics is kept under 210 grams. While the work demonstrates excellent engineering discipline in power management and dual-mode communication, it does not incorporate any continuous biometric health monitoring.

2. IoT-based Smart Helmet for Bike Rider Safety (Venkateswara Rao et al., 2023)

This system places strong emphasis on preventive safety measures. An infrared (IR) sensor combined with a push switch mounted inside the helmet verifies that the rider is actually wearing the helmet; the motorcycle ignition remains disabled until this condition is satisfied. An MQ-series gas sensor continuously samples the air near the rider's mouth and prevents engine start if alcohol is detected above a predefined threshold. Accident detection is performed by an MPU6050 sensor that identifies sudden falls or collisions. Communication between the helmet unit and the motorcycle unit is realized via Bluetooth. Once an accident is confirmed, GPS coordinates are transmitted to pre-configured emergency contacts using a GSM module. The system also includes a simple LCD display on the motorcycle side for status messages. Although the design effectively addresses two major causes of accidents—non-use of helmets and drunk driving—it lacks post-crash biometric monitoring and does not employ any form of Artificial Intelligence fordecision making or false-alarm reductio

3. Multi-Functional Smart Helmet for Health Monitoring (Sumon et al., 2024)

Among the five reviewed works, the system proposed by Sumon et al. is the most comprehensive in terms of health monitoring. The hardware platform is built around an Arduino Mega 2560 and integrates an ADXL345 three-axis accelerometer for fall and collision detection, a MAX30100 pulse oximeter for continuous measurement of heart rate and blood oxygen saturation

(SpOn), an MQ-2 gas sensor and a flame sensor for environmental hazard detection, a Neo-6M GPS module, and a SIM900L GSM module for emergency messaging. A TTP223 capacitive touch sensor verifies that the helmet is being worn before the motorcycle ignition is enabled. When an accident is detected, the system automatically composes an SOS message that contains both the rider's GPS coordinates and the most recent vital-sign readings. The entire electronics assembly is housed inside a custom 3D-printed enclosure that is attached to a standard helmet. Controlled laboratory and field tests confirmed reliable detection of falls, accurate GPS reporting, and successful SMS delivery. The principal limitation of this otherwise strong design is the absence of an Artificial Intelligence component that could assess crash severity and further reduce false positives

4. SafeRide: Smart Helmet with Road-Condition Intelligence (Hasan et al., 2025)
SafeRide expands the functional scope of smart helmets by incorporating a rich set of safety features: helmet-wear detection, alcohol sensing, drowsiness detection via eye-blink rate, accident/fall detection, weather monitoring, and rear-vehicle proximity alerts using ultrasonic sensors. A distinctive contribution of this work is a machine-learning model that classifies upcoming road segments as Excellent, Good, Poor, or Very Poor, based on GPS traces and crowdsourced image labels uploaded through a companion mobile application.

The helmet and motorcycle units communicate in real time; ignition is interlocked with helmet status and alcohol level. Hazard information is uploaded to Firebase so that other riders can receive community alerts. Experimental evaluation demonstrates high accuracy across most modules (for example, alcohol detection AUC-ROC of 0.98 and fall detection recall of 97%). Despite its breadth of features and the novel use of machine learning for road-condition prediction, SafeRide does not provide continuous post-accident biometric monitoring of heart rate or SpO2

5. Smart Helmet for Safety Driving using YOLOv8 (Hemalatha et al., 2025)
Hemalatha and co-authors introduce a computer-vision-based approach to helmet compliance enforcement. A camera captures video frames that are processed by a YOLOv8 object-detection model trained to distinguish riders wearing helmets from those without helmets. The system achieved a precision of 95.2% and a recall of 93.5% on the authors' test set, demonstrating its effectiveness in identifying helmet usage.

If the model determines that a helmet is absent, the motorcycle's ignition or gear system remains locked, thereby discouraging riders from operating the vehicle without appropriate head protection. In addition to vision-based detection, the helmet incorporates an alcohol sensor, a body-temperature sensor, and an air-quality sensor to improve rider safety. Accident-related alerts are handled by conventional GSM and GPS modules, which facilitate emergency notifications and location tracking.

Although the high accuracy of the YOLOv8 model represents a significant advancement in AI-based helmet detection, the study primarily focuses on preventive safety measures and helmet compliance rather than post-accident health assessment. The system provides limited support for continuous physiological monitoring and real-time evaluation of a rider's condition following a crash. Furthermore, the effectiveness of the vision-based approach may be influenced by environmental conditions such as poor lighting, adverse weather, camera positioning, and partial occlusion of the rider. The reported precision and recall values also indicate that some false-positive and false-negative detections may occur, potentially resulting in incorrect helmet classification or unnecessary ignition restrictions.

Another limitation is the reliance on GSM and GPS modules for emergency communication and location tracking, which may be affected by poor network coverage or unavailable satellite signals. Although the integrated sensors enhance preventive monitoring, the system does not extensively address the continuous assessment of vital physiological parameters, such as heart rate, blood oxygen saturation, and changes in body movement or consciousness after an accident. Moreover, the absence of a comprehensive post-crash monitoring mechanism may delay the identification of serious injuries or abnormal physiological conditions. The study also leaves scope for evaluating the system under diverse real-world conditions, improving sensor reliability, and minimizing false alarms.

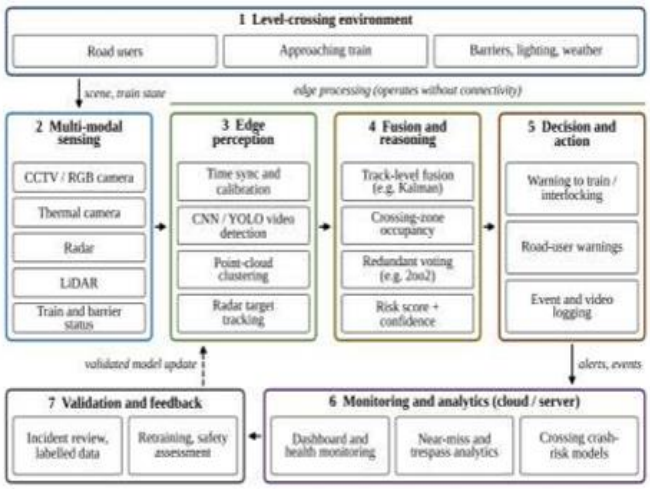
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III. Comparative Analysis

A side-by-side comparison of the five selected systems reveals clear patterns in design priorities and remaining deficiencies. Table 1 summarizes the presence or absence of key features across all reviewed works.

Table 1 Feature-wise Comparison of Reviewed Smart Helmet Systems

Feature	Rahman 2025	Rao 2023	Sumon 2024	Hasan 2025	Hemalatha 2025
Accident Detection	Yes (MPU+FSR)	Yes (MPU6050)	Yes (ADXL345)	Yes (Vibration)	Limited
Health Monitoring (HR / SpO■)	No	No	Yes (MAX30100)	No	No
Alcohol Detection	No	Yes	No	Yes	Yes
Emergency Alert (GPS+GSM)	Yes (Dual-mode)	Yes	Yes	Yes	Yes
AI / Machine Learning	No	No	No	Yes (Road ML)	Yes (YOLOv8)
False Alarm Handling	Yes (10s Override)	Limited	Limited	Timer-based	Limited
Battery Optimization	Strong (PSM)	Weak	Moderate	Moderate	Weak
Helmet Wear Interlock	No	Yes	Yes	Yes	Yes
Medical Data in Alert	Location only	Location only	Loc. + Vitals	Loc. + Sensors	Location only
Cloud Integration	Limited	Limited	Limited	Yes (Firebase)	Limited



IV. Proposed Conceptual Architecture

To overcome the limitations identified in the preceding analysis, this paper proposes a structured, multi-stage AI-Powered Smart Helmet architecture. The design is conceived as an edge-computing safety engine that tightly integrates multi-sensor data acquisition, on-device intelligent decision-making, and reliable dual-mode emergency communication. The architecture is organized into seven clearly defined stages, each with well-specified responsibilities

Stage 1 – Sensing Layer
The sensing layer is responsible for continuous, real-time data acquisition from the rider and the immediate environment. It comprises four primary sensor groups:

- Motion and Impact Sensors (MPU-6050 or ADXL345): capture linear acceleration and
- angular velocity to detect sudden falls, collisions, or abnormal orientation changes.

- angular velocity to detect sudden falls, collisions, or abnormal orientation changes.
- Biometric Sensors (MAX30100 or equivalent pulse oximeter): continuously measure heart rate and blood oxygen saturation (SpO■), with heightened sampling after an impact is detected.
- Alcohol Sensor (MQ-3): samples the air near the rider's mouth to detect ethanol vapor and support ignition interlock functionality.
- Helmet-Wear Detection Sensor: confirms that the helmet is properly fastened before the system enters full operational mode.

Stage 2 – Edge Processing (ESP32 Microcontroller)
The ESP32 serves as the central processing and coordination unit. Its responsibilities include:

- High-rate data acquisition from all analog and digital sensors.
- Preprocessing and digital filtering to remove noise and transient spikes.
- Adaptive power management, including selective activation of high-current modules and GPS Power Saving Mode.
- Time synchronization and maintenance of a local event log.
- Management of optional voice-command interfaces for hands-free interaction.

Stage 3 – AI Severity Engine
This stage constitutes the intelligent core of the proposed system. Running on the ESP32 (or a co-processor if required), the AI Severity Engine performs:

- Multi-sensor impact-pattern analysis that examines both the magnitude and the temporal signature of the acceleration and force signals.
- Evaluation of post-impact vital signs (heart-rate variability and SpO■ trend).
- False-alarm filtering that suppresses alerts caused by minor bumps or intentional helmet handling.
- Classification of the event into one of three severity levels: Minor, Moderate, or Critical.

Stage 4 – Decision and Action
Based on the output of the AI Severity Engine, the Decision and Action stage executes the following logic:

- If the event is classified as Minor, the system returns to normal monitoring without generating an external alert.
- If the event is classified as Moderate or Critical, a piezoelectric buzzer is activated and a short, configurable cancellation window (typically 8–12 seconds) is opened, allowing the rider to abort a false alarm.
- If the cancellation window expires without rider intervention, the full emergency protocol is triggered.

Stage 5 – Communication Layer

Once the emergency protocol is activated, the Communication Layer assembles and transmits a rich alert package:

- The NEO-6M GPS module supplies the most recent high-accuracy location coordinates.
- Current heart-rate and SpO■ values, together with the AI-assigned severity level, are appended to the message.
- Optionally, the system queries a secure cloud service to retrieve the rider's blood group and relevant medical history.
- The complete message is sent via the SIM800L GSM/GPRS module as an SMS (and, when available, via WiFi/MQTT to a cloud dashboard).

Stage 6 – Alert and Monitoring

The generated alert is delivered simultaneously to multiple stakeholders:

- Pre-configured family members and personal emergency contacts receive an SMS containing a map
- link, vital signs, and severity.
- Nearby hospitals or regional emergency medical services receive the same information to enable early preparation.
- A cloud dashboard records the incident for later analysis, fleet management, or integration with smart-city emergency systems.

Stage 7 – Feedback and Continuous Improvement

Every confirmed or cancelled incident is logged locally and, when connectivity permits, uploaded to the cloud. These labeled records form a growing dataset that can be used to retrain and refine the AI Severity Engine, thereby improving classification accuracy over time and further reducing false alarms.

IV. Research Challenges and Identified Gaps

A critical synthesis of the reviewed literature reveals seven major research challenges that continue to limit the effectiveness of current smart-helmet solutions. These gaps form the direct motivation for the architecture proposed in the next section.

Limited Continuous Health Monitoring

Most existing systems concentrate on detecting the occurrence of an accident. Only Sumon et al. (2024) incorporate real-time measurement of heart rate and SpO■. Continuous biometric assessment in the minutes following a crash is clinically essential: it allows emergency responders to gauge the rider's physiological stability before they arrive on scene and supports more accurate triage decisions during the Golden Hour.

Absence of Intelligent Crash Severity Assessment

The great majority of prototypes rely on fixed numerical thresholds applied to accelerometer or force-sensor readings. Such threshold logic cannot reliably distinguish a genuine high-energy collision from a helmet being dropped onto a hard surface or subjected to a minor bump. Consequently, false-alarm rates remain unacceptably high. Very few systems employ Artificial Intelligence or multi-sensor fusion to classify impact severity.

Incomplete Emergency Information

In most designs the emergency message contains only GPS coordinates. Critical contextual data—current heart rate, SpO■ level, estimated severity, blood group, and relevant medical history—are almost never included. As a result, receiving hospitals and ambulance crews must begin assessment from a near-zero information baseline.

Lack of Cloud-Based Medical Record Access

None of the five reviewed systems automatically retrieves a rider's pre-stored medical profile (blood group, allergies, chronic conditions) from a secure cloud repository and appends that information to the emergency alert. Such integration would be of immediate practical value to emergency physicians.

Battery Life versus Feature Richness Trade-off
Adding continuous biometric sensing, always-on communication modules, and AI inference significantly increases power consumption. Only Rahman et al. (2025) treat energy efficiency as a first-class design objective. Without careful power-management strategies, a feature-rich helmet may require impractically frequent recharging, reducing user acceptance.

Insufficient Multi-Stage False-Alarm Mitigation
Although a few systems provide a short manual-override window, robust multi-stage validation that combines temporal filtering, sensor fusion, and AI confidence scoring is still missing from the literature.

Limited Real-World Validation
Many prototypes are evaluated under controlled laboratory conditions or on a small number of scripted trials. Comprehensive testing across diverse road surfaces, weather conditions, traffic densities, and rider behaviors remains comparatively rare.

Research Gaps and Future Directions

Training and Validation of the AI Severity Engine
A high-quality, labeled dataset of real and simulated motorcycle impacts, together with corresponding biometric responses, must be collected. Supervised and semi-supervised learning techniques can then be applied to train a compact model suitable for edge deployment on the ESP32 or a low-power co-processor. Cross-validation against held-out real-world incidents will be essential to quantify false-positive and false-negative rates.

Secure Cloud Integration for Medical Records
A privacy-preserving mechanism should be designed that allows the helmet, after successful rider authentication, to retrieve blood group, allergy information, and chronic-condition flags from a secure cloud repository and to embed selected fields in the emergency SMS. Compliance with relevant data-protection regulations must be demonstrated.

Advanced Energy-Management Strategies
Further research is needed on adaptive sampling rates, event-driven sensor activation, and hierarchical wake-up policies so that the addition of continuous biometric sensing and occasional AI inference does not unacceptably shorten battery life. Target autonomy should be at least a full day of typical commuting use.

Extensive Real-World Field Trials
Prototype helmets should be evaluated by a diverse cohort of riders across urban, highway, and rural environments, under varying weather and lighting conditions. Both technical performance metrics and user-acceptance feedback must be collected.

Companion Mobile Application
A cross-platform smartphone application should be developed to support initial system configuration, emergency-contact management, real-time status display, historical incident review, and over-the-air model updates.

Voice-Command and Hands-Free Interaction
Lightweight on-device or cloud-assisted speech recognition can enable riders to query system status or cancel alerts without removing their hands from the handlebars, further improving safety and usability.

Integration with Smart-City Emergency Infrastructure

In the longer term, standardized interfaces should be defined so that alerts generated by the helmet can be ingested directly by municipal emergency dispatch systems and hospital pre-arrival notification platforms.

V. Conclusion

This review paper has presented a systematic examination of recent IEEE research on AI- and IoT-enabled smart helmets for motorcycle safety. Five representative works published between 2023 and 2025 were analyzed in depth with respect to accident detection methods, health-monitoring capabilities, emergency-alert mechanisms, use of Artificial Intelligence, false-alarm handling, and energy efficiency.

comparative analysis demonstrates that while basic accident detection and GPS/GSM alerting have become relatively mature, continuous biometric monitoring after a crash remains rare, intelligent severity assessment is almost entirely absent, and emergency messages are still information-poor. Battery life and false-alarm rates continue to pose practical obstacles to widespread adoption.

In response to these shortcomings, a structured seven-stage architecture for an AI-Powered Smart Helmet has been proposed. The architecture integrates multi-modal sensing (motion, biometrics, alcohol), edge processing on an ESP32 platform, an AI Severity Engine for intelligent classification and false-alarm reduction, dual-mode communication, and a feedback loop for continuous model improvement. By delivering not only location but also vital signs and optional medical history to emergency responders, the system aims to make the critical Golden Hour substantially more effective.

Future work will focus on the collection of real-world impact datasets, training and edge deployment of the severity-classification model, implementation of secure medical-record retrieval, rigorous field evaluation, and the development of a companion mobile application. Successful realization of this vision has the potential to reduce motorcycle-accident mortality by ensuring that help is summoned automatically, informed by accurate physiological data, and delivered with minimal delay.

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