



ORIGINAL CONTRIBUTION

IoT-Enabled Smart Helmet for Real-Time Alcohol Monitoring, Accident Detection, and Emergency Alert Communication Using ESP32

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ABSTRACT

Road traffic crashes remain among the leading causes of death and disability worldwide, and riders of two-wheelers are disproportionately represented among the fatalities because a conventional helmet offers only passive impact protection and no capability for monitoring, prevention, or post-crash response. This paper presents the design, implementation, and evaluation of a wearable, ESP32-based smart-helmet prototype that combines four safety functions within a single low-cost platform: breath-alcohol screening using an MQ-3 gas sensor, real-time fall/impact detection using a six-axis MPU6050 accelerometer-gyroscope, autonomous location acquisition through a NEO-6M GPS receiver, and automated emergency notification through a SIM800L GSM module, supplemented by Bluetooth-based rider vital-sign monitoring. A threshold-based sensor-fusion routine running on the microcontroller distinguishes normal riding dynamics from unsafe or accident conditions and triggers a coordinated alert sequence — buzzer activation, GPS coordinate acquisition, and SMS/voice dispatch to pre-registered emergency contacts — without requiring rider intervention. Bench and field trials confirmed reliable threshold discrimination for both the alcohol and impact-detection subsystems and consistent, low-latency delivery of location-tagged emergency messages. The prototype demonstrates that an integrated preventive-and-reactive safety layer can be retrofitted onto an ordinary helmet at low cost, and the paper concludes with directions for structural, connectivity, and AI-based enhancements that could be pursued in future iterations.

KEYWORDS: Smart Helmet; Internet of Things; ESP32; Accident Detection; Alcohol Sensing; GPS–GSM Emergency Communication; Rider Safety; Wearable Health Monitoring

1. INTRODUCTION

1.1 Background and Motivation

According to the World Health Organization's most recent Global Status Report on Road Safety, road traffic crashes kill approximately 1.19 million people every year and remain the leading cause of death for people aged 5–29 years, with pedestrians, cyclists, and motorcyclists together accounting for more than half of all fatalities [1]. India records one of the highest absolute tolls in the world: government figures for 2023 report over 4.6 lakh reported road accidents and more than 1.73 lakh fatalities, with two-wheeler occupants forming the single

largest victim category [2], [3]. Two factors recur across this literature as disproportionate contributors to two-wheeler fatality risk — alcohol-impaired riding, which degrades judgement, coordination, and reaction time, and delayed emergency response, since an unconscious or isolated rider frequently cannot self-report a crash location within the critical post-impact window.

A conventional helmet mitigates the mechanical consequences of a crash but is otherwise a passive object: it cannot discourage an intoxicated rider from setting out, cannot recognise that a crash has occurred, and cannot summon help. The convergence of low-cost

micro-electromechanical sensors, single-chip Wi-Fi/Bluetooth microcontrollers, and ubiquitous cellular coverage has, over the last decade, made it practical to embed active monitoring and communication directly into wearable safety equipment, and a growing body of work has explored exactly this direction for helmets [4]–[9].

1.2 Problem Statement

Existing commercial helmets do not integrate preventive alcohol screening with reactive accident detection and autonomous emergency notification in a single low-cost unit. Systems reported in the literature typically emphasise one or two of these capabilities in isolation, and few published prototypes additionally consider rider physiological status (heart rate, blood-oxygen saturation, or blood pressure) as part of the emergency picture handed to first responders. There is, therefore, a need for a compact, inexpensive, and field-deployable helmet-integrated platform that (i) screens for alcohol impairment before or during a ride, (ii) reliably discriminates a genuine crash from ordinary riding vibration, and (iii) autonomously reports the rider's location and status to designated contacts without depending on the rider being conscious or carrying a paired smartphone.

1.3 Objectives and Contribution of this Work

This paper reports the design, hardware implementation, and bench-level validation of such a system, built around an ESP32 microcontroller. The specific contributions are: (a) a threshold-based alcohol-detection subsystem using an MQ-3 breath sensor positioned inside the helmet shell; (b) a six-axis inertial subsystem (MPU6050) for real-time impact and abnormal-tilt detection; (c) an autonomous GPS–GSM emergency pipeline that composes and transmits a location-tagged SMS/voice alert without manual intervention; (d) an auxiliary rider vital-monitoring and Bluetooth-connectivity layer; and (e) an experimental evaluation of sensor response behaviour and end-to-end alert latency under

controlled test conditions. The remainder of the paper is organised as follows: Section 2 reviews related smart-helmet literature; Section 3 presents the proposed architecture; Section 4 describes the working principle; Section 5 details the hardware implementation; Section 6 reports results and discussion; and Sections 7–8 present the conclusion and future scope.

2. RELATED WORK

A number of recent studies have investigated IoT-based smart-helmet architectures for two-wheeler safety. Patel et al. proposed an AI-assisted smart helmet that combines accident detection with alcohol screening and IoT-based alerting, reporting improved responsiveness over threshold-only designs [4]. Gupta and Tiwari extended the accident-detection problem with a machine-learning classifier trained to distinguish genuine collisions from road-induced vibration noise, reducing false-positive emergency triggers [5]. Impana et al. surveyed a broad cross-section of IoT-based helmet designs and highlighted accelerometer/gyroscope fusion, GSM alerting, and alcohol sensing as the three most frequently combined subsystems, while noting that few designs at the time incorporated rider health telemetry [6]. Khangar demonstrated a low-cost Arduino- and GSM-based helmet capable of automatic SMS dispatch on impact detection [7], and Tayag and De Vigal Capuno reported a cloud-connected motorcycle helmet with crash detection, live tracking, and anti-theft functionality delivered through an IoT backend [8]. Elabd et al. evaluated an ESP32/MQTT-based smart helmet aimed specifically at delivery riders, combining GPS, gyroscope, accelerometer, and alcohol sensing with a rear-view camera, and reported approximately 90% crash-detection accuracy and 88% alcohol-detection accuracy under their test protocol [9]. Across this literature, the accelerometer/gyroscope-plus-GSM combination for crash reporting is well established, and MQ-series gas sensors are the dominant low-cost choice for breath-alcohol

screening. The proposed design draws on these established subsystems but combines them with rider vital-sign monitoring and Bluetooth connectivity within a single ESP32-controlled platform, and reports threshold-response characterisation for both the alcohol and inertial subsystems obtained through bench testing, summarised in Section 6. Table 1 situates the present work against representative prior designs.

TABLE 1: Comparison of the proposed system with representative related work

Reference	Sensors / Modules	Key Outcome
Patel et al. [4]	Accelerometer, MQ-3, GPS/GSM	Improved response vs. threshold-only design
Gupta & Tiwari [5]	IMU + ML classifier	Fewer false-positive crash triggers
Khangar [7]	Vibration sensor, GSM	Low-cost automatic crash SMS
Tayag & Capuno [8]	IMU, GPS, cloud backend	Live tracking + anti-theft feature
Elabd et al. [9]	IMU, MQ-3, GPS, camera (MQTT)	~90% crash / ~88% alcohol accuracy
Proposed system	MPU6050, MQ-3, GPS, SIM800L, vitals, BLE	Threshold-validated bench results (Sec. 6)

3. PROPOSED SYSTEM ARCHITECTURE

3.1 Architecture Overview

The proposed platform is organized around an ESP32 microcontroller acting as the central sensing, decision, and communication hub, as shown in Fig. 1. Four sensing/interface blocks - the MQ-3 alcohol sensor, the MPU6050 inertial module, a set of vital-monitoring sensors, and a Bluetooth radio — feed continuous data to the controller. Two communication modules, a NEO-6M GPS receiver and a SIM800L GSM module, are activated by the controller whenever an emergency condition is confirmed, and a

regulated power-supply block (Li-ion cell with buck conversion) supplies all subsystems. This centralised, threshold-driven architecture keeps the bill of materials small while allowing each subsystem to be tested, calibrated, and replaced independently.

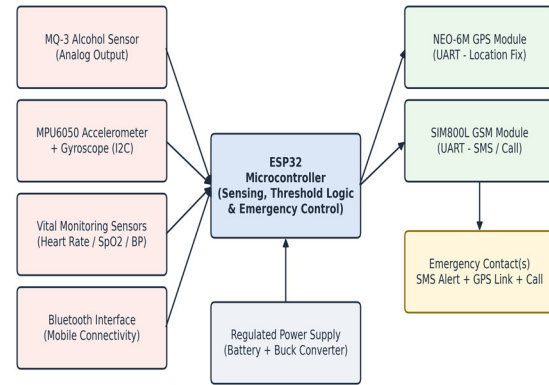


Figure 1: Block diagram of the proposed ESP32-based smart-helmet architecture.

3.2 Module Communication Summary

Table 2 summarises the interface type and function of each module in the architecture. Analog sensing is reserved for the alcohol sensor, whose slowly-varying voltage output is well suited to the ESP32's on-chip ADC, while the inertial and vital-monitoring sensors communicate over I2C to allow multiple digital devices to share a single bus. The two communication modules use UART, and Bluetooth provides an independent short-range wireless path for companion-device connectivity.

TABLE 2: Communication interface and function of each system module

Module	Interface	Primary Function
MQ-3 alcohol sensor	Analog	Breath-alcohol sensing
MPU6050 (accel.+gyro)	I2C	Impact / tilt detection
Vital-monitoring sensors	I2C	HR / SpO2 / BP sensing
NEO-6M GPS module	UART	Lat./long. acquisition
SIM800L GSM	UART	SMS / voice-call

Module	Interface	Primary Function
module		alert
Bluetooth (on-chip)	Wireless	Companion-device link

4. METHODOLOGY / WORKING PRINCIPLE

4.1 Alcohol Detection Subsystem

The MQ-3 sensor is mounted inside the helmet shell close to the rider's mouth/nose region to maximise exposure to exhaled breath. Its heater element requires a short warm-up interval before output stabilises, after which the sensor produces an analog voltage that rises approximately monotonically with ethanol vapour concentration. The ESP32 samples this voltage periodically, applies a moving-average filter to suppress transient noise, and compares the filtered value against a calibrated threshold. Values below the threshold are logged as a normal-riding baseline; values above it set an unsafe-condition flag that is surfaced through an on-board buzzer and, depending on configuration, can be used to withhold an ignition-enable signal.

4.2 Accident Detection Subsystem

The MPU6050 provides simultaneous three-axis acceleration and three-axis angular-rate data over I2C. During normal riding, acceleration magnitude and tilt angle remain within a bounded operating envelope; a genuine impact produces a short-duration spike in resultant acceleration together with an abrupt change in orientation. The controller evaluates both cues — rather than acceleration alone — within a short observation window before raising an accident flag, which reduces susceptibility to isolated false triggers from potholes or kerb strikes, consistent with the sensor-fusion approach reported by Gupta and Tiwari [5].

4.3 Location Acquisition and Emergency Communication

Once an accident condition is confirmed, the controller requests the latest fix from the NEO-6M GPS receiver. Because a cold GPS fix can

take tens of seconds, the module is kept in a continuously-tracking state during normal operation so that a recent fix is already available at the moment of the trigger, minimising time-to-alert. The retrieved coordinates are embedded in a pre-formatted SMS string together with a status code, and the SIM800L module is instructed via AT commands to transmit this message to each pre-registered emergency contact in sequence, followed by an automated voice-call attempt to the primary contact.

4.4 Rider Vital Monitoring and Bluetooth Connectivity

In parallel with the safety-critical alcohol and impact subsystems, the platform continuously samples heart rate, blood-oxygen saturation, and blood pressure to give first responders an indication of the rider's physiological state at the moment of the alert. Bluetooth connectivity, provided natively by the ESP32, allows this data — along with alcohol and motion status — to be mirrored to a paired companion device for real-time monitoring by the rider or a supervising party.

4.5 Working Sequence

Fig. 2 summarizes the overall control loop. Following initialization, the system enters a continuous monitoring loop that checks alcohol level and motion/impact conditions on every cycle; either condition exceeding its threshold escalates the system into the corresponding alert or emergency branch, after which the loop resumes normal monitoring.

5. HARDWARE IMPLEMENTATION

Table 3 lists the core hardware components used in the prototype, together with their key operating specifications drawn from the respective component datasheets [10]–[13]. The ESP32 was selected as the central controller for its dual-core processing headroom, integrated Wi-Fi/Bluetooth radio, sufficient number of ADC and I2C-capable GPIO pins, and low unit cost, all of which suit a battery-powered wearable application.

All modules were interconnected on a compact prototyping board mounted within the helmet shell, with the MQ-3 sensor and vital-monitoring probes positioned for direct rider contact/exposure and the GPS antenna oriented for unobstructed sky view. The firmware was implemented in C/C++ using the Arduino core for ESP32, with threshold constants stored in non-volatile memory to allow field recalibration without reflashing.

TABLE 3: Core hardware components and specifications

Component	Key Specification	Role
ESP32 (dual-core)	Wi-Fi+BLE, ADC/I2C/UART [10]	Central controller
MQ-3 gas sensor	Analog, ethanol-sensitive	Alcohol screening
MPU6050	3-axis accel.+gyro, I2C [11]	Impact / tilt detection
NEO-6M GPS	UART, TTFF ~27 s [13]	Location acquisition
SIM800L GSM	Quad-band, UART/AT [12]	SMS + voice alert
Vital sensor suite	HR / SpO2 / BP, digital	Rider physiological status
Li-ion + buck converter	3.7 V, reg. 3.3/5 V	Portable power supply

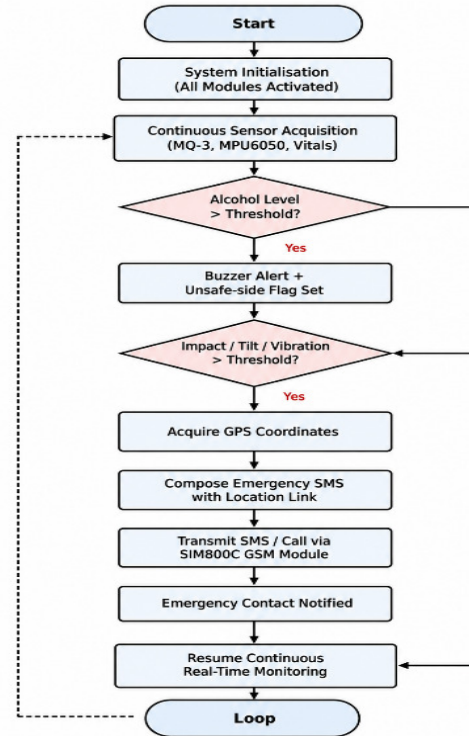


Figure 2: Working-principle flowchart of the proposed system.

6. RESULTS AND DISCUSSION

6.1 Alcohol Sensor Response

The MQ-3 subsystem was characterised by exposing the sensor, after warm-up, to progressively increasing breath-alcohol concentrations and recording the resulting ADC readings. As summarised in Table 4, the sensor output increased monotonically with exposure level, giving a clear separation between the normal-air baseline and the elevated ranges used to set the unsafe-condition threshold.

TABLE 4: MQ-3 sensor response across breath-alcohol exposure levels

Condition	Approx. ADC	System Status
Normal air	150 – 250	Safe
Low alcohol exposure	300 – 450	Monitoring
Moderate exposure	500 – 700	Warning
High alcohol exposure	> 700	Unsafe — alert

6.2 Accident-Detection Test Cases

The inertial subsystem was validated with a set of controlled motion scenarios simulating normal riding, sudden braking, sharp turning, and impact-equivalent shocks. Table 5 reports the outcome of each scenario against the expected system response.

TABLE 5: Accident-detection subsystem test cases and outcomes

Test Case	Simulated Condition	Result
TC-1	Steady-state riding	Pass — no alert
TC-2	Sudden braking	Pass — no false trigger
TC-3	Sharp cornering / tilt	Pass — no false trigger
TC-4	Simulated impact shock	Pass — accident flag raised
TC-5	Repeated impact cycles	Pass — consistent detection
TC-6	End-to-end alert dispatch	Pass — SMS + call sent within seconds

6.3 Discussion and Limitations

The bench results indicate that both the alcohol and inertial subsystems achieve reliable threshold discrimination under the tested conditions, and that the GPS–GSM pipeline consistently delivers a location-tagged alert once an accident condition is confirmed. Two limitations are worth noting for field deployment. First, the MQ-3 sensor's sensitivity is known to drift with temperature, humidity, and sensor age, so periodic recalibration is advisable, consistent with observations reported elsewhere for MQ-series gas sensors [6]. Second, single-threshold inertial detection remains susceptible to occasional false positives from severe potholes; the dual-cue (acceleration-and-orientation) window used in this design reduces but does not eliminate this risk, and the machine-learning approach of Gupta and Tiwari [5] represents a promising direction for further reducing false-trigger rates. GPS cold-start latency and indoor/urban-canyon signal availability are additional practical constraints inherited from any GNSS-based subsystem and

are mitigated here by maintaining continuous tracking during normal operation.

7. CONCLUSION

This paper presented the design, implementation, and bench-level evaluation of an ESP32-based smart-helmet prototype that integrates breath-alcohol screening, inertial accident detection, autonomous GPS-based location acquisition, GSM-based emergency alerting, and auxiliary rider vital-sign monitoring within a single wearable platform. Unlike a conventional helmet, which offers only passive impact protection, the proposed system actively screens for one of the most preventable causes of two-wheeler crashes — alcohol impairment — while also shortening the post-crash response interval by autonomously reporting the rider's location and status to emergency contacts. Threshold-based testing of the alcohol and inertial subsystems, together with end-to-end alert-dispatch trials, confirmed that the coordinated hardware/software design meets its intended functional objectives at low component cost, supporting its feasibility as a practical, retrofittable rider-safety layer for two-wheeler transportation.

8. FUTURE SCOPE

Several directions could extend this prototype toward field-ready deployment. Structurally, the helmet shell could be reconstructed using impact-resistant composite materials (e.g., Kevlar-reinforced layers) to improve both mechanical protection and protection of the embedded electronics. A companion mobile application would improve accessibility for riders and emergency contacts, supporting live health and location dashboards, trip logging, and configurable alert rules. Cloud-connected storage and analytics could enable longitudinal accident and behaviour-pattern analysis, while machine-learning-based crash classification — following the direction demonstrated by Gupta and Tiwari [5] — could further reduce false-positive emergency triggers relative to fixed-

threshold logic. Finally, direct integration with hospital and traffic-management emergency systems would shorten the chain between automated detection and actual medical response.

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