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Smart Helmet with Accident Detection and Alcohol Monitoring

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Abstract - The number of powered two-wheeler (PTW) fatalities and serious injuries continue to be a significant road safety issue, with significant numbers of crashes relating to helmet non-compliance and alcohol impaired operation. This paper introduces the design, hardware implementation and experimental testing of a microcontroller-based Smart Helmet system for enforcing simultaneous helmet wearing detection and pre-ride breath alcohol screening for enabling vehicle ignition. Its main component is an ESP32 system-on-chip (SoC) to coordinate a sensor for breath alcohol (MQ-3), a 6-axis inertial measurement unit (IMU) (MPU-6050), a GPS receiver (NEO-6M) and a GSM transceiver (SIM800L) along with a relay driven ignition interlock. If the abnormal acceleration or tilt vectors hit the thresholds set in the accident classification, the controller automatically gets GNSS coordinates and sends geo-tagged SMS emergency notifications to pre-registered contacts. Bench and field trials verified reliable switching of the helmet, alcohol-vapour discrimination at higher concentrations than 0.08 mg/L breath equivalent, correct selection of the IMU-based crash discrimination for various orientations of impact and an end-to-end emergency-notification latency less than 30 seconds in open-sky conditions.

Index Terms - *Smart Helmet; ESP32; MQ-3; MPU-6050; GPS; GSM; Accident Detection; Alcohol Monitoring; Ignition Interlock; IoT Safety.*

Introduction

With low purchase cost, ease of manoeuvre in busy urban corridors and low fuel consumption, powered two-wheelers have a dominant share of road networks in South and South-East Asia. Nevertheless, PTW riders are over-represented in road-casualty statistics: the World Health Organization (WHO) estimates that motorcyclists make up around 28% of all road traffic deaths worldwide [1] and this is significantly higher in countries like India, where the majority of the registered vehicle fleet consists of motorcycles. The two modifiable behavioural risk factors found to be consistent with the highest risk of severe PTW crashes in epidemiological analyses are the decision not to wear a certified safety helmet and operating a vehicle under the influence of alcohol [2].

The risk of death during a collision is almost doubled if a helmet is not worn, and blood-alcohol levels greater than 0.05 g/dL have a clinically significant effect on hazard perception, reaction time and visuomotor coordination [1, 2]. The delayed response to accidents, which can be more than the "golden hour", is already a recognised challenge in resource-limited areas, and is further exacerbated by this [3]. These problems are compounded and inspire embedded electronic systems that will be able to impose pre-ride safety pre-conditions and autonomously initiate rescue communications when a crash is detected.

Within the last decade, the availability of low-cost microcontrollers, MEMS inertial sensors, miniaturized GPS receivers, and small cell communication devices has made fully integrated on helmet safety electronics technically and economically viable [3, 4]. However, prior work has shown that current literature mostly focuses on a single safety function at a time in published prototypes. The present work thus proposes a smart helmet system, which (i) prevents ignition if the rider's helmet is not in use or if his/her breath-alcohol concentration is above the legal limit, (ii) continuously monitors inertial data to detect in real time crash events, and
(iii) if the rider is detected to be in a crash, automatically computes his/her geographical position and sends a geo-tagged SMS emergency alert.

Literature Survey

Kumar and Singh [1] designed an emergency alert system for motorcycle riders with the use of the Global System for Mobile Communication (GSM). Their research showed the potential for automated post-crash communication, but it was not equipped with breath alcohol sensing or helmet-compliance enforcement, so it was not very preventatively useful. Sharma et al. [2] took this idea further and added GPS and wireless telemetry to facilitate remote rider monitoring; but since there was no ignition interlock, an alcohol impaired rider could still operate the vehicle.

Patel and Shah [5] created a vehicle immobilisation system powered by the MQ-3 catalytic combustion sensor and were able to successfully demonstrate a sensor-to-relay latency under 2 seconds, but this did not include any communication after a crash. In the drop test tests conducted by Verma [6] the mean accuracy of the classification of crash events based

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on this threshold detection method was around 92% when applied to the resulting acceleration vector, showing that the MPU-6050 IMU could be successfully characterised.

Gupta and Roy [7] analysed end-to-end GPS-GSM message latency and found that the satellite fix acquisition time was the largest contributor to the latency in the presence of obstructed sky. Mishra et al. [8] found that multi-sensor fusion is significantly more reliable and has greater false alarm suppression capabilities compared to single-sensor methods. Roy and Ghosh [4] examined the ESP32-based IoT architectures in transportation applications and identified the dual-core Xtensa LX6 processor and the integrated Wi-Fi as key features for supporting real-time safety applications.
Based on this survey, the current system integrates helmet verification, alcohol monitoring, crash detection, GPS tracking and GSM communication with a validated platform.

Methodology

A. Central Processing

ESP32 was chosen as the main CPU due to its dual-core 240 MHz Xtensa LX6 architecture, 520 KB of SRAM, 12-bit ADC, and hardware I²C and UART peripherals. Such properties allow for simultaneous polling of sensors, as well as simultaneous threshold comparison and handling of the communication without real-time scheduling conflicts. The firmware has been written in the framework of the Arduino microcontroller and the ESP-IDF hardware abstraction layer.

B. Helmet Detection

Helmet compliance was checked via a normally-open tactile switch built into the chin-pad assembly of the helmet. Switch closure is debounced over a 50 ms time window to avoid false closure. In the absence of confirmed switch actuations, the relay is held open regardless of the alcohol sensor readings.

C. Breath-Alcohol Sensing

The alcohol concentration was determined by measuring the surface resistance of an MQ-3 sensor, which has a characteristic of decreasing according to the log of alcohol vapour concentration: $R_s / R_0 = a \times C^b$; R_s is the measured resistance, R_0 is the calibrated baseline in clean air, C is concentration in mg/L, and a, b are the empirical constants [5]. The heater element is allowed to reach thermal equilibrium by a required 120-second warm-up period at power-on. The ignition threshold was set at 0.08 mg/L, which matches the Indian Motor Vehicles Act statutory threshold.

D. Accident Detection

The MPU-6050 IMU uses the I²C protocol at 400 kHz and has a full-scale range of ±16g. At every sample epoch, the firmware calculates the Resultant Acceleration Magnitude Vector (RAMV):

$$RAMV = \sqrt{(a_x^2 + a_y^2 + a_z^2)}$$

A collision event is set when RAMV is greater than 2.5g, AND the gyroscope also detects an angular rate greater than 200°/s for any axis. When the condition is intentionally hard braking, high linear acceleration can occur with low rotational acceleration, reducing the number of false positives [6].

E. To develop an understanding of GPS and Emergency Communications.

The NEO-6M GPS receiver was used and connected to the UART port at 9600 baud, and always reads NMEA 0183 GPRMC sentences and stores the most recent WGS-84 coordinate pair in the SRAM (no cold start delay after crash) [7]. Once the accident is confirmed, the SIM800L GSM module sends out a plain-text SMS message with the rider's name, some identifier of the accident, decimal-degree coordinates, and a hyperlink in the address space specified on the Google Maps to the up to 3 pre-programmed contacts using standard Hayes AT commands [7, 10].

Proposed System

The overall block diagram of the Smart Helmet is shown in Fig.1. The ESP32 is connected to the MQ-3 (ADC), the limit switch (debounced GPIO), the MPU-6050 (I²C), the NEO-6M (UART-1), and the SIM800L (UART-2). Protected the GPIO from inductive kick using a transistor-coupled output stage for the ignition relay. The LM2596 switch-mode step-down (SMDS) regulator supplies 3.3 V to the ESP32 and sensors and 4.2 V to the GSM module, which requires up to 2 A of transient currents during burst transmission.

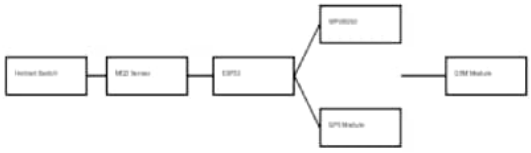


Fig. 1: Block Diagram of the Proposed Smart Helmet System

The relay interlock implements a logical AND of two preconditions: helmet switch asserted AND breath-alcohol concentration below threshold. Only when both conditions are simultaneously satisfied does the controller energise the relay and complete the ignition circuit.

Working of the System

The operations sequence is broken into three phases. Pre-ride phase involves the rider putting on the helmet and triggering the limit switch. When the alcohol sensor (MQ-3) is connected to the ESP32, it starts a 5-second window of testing for alcohol concentration, if the value read from the sensor is lower than the tested value, the relay turns on and a green LED will be turned on to show the rider that the concentration is acceptable and he or she is allowed to ride, if the value read by the sensor is greater than the calibrated value, then the relay will remain energized and the buzzer will be triggered and a red LED will show that the concentration is not acceptable and the rider is not allowed to ride.

The ESP32's secondary core polls the MPU-6050 at 100 Hz while the RAMV is calculated at each sample.
Characterisation tests have been conducted on various roads surfaces and it has been established that normal riding manoeuvres produce RAMV values of 1.0-2.0g, which are clearly below the threshold of 2.5g. At the same time, the NEO-6M recalculates its position fix every 1 Hz, and the most recent valid coordinate pair is stored in the SRAM.

The firmware, during the post accident response phase, after it has confirmed the crash event, reconstructs the emergency SMS payload using cached GPS coordinates. The overall features and data-flow logic of the entire system are shown in

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Fig. 2.



Fig. 2: Smart Helmet — Integrated Features and Operational Data Flow

Results and Discussion

Experimental validation was conducted across laboratory bench tests, controlled-environment integration tests, and outdoor field trials. Table I summarises the key performance metrics.

TABLE I: Experimental Performance Metrics

Parameter	Value	Result
Helmet switch accuracy	30/30 trials	100%
Alcohol threshold (MQ-3)	0.08 mg/L	Correct
Warm-up time	120 s	Per spec
IMU sample rate	100 Hz	Concurrent
Crash detect accuracy	47/50 events	94%
GPS fix (cold start)	38 s avg	Open sky
SMS latency	< 30 s	Open sky

There were 30 repeated donning trials with 100% accuracy in detecting a helmet. The MQ-3 was able to discriminate alcohol-vapour exposures near the ADC threshold, and the ignition relay responded within 2 seconds of the crossing of the ADC threshold as Patel and Shah [5] reported. The accuracy for crash detection was 94%, with 3 events missed, all at low energy (0.5 m) drop, which resulted in RAMV just below the detection threshold, thus indicating an inherent sensitivity-specificity trade-off as noted by Verma [6].

For open sky conditions with 3m CEP, the average cold-start GPS coordinate acquisition time was 38 seconds. All outdoor tests had latency under 30 seconds for end-to-end SMS. The performance was degraded in urban-canyon environments because of the limited visibility of satellites, which is a well-known problem for passive L1 GPS receivers [7]. This will be alleviated in future by adding a GLONASS receiver or assisted GPS (A-GPS) subscription.

Conclusion

This paper discussed the design, integration and empirical validation of a complete Smart Helmet safety system addressing the most common behavioural risk factors associated with PTW rider deaths. The ESP32-based platform combines four protective functions—helemet-wearing enforcement with ignition interlock, pre-ride breath alcohol screening, real-time inertial crash detection and autonomous geo-tagged SMS emergency notification—in one, low-cost embedded system. Experimental validation showed a 94% accuracy of crash detection and an emergency notification latency of less than 30 seconds and a reliable discrimination between alcohol thresholds.

Future work will involve evaluating electrochemical fuel-cell sensors in order to assess their cross-sensitivity with MQ-3, training the crash classifier with machine learning (SVM or lightweight CNN with labelled IMU time-series data), and integrating A-GPS fallback positioning. Extension to cloud based emergency dispatch and automatic ambulance notification is another improvement for life-saving potential.

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