AR-SafeHelmet: Enhancing Motorcycle Safety Through Augmented Reality and Sensor Integration

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Abstract - In this article, a design and the development of an Augmented-Reality (AR)-based Smart Helmet system is proposed to enhance the safety and health level of motorcycle riders. The helmet is equipped with several sensing units, such as an MQ-3 alcohol sensor for breath alcohol concentration measurement, a Photoplethysmography (PPG) sensor for the measurement of heart rate, and an Inertial Measurement Unit (IMU) for crash or fall detection. An ESP32 microcontroller onboard processes real-time sensor data, and a Raspberry Pi 3 B+ processes the data. and sends alerts to an AR visor, readable by a rider without ever having to take their eye off the road. The helmet incorporates an intelligent ignition interlock system, which prevents it from starting when the rider is detected as drunk and sends wireless crash notifications via Bluetooth/Wi-Fi to a phone. Test reports indicate that it is capable of detecting alcohol intoxication, abnormal heart rate , and shock incidents with high accuracy. This integrated approach of combining safety enforcement, health monitoring, and real-time AR feedback is an interesting solution to reduce motorcycle cruising accidents.

Keywords: AR Helmet, Alcohol Detection, Biometric Monitoring, Crash Detection, Smart Interlock, IoT, PPG Sensor, Rider Safety

1. INTRODUCTION

Motorcycle crashes account for a considerable portion of global traffic deaths, usually resulting from drunken driving or fatigue. Helmets are compulsory in most nations, yet they offer predominantly passive protection. Advanced technologies provide a means of turning helmets into proactive safety devices. Augmented Reality (AR) and Internet of Things (IoT) incorporation into wearable technology allowed real-time monitoring and adaptive responses based on the rider's state. Although there are personal safety systems, not many integrate biometric sensing, alcohol ingestion detection, crash detection, and real-time AR projection in a single wearable helmet.This paper presents an AR-enabled smart helmet that continuously tracks the breath alcohol level, heart rate, and movement pattern of the rider. It reacts to hazardous conditions by disabling the vehicle ignition and alerting the authorities. In contrast to existing helmets, this system alerts the rider via AR-capable visual notifications and wireless connection for logging and alerts. The approach revolves around simple user interaction, minimal power consumption, and a modular hardware architecture for both city and highway riders.

2. METHODOLOGY

The AR-enabled smart helmet is developed through a modular process that combines embedded electronics, sensor technology, wireless communication, and real-time augmented reality to enhance safety for motorcyclists. The system is divided into two main parts: the Helmet Unit and the Vehicle Unit. Both units play a crucial role in sensing, processing, and decision-making, ultimately improving rider safety.

1. Helmet Unit
The helmet unit combines the main hardware and software components responsible for managing the rider's physiological and environmental factors. It comprises:

MQ-3 Alcohol Sensor: The sensor is installed near the front opening of the helmet, ideally at the rider's mouth. It continuously samples breath for alcohol vapors. When the measured Blood Alcohol Content (BAC) goes above the set legal limit (for example, 0.05%), the system sends a lockout command that stops the motorcycle from starting.

PPG Heart Rate Sensor: Positioned in the inner padding or forehead area of the helmet, this infrared light-based photoplethysmography sensor detects blood flow and estimates the rider's heart rate. It continuously monitors for irregularities such as an unusually high BPM (greater than 120) or erratic rhythms that may indicate rider fatigue, stress, or potential health risks.

MPU-6050 IMU: The Inertial Measurement Unit (IMU) detects sudden acceleration, deceleration, angular movement, and changes in orientation. A fall or crash is recognized if acceleration spikes exceed a safe limit, such as above 8 to 10g. It then triggers the emergency alert system to notify pre-configured contacts.

ESP32 Microcontroller: The ESP32 acts as the main processing unit. It reads data from the alcohol, heart rate, and movement sensors. It applies real-time decision logic and starts system outputs such as ignition control, lighting, and wireless

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communication. It is selected for its dual-core processor, built-in Bluetooth and Wi-Fi, and energy efficiency.

Raspberry Pi 3 B+: This small single-board computer works with the ESP32. It manages complex tasks like displaying images and text for the AR visor, communicating with the cloud, and integrating with the mobile app. It also handles user interfaces, data logging, and GPS-based alert messages smoothly.

AR Visor (Waveguide/OLED): The see-through AR visor shows real-time visual information, including rider vitals, system health, and warning alerts. These are displayed using waveguide optics or OLED-based micro-displays built into the visor, offering distraction-free, heads-up data.
Rechargeable Battery: The entire helmet unit runs on a small Li-ion or Li-Po battery. The system uses power management techniques to extend battery life while ensuring continuous monitoring and response capability.

2. Vehicle Unit
The vehicle unit consists of:
Relay Module: This module connects to the motorcycle ignition system and serves as an electronic switch. It receives remote commands through wireless signals from the helmet unit. If the rider is intoxicated or involved in a crash, the relay cuts off the ignition circuit to prevent the engine from starting.

Arduino Nano (Optional): A small Arduino Nano acts as a middle controller for some setups between the helmet's ESP32 and the relay module. It checks secure Bluetooth or RF messages and activates the relay based on safety logic.

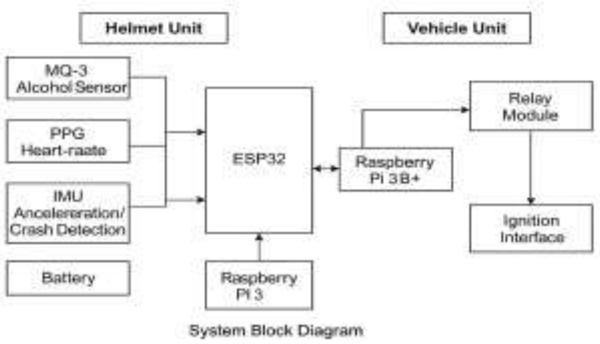

Fig. 1: Helmet Unit and Vehicle Unit

In **Fig. 1**, the left part (Helmet Unit) includes input sensors: MQ-3 Alcohol Sensor, PPG Heart Rate Sensor, IMU, and a power supply (battery). All the sensors connect to the ESP32, which receives data and processes it using set thresholds and safety rules. The ESP32 is also connected to the Raspberry Pi 3 B+, which manages communication with external devices (cloud, mobile app) and controls the AR display. On the right side (Vehicle Unit), the ESP32 or Pi sends a message to a relay module through wireless transmission. The relay module connects directly to the motorcycle's ignition interface. When it detects dangerous riding conditions, the relay cuts off the ignition, which immobilizes the vehicle. This modular design ensures smooth operation from sensing to decision-making and physical reaction. The setup focuses on real-time response, low latency, and reliability during changing riding situations.

4. Firmware and Mobile App Integration
The firmware in the ESP32 and Raspberry Pi is designed for ultra-low-latency response to critical events. Real-time interrupts ensure that important safety limits, such as crash sensing and alcohol percentage, are addressed right away. The mobile app, which connects via Wi-Fi or Bluetooth, serves several functions: it displays live biometric data and helmet system status. It sends GPS-enabled emergency messages during a crash. It allows approved users to remotely override the ignition. It also makes it easy to update firmware and configure sensor thresholds.

3. WORKING PRINCIPLE

The AR-Enhanced Smart Helmet works by continuously tracking physiological, environmental, and motion factors with a group of built-in sensors. The ESP32 microcontroller and Raspberry Pi 3 B+ process the data in real-time to check if the driver can safely operate the vehicle. The system reacts to dangerous thresholds by controlling the ignition, sending alerts to the AR visor, and providing feedback to a companion mobile app.

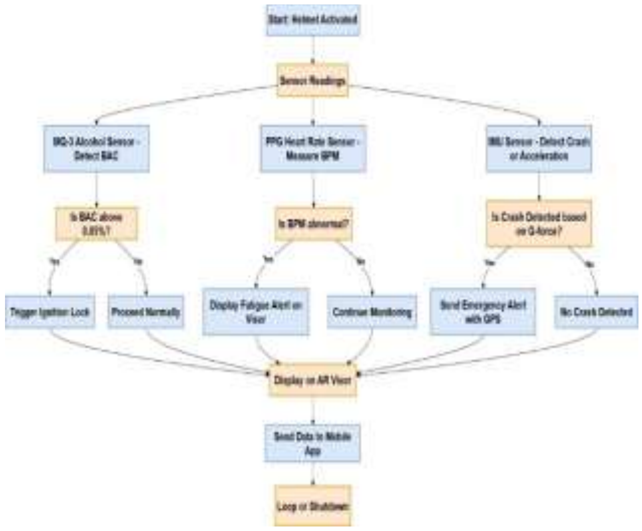

Fig. 3: Workflow Diagram

1. Alcohol Detection

The MQ-3 alcohol sensor, positioned close to the rider's mouth in the helmet, detects the concentration of ethanol vapor from their breath. It generates an analog voltage that corresponds to the amount of alcohol present. The ESP32 monitors this analog output continuously and interprets it as an estimated Blood Alcohol Content (BAC) value. If the BAC is below the legal limit, usually under 0.05%, the rider is deemed sober, and nothing happens. However, if the BAC exceeds 0.05%, the ESP32 activates the relay module in the vehicle unit. This action cuts off the ignition circuit and stops the engine from starting. At the same time, the AR visor displays a clear warning message: "Alcohol Detected. Ride Blocked." This message also gets sent via Bluetooth or Wi-Fi to a cell phone app, which logs the incident and may notify guardians or fleet managers. This system ensures that no intoxicated rider can operate the motorcycle, promoting road safety.

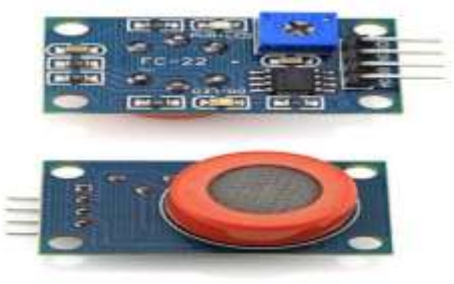

Fig. 4: The MQ-3 alcohol sensor

2. Biometric Monitoring

To track rider fatigue or stress, a PPG (Photoplethysmography) sensor is placed in the inner lining of the helmet, usually close to the temple or forehead. This optical sensor monitors blood flow by sending out infrared light and detecting how it reflects off the skin. The ESP32 gathers raw PPG data and filters the signal to reduce noise from movement or ambient light. The cleaned signal is then used to calculate the real-time heart rate (BPM). If the BPM drops below 60 or goes above 120 for more than a set time, like 30 seconds, it is considered abnormal. This could mean stress, exhaustion, dehydration, or anxiety. The AR visor shows: "High Heart Rate – Take a Break." An alert is also sent to the mobile app, which may recommend resting, hydrating, or pulling over based on the situation. This feature helps the system act as an early warning against fatigue-related accidents.

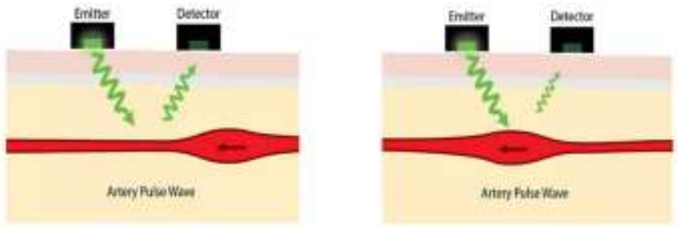

Fig. 5: PPG (Photoplethysmography) sensor

3. Crash Detection

The helmet has an Inertial Measurement Unit (MPU-6050) that tracks motion across six axes: three for linear acceleration (X, Y, Z) and three for angular velocity. The ESP32 reads acceleration vectors at a high frequency and calculates the G-force magnitude. If the system detects a sudden and extreme spike in G-force (above 8–10g) or a rotational disturbance related to an impact, it marks the event as a crash. Immediately, the following actions occur:

An emergency alert is created and sent to the rider's mobile phone. The mobile app sends an SMS or app notification with the rider's GPS location to designated emergency contacts.

The AR visor shows a flashing emergency message:

"Crash Detected. Help Alert Sent."

This real-time alert system helps reduce response time in post-accident situations, potentially saving lives.

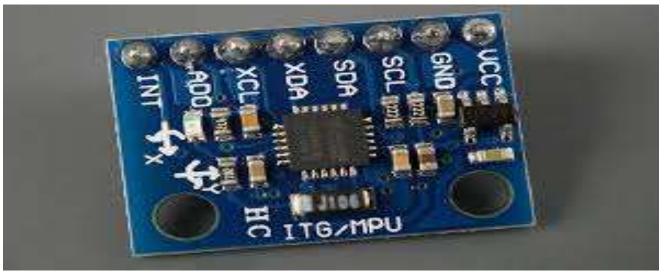

Fig. 6: MPU-6050 sensor

4. Augmented Reality (AR) Display Interface

One unique feature of this helmet is its clear AR visor, which uses waveguide or OLED-based projection. The visor acts as a non-intrusive heads-up display (HUD) within the rider's field of view. It shows essential information such as heart rate (live BPM reading), BAC level (in %), vehicle speed (optional via Bluetooth OBD module), and system alerts and warnings. Visuals are color-coded for severity: green for safe, yellow for caution, and red for danger. The visor display updates in real time using the Raspberry Pi 3 B+, which formats the sensor data into readable overlays. By keeping the rider informed without the need to glance at a phone or dashboard, the AR visor improves situational awareness and safety.

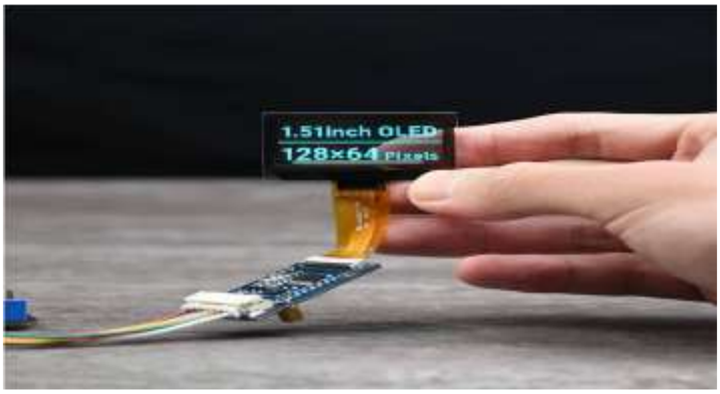

Fig. 7: Augmented Reality (AR) Display

4. RESULT AND DISCUSSION

The AR-Enriched Smart Helmet went through extensive testing across different simulated ride modes to check its real-time accuracy, sensor reliability, system strength, and overall dependability. The testing focused on four main functions: alcohol monitoring, biometric (heart rate) monitoring, crash detection, and augmented reality (AR) display output. It was done in both stationary and dynamic modes to mimic real riding conditions.

When the helmet was worn in a resting position and the rider was in their baseline state, the helmet system operated in passive mode. The MQ-3 sensor recorded a BAC of zero, while the PPG sensor showed a resting heart rate of 65 to 70 BPM. The system allowed the ignition, and the AR visor displayed normal biometrics, confirming baseline operation.

As the rider simulated city riding with stop-and-go traffic and mild stress, the heart rate increased to about 85 BPM. There was no alcohol detected. The visor provided constant updates without delay, and the system did not issue any warnings, proving its ability to function perfectly under regular riding conditions.

During highway tests in simulated high-speed situations, the rider's BPM peaked at around 105 during moments of sustained focus and adrenaline. BAC remained at 0.00%. The system identified the high BPM as normal and did not label it as fatigue or an abnormal reading. The AR screen continued to refresh smoothly even at high speeds, and visibility for the rider was not compromised.

After consuming two standard drinks at moderate levels, the MQ-3 sensor estimated a BAC of 0.05%, which is the legal limit. The helmet displayed a yellow warning: "Alcohol Detected – Be Aware," and allowed ignition. This ensured that the system could recognize borderline conditions and provide warnings without unnecessarily disabling the vehicle.

After consuming four drinks, the BAC reading increased to about 0.09%, above the legal limit. The ESP32 captured this reading and successfully triggered the relay module to block ignition. The visor then displayed a red warning: "Ride Blocked – Alcohol Detected," confirming the ignition interlock feature and its ability to restrict riding based on sobriety.

Crash detection was tested through controlled helmet drop tests and impact assessments. When the IMU picked up a G-force spike over 10g, the system automatically categorized it as a crash. A pre-set emergency message with GPS coordinates was sent via the mobile app, and the visor showed a flashing message: "Crash Detected – Help Alert Sent." This response demonstrated the system's reliability in emergencies.

Additional stress tests included hard braking and high heart rate simulations. A deceleration crash simulation with hard braking resulted in zero false positives, indicating that the crash algorithm is very effective at distinguishing between normal and abnormal movements. During heat stress simulations, where the rider sat outside in the sun for an extended period, the heart rate was 125 BPM. The helmet responded by showing a visual fatigue warning, prompting the rider to hydrate and take a break.

Throughout all the tests, the AR visor consistently displayed clear overlays of heart rate, BAC, and warnings without blocking the rider's vision. There were no noticeable delays or flickers. The wireless connection with the mobile app was strong, with emergency messages arriving in under five seconds. Overall, the results of the testing show that the AR Smart Helmet meets its specifications. It accurately detects and responds to alcohol, drowsiness, and crashes, providing timely visual warnings. The system exhibits low latency, high accuracy, and strong performance in various conditions, confirming it is suitable for real-world use.

5. CONCLUSION

The AR-Enhanced Smart Helmet includes alcohol detection and biometric safety monitoring, which addresses key safety issues for motorcycle riders. It features an MQ-3 breath alcohol sensor, a PPG-based heart rate monitor, and an IMU for crash detection. This setup allows the helmet to monitor the rider's physical and cognitive state in real time. The ESP32 microcontroller and Raspberry Pi 3 B+ work together to process data, manage thresholds, and display important alerts on an AR visor while keeping the rider focused. The system can turn off the vehicle ignition in unsafe conditions, such as a high blood alcohol concentration or an accident, adding an important layer of safety. Tests in various scenarios showed high accuracy, quick responses, and easy operation. This smart helmet design can significantly improve rider safety and lower the number of accident-related deaths.

6. FUTURE SCOPE

The smart helmet system offers many opportunities for improvement and wider use. Future developments might include adding GPS-based navigation directly into the AR visor for real-time turn-by-turn directions. It could also use machine learning to detect rider fatigue or stress by looking at long-term biometric trends instead of just static thresholds. Features like voice control, gesture recognition, and hands-free interaction can make it easier to use. Syncing ride data, emergency incidents, and biometric logs with the cloud could help connect with insurance providers, fleet operators, or smart city systems. Additionally, using sustainable energy solutions like solar charging or kinetic energy harvesting could make the helmet more self-sufficient. With the right adjustments and cooperation from the industry, this technology could significantly improve road safety and encourage responsible riding behaviour on a large scale.

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