Design and Development of IoT Based Smart Safety Helmet for Bike Riders

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Abstract-The rise in road traffic accidents, particularly among two-wheeler riders, has highlighted the urgent need for enhanced safety measures. The 'IoT-Based Smart Safety Helmet System for Bike Riders' addresses critical safety challenges such as helmet non-compliance, drunk driving, and delayed accident response through an integrated, real-time safety mechanism. This system leverages the Internet of Things (IoT) to enforce helmet usage, monitor alcohol consumption, detect accidents, and send automated emergency alerts. It comprises two ESP32-based units one embedded within the helmet and the other installed on the bike. To ensure safety, the helmet section incorporates an IR sensor for helmet detection, an MQ-3 alcohol sensor for intoxication monitoring, and an MPU6050 sensor for identifying abrupt movements associated with falls. The bike unit receives this data via ESP-NOW wireless communication. A relay module connected to the bike's ignition allows the bike to start only if the rider is sober, wearing a helmet, and no accident is detected. In case of a fall, the system triggers the GSM module to send an SMS alert to a preconfigured emergency contact. The system continuously monitors rider safety conditions even after ignition. Real-time enforcement of safety rules eliminates dependency on manual checks and significantly improves response time in emergencies. The proposed system is cost-effective, scalable, and highly applicable in both personal and commercial transportation. It enhances road safety standards and supports intelligent accident prevention, making it a viable solution for reducing road fatalities and promoting responsible riding practices.

Keywords— IoT, Smart Helmet, ESP32, Alcohol Detection, Accident Alert, GSM, Safety System, Two-Wheeler, Real-time Monitoring

I. INTRODUCTION

Motorcycles are among the most commonly used modes of transportation worldwide due to their affordability, fuel efficiency, and ability to navigate through congested roads. However, they also pose significant safety risks, particularly in developing countries where road safety regulations are not strictly enforced. A major concern in motorcycle-related accidents is the non-compliance with helmet usage and the prevalence of drunk driving, both of which contribute to severe injuries and fatalities.

According to the World Health Organization (WHO), head injuries are the leading cause of death in motorcycle accidents, and wearing a helmet can lower the likelihood of fatal outcomes by nearly half and decrease the chance of head trauma by more than two-thirds. Despite these statistics, many riders either fail to wear helmets or do not wear them properly, significantly increasing the likelihood of fatal injuries. Similarly, drunk driving remains one of the major causes of road accidents, as alcohol impairs a rider's judgment, reflexes, and coordination, making them more prone to collisions. Although traffic laws mandate helmet usage and prohibit driving under the influence of alcohol, enforcement is challenging. Riders often neglect safety rules unless actively monitored by authorities. To address these challenges, an automated safety mechanism that ensures helmet compliance and prevents drunk riding before the vehicle starts can significantly reduce accidents.

The proposed IoT-Based Smart Safety Helmet System offers an innovative approach to motorcycle safety by integrating helmet detection, alcohol monitoring, and accident alert mechanisms. Unlike traditional safety measures that rely on manual enforcement, this system provides an automated, real-time solution that prevents the bike from starting unless the rider meets the required safety conditions. Many riders often avoid wearing helmets due to discomfort, negligence, or the absence of strict law enforcement. Such practices greatly elevate the chances of sustaining critical injuries in the event of an accident. To address this issue, the Smart Safety Helmet system integrates a helmet detection mechanism that ensures the bike will only start when the rider is wearing the helmet properly. Requiring helmet use for ignition activation encourages riders to consistently adhere to safety protocol.

Drunk riding is another major cause of road accidents, as alcohol consumption impairs reaction time and judgment. To combat this, the Smart Safety Helmet is equipped with an MQ-3 alcohol sensor that detects the rider's breath alcohol level. If alcohol is detected beyond a safe threshold, the system prevents the bike from starting, thereby ensuring that intoxicated individuals are unable to operate the vehicle. Timely medical assistance after an accident can be crucial in saving lives. However, many accident victims suffer due to delays in receiving emergency help. The Smart Safety Helmet includes automatic accident detection and an emergency SMS alert system. In the event of a fall or collision, the system sends a location-based alert to the rider's guardians or emergency services, enabling quicker medical response.

In conclusion, the IoT-Based Smart Safety Helmet system bridges the gap between existing rider safety regulations and their practical implementation. By automating helmet detection, alcohol monitoring, and emergency alerts, the system reduces the need for manual enforcement and minimizes the risks caused by human error. This integration of IoT into transportation safety provides a scalable, effective, and reliable method for enhancing road safety and saving lives.

II. LITERATURE REVIEW

A. Background and Related Work

Ranjan et al. (2024) introduced an Arduino-based alcohol detection and engine locking system that utilizes the MQ-3 gas sensor to monitor alcohol concentration in the driver's breath. If the alcohol level exceeds a predefined threshold, the system activates a relay to prevent the vehicle from starting. Additionally, it includes GPS tracking and GSM functionality to notify family members or authorities in real-time when alcohol is detected. While effective for alcohol prevention and vehicle tracking, the system lacks helmet detection, overspeed monitoring, and real-time accident response capabilities, limiting its overall effectiveness in comprehensive rider safety enforcement.

Dubey et al. (2014) proposed an Automated Security and Rider Safety System for two-wheelers that integrates multiple safety checks. The system uses the MQ-303A sensor for alcohol detection and an IR sensor to confirm helmet compliance. Both conditions must be met for the vehicle to start, reinforcing basic safety requirements. It also features accident detection via pressure sensors, triggering GSM-based alerts to emergency contacts. Despite these strengths, the system does not support real-time IoT monitoring or speed control, which limits its capacity for continuous rider safety tracking and proactive intervention.

Pathak et al. (2020) advanced the concept of smart helmet systems by integrating IoT-enabled features like pulse rate monitoring to verify helmet usage, MQ-3 sensor for alcohol detection, and accelerometers for crash detection. The system supports GPS-GSM alerting in case of an accident and uses a Hall Effect sensor for speed monitoring, helping prevent overspeeding. This comprehensive approach allows real-time rider tracking and rapid emergency responses, offering enhanced protection. However, the reliance on external sensors increases complexity and may require robust calibration to ensure consistent performance.

Alim et al. (2020) developed another smart helmet system focusing on accident detection and real-time alerts. It employs a Sharp IR sensor for helmet detection and an MQ-3 sensor for alcohol monitoring. The SW420 vibration sensor identifies crashes and triggers GPS and GSM-based alerts. Communication between the helmet and bike unit is enabled using the nRF24L01 module. While the system covers essential safety functions, it lacks speed monitoring and fatigue detection, which are crucial for preventing accidents caused by high-speed riding or rider exhaustion. Integrating these could further improve its effectiveness in ensuring rider safety**.**

Rahman et al. (2020) proposed an IoT-based Smart Helmet and Accident Identification System comprising three interconnected components: the helmet circuit, the automobile circuit, and a mobile application. The helmet circuit utilizes IR sensors to ensure the rider is wearing a helmet and includes alcohol detection to prevent intoxicated riding, acting as a pre-condition for ignition. The automobile circuit enhances safety through a 3-axis accelerometer for accident detection, a relay-controlled engine ignition system, a Bluetooth module for communication, and a load sensor to prevent overloading. Complementing these hardware systems, the mobile application delivers real-time alerts and maintains a database for recording accident events, enabling better analysis and safety enforcement. This integrated solution ensures that a vehicle only operates under safe conditions while maintaining continuous monitoring during rides, offering a comprehensive, technology-driven approach to two-wheeler safety.

III. METHODOLOGY

The proposed methodology of the IoT-Based Smart Safety Helmet system focuses on real-time monitoring and safety enforcement for two-wheeler riders. It begins with the initial condition check using an IR sensor embedded within the helmet. This sensor detects whether the rider is wearing the helmet properly by identifying the proximity or reflection from the head surface. If the helmet is not detected, the bike ignition system remains disabled, effectively preventing the rider from starting the motorcycle. This automatic validation promotes helmet compliance without relying on manual enforcement. If the helmet is confirmed to be worn, the system proceeds to the second critical safety check—alcohol detection. An MQ-3 alcohol sensor placed near the rider's mouth area detects the presence of alcohol vapor in the breath. The analog output from the sensor is compared against a predefined threshold. If the alcohol level exceeds this threshold, it indicates that the rider is intoxicated, and as a result, the system sends a command to keep the bike ignition turned off. This ensures that individuals under the influence of alcohol cannot start or operate the vehicle, preventing potentially fatal drunk-driving incidents.

If both safety conditions helmet worn and no alcohol detected are satisfied, the system allows the bike to start by activating the relay module connected to the ignition system. The relay is controlled by the bike-side ESP32, which receives real-time sensor data from the helmet-side ESP32 via the ESP-NOW protocol. Once the relay is triggered, the bike ignition system (simulated via a DC motor in the prototype) powers ON, allowing the rider to begin the journey. This seamless integration between hardware and wireless communication ensures secure and efficient operation of the vehicle. Upon ignition, the system enters the continuous monitoring phase, using the MPU6050 accelerometer and gyroscope sensor. This sensor constantly tracks the rider's motion and orientation. By measuring the gyroscopic activity and acceleration across multiple axes, the system can identify abnormal movements or sudden impacts that may indicate a fall or collision. This ensures that rider safety is not only verified at the beginning but maintained throughout the journey.

If the MPU6050 detects abrupt movements that exceed a certain threshold and persist for a specified duration (e.g., 500 milliseconds or more), it interprets this as a potential accident. A software timer confirms this abnormal activity to avoid false positives due to minor bumps or sudden braking. Once a fall or accident is verified, the system immediately activates the emergency alert protocol. This includes sending a preconfigured SMS message to the rider's guardians or emergency contacts using the SIM800L GSM module.

The SMS alert message includes an emergency notification indicating that an accident has occurred and advises the receiver to check on the rider's well-being. This rapid communication ensures that help can be dispatched quickly, reducing the chances of prolonged medical delays. As the GSM module operates independently of Wi-Fi, it ensures communication even in areas with limited internet access, improving the reliability of the alert system. Throughout the process, the system operates autonomously and does not require manual input from the rider or external personnel. The ESP32 microcontrollers at both ends continuously exchange and process sensor data to maintain real-time status updates. This approach not only enforces compliance with road safety norms but also brings an intelligent, automated solution into day-to-day motorcycle use.

The proposed methodology delivers a comprehensive safety mechanism by combining helmet detection, alcohol monitoring, ignition control, fall detection, and emergency alerting into a single IoT-based solution. This methodology ensures that safety is enforced before and during the ride, thereby minimizing risks and improving response times during emergencies. The system's modular and scalable design also allows future integration of features like GPS tracking and mobile app connectivity for even more robust monitoring.

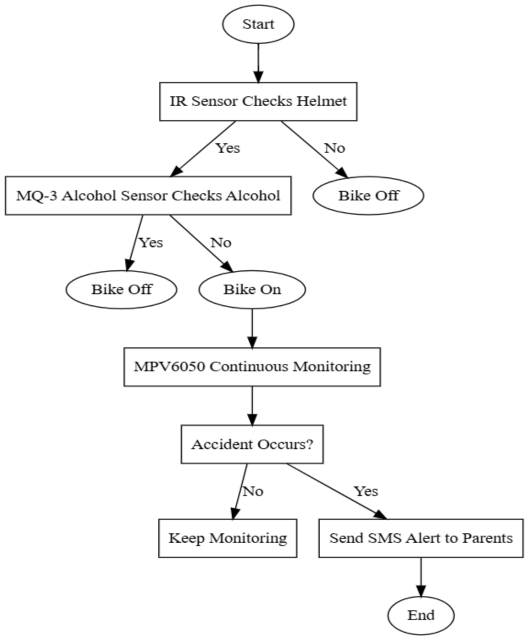

Fig. 1. Proposed Methodology Work Flow

IV. PROPOSED SCHEME

A. Transmitter Unit Helmet Side

The ESP32 Dev Module serves as the central processing unit of the helmet-side module. It handles the integration and control of all sensors, executes logic-based decisions, and manages the data flow necessary for enforcing rider safety. This microcontroller receives input signals, processes safety conditions, and transmits results wirelessly to the receiver side, ensuring that all decisions—such as enabling or disabling bike ignition—are made based on real-time sensor data. To enforce helmet compliance, an Infrared (IR) sensor is connected to the ESP32 via digital pin D18. This sensor detects whether the rider is wearing the helmet by sensing the presence of the rider's head. If the helmet is not properly worn, the IR sensor triggers a signal that prevents the ignition system from activating, thereby ensuring that the vehicle cannot be started without following basic safety protocols.

For alcohol detection, the system uses the MQ-3 alcohol sensor, connected to the analog pin GPIO34 (A0) of the ESP32. This sensor detects the presence and concentration of alcohol in the rider's breath. If the measured value exceeds a predefined safety threshold, the ESP32 logic disallows ignition, effectively preventing intoxicated individuals from operating the bike. This functionality is vital for avoiding alcohol-related accidents.

The system also includes an MPU6050 accelerometer and gyroscope module, which is interfaced with the ESP32 using the I2C communication protocol (SCL on GPIO22 and SDA on GPIO21). This sensor continuously monitors motion and orientation. In the event of a fall or impact, the MPU6050 detects abnormal motion patterns and flags them as accidents. The ESP32 responds by sending an emergency SMS through the SIM800L GSM module, which is connected via Serial1 (TX on GPIO16 and RX on GPIO17). This alert ensures timely communication with emergency contacts. Additionally, data is transmitted wirelessly to the receiver ESP32 through ESP-NOW, enabling real-time safety monitoring throughout the journey.

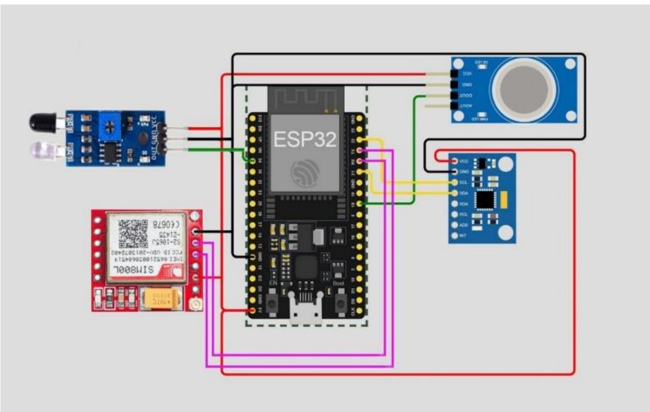

Fig. 2. Transmitter Unit Helmet Side Circuit Connections

B. Receiver Unit Bike Side

The ESP32 microcontroller on the bike-side unit is configured in Wi-Fi Station mode to facilitate seamless communication via the ESP-NOW protocol. This configuration enables the receiver ESP32 to collect real-time sensor data from the helmet unit without relying on external network infrastructure, allowing for a lightweight and fast peer-to-peer data transmission system ideal for safety-critical applications.

To control the ignition system, a relay module is connected to digital pin GPIO5 of the receiver ESP32. The relay functions as an electronic switch that controls a DC motor, which simulates the bike's ignition system. Based on the data received—specifically the helmet detection status, alcohol level, and fall detection status—the ESP32 makes a decision to either energize or de-energize the relay. If all safety conditions are met (helmet worn, no alcohol detected, and no fall detected), the relay activates the motor, simulating a bike start. Otherwise, the system keeps the motor OFF, preventing unsafe operation.

The entire system is powered using rechargeable batteries, typically 12V lead-acid or 3.7V Li-ion cells. To accommodate the voltage requirements of different components such as the ESP32, sensors, and relay modules, voltage regulators are used to step down or stabilize the supply to appropriate levels (commonly 3.3V or 5V). This ensures safe and reliable operation of all electronic components without the risk of overvoltage damage. With these electrical connections and logic control mechanisms in place, the receiver unit ensures that the vehicle ignition only occurs under safe operating conditions. The system's capability to process live data from the helmet unit and take immediate control actions makes it a robust, real-time safety solution for two-wheeler riders.

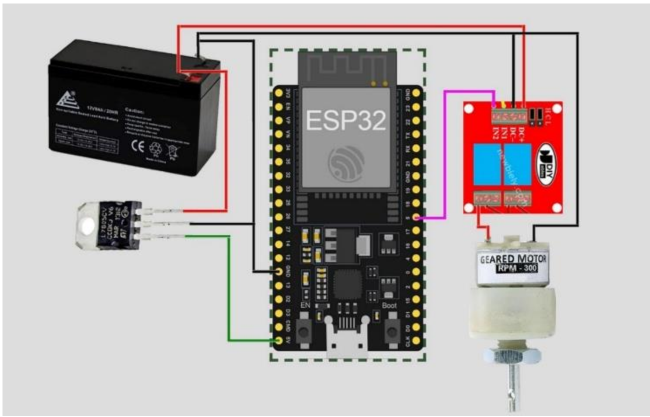

Fig. 3. Receiver Unit Bike Side Circuit Connections

IV. RESULTS AND DISCUSSION

The implementation of the IoT-based Smart Safety Helmet System was carried out using a prototype model consisting of transmitter and receiver ESP32 units. Each hardware module—helmet detection, alcohol sensing, accident monitoring, and GSM communication—was integrated and tested thoroughly. The transmitter unit was installed on a dummy helmet with all the relevant sensors, while the receiver unit was connected to a relay-driven DC motor simulating a bike's ignition system. Initial power-on diagnostics confirmed the successful operation of sensor calibration and module initialization.

During functional testing, the system effectively validated helmet usage through the IR sensor before enabling ignition. If the helmet was not worn, the digital input from the IR sensor prevented the bike from starting. Similarly, the MQ-3 alcohol sensor was able to detect elevated alcohol levels in the rider's breath. If intoxication was identified beyond the safety threshold, the system disabled ignition, reinforcing the core objective of preventing drunk driving.

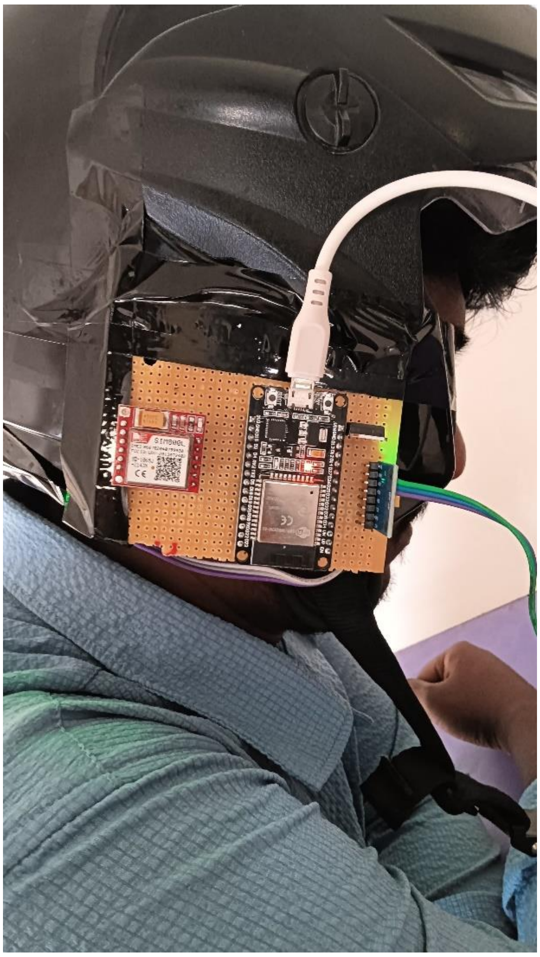

Fig. 4. Smart Helmet worn by the user during testing

Once the ignition conditions were satisfied and the bike was turned on, the MPU6050 accelerometer and gyroscope module actively monitored motion and orientation. In scenarios simulating a fall, the sensor detected sudden changes in angular velocity. A fall condition persisted for more than 500 milliseconds was flagged as an accident, triggering the GSM module to send an SMS alert to a predefined mobile number. This ensured timely communication with the rider's emergency contact.

Wireless communication between the helmet and bike units was established using the ESP-NOW protocol, a low-latency, peer-to-peer Wi-Fi-based communication method. It enabled reliable and fast transmission of safety-critical data such as helmet status, alcohol level, and fall detection. The system proved stable across multiple trials and operated consistently under varied power supply conditions using regulated 12V batteries. These results validated the system's capability to perform real-time safety monitoring and response with minimal latency, confirming its practical feasibility for real-world applications.

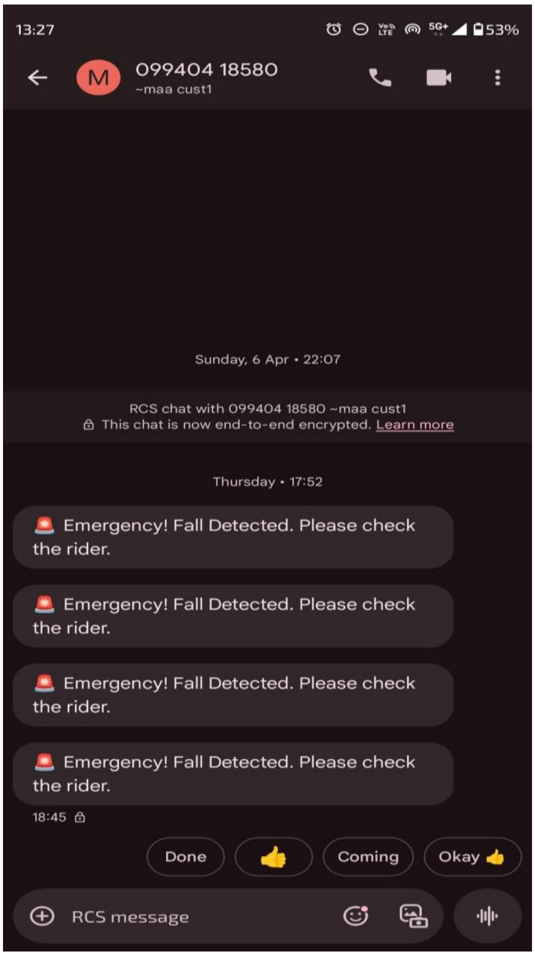

Fig. 5. Accident Emergency Alert from GSM Module

V. FUTURE WORK

The current implementation of the Smart Safety Helmet system provides a reliable foundation for enhancing two-wheeler rider safety. However, future enhancements can expand its functionality and user interactivity. One major improvement would be the integration of Voice Assistance, enabling the system to deliver real-time audio alerts regarding helmet usage, alcohol detection, or overspeed warnings. This hands-free communication mechanism will improve user awareness and safety compliance without distracting the rider's attention from the road.

Incorporating GPS functionality will add location-tracking capabilities to the system. In case of an accident, the system could transmit the rider’s exact coordinates along with the emergency SMS alert. This enhancement would ensure faster medical assistance and more effective emergency response. The GPS data could also be used to track route history and accident-prone zones, providing actionable insights for both riders and authorities.

Further development could include Cloud Connectivity and Speed Monitoring. By storing data in the cloud, the system can log ride history and safety events accessible through a mobile application. Real-time dashboards could be created for guardians, fleet managers, or authorities. Additionally, implementing continuous speed tracking could allow alerts to be sent to traffic authorities if a rider exceeds speed limits for a prolonged duration (e.g., over one minute). These upgrades would transform the helmet into a comprehensive IoT-enabled safety solution for smart transportation ecosystems.

VI. CONCLUSION

This project successfully presents the development of an IoT-based Smart Safety Helmet designed to enhance the safety of two-wheeler riders through real-time monitoring and automated safety controls. The system is built with a focus on preventing unsafe riding behavior and responding effectively in case of accidents. It begins with pre-ride safety checks, where an Infrared (IR) sensor ensures the rider is wearing the helmet before ignition. Simultaneously, an MQ-3 alcohol sensor detects if the rider is under the influence of alcohol. These two essential conditions work in tandem with a relay-based ignition control mechanism that allows the bike to start only when both safety parameters are satisfied.

Beyond the initial checks, the system features continuous monitoring while the bike is in motion. An MPU6050 sensor is used to detect any sudden movements or falls that may indicate an accident. If such an incident occurs, the system immediately triggers a response mechanism. A GSM module is employed to send an SMS alert to the rider's parents or guardians, along with the location details of the accident. This quick and automated response can be critical in emergency situations, helping to reduce response time and potentially save lives.

In conclusion, the Smart Safety Helmet integrates multiple sensors and communication modules into a single, compact, and efficient safety system. It enforces responsible riding behavior by blocking ignition when safety conditions aren't met, and it ensures that help is notified promptly during emergencies. The project highlights the effective use of IoT in addressing real-world road safety concerns and offers a scalable solution that could be implemented widely to reduce road accidents and improve rider accountability.

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