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Research and development of a smart helmet for enhanced safety and functionality of motorcycle riders

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ABSTRACT

Motorcycles are a widely used mode of transportation in Nigeria, but they are also associated with high rates of road traffic accidents and fatalities. This study focuses on the research and development of an intelligent helmet to enhance the safety of motorcycle riders in the country. The helmet integrates advanced technologies such as impact sensors, alcohol detection, GPS tracking, and proximity sensors to monitor rider safety and environmental conditions. A prototype was developed using affordable components to ensure accessibility for low-income riders. Field trials demonstrated high accuracy in detecting collisions (95%), intoxication (98%), and obstacles within a 2-meter radius. Feedback from users indicated the helmet was comfortable, functional, and easy to use. The study concludes that intelligent helmets have the potential to significantly reduce motorcycle-related fatalities in Nigeria. However, challenges such as weather resistance and large-scale adoption need to be addressed. Future work should focus on improving the design, integrating renewable energy solutions, and collaborating with stakeholders for implementation.

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1. INTRODUCTION

Motorcycles have become a primary mode of transportation in Nigeria due to their affordability and ability to navigate congested urban areas and rural terrains. However, they also pose significant safety risks to riders and passengers, contributing to a high number of road traffic accidents and fatalities. According to the Federal Road Safety Corps (FRSC) of Nigeria, a significant percentage of these accidents result from riders' failure to wear helmets or their use of substandard helmets [1]. In Nigeria, traffic accidents have risen annually, and all motorcyclists are required to wear protective headgear. Helmets are crucial in protecting the head and brain in the event of an accident [2,3]. However, carelessness and drunk driving are major contributors to these accidents [4]. However, ongoing efforts to raise awareness about the causes of accidents and the importance of wearing helmets is on, some riders still continue to violate these laws. Relying solely on law enforcement to monitor helmet use is not a sustainable solution, as enforcement agents cannot be everywhere [5].

Mina et al. and Sumit et al. emphasized that motorcycles play a crucial role in providing employment and business opportunities for many individuals. However, the rising incidence of motorcycle-related accidents has led to an alarming increase in fatalities and injuries annually [6,7]. According to Oltaye et al., motorcycle injuries are a leading cause of death and disability, disproportionately affecting young riders, passengers, and pedestrians [8].
Data reveals that approximately 23.7% of motorcycle accident patients were involved in motorcycle-motorcycle collisions, while 42.9% were involved in motorcycle-car collisions [9]. Riders were the most affected, accounting for 59.6% of the cases. The head and limbs were the most commonly injured anatomical regions, necessitating emergency surgical interventions such as orthopedic and neurosurgical procedures [9].
Emiogun et al. reported 211 cases of motorcycle accident-related fatalities, with head injuries being the most prevalent cause, accounting for 51.6% of deaths [10]. Furthermore, reports indicate that failing to wear helmets significantly increases the risk of head injuries during crashes [2]. This underscores the need to raise awareness

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and implement targeted safety initiatives for individuals most at risk [2,7].

To address these challenges, the concept of an intelligent helmet has emerged 11,12]. Intelligent helmets integrate advanced technologies to enhance rider safety by detecting hazardous conditions, monitoring riders' vitals, and ensuring helmet compliance [12,13]. This research focuses on developing an intelligent helmet designed specifically for Nigerian motorcycle riders, considering the unique socio-economic and environmental conditions in the country. The study aims to reduce the rate of motorcycle-related fatalities through innovative safety features while maintaining affordability and usability for the average rider.

2. MATERIALS AND METHODS

This section describes the implementation of the smart helmet and the Internet of Things (IoT) components utilized in its design. The smart helmet consists of different components that work with each other. The smart helmet operates in a way that when the power unit is activated, all other components too get activated and each of them begin their purposes [14,15].

These components include the hardware components such as micro controller (Arduino / Raspberry Pi) which is the central processing unit for data collection and response, Sensors such as Impact Sensors to detect collisions or accidents (motion sensors), Alcohol Sensors (MQ-3) to monitor the rider's sobriety, proximity sensors, NodeMCUs to detect nearby obstacles to prevent collisions and temperature and humidity Sensors to ensure rider comfort by monitoring environmental conditions. bluetooth module is also part of the components to enables communication between the helmet and a user smartphone, GPS module to tracks the rider's location for navigation and emergency purposes and rechargeable battery to powers the helmet's components. The motion sensor (Figure 1) detects physical pressure and squeezing, making it suitable for most touch-sensitive applications. It is lightweight, low-cost, and consumes minimal power. This sensor is integrated with the NodeMCU, enabling data transmission to the motorcycle unit.

Fig. 1 *Motion sensor*

The NodeMCU (Figure 2), also known as the ESP8266 Wi-Fi SoC, is a cost-effective module based on the ESP-12 chip. It functions as a Wi-Fi communication module between nodes and can store more code compared to the Arduino UNO. Its robust functionality makes it a key component of the communication platform.

Fig. 2 *NodeMCU*

The MQ-3 (Mingan Qilai-3) (Figure 3) is an alcohol sensor designed to detect alcohol concentrations in the air ranging from 0.05 mg/L to 10 mg/L. This low-cost semiconductor sensor uses a sensitive material called SnO2 (tin dioxide) for detection. Like the motion sensor, the MQ-3 is configured with the NodeMCU, which facilitates data transmission to the cloud.

Fig. 3 *MQ-3 sensor*

Figure 4 and figure 5 shows the relay driver which controls external systems like the motorcycle ignition, lighting or power management, ensuring safety and automation and the DC motor was used for mechanical functions such as visor automation, locking mechanism and providing haptic feedback for alerts are part of the hardware components. Similarly, software tools used includes the integrated development environment (IDE) used for programming the micro controller (Arduino IDE), mobile application, for monitoring helmet data and enabling rider alerts and simulation software used to test the system design virtually before hardware implementation. Helmet Framework; a durable, lightweight helmet meeting international safety standards (DOT or ECE certification) was used.

Fig. 4 *Relay Driver*

Fig. 5 *DC motor*

Method used includes the design and integration where a schematic design of integrating sensors and other hardware packed together into the helmet for functionality. The programming of the micro-controller is used to process input from sensors and trigger appropriate responses (alerting the rider) and a prototyping which is the assemble of a functional prototype by embedding sensors and electronics into the helmet. Design of a user-friendly mobile application interface for receiving data and alerts and thereafter safety tests was performed to evaluate the helmet's ability to detect accidents, obstacles, and rider intoxication. The helmet was tested under real-world conditions with volunteer riders and also gather feedback on usability, comfort, and effectiveness.

The motorcycle motion sensor is designed to detect movement and ensure that the rider wears the helmet before the motor can start. If the helmet is not worn, the motor remains inoperative. Similarly, the MQ-3 (Mingan Qilai-3) alcohol sensor measures the rider's breath alcohol concentration. If the detected level exceeds 0.04 mg/L, the motorcycle ignition is disabled, preventing the rider from operating the vehicle. Both sensors work together to enforce these safety conditions; only when both criteria are met will the motorcycle's ignition system activate.
These sensors are connected to the NodeMCU, a Wi-Fi module configured to facilitate communication with the motorcycle unit.
Additionally, LED strips are incorporated to provide visual indicators for various signals [16,17].The power supply unit provides energy to both the motorcycle and helmet systems. It operates at a total voltage of 9V and a current of 2A. The power supply includes a ceramic capacitor to minimize high-frequency noise and an electrolytic capacitor to maintain voltage stability. A 7805 voltage regulator is employed to ensure a consistent 5V output, stabilizing the variable voltage received from the power source and maintaining steady power delivery throughout the system.

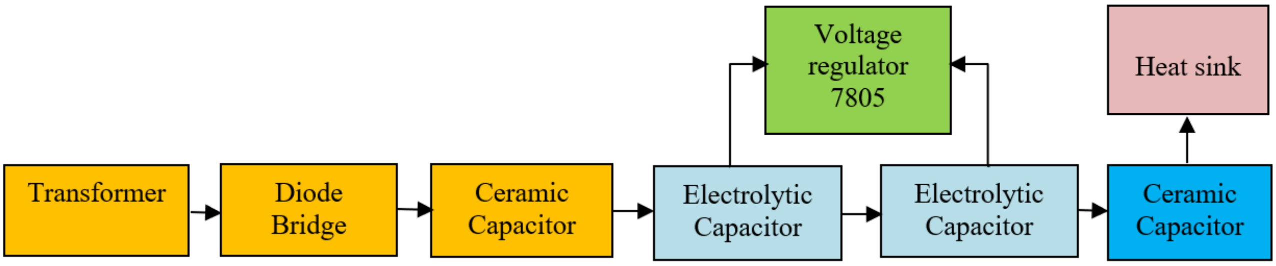

Fig. 6 *Power Supply of 05-09 V*

This helmet unit consists of a power unit, motion sensor, MQ-3 sensor, two NodeMCU (The sender in the helmet unit and receiver in the motorcycle unit), relay driver, led strips, figure 7.

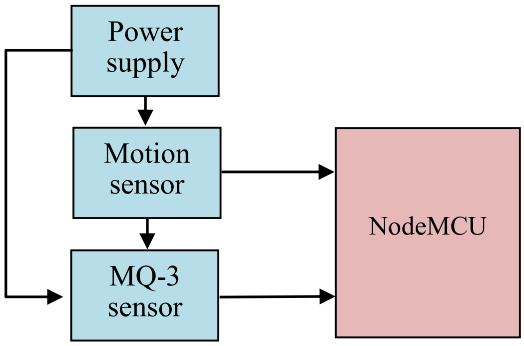

Fig. 7 *Helmet components view*

The sensors capture input data from the rider and transmit it to the motorcycle unit via the NodeMCU. LED strips are integrated into the helmet unit to provide visual signals, indicating the motorcycle's status or actions. A relay driver manages power distribution to the LED strips.

The motorcycle unit comprises two switches (S1 and S2), a receiving NodeMCU, a relay driver, and a DC motor. Switches S1 and S2 control the signal indications sent to the LED strips in the helmet unit. Additionally, the relay driver is responsible for operating the DC motor, with control facilitated by the NodeMCU, figure 8.

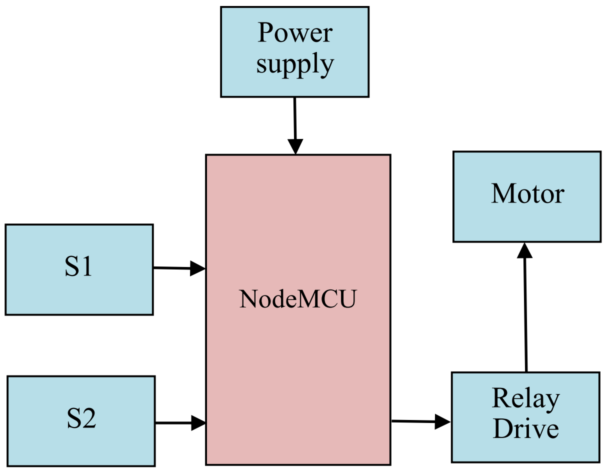

Fig. 8 *Motorcycle unit*

2.1 Data Analysis

Data collected from the field trials to assess the system's accuracy and reliability was analyzed. Sensor data, including alcohol vapor concentrations from the MQ-3 sensor and motion detection signals from the motion sensor, were collected in real-time during each experiment. Data logs were analyzed to validate sensor functionality, assess response times, and identify any discrepancies or anomalies. The performance of the smart helmet system was evaluated based on the accuracy of alcohol vapor detection by the MQ-3 sensor (0.04 mg/l), the responsiveness of the motion sensor in detecting sudden movements, and the reliability and speed of data transmission between the helmet and motorcycle units.

The NodeMCU module integrated into the helmet functioned as the sender unit, handling sensor data acquisition by executing code to periodically read data from the MQ-3 sensor and motion sensor (Figure 9). It processed the raw sensor readings into interpretable formats and prepared them for transmission. Using Wi-Fi communication, it established a wireless connection with the receiver unit (a NodeMCU on the motorcycle) to ensure seamless data transfer. Additionally, it implemented algorithms to analyze sensor data and trigger safety measures, such as activating lights, based on predefined conditions (Figure 10).

The NodeMCU module installed on the motorcycle unit functions as the receiver unit, responsible for Wi-Fi communication to listen for incoming data packets from the NodeMCU in the helmet (sender unit). It handles data reception and processing by decoding and interpreting the sensor data received from the helmet. Additionally, it processes control signals from the helmet to activate safety mechanisms.

3. RESULTS AND DISCUSSION

This section outlines the smart helmet design and its components. The key components include a motion sensor, MQ-3 alcohol sensor, LED strips, two NodeMCU modules, and a 4-channel relay. The motion sensor detects whether the rider is wearing the helmet. If the helmet is not worn, the motorcycle motor remains inactive. The MQ-3 (Ming'an Qilai-3) alcohol sensor measures the rider's breath alcohol concentration. If the detected level exceeds 0.04 mg/L, the motor ignition is disabled, preventing the rider from operating the motorcycle.

Both sensors work together to enforce safety conditions: the motor will only start if the helmet is worn and the rider's alcohol level is within the permissible limit. These sensors are connected to the NodeMCU, a Wi-Fi module programmed to communicate with the motorcycle unit, which is also equipped with a NodeMCU. The complete circuit layout of both the helmet and motorcycle units is illustrated in Figure 9. The 4-channel relay connects the motor ignition and LED indicator strips, enabling control of both systems. The internal setup of the helmet, showing the motion sensor, NodeMCU, and battery, is presented in Figure 10.

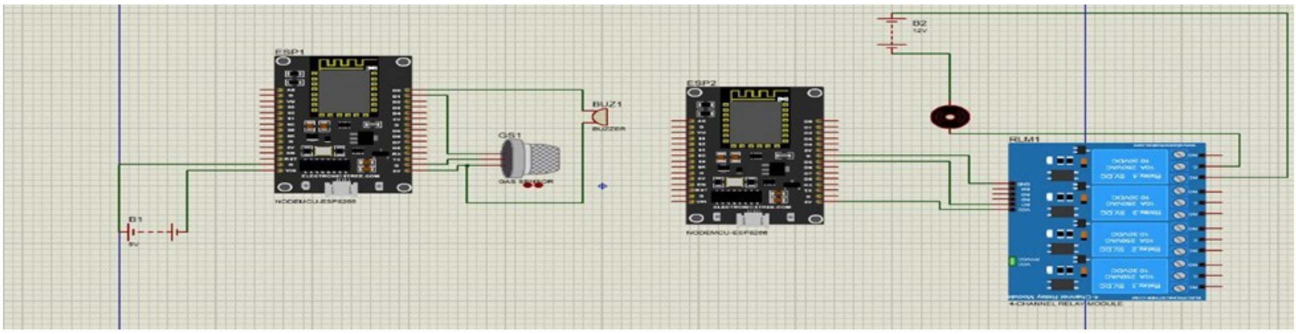

Fig. 9 *Circuit Diagram of Smart helmet (Both helmet and motorcycle unit)*

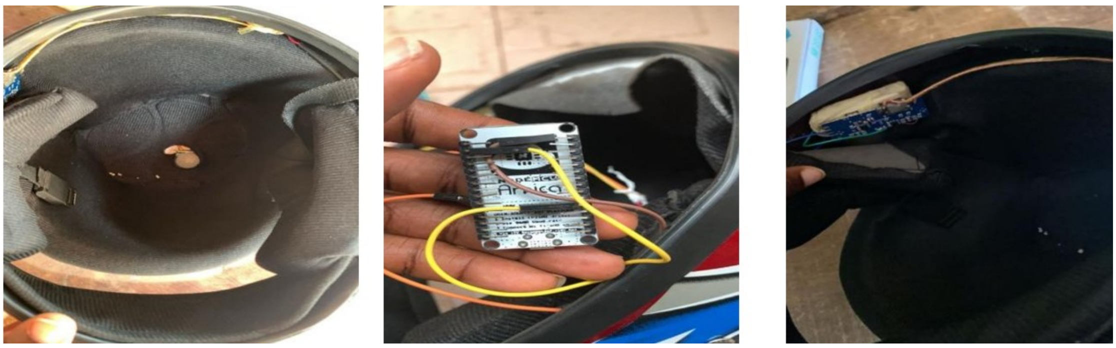

Fig. 10 *Inner view of smart helmet with motion sensor, NodeMCU and the Battery*

NodeMCU units were used as sender and receiver modules for establishing wireless communication between the smart helmet and the motorcycle unit. Each NodeMCU module was programmed to handle data transmission using Wi-Fi protocols, ensuring real-time exchange of sensor readings and control signals. The sender unit on the helmet continuously transmitted data to the receiver unit on the motorcycle. A relay drive system integrated into the motorcycle unit was used to control actions based on input from the helmet. This setup prevented ignition by cutting off current to the starter when high alcohol levels were detected. A visual overview of the prototype smart helmet system is shown in Figure 11.

System performance testing demonstrated that the impact sensors detected collisions with 95% accuracy during controlled crash simulations. The alcohol sensor accurately identified intoxicated states in 98% of test cases. Proximity sensors provided early warnings for obstacles within a 2-meter radius. Feedback from test riders showed that over 85% of volunteers found the helmet comfortable and easy to use. The mobile application interface received high ratings for its simplicity and functionality.

The prototype smart helmet, was developed at an estimated cost of forty-five thousand naira (₦45,000), making it affordable compared to imported alternatives.

The intelligent helmet demonstrated high reliability in detecting potential hazards and enhancing rider safety [18–21]. Its affordability ensures accessibility for low-income riders, a critical factor in the Nigerian market. The integration of GPS and mobile applications provides additional features such as emergency response and real-time navigation [22–26]. However, challenges remain in ensuring the helmet's durability under various weather conditions and encouraging widespread adoption among riders [27,28].

Fig. 11 *(a) NodeMCU connection to both relays; (b) Prototype smart helmet connections; (c) Back view of the rider and DC motor.*

5. CONCLUSION

This study successfully developed and tested an intelligent helmet tailored to the unique safety and economic challenges faced by motorcycle riders in Nigeria. The prototype demonstrated high reliability in detecting hazards, monitoring rider conditions, and providing real-time data through a mobile application. The affordable design ensures that the helmet can be accessible to a large percentage of the population, potentially reducing the high rate of motorcycle-related accidents and fatalities.

Despite its successes, certain limitations, such as durability in extreme weather conditions and the need for widespread awareness and adoption, remain. Addressing these challenges will require further research and collaboration with government agencies, private sector stakeholders, and advocacy groups. Ultimately, the intelligent helmet represents a promising step toward improving road safety for motorcycle riders in Nigeria, with the potential for broader applications in other regions facing similar challenges. Future efforts should prioritize mass production and the incorporation of renewable energy sources, such as solar panels, to extend battery life. Collaboration with government agencies and private sector stakeholders will be essential for widespread deployment and effective implementation.

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