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AI-Enabled Voice-Interactive Smart Helmet for Two-Wheeler Road Safety

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Abstract

The goal of this project is to improve rider safety through voice-controlled vehicle operations, automated emergency response, and real-time monitoring by designing and implementing a smart helmet system. The system continuously monitors motion and abrupt impact variations using an accelerometer (MPU6050) to identify accidents based on predetermined threshold values. When a fall or unusual impact is detected, a GSM module is triggered to send emergency alerts and location information to pre-designated contacts, facilitating quick assistance and cutting down on response time The vehicle can only start when the rider is wearing the helmet thanks to an ignition interlock mechanism, which increases safety compliance and reduces accidents caused by carelessness. To enable hands-free control of crucial features like ignition switching and directional indicators (left and right), a voice assistance module is also incorporated. This reduces distraction and increases riding safety by enabling the rider to operate necessary controls without taking their hands off the handlebar. The system's microcontroller-based architecture guarantees low power consumption, dependability, and affordability for realistic implementation. Under controlled circumstances, experimental validation shows precise fall detection, reliable communication performance, and responsive voice command execution. The suggested smart helmet provides a complete and scalable solution to improve rider safety and lower accident-related risks by integrating sensing, communication, and intelligent control features.

Keywords: Smart helmet system, voice recognition system, accident detection, GPS-GSM emergency alert, two-wheeler road safety

INTRODUCTION

A large percentage of traffic fatalities worldwide are caused by two-wheeler-related road accidents, primarily because of inadequate safety compliance and delayed emergency response [1]. Conventional helmets do not support post-accident communication or real-time monitoring; they only offer passive protection. The absence of automated accident reporting systems causes serious delays in medical care, which dramatically increases mortality rates, particularly during the "golden hour" [2, 3]. Further increasing the risk of an accident are risky behaviors such as driving while intoxicated and riding without a helmet.

An AI-enabled smart helmet system that combines embedded systems, IoT communication, and intelligent sensing technologies has been suggested as a solution to these problems [4, 5].

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The system uses GPS modules for real-time location tracking, alcohol sensors (MQ-3) for monitoring intoxication [6], and motion sensors such as MPU6050 for accident detection [7]. Emergency alerts are automatically sent to predetermined contacts via a GSM module [8]. Additionally, a voice recognition module allows hands-free control of vehicle functions [9], lowering rider distraction and enhancing operational safety, and a helmet detection mechanism is connected to the ignition system to enforce helmet usage [10, 11]. By transforming a conventional helmet into an active safety device with real-time monitoring, automated emergency response, and preventive control, this system reduces the severity of accidents and increases survival rates.

OBJECTIVES

The objective of this project is to create and build an Intelligent Smart Helmet System (ISHS) that improves rider safety through real-time monitoring, preventive control, and automatic emergency response systems.

The ISHS should include:

- A Helmet Detection method that only allows ignition of the vehicle if the rider is wearing their approved helmet.
- An Alcohol Detection system that will prevent the vehicle from starting if the rider has been drinking alcohol.
- An Accident Detection Module (Using Sensors) that identifies when a rider has fallen or been hit in a way that may result in injury.
- A global positioning system (GPS) was used to accurately track the location of the rider for emergency response.
- A GSM communication system allows the automatic transmission of alert messages to predefined contacts when an accident is detected.
- A Voice Recognition System allows the rider to use voice commands to control the vehicle, such as turning on the ignition or using the turn signal.
- Methods to minimize the time required for emergency responders to reach an accident scene by enabling the ability to send alerts and share location information immediately.
- To develop a reliable, cost-efficient, and scalable embedded system that can be deployed in the real world.

Problem Statement

- The main reasons for the high accident risk associated with two-wheeled vehicle (such as motorbikes) operation are low protective equipment (helmet) usage coupled with risky riding behaviors.
- Conventional motorcycle (bike) helmets provide only passive safety and lack intelligent monitoring or communication features.
- The time between an accident occurring and it being reported delays potential medical assistance, contributing to higher death rates.
- Riders who are unconscious or seriously injured cannot call for assistance manually.
- Currently, there is no enforcement to ensure that riders wear helmets before they can start their motorcycles (bikes).
- Alcohol continues to be one of the primary causes of road accidents.
- Current systems utilize one sensor for accident detection, which creates a high rate of false alarms and inaccurate accident detection.
- A complete integrated system (integrated systems of accident detection, GPS tracking, and automatic alerting) has not yet been created.
- Without the availability of hands-free devices (hands-free operation) to control their motorcycle, riders become further distracted from riding safely.
- Currently, no reliable and cost-effective smart helmet solution is available that can be deployed consistently in the real world.

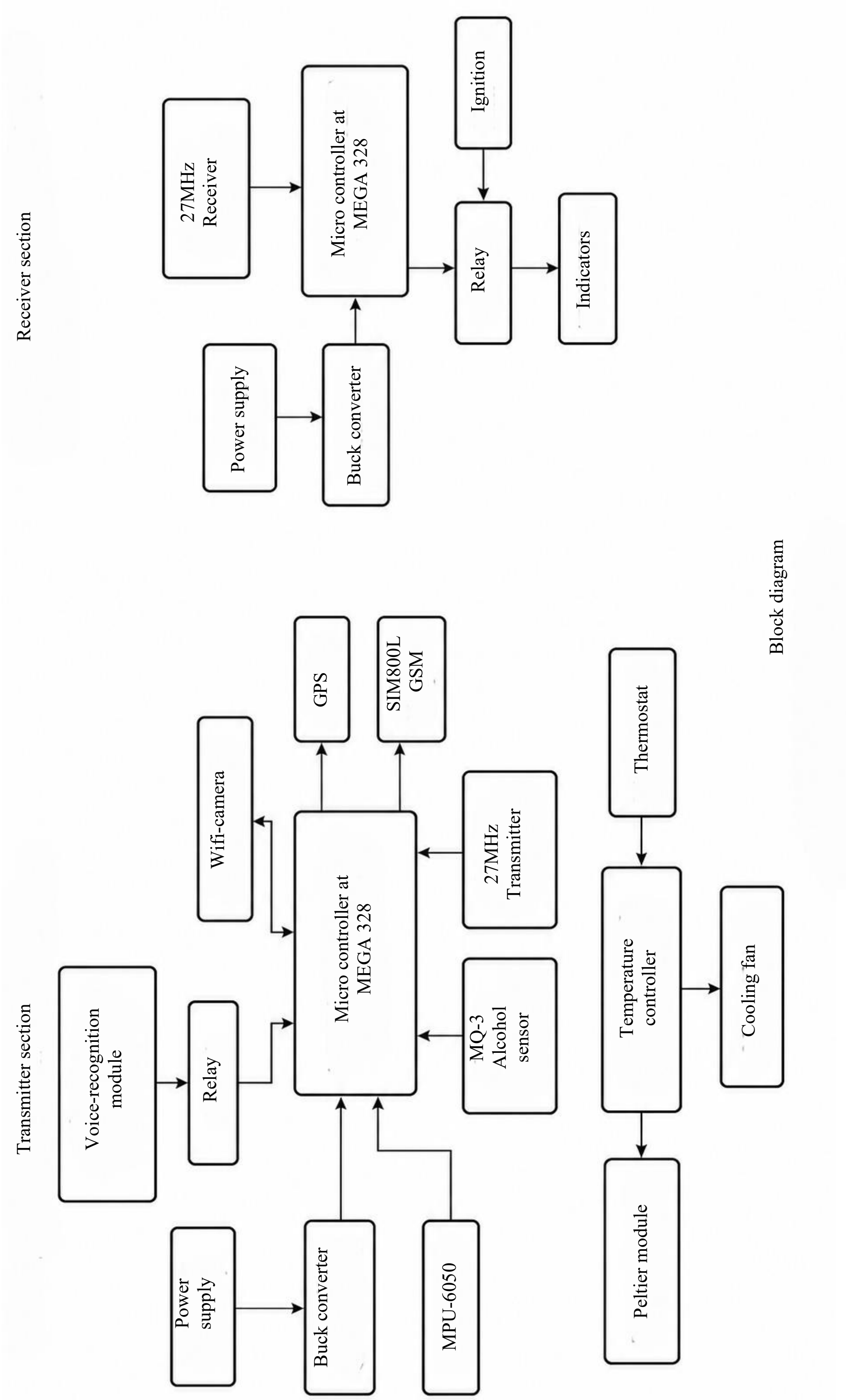

Figure 1. Block diagram of proposed system.

Proposed System

The overall architecture of the proposed smart helmet system is shown in Figure 1

The system design encompasses both a transmitter and receiver unit that can be used for intelligent vehicle monitoring and control. The transmitter unit is based on an ATmega328 microcontroller, which interfaces with a variety of sensors (MPU-6050 for motion detection and MQ-3 alcohol sensor to assess driver safety) to detect motion and assess driver safety [6, 7]. A voice recognition module allows the user to interact with the unit [9]. Additionally, the transmitter unit contains a Wi-Fi camera, GPS receiver, and SIM800L GSM modem to allow real-time monitoring of the vehicle and provide the capability to communicate with the vehicle in real time (via a telephone link) [8]. The transmitter unit also utilizes a buck converter to regulate power and has a 27 MHz transmitter for transmitting data without a wire. The vehicle also has a temperature control subsystem that contains a thermostat, temperature controller, Peltier element (i.e., heat sink), and cooling fan to assist in managing the temperature of the vehicle.

The receiver unit has a 27 MHz receiver that connects to an ATmega328 microcontroller that receives and processes the data to control the ignition system by activating a relay. The receiver also has indicators that show the status of the system. The indicator provides feedback on vehicle operation and indicates whether the vehicle is operating safely and efficiently.

Circuit Diagram

The hardware implementation of the proposed system was divided into transmitter and receiver sections. The circuit diagram of the transmitter section is shown in Figure 2, and the circuit diagram of the receiver section is shown in Figure 3.

METHODOLOGY

Table 1 shows the components, specifications, and functional description of the system. To guarantee rider safety and prompt emergency response, the proposed smart-helmet system functions as an integrated embedded platform comprising sensing, control, communication, and actuation units.

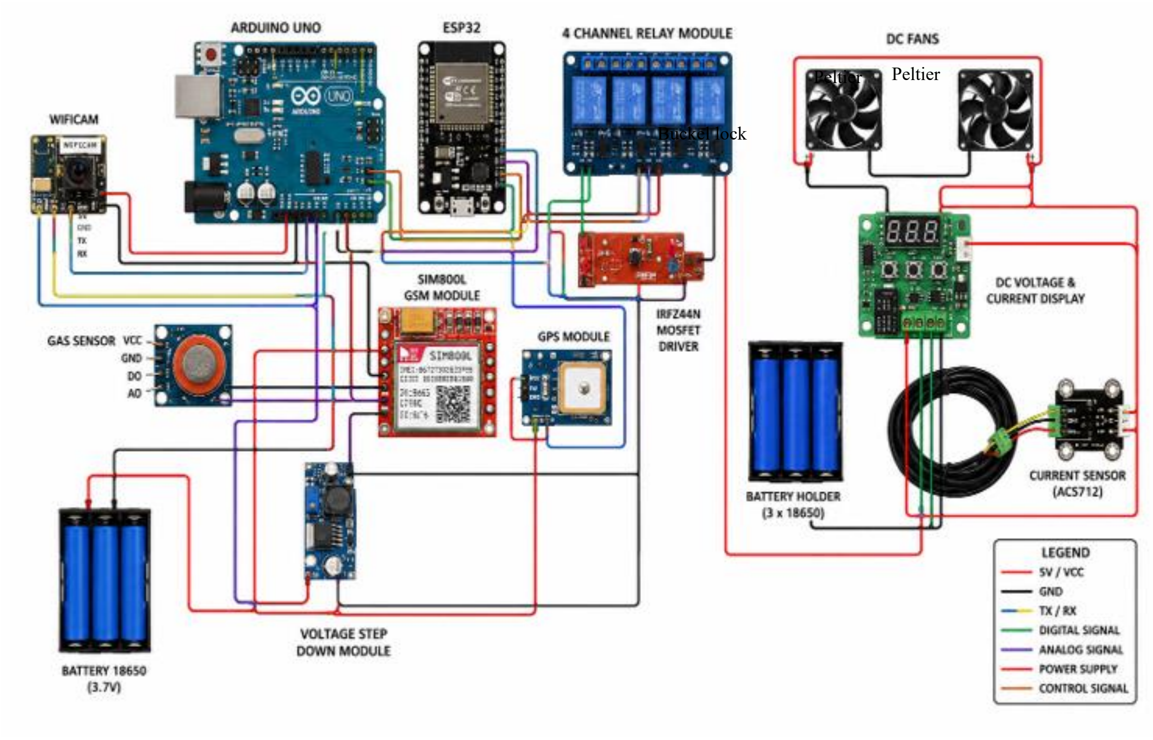

Figure 2. Circuit diagram of transmitter section.

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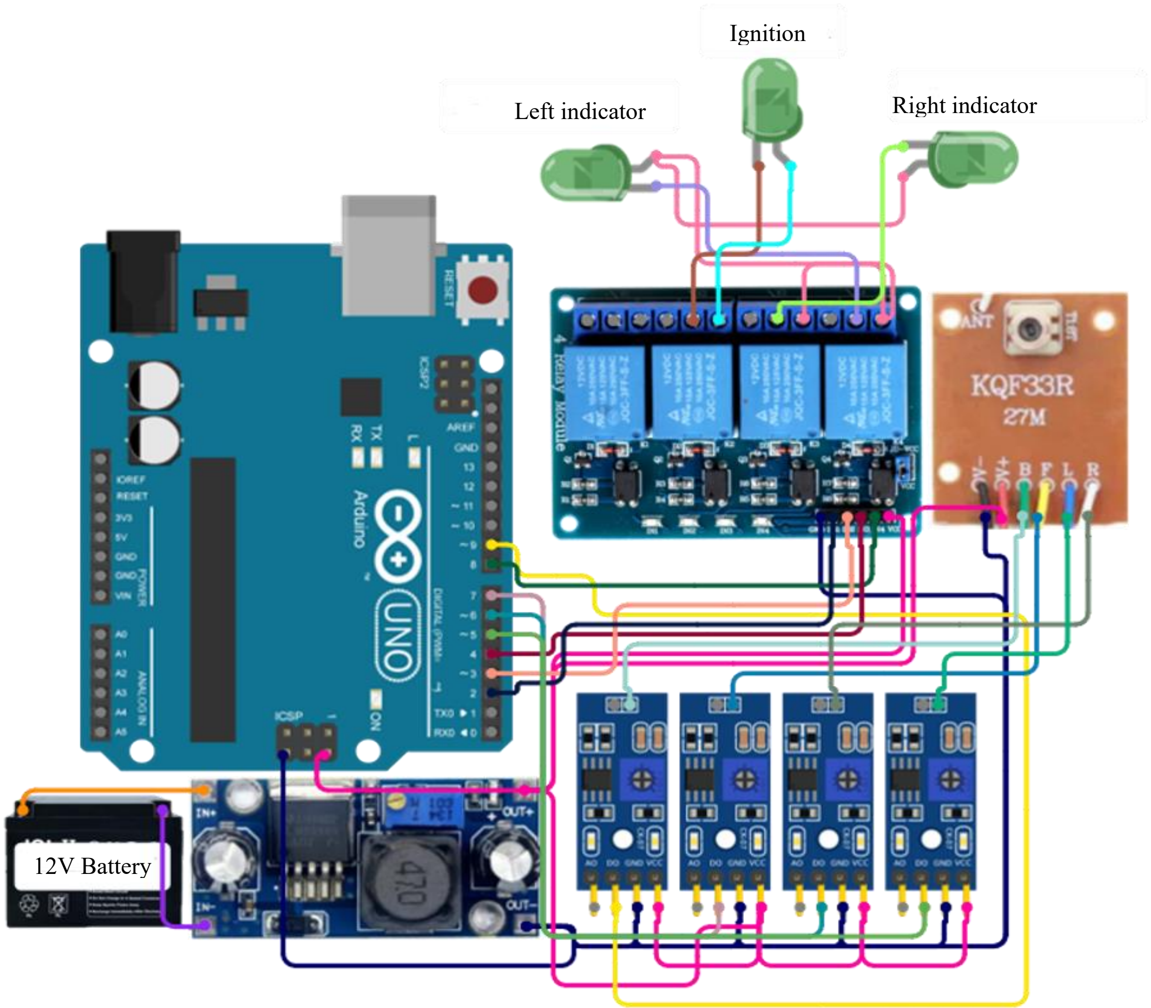


Figure 3. Circuit diagram of receiver section.

All modules, including the microcontroller, sensors, communication interfaces, and control units, were first initialized when the system was turned on. The system checks whether the helmet is correctly worn after activating the helmet-wear detection mechanism. Until this requirement is met, the ignition control is kept off, guaranteeing that a helmet must be worn.

The rider's breath alcohol content was simultaneously measured using an alcohol detection module (MQ-3) [6]. The microcontroller's ADC or a comparator-based threshold circuit are the two methods used to process the analog output. The ignition system locks if the detected value is higher than the predetermined limit, making it impossible to operate the vehicle while intoxicated.

After the conditions for the safe operation of the system are met, a relay is energized to allow ignition and enter normal operations. During normal operations, the system continuously monitors the motion of the user with the MPU6050 sensor and monitors the acceleration and angular velocity in real time using threshold-based logic to identify abnormal conditions, such as a sudden impact, free fall, or excessive tilt [7].

In the event of an accident, the system initiates an emergency response protocol. This includes using the GPS module to obtain the current coordinates and sending an alert message containing this information (via the SIM800L GSM module) to a pre-determined list of emergency contacts. The system can also be programmed with a timer to allow the user to cancel the alert in the event of a false positive [8].

Table 1. Components, specifications and functional description of the system.

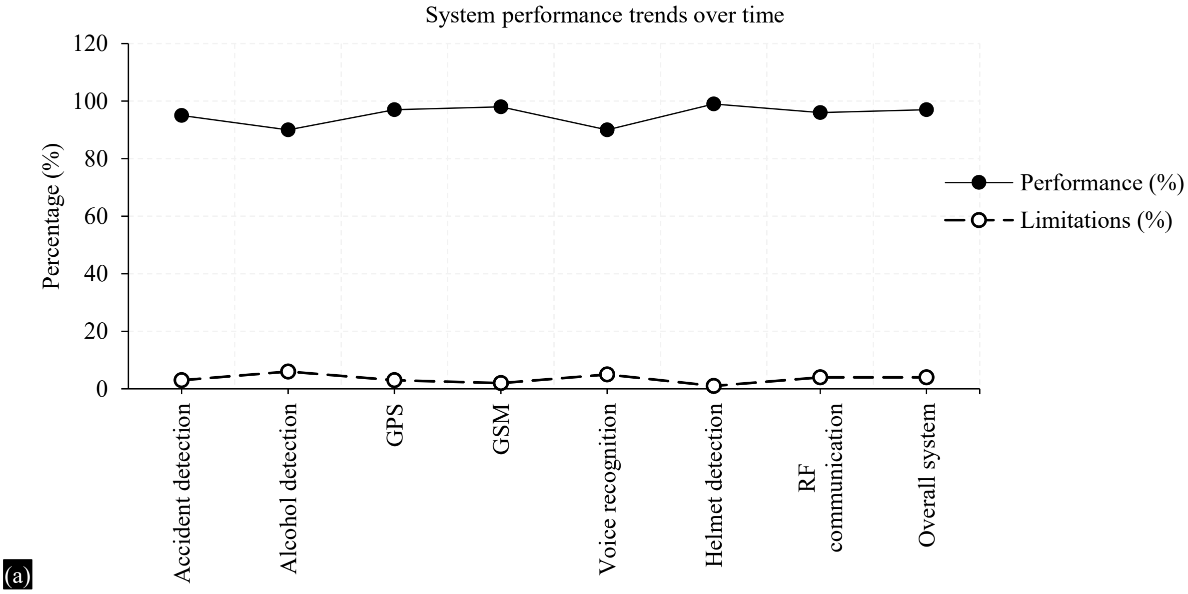
Components	Key specification	Function
ATmega328 [12]	8-bit MCU, 16 MHz clock, 32 KB Flash, 2 KB SRAM, 5V operating voltage	Executes control logic, processes sensor data, and manages system operations.
ESP32	Dual-core 32-bit CPU, up to 240 MHz, Wi-Fi (802.11 b/g/n), Bluetooth v4.2, 3.3V logic	Enables IoT connectivity, wireless communication, and optional cloud integration.
MPU6050 [12]	3-axis accelerometer (±2g to ±16g), 3-axis gyroscope (±250°/s to ±2000°/s), I2C interface	Detects motion, tilt, and impact for accident detection.
MQ-3 Alcohol sensor [13]	Detection range: 0.04–4 mg/L, analog output, 5V supply	Measures alcohol concentration in breath to prevent drunk driving.
4-Channel Relay	5V logic, 4 relays, switching: 10A @ 250V AC / 30V DC	Controls multiple high-power loads (ignition, indicators, auxiliary systems).
Neo-6M GPS [14]	Accuracy ~5 m, UART, 3.3–5V, 1 Hz update	Provides real-time location tracking.
SIM800L GSM [15]	Quad-band GSM, UART, 3.7–4.2V	Sends SMS alerts with location data during emergencies.
Voice Recognition VC-O2	Voltage: 3.3–5V, UART interface, supports offline voice commands	Enables hands-free voice control of ignition, indicators, and system functions.
Peltier Module	3.8–5V, 2.5–3A, ~12–15W, ΔT max ~60°C	Provides thermoelectric cooling by transferring heat from inside to outside of the helmet
27MHz RF Transmitter and Receiver	Frequency: 27 MHz, range: 10–100 m, ASK modulation Frequency: 27 MHz, 5V operation	Transmits control signals from helmet to vehicle unit. Receives transmitted signals and triggers actions.
Wi-Fi Camera Module (ESP32 -CAM)	2 MP, Wi-Fi enabled, 3.3V	Captures and streams visual data for monitoring.
Battery (Li-ion)	3.7V, 3000 mAh	Supplies power to helmet system.
Thermostat	Adjustable control, relay-based	Maintains temperature within limits.
LM393 Comparator	Dual comparator IC, supply: 2V–36V, open collector output	Converts analog signals (e.g., sensor output) into digital threshold-based signals.
Cooling Fan	5v DC	Enhances airflow and cooling efficiency.
Buck Converter (DC-DC)	Input up to 12V, output 3.3V/5V, >85% efficiency	Regulates voltage for stable system operation.

The user can also operate the system without using their hands by utilizing the VC-02 voice recognition module to issue voice commands, thereby minimizing rider distraction and enhancing operational safety [9].

Communication is established between the helmet unit (transmitter) and vehicle unit (receiver) using a 27 MHz RF module. The helmet produces a control signal that is transmitted via RF wireless transmission to the vehicle unit, where relays provide corresponding actions such as Ignition ON/OFF, and Indicator Control.

In addition, a low-power Peltier module for thermoelectric cooling of the rider's head is provided to enhance comfort. The Peltier module operated under controlled conditions with heat dissipation supported by a heat sink and fan assembly.

In total, this system provides a real-time safety monitoring/control unit that utilizes preventive mechanisms, continuous sensing, and automated emergency communication to reduce the likelihood of an accident and improve the efficiency of the response to accidents.



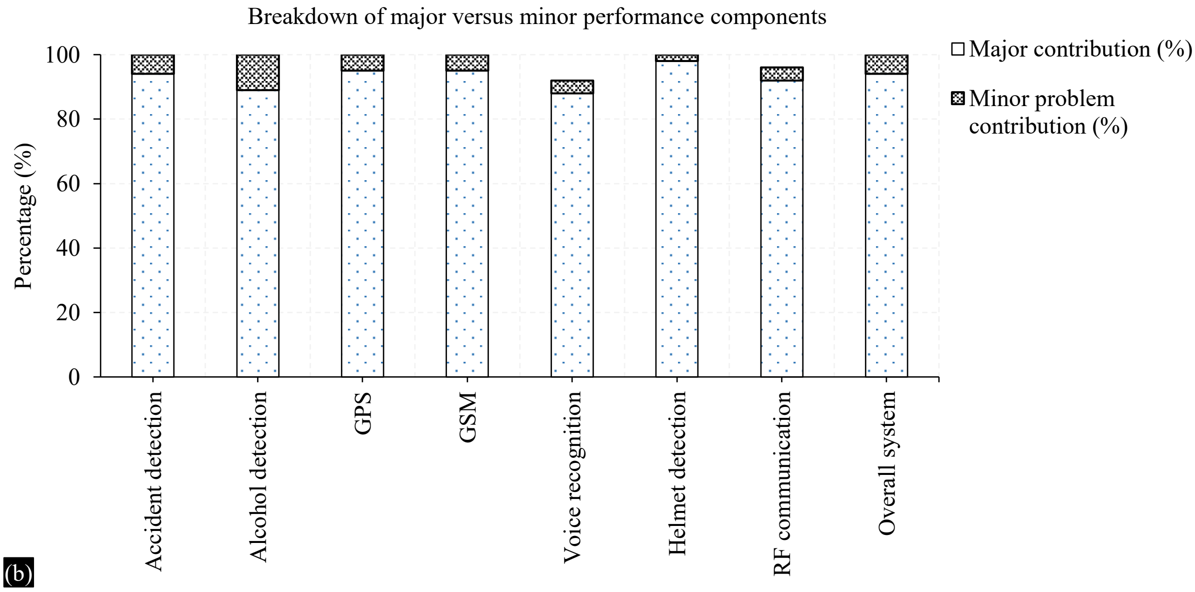


Figure 4. (a) and (b) Comparative analysis of overall system performance trends and detailed components of success.

RESULT AND DISCUSSION

Performance in Detecting Accidents

- Tests of actual drops at heights of 30, 60, and 90 cm indicated that the detection accuracy was greater than 95%. The ability to differentiate crash occurrences from usual riding circumstances is based on an amalgamation of several sensors.
- The number of times a fall may not be classified as an accident was approximately 2–3%.

Performance in Detecting Alcohol

- The MQ-3 sensor, when calibrated, was able to detect the presence of alcohol with an accuracy of 90–92%.
- Control of the ignition system disallowed the starting of a vehicle when there was a detection of alcohol in the driver's system.

GPS Tracking Performance

- The GPS module could provide real-time locations within approximately 5 meters (approximately) and maintain stable performance throughout testing outdoors, with minimal variations of 2–3% when tracking was blocked by obstacles.

Performance in SMS transmissions

- In tests, > 98% of alerts were transmitted via SMS.
- The time taken to transmit an alert was between 3 and 8 s under standard conditions.

Performance of Voice Commands

- The VC-02 module can receive voice commands with an accuracy of 90–92% in moderately noisy environments.
- Commands were performed with a minimal amount of time taken (2–3%) when the level of environmental noise was elevated.

Performance of Helmet Detection and Ignition Control

- Except for one test, the trials were able to use 99% or more of the time without system failure.
- Ignition was enabled only when a helmet was applied.

Performance in RF transmission

- The RF transmissions were stable at a range of 10-50 m with a high rate of reliability.
- Minimal losses of the signal were experienced at a minimum of "near" (2-3%) while a blockage from physical objects was present between the system and the endpoint of the system.

Power Consumption

- Using nine lithium-ion batteries (Li-ion), the system could typically operate for 6-8 hours under normal usage, with the exception of devices that draw high amounts of power, such as the GSM and cooling systems. Figure 4 illustrates a comparative analysis of the overall system performance trends and detailed components of success.

CONCLUSIONS

As a cutting-edge safety solution for two-wheeler riders, the proposed AI-enabled smart helmet system was effectively developed, implemented, and verified through experiments. To overcome the main drawbacks of traditional helmets, especially regarding accident detection, emergency response, and preventive safety enforcement, the system combines embedded control, intelligent sensing, and wireless communication technologies.

Helmet detection, alcohol detection, motion analysis, GPS tracking, GSM communication, and voice-controlled operation are just a few of the functional modules included in the proposed system. To enforce safety compliance, the helmet detection mechanism ensures that the vehicle ignition is only turned on when the rider is wearing the helmet correctly. By effectively limiting vehicle operation while intoxicated, the alcohol detection system lowers the chances of accidents caused by drunk driving.

During practical testing, the accident detection subsystem, which used the MPU6050 sensor, showed excellent dependability, attaining an accuracy of approximately 95%. Accurate crash event identification was made possible by reducing false triggers using combined accelerometer and gyroscope data. When an accident is detected, the system initiates an automated emergency response using the GPS module to gather real-time location data and the GSM module to send alert messages. With an average response time of 3–8 s, the success rate of the communication system exceeded 98%, guaranteeing prompt assistance.

The integration of the voice recognition module reduced rider distraction and increased operational safety by enabling hands-free control of crucial vehicle functions, such as the ignition and indicators. Furthermore, dependable control signal transmission within a useful operating range was guaranteed by RF communication between the vehicle and helmet units.

When the system was tested in real time, its overall performance was found to be steady and effective, with only a small amount of variation roughly 2-3% caused by sensor-related and environmental factors. Depending on the system usage, a 9-cell Li-ion battery allowed for a useful operating duration of roughly 6-8 hours. Although the thermoelectric cooling subsystem offers localized comfort, there is room for improvement because of its low efficiency in relation to power consumption.

Overall, the proposed system offers an affordable, portable, and dependable method for improving rider safety through automated emergency communication, preventive control, and real-time monitoring. Power optimization, improved sensor fusion algorithms, cloud-based data integration, and sophisticated intelligent features are just a few of the future advancements for which the project lays a solid foundation. The success of the implementation attests to the viability of combining IoT and embedded systems to drastically lower accident risks and enhance emergency response in practical situations.

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