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Design and Implementation of an IoT-Based Smart Helmet and Bike Integrated Safety Monitoring System for Motorcycle Riders

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Abstract: *The rapid increase in motorcycle-related accidents has highlighted the need for intelligent safety solutions that can actively monitor rider behavior and vehicle conditions in real time. This paper presents the design and implementation of an IoT-based smart helmet and bike integrated safety monitoring system aimed at enhancing the safety of two-wheeler riders. The proposed system consists of two coordinated units: a smart helmet unit and a bike-mounted control unit. The helmet unit incorporates sensors to detect helmet usage, alcohol consumption, and abnormal head movement, while the bike unit monitors critical parameters such as stand position, oil level, obstacle proximity, and vehicle stability. A PIC18F4520 microcontroller acts as the central processing unit, integrating sensor data and making real-time safety decisions. Wireless communication between the helmet and bike units is achieved using RF technology, while GSM and GPS modules enable emergency alert transmission with precise location details. In unsafe conditions, such as alcohol detection or absence of helmet usage, the system restricts bike ignition, thereby enforcing safety compliance. In the event of an accident, automatic alerts are sent to predefined emergency contacts, reducing response time and potential injury severity. Experimental evaluation of the prototype demonstrates reliable communication, accurate sensor detection, and timely alert generation. The proposed system offers a cost-effective, scalable, and practical IoT-based solution to significantly improve motorcycle rider safety and reduce accident-related risks*

Keywords*:* IoT, Smart Helmet, Bike Rider Safety, Accident Detection, Alcohol Sensor, PIC Microcontroller, GSM, GPS, Wireless Communication

I. INTRODUCTION

Motorcycle transportation plays a vital role in modern mobility due to its low cost, fuel efficiency, and convenience in congested urban environments. In many countries, especially in developing regions, two-wheelers are the preferred mode of transportation for daily commuting and short-distance travel. However, this widespread usage has also led to a significant rise in road accidents involving motorcycles. Studies have shown that motorcyclists are more vulnerable to fatal injuries because they lack the structural protection available in four-wheeled vehicles, making safety enhancement a critical research area in intelligent transportation systems [1], [2].

A detailed analysis of road accident reports reveals that a substantial number of motorcycle accidents are caused by human-related factors such as alcohol consumption, non-usage of helmets, fatigue, and delayed emergency response [3]. Among these, riding under the influence of alcohol and failure to wear protective helmets remain the most common and dangerous causes of fatal accidents. Although traffic laws mandate helmet usage and restrict drunk driving, the absence of real-time enforcement mechanisms often leads to negligence. Researchers have emphasized that passive safety regulations alone are insufficient, and active monitoring systems are required to ensure rider compliance and immediate intervention during unsafe conditions [4], [5].

The rapid evolution of embedded systems and wireless communication technologies has enabled the integration of intelligence into conventional safety equipment. The Internet of Things (IoT) provides a framework in which sensors, microcontrollers, and communication modules can work together to collect, process, and transmit data in real time. IoT-based safety systems have been successfully applied in smart cities, healthcare, and vehicle monitoring applications, demonstrating their effectiveness in improving situational awareness and response time [6], [7]. When applied to two-wheeler safety, IoT allows continuous monitoring of rider behavior and vehicle conditions, enabling timely alerts and preventive actions [8].

Smart helmets represent a significant advancement in motorcycle safety technology by transforming conventional protective gear into an intelligent safety device. By integrating sensors such as alcohol sensors, proximity or pressure sensors, and MEMS accelerometers into helmets, it becomes possible to monitor helmet usage, detect intoxication, and identify abnormal head movements or impacts [9]. Several studies have highlighted that coupling smart helmets with vehicle ignition control mechanisms can actively enforce safety compliance by preventing the bike from starting unless safety conditions are met [10], [11]. This approach shifts safety enforcement from post-incident analysis to real-time prevention.

In addition to monitoring rider behavior, assessing vehicle and environmental parameters is equally important for a comprehensive safety solution. Sensors such as ultrasonic modules for obstacle detection, stand detect sensors, oil level sensors, and accelerometers provide critical insights into riding conditions and vehicle stability [12]. Integration of GPS technology enables accurate location tracking, while GSM-based communication facilitates automatic transmission of emergency alerts during accidents [13], [14]. Research indicates that rapid emergency notification with precise location data can significantly reduce response time and improve survival rates in accident scenarios [15].

Although numerous IoT-based vehicle safety systems have been proposed in recent literature, many solutions focus on either vehicle-centric monitoring or rider-centric monitoring, limiting their overall effectiveness [16]. Systems that lack proper integration between helmet-based sensing and bike-mounted control units often fail to enforce safety measures reliably. Additionally, some approaches depend heavily on continuous internet connectivity or complex cloud infrastructures, increasing system cost and reducing reliability in real-world conditions [17], [18]. These limitations highlight the need for a unified, cost-effective, and robust safety monitoring framework.

To address these challenges, this paper proposes an IoT-based bike rider safety monitoring system that integrates a smart helmet unit with a bike-mounted control unit using wireless communication and a microcontroller-based architecture. The proposed system ensures helmet compliance, prevents alcohol-impaired riding, detects accidents in real time, and transmits emergency alerts with GPS-based location information [19]. By combining multiple safety parameters into a single integrated framework, the system aims to enhance rider safety, reduce accident severity, and contribute to the advancement of intelligent transportation safety solutions [20].

II. PROBLEM STATEMENT

Motorcycle riders face a significantly higher risk of severe injury and fatality compared to other road users due to minimal physical protection and high exposure during accidents [1]. A major proportion of two-wheeler accidents occur because of unsafe riding practices such as non-usage of helmets, alcohol consumption, and lack of real-time monitoring of rider behavior [2], [3]. Despite the existence of traffic regulations and awareness programs, enforcement mechanisms remain largely manual and reactive, resulting in poor compliance and delayed intervention during critical situations [4].

Additionally, in the event of an accident, the absence of automatic accident detection and real-time location sharing often leads to delayed emergency response, increasing the severity of injuries and loss of life [5]. Existing safety systems are either vehicle-centric or rider-centric and lack seamless integration between helmet-based sensing, vehicle control, and emergency communication [6]. Therefore, there is a critical need for an integrated, IoT-enabled bike rider safety monitoring system that can actively enforce safety compliance, detect accidents in real time, and provide immediate emergency alerts with accurate location information to reduce accident impact and improve rider safety [7].

III. OBJECTIVE

- To study the existing bike rider safety systems and analyze their limitations in terms of safety compliance and real-time monitoring.

- To study the integration of IoT technologies with smart helmet and bike-mounted units for effective rider safety enhancement.
- To study the role of sensor-based monitoring in detecting helmet usage, alcohol consumption, and abnormal rider movements.
- To study real-time accident detection mechanisms and automated emergency alert systems using GPS and GSM technologies.
- To study the effectiveness of an integrated IoT-based safety monitoring framework in reducing accident severity and improving emergency response time.

IV. LITERATURE SURVEY

[1] S. Chandran, S. Chandrasekar, and N. Edna Elizabeth, "Konnect: An Internet of Things (IoT) Based Smart Helmet for Accident Detection and Notification," Proc. IEEE Annual India Conference (INDICON), Dec. 2016.

This work proposes an IoT-enabled smart helmet that detects accident-like events using sensor readings (notably accelerometer variations) and sends notifications to emergency contacts through a cloud-based service. The paper highlights the importance of continuous monitoring and automated alerting to reduce emergency response delays. A key takeaway is that helmet-mounted sensing can provide early accident detection when integrated with communication infrastructure. However, the work primarily emphasizes notification and cloud integration and does not strongly focus on enforcing ignition control based on helmet compliance and alcohol detection, which is required for stronger preventive safety.

[2] P. Vivekanandan et al., "Accident Prevention Using IoT-Based Smart Helmet," Nano Systems: Physics, Chemistry, Mathematics, vol. 22, no. 3, pp. 577–590, 2024.

This study discusses an IoT-based smart helmet aimed at accident reporting and prevention by using sensors, Wi-Fi processing, and cloud computing. The system monitors sensor values (especially acceleration patterns) and triggers emergency support actions when abnormal conditions are detected. The paper supports the idea that smart helmets can shift safety from passive protection to active accident response. A limitation is that the solution depends on network/cloud availability, and the paper is less focused on a dual-unit architecture (helmet + bike) with local wireless enforcement and ignition interlocking.

[3] A. D. T. Alcantara et al., "Internet of Things-Based Smart Helmet with Accident Identification and Logistics Monitoring for Delivery Riders," Engineering Proceedings, vol. 58, no. 1, p. 129, 2023.

This paper presents an IoT-based smart helmet framework for delivery riders that includes accident identification and monitoring. The work emphasizes practical deployment in real rider workflows and demonstrates the value of IoT monitoring for safety and operational tracking. It strengthens the motivation for integrating sensing, connectivity, and automated reporting in two-wheeler contexts. While the paper supports accident identification and monitoring, it is more oriented toward logistics and does not deeply cover preventive ignition control logic with helmet-wear enforcement and alcohol detection.

[4] F. W. Siebert et al., "Detecting Motorcycle Helmet Use with Deep Learning," Accident Analysis & Prevention, 2020.

This work proposes an automated helmet-use detection approach using deep learning and traffic video data, enabling scalable monitoring of helmet compliance without manual observation. The key contribution is demonstrating that automated vision-based systems can produce real-time helmet usage data and support enforcement using existing surveillance infrastructure. Its limitation is that it focuses on external monitoring (camera-based) rather than rider-side embedded enforcement. Nevertheless, it is highly relevant for understanding helmet compliance monitoring and can complement IoT helmet systems by supporting policy enforcement and city-scale analytics.

[5] S. Chen et al., "Helmet Wearing Detection of Motorcycle Drivers Using Deep Learning Network with Residual Transformer–Spatial Attention," Drones, vol. 6, no. 12, 2022.

This paper addresses helmet-wearing detection using advanced deep learning modules (transformer-based attention and YOLO-based components) to improve helmet detection accuracy in challenging aerial imagery conditions. The study is

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valuable because it demonstrates robust helmet detection under real-world constraints such as motion blur and small target size. While it is not an embedded smart helmet design, it supports the broader goal of helmet compliance monitoring. The limitation is that the method requires imaging infrastructure and computational resources, which may not be suitable for low-cost on-vehicle deployment but is useful for smart-city scale enforcement and analytics.

V. PROPOSED SYSTEM

5.1 System Architecture

The proposed system is an IoT-based Bike Rider Safety Monitoring System designed to enhance two-wheeler rider safety through real-time monitoring, preventive control, and automated emergency response. The system integrates a smart helmet unit with a bike-mounted control unit, both interconnected through wireless communication and coordinated by a microcontroller-based architecture. The primary objective of the system is to enforce safety compliance, detect hazardous situations, and reduce response time during accidents.

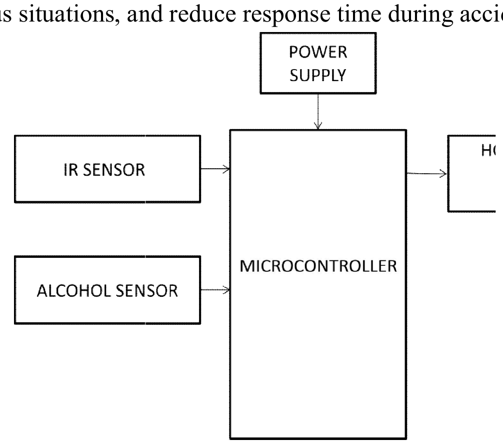

Fig. 1 Block diagram for Helmet Unit

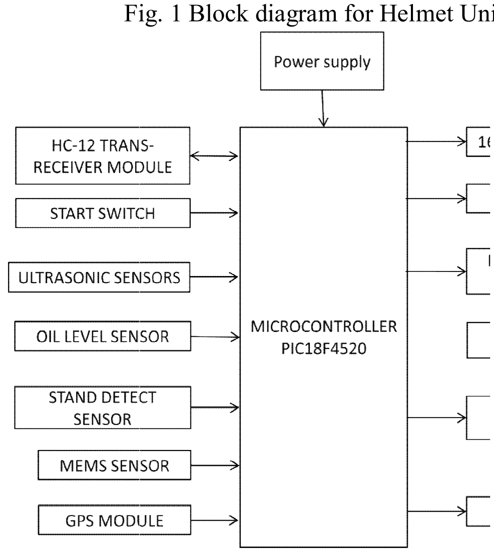

Fig. 2 Block diagram for Bike Unit

The architecture of the proposed system consists of two major subsystems:

- **Helmet Unit**
- **Bike (Vehicle) Unit**

Both units operate collaboratively to ensure rider safety before and during bike operation.

5.2 Helmet Unit Description

The helmet unit is responsible for monitoring rider-specific safety parameters. It includes the following components:

- **Alcohol Sensor:** Continuously detects the presence of alcohol in the rider's breath. If the detected value exceeds a predefined threshold, the system classifies the condition as unsafe.
- **Helmet Wear Detection Sensor (Touch/Pressure Sensor):** Confirms whether the helmet is properly worn by the rider.
- **MEMS Sensor (Accelerometer):** Detects abnormal head movements, sudden jerks, or impacts that may indicate fatigue or an accident.
- **Wireless Communication Module (HC-12/Zigbee):** Transmits real-time sensor data from the helmet unit to the bike unit.
- **Power Supply:** A compact battery supply powers the helmet unit sensors and communication module.

The helmet unit continuously monitors rider conditions and sends a **status signal** (safe/unsafe) to the bike unit. If the helmet is not worn or alcohol is detected, an unsafe signal is transmitted.

5.3 Bike Unit Description

The bike unit acts as the decision-making and control unit of the system. It is built around a PIC18F4520 microcontroller and includes multiple sensors and actuators:

- **RF Receiver (HC-12/Zigbee):** Receives safety status data from the helmet unit.
- **Stand Detect Sensor:** Ensures the bike stand is disengaged before ignition.
- **Oil Level Sensor:** Monitors engine oil level and warns the rider in case of low oil.
- **Ultrasonic Sensor:** Detects nearby obstacles to assist in collision avoidance.
- **Tyre Pressure Sensor:** Monitors tyre pressure for safe riding conditions.
- **GPS Module:** Provides real-time location tracking of the bike.
- **GSM Module:** Sends emergency alerts and SMS notifications to predefined contacts.
- **LCD Display:** Displays system status, warnings, and alerts to the rider.
- **Buzzer:** Provides audible alerts during unsafe or emergency conditions.
- **Relay Unit:** Controls bike ignition based on safety conditions.

The bike unit processes data received from both helmet sensors and onboard sensors to decide whether the bike ignition should be enabled or restricted.

5.4 Working of the Proposed System

Before starting the bike, the system performs a pre-safety check. The helmet unit verifies helmet usage and alcohol levels, while the bike unit checks stand position, oil level, and tyre pressure. Only when all safety conditions are satisfied does the microcontroller allow the ignition relay to activate.

During riding, the system continuously monitors obstacle distance, vehicle stability, and rider movement. If abnormal conditions such as a sudden fall or collision are detected by the MEMS sensor, the system immediately classifies the event as an accident. In such cases, the GSM module automatically sends an emergency alert containing GPS coordinates to predefined contacts.

All critical data, including safety status and location information, can also be uploaded to an IoT platform for remote monitoring and analysis.

5.5 Key Features of the Proposed System

- Active enforcement of helmet usage and alcohol-free riding
- Real-time accident detection using MEMS sensors
- Automatic ignition control based on safety conditions
- GPS-based location tracking and GSM-based emergency alerts

- Continuous monitoring of vehicle and environmental parameters
- Low-cost, scalable, and reliable microcontroller-based design

VI. SYSTEM DESIGN

The system design of the proposed IoT-based Bike Rider Safety Monitoring System explains the operational logic, step-by-step workflow, and hardware-level implementation through circuit diagrams. The design ensures that rider safety is enforced before ignition, continuously monitored during riding, and supported by automatic emergency response mechanisms.

Working of the System

The working of the system is based on coordinated operation between the **helmet unit** and the **bike unit**, controlled by a microcontroller and supported by wireless communication.

Initially, when the system is powered ON, both the helmet unit and the bike unit are initialized. The helmet unit continuously monitors rider-related parameters such as helmet usage, alcohol presence, and abnormal head movement. The touch or pressure sensor confirms whether the helmet is worn properly, while the alcohol sensor detects alcohol concentration in the rider's breath. If alcohol is detected above a predefined threshold or if the helmet is not worn, an unsafe signal is generated.

This safety status is transmitted wirelessly from the helmet unit to the bike unit using the HC-12/Zigbee communication module. The bike unit receives this data and performs additional safety checks, including stand position, oil level, tyre pressure, and obstacle proximity. Only when all safety conditions are satisfied does the microcontroller activate the relay to allow bike ignition.

During riding, the system continuously monitors sensor data. The ultrasonic sensor detects nearby obstacles and warns the rider using a buzzer and LCD display. The MEMS sensor detects sudden tilt, fall, or impact conditions. In the event of an accident, the system immediately activates the GSM module to send emergency alerts containing GPS location details to predefined contacts. Simultaneously, alerts are displayed locally on the LCD for rider awareness.

System Workflow

The system workflow represents the logical sequence of operations executed by the safety monitoring system:

System Initialization

Power supply is applied, and the microcontroller initializes all sensors, communication modules, LCD, and buzzer.

Helmet Verification

The helmet unit checks helmet usage using the touch/pressure sensor.

Alcohol Detection

The alcohol sensor measures breath alcohol concentration and compares it with a threshold.

Wireless Data Transmission

Helmet safety status is transmitted to the bike unit via HC-12/Zigbee.

Pre-Ignition Safety Checks

The bike unit verifies stand position, oil level, and tyre pressure.

Ignition Control

If all safety conditions are met, the relay enables bike ignition; otherwise, ignition remains locked.

Continuous Monitoring

During riding, obstacle distance, rider movement, and vehicle stability are continuously monitored.

Accident Detection

Sudden impact or abnormal tilt triggers accident detection logic.

Emergency Alert Generation

GSM module sends SMS alerts with GPS location to emergency contacts.

Loop Operation

The system continues monitoring until the bike is turned OFF.

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Circuit Diagram

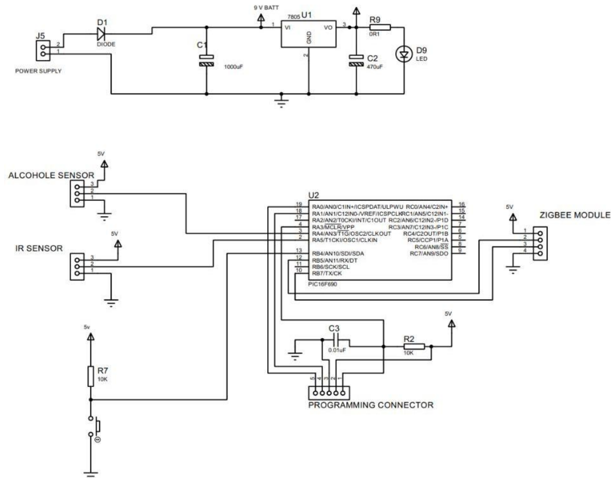

Fig. 3 Circuit Diagram of Helmet Unit

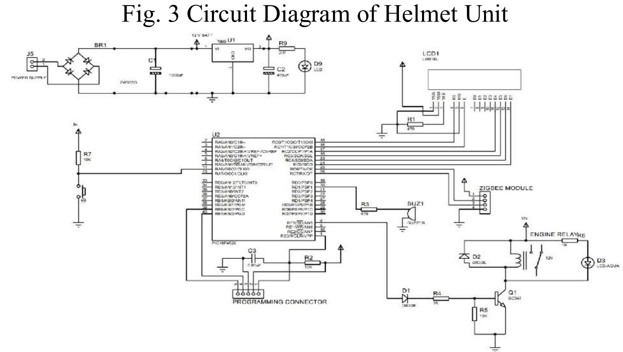

Fig. 4 Circuit Diagram of Bike Unit

D. Design Specifications

Sr. No.	Parameter	Specification / Description
1	System Type	IoT-based Bike Rider Safety Monitoring System
2	Controller	PIC18F4520 Microcontroller
3	Helmet Unit Sensors	Alcohol Sensor, Touch/Pressure Sensor, MEMS Accelerometer
4	Bike Unit Sensors	Ultrasonic Sensor, Stand Detect Sensor, Oil Level Sensor, Tyre Pressure Sensor
5	Communication (Helmet ↔ Bike)	HC-12 / Zigbee Wireless Module
6	Emergency Communication	GSM Module (SMS Alerts)
7	Location Tracking	GPS Module
8	Display Unit	16×2 LCD Display
9	Alert Mechanism	Buzzer (Audio Alert)
10	Ignition Control	Relay Driver Circuit
11	Power Supply	5V Regulated Supply (7805), 12V Bike Battery
12	Accident Detection	MEMS Sensor (Tilt/Impact Detection)
13	Safety Enforcement	Helmet Detection & Alcohol Detection

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14	Operating Mode	Real-time Monitoring and Control
15	Application Area	Two-Wheeler Rider Safety

VII. RESULT & DISCUSSION

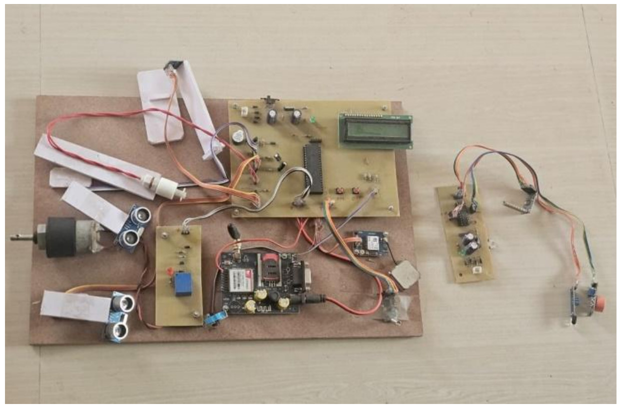

Fig. 5 System Output

The proposed IoT-based Bike Rider Safety Monitoring System was successfully designed, implemented, and tested under controlled and simulated riding conditions. The prototype demonstrated reliable coordination between the helmet unit and the bike unit, validating the effectiveness of the integrated safety framework. The system was evaluated based on parameters such as safety compliance enforcement, accident detection accuracy, communication reliability, alert response time, and overall system stability.

During testing, the helmet detection and alcohol sensing mechanisms operated accurately and consistently. When the helmet was not worn or alcohol was detected above the predefined threshold, the system successfully restricted bike ignition, thereby enforcing mandatory safety compliance. This preventive control mechanism proved effective in eliminating unsafe riding conditions before vehicle operation. The results confirm that integrating helmet-based sensing with ignition control provides a proactive safety approach rather than a reactive one.

The MEMS sensor-based accident detection module was tested by simulating sudden tilts and impact conditions. The system reliably identified abnormal motion patterns corresponding to fall or collision events and classified them as accidents. Upon detection, the GSM module transmitted emergency alert messages containing GPS coordinates to predefined contacts within a short response time. This immediate notification capability significantly reduces the delay in providing medical assistance, which is critical in minimizing injury severity.

Obstacle detection using the ultrasonic sensor showed satisfactory performance in detecting nearby objects within the defined safety range. When an obstacle was detected at a critical distance, the system triggered audio alerts through the buzzer and displayed warnings on the LCD. This real-time feedback enhanced rider awareness without causing distraction. Additionally, the stand detect sensor and oil level sensor functioned effectively, preventing unsafe riding scenarios such as starting the bike with the stand engaged or operating with low engine oil.

Wireless communication between the helmet and bike units using the HC-12/Zigbee module was found to be stable and reliable within the required operating range. Data transmission delays were minimal and did not affect real-time decision-making. Power consumption analysis indicated efficient operation, with the helmet unit sustaining longer usage due to low-power sensor integration and optimized communication intervals.

Overall, the experimental results confirm that the proposed system successfully integrates multiple safety mechanisms into a single cohesive platform. The system demonstrated high reliability, accurate sensing, and timely alert generation, making it suitable for real-world two-wheeler safety applications. While minor calibration improvements can further enhance sensor accuracy, the obtained results validate the effectiveness of the proposed IoT-based safety monitoring system in reducing accident risks and improving rider safety.

VIII. CONCLUSION

This paper presented the design and implementation of an IoT-based bike rider safety monitoring system that integrates a smart helmet with a bike-mounted control unit to enhance two-wheeler safety. The proposed system effectively enforces helmet usage, prevents alcohol-impaired riding, detects accidents in real time, and provides automated emergency alerts with GPS-based location information. Experimental evaluation of the prototype demonstrated reliable sensor performance, stable wireless communication, and timely alert generation. By combining preventive safety enforcement with rapid emergency response, the system offers a practical, cost-effective, and scalable solution for improving motorcycle rider safety and reducing accident severity.

IX. FUTURE SCOPE

The proposed IoT-based bike rider safety monitoring system can be further enhanced and extended in several ways to improve functionality, reliability, and large-scale adoption. Future developments may include the integration of biometric sensors such as heart rate and body temperature sensors to continuously monitor the rider's health condition during travel. Advanced communication technologies like 4G/5G and NB-IoT can be incorporated to improve data transmission speed, reliability, and cloud connectivity. The system can also be enhanced with mobile application support to allow real-time monitoring, alert customization, and data analytics for riders and family members. Machine learning techniques may be applied to analyze riding patterns and predict potential accident risks in advance. Additionally, integration with smart city infrastructure and traffic management systems can enable centralized monitoring and policy enforcement, making the system suitable for large-scale deployment and contributing to safer and more intelligent transportation ecosystems.

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