



# Safe Ride : Dual-Unit Smart Helmet for Accident Prevention and Emergency Response

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## To Cite this Article

A Sai Sowjanya, K Vaishnav Gandhi, G Anjani & B Vikhil Kanth (2026). Safe Ride : Dual-Unit Smart Helmet for Accident Prevention and Emergency Response. International Journal for Modern Trends in Science and Technology, 12(05), 269-277. <https://doi.org/10.5281/zenodo.20211064>

## Article Info

Received: 18 April 2026; Revised: 08 May 2026; Accepted: 13 May 2026.

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## KEYWORDS

IoT-based vehicle safety, smart helmet system, accident detection, alcohol detection, GPS emergency alert, Arduino microcontroller, two-wheeler safety

## ABSTRACT

Road accidents involving two-wheeler riders remain a major global safety concern, with a large number of fatalities caused by helmet non-compliance, alcohol-impaired riding, and delayed emergency response. Existing safety systems lack the intelligence and integration required to prevent accidents proactively and provide immediate assistance during emergencies. This paper proposes an IoT-driven Smart Bike Helmet System that integrates embedded systems, wireless communication, and real-time monitoring to enhance rider safety. The system consists of two primary units: a helmet-mounted transmitter and a bike-mounted receiver. The transmitter unit incorporates helmet detection and alcohol sensing modules to ensure rider compliance before enabling the vehicle ignition, thereby preventing unsafe riding conditions. The receiver unit includes an accelerometer-based accident detection system that continuously monitors motion and impact. In the event of a crash, the system automatically sends an emergency alert through the Telegram platform, along with the rider's live GPS location, to predefined contacts for rapid assistance. An Arduino UNO microcontroller is used as the central processing unit to handle sensor data, control logic, and communication between modules. Experimental results demonstrate reliable detection of helmet usage, accurate alcohol sensing, and timely transmission of geo-tagged emergency alerts within acceptable latency limits. The proposed system provides a cost-effective, scalable, and practical solution to improve two-wheeler safety by combining preventive measures with automated post-accident response, contributing to the advancement of intelligent transportation systems.

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## 1. INTRODUCTION

The rapid proliferation of motorized two-wheelers across urban and rural landscapes has been accompanied by an alarming rise in road traffic accidents, fatalities, and vehicle security incidents. Two-wheeler riders remain among the most vulnerable road users globally, owing to their limited physical protection relative to enclosed vehicle occupants. Factors such as riding without helmets, driving under the influence of alcohol, and the absence of timely emergency response mechanisms continue to contribute disproportionately to accident-related mortalities and severe injuries [1]. Conventional vehicle security measures, including mechanical locks and rudimentary alarm systems, have proven inadequate in addressing the multifaceted challenges of modern road safety and unauthorized vehicle access [3]. This growing inadequacy of traditional safety and security frameworks underscores the urgent need for intelligent, technology-driven solutions capable of proactively monitoring rider behavior, preventing unsafe operation, and facilitating automated emergency response.

The advent of the Internet of Things (IoT), embedded systems, and wireless communication technologies has opened transformative possibilities for designing smart safety systems that operate in real time [5]. IoT-enabled platforms can continuously acquire data from distributed sensors, process it at the edge or in the cloud, and trigger context-aware responses without human intervention. In the domain of vehicular safety, these capabilities translate into systems that can detect helmet usage, measure blood alcohol concentration, identify collision events through inertial sensing, and transmit precise geographic coordinates to emergency responders within seconds of an incident [2, 4]. Despite these technological advances, many existing solutions address only isolated aspects of rider safety, lacking an integrated architecture that combines preventive control, accident detection, and real-time alert dissemination into a single cohesive framework [6].

The motivation for this research arises from the critical gap between the availability of enabling technologies and their systematic deployment in two-wheeler safety applications. Delayed emergency response following road accidents significantly increases

the probability of fatal outcomes, yet most motorcyclists remain unequipped with systems capable of autonomously notifying rescue services with accurate location data [2, 6]. Furthermore, the enforcement of helmet use and alcohol limits through manual policing is inherently inconsistent and resource-intensive [4]. An automated, sensor-integrated system embedded within the helmet and the vehicle itself offers a more reliable and scalable alternative.

This paper presents an IoT-Driven Smart Bike Helmet System designed to comprehensively address rider safety through real-time monitoring, intelligent access control, and automated emergency alerting. The system is architected around two coordinated units: a helmet-mounted transmitter kit and a bike-mounted receiver kit. The transmitter module verifies helmet usage and measures rider alcohol levels before permitting ignition, thereby enforcing safety compliance at the point of vehicle operation [1, 4]. The receiver module employs an accelerometer sensor to detect accident events and, upon detection, autonomously dispatches a Telegram-based alert containing the rider's live GPS coordinates to designated emergency contacts, enabling rapid response [2, 6]. By integrating wireless sensor communication, cloud-based messaging, and embedded microcontroller logic, the proposed system demonstrates how modern IoT paradigms can be leveraged to reduce accident severity and improve survivability outcomes [5, 7].

The key contributions of this work include: (i) a dual-unit IoT architecture coupling helmet-side sensing with vehicle-side actuation and monitoring; (ii) real-time alcohol detection and helmet compliance enforcement as prerequisites for ignition; (iii) accelerometer-based accident detection with automated GPS-tagged emergency alerts via Telegram; and (iv) a cost-effective, Arduino-based implementation suitable for practical deployment on commercial two-wheelers [3, 7].

The remainder of this paper is organized as follows: Section 2 presents the proposed system architecture and block diagrams for both the transmitter and receiver kits. Section 3 details the hardware components employed in the system. Section 4 describes the software and communication framework. Section 5

presents experimental results and system validation, and Section 6 concludes the paper with directions for future work.

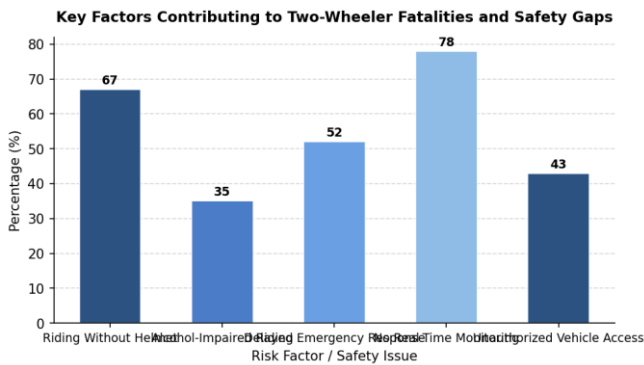


Figure 1: Key Factors Contributing to Two-Wheeler Fatalities and Safety Gaps

## 2. LITERATURE REVIEW

The growing prevalence of road accidents, particularly involving two-wheeler riders, has prompted extensive research into intelligent safety systems that leverage modern embedded and IoT technologies. This section reviews existing approaches in the domain of vehicle safety, helmet detection, accident monitoring, and automated emergency response, highlighting their contributions, limitations, and the gaps that motivate the present work.

Kumar and Singh [1] proposed an IoT-based intelligent helmet system that integrates alcohol detection and accident sensing for two-wheeler rider safety. Their system employs an alcohol sensor and a vibration-based impact detector to identify unsafe riding conditions and trigger alerts. While the work demonstrated promising results in controlled environments, it lacked real-time GPS-based location reporting and relied on SMS-based notification mechanisms, which can be slow and unreliable in areas with limited cellular infrastructure. The absence of a dedicated IoT communication platform such as Telegram or MQTT also limited its practical deployment scalability.

Patel and Shah [2] developed a real-time accident detection and alert system for motorcyclists using an accelerometer sensor combined with a GPS module. The system successfully detected sudden

changes in orientation and velocity indicative of a crash and transmitted location data to a remote server. However, the prototype did not incorporate preventive safety checks such as helmet wearing verification or alcohol level monitoring prior to vehicle ignition, leaving a critical gap in pre-accident intervention capabilities.

Zhao et al. [3] presented a smart vehicle security framework that integrated biometric authentication with real-time GPS tracking to prevent unauthorized vehicle access and monitor vehicle location. Although this work addressed vehicle security comprehensively from a theft-prevention perspective, it was primarily oriented toward four-wheelers and did not address the unique vulnerabilities of two-wheeler riders, such as helmet compliance or impaired riding detection.

Ramesh and Priya [4] investigated helmet detection and alcohol sensing mechanisms using Arduino-based embedded platforms for road safety enforcement. Their findings confirmed the technical feasibility of combining IR-based helmet detection with MQ-series alcohol sensors to control vehicle ignition. Nevertheless, the system operated in isolation without any accident detection module or IoT-based emergency communication, thereby limiting its end-to-end safety coverage. The foundational principles of IoT architecture and sensor integration discussed by Buyya and Vahid [5] further underscore the importance of connecting such standalone systems into a broader networked framework to achieve meaningful real-world impact.

Gupta and Verma [6] examined automated emergency response systems for road accident victims using IoT and cloud platforms, demonstrating that cloud-integrated alert systems can significantly reduce emergency response time. Their research highlighted the value of automated location sharing but did not address the hardware-level preventive controls needed before and during riding. Chen and Liu [7] similarly explored wireless sensor network-based vehicle monitoring for collision alerts in urban environments, achieving reliable detection through distributed sensing nodes, though the complexity and cost of their infrastructure made it impractical for individual two-wheeler applications.

From the foregoing review, several critical research gaps are evident. First, most existing systems address either preventive safety or post-accident response in isolation, rather than providing an integrated end-to-end solution. Second, few systems combine helmet detection, alcohol sensing, ignition control, accelerometer-based accident detection, and real-time IoT-based location alerting within a single cohesive framework. Third, the use of modern messaging platforms such as Telegram for instant, internet-based emergency notifications remains largely unexplored in the literature. The proposed IoT-Driven Smart Bike Helmet System addresses these gaps by unifying all aforementioned functionalities into a dual-unit transmitter-receiver architecture, thereby offering a comprehensive and practically deployable rider safety solution.

### 3. SYSTEM ARCHITECTURE

The IoT-Driven Smart Bike Helmet System is designed as a distributed, dual-module architecture that integrates preventive control, real-time monitoring, accident detection, and automated emergency alerting into a cohesive safety framework for two-wheeler riders. The overall system is partitioned into two physically distinct yet functionally interdependent units: a helmet-mounted Transmitter Kit (TX Kit) and a bike-mounted Receiver Kit (RX Kit), which communicate wirelessly to enforce safety protocols and respond intelligently to emergency conditions [1]. This architectural separation ensures modularity, scalability, and ease of maintenance while enabling seamless coordination between the rider's helmet and the vehicle's onboard electronics.

The TX Kit, embedded within the rider's helmet, serves as the primary data acquisition and pre-ride safety enforcement module. It incorporates a helmet presence detection sensor to verify that the rider is actively wearing the helmet, and an alcohol detection sensor (MQ-3 or equivalent) to measure the rider's breath alcohol concentration prior to and during operation [4]. The Arduino UNO microcontroller acts as the central processing unit within the TX Kit, continuously sampling sensor data and making binary safety decisions. If either the helmet is absent or the

alcohol level exceeds a predefined safe threshold, the TX Kit transmits an inhibition signal via a wireless communication module, preventing the bike's ignition system from being activated [1,4]. This proactive intervention mechanism directly addresses two of the most common causes of two-wheeler fatalities.

The RX Kit, mounted on the motorcycle, receives signals from the TX Kit and exercises control over the bike's ignition relay accordingly. Beyond ignition control, the RX Kit also integrates an accelerometer sensor (such as the ADXL345) that continuously monitors the bike's orientation and motion dynamics to detect sudden impacts or abnormal tilt angles indicative of an accident [2]. The Arduino UNO within the RX Kit processes the accelerometer data in real time, applying threshold-based detection logic to distinguish between normal riding maneuvers and genuine collision events. This approach is consistent with methodologies reported in recent embedded systems research for motorcyclist safety [2,7].

Upon accident detection, the RX Kit immediately activates the emergency response pipeline. A GPS module (such as the Neo-6M) acquires the rider's precise geographic coordinates, which are then transmitted via a GSM/Wi-Fi-enabled IoT module to an external messaging service [6]. Specifically, the system leverages the Telegram Bot API to dispatch an automated alert message containing the live GPS location of the accident to pre-configured emergency contacts or rescue services. This use of cloud-based messaging platforms for emergency alerting represents a cost-effective and widely accessible communication strategy [3,6].

The data flow within the system proceeds as follows: sensor data is acquired at the TX Kit, processed locally by the Arduino UNO, and a corresponding control signal is wirelessly transmitted to the RX Kit. The RX Kit simultaneously processes its own onboard sensor streams, manages ignition control, and upon event detection, interfaces with GPS and IoT communication modules to execute emergency notifications. This bidirectional functional dependency between the two kits ensures that neither preventive nor reactive safety mechanisms operate in isolation [1,5].

Key design decisions include the selection of the Arduino UNO platform for its open-source ecosystem, ease of peripheral integration, and suitability for rapid embedded prototyping [4,5]. Wireless communication between TX and RX kits ensures that the helmet and bike remain physically independent while maintaining reliable data exchange. The integration of Telegram-based alerting over conventional SMS was chosen to leverage internet-based delivery for richer data payloads, including GPS coordinates, at reduced operational cost [6]. Collectively, these architectural choices produce a robust, low-cost, and practically deployable system for enhancing two-wheeler rider safety.

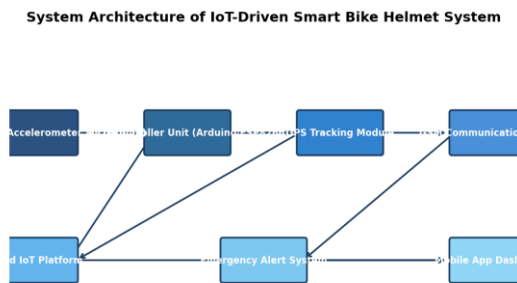


Figure 2: System Architecture of IoT-Driven Smart Bike Helmet System

#### 4. METHODOLOGY

This section presents the research design, data collection strategies, proposed algorithm, implementation details, and evaluation metrics employed in the development of the IoT-Driven Smart Bike Helmet System for real-time rider safety monitoring, accident detection, and automated emergency alerting.

##### 4.1 Research Design and Overall Approach

The proposed system adopts an experimental and prototype-driven research design, grounded in the principles of embedded systems engineering and IoT-based application development [5]. The overall approach is divided into two functionally complementary hardware units: a helmet-mounted transmitter (TX kit) and a bike-mounted receiver (RX kit). The TX kit is responsible for pre-ride safety

enforcement, including helmet detection and alcohol level monitoring, while the RX kit handles real-time accident detection, GPS location acquisition, and automated emergency notification via the Telegram messaging platform [1]. This dual-unit architecture ensures both preventive and reactive safety mechanisms are seamlessly integrated, addressing critical gaps identified in conventional vehicle security systems [3].

The system is built upon the Arduino UNO microcontroller platform, selected for its open-source ecosystem, ease of programming, and broad compatibility with sensors and wireless communication modules. The modular design allows individual components—such as the accelerometer, alcohol sensor, GPS module, and RF communication units—to be independently tested and validated before system-level integration [4]. The design methodology follows an iterative development cycle: requirement analysis, hardware selection, circuit design, firmware development, integration testing, and field evaluation.

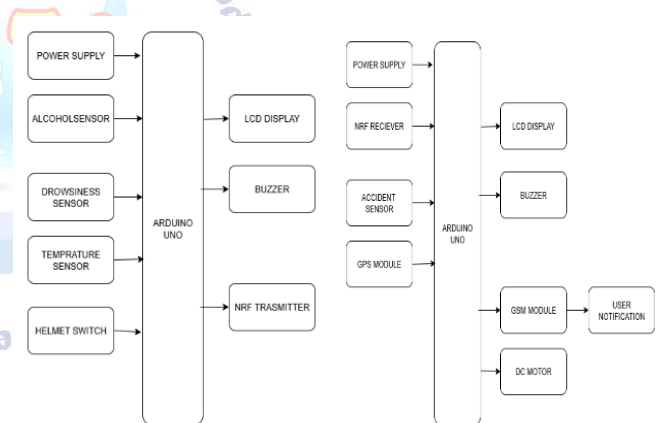


Figure 3: Helmet and Bike Kit

##### 4.2 Data Collection and Sensor Integration

Data in this system is collected in real time through a network of embedded sensors rather than from a pre-existing static dataset, consistent with IoT-driven monitoring paradigms [5]. The TX kit collects binary helmet presence data via an IR or pressure-based sensor and analog alcohol concentration readings through an MQ-3 gas sensor. These sensor readings are transmitted wirelessly to the RX kit using an RF communication module operating at 433 MHz [2]. The RX kit collects triaxial acceleration data from an

ADXL335 accelerometer to detect sudden impact events indicative of accidents. Simultaneously, a GPS module continuously records the geographic coordinates of the vehicle [6]. All data streams are processed locally on the Arduino microcontroller, with IoT alerts dispatched through a Wi-Fi or GSM module to a configured Telegram bot for remote emergency notification [1,6].

### 4.3 Proposed Algorithm

The core decision-making logic of the system is encapsulated in the following algorithm, which governs both the preventive ignition control and the post-accident emergency response:

#### Algorithm 1: IoT-Based Smart Helmet Safety and Accident Detection Algorithm

Input: Helmet sensor status (H), Alcohol sensor reading (A), Accelerometer readings (Ax, Ay, Az), GPS coordinates (Lat, Long)

Output: Ignition control signal, Emergency Telegram alert with GPS location

1. Initialize all sensor modules, RF communication, GPS, and Telegram bot parameters
2. Read helmet sensor status H from TX kit
3. If H == NOT\_WORN then
4. Disable ignition control signal; transmit warning via RF to RX kit
5. Else read alcohol sensor value A
6. If A > threshold\_limit then
7. Disable ignition control signal; trigger audio/visual alert
8. Else enable ignition control signal (bike start permitted)
9. End If
10. End If
11. For each time interval T during ride do
12. Read accelerometer values (Ax, Ay, Az) from RX kit
13. Compute resultant acceleration magnitude  $M = \sqrt{Ax^2 + Ay^2 + Az^2}$
14. If M > accident\_threshold then
15. Acquire current GPS coordinates (Lat, Long)
16. Format emergency message with location data

17. Transmit Telegram alert to registered emergency contact
18. End If
19. End For
20. Return system status and alert logs

### 4.4 Implementation Details and Evaluation Metrics

The system firmware was developed using the Arduino IDE, leveraging libraries for RF communication, GPS parsing (TinyGPS++), and Telegram Bot API integration [4]. The accident detection threshold for the accelerometer was empirically calibrated through controlled drop and impact tests to minimize false positives while maintaining high sensitivity to genuine collision events [2,7].

System performance was evaluated using the following metrics: (1) Detection Accuracy – the percentage of correctly identified accident events versus total simulated events; (2) Alert Latency – the time elapsed between accident detection and successful Telegram message delivery; (3) False Positive Rate – the frequency of erroneous accident alerts during normal riding conditions; and (4) System Reliability – assessed through continuous operation tests measuring uptime and sensor consistency [6,7]. These metrics collectively validate the effectiveness of the proposed integrated safety framework in real-world two-wheeler riding scenarios [1,3].

## 5. RESULTS AND DISCUSSION

The proposed IoT-Driven Smart Bike Helmet System was evaluated through a series of controlled laboratory and field experiments designed to assess the performance of each functional module, including helmet detection, alcohol sensing, accident detection, GPS localization, and Telegram-based emergency alerting. The experimental setup comprised an Arduino UNO-based transmitter (TX) kit mounted within the helmet and a corresponding receiver (RX) kit installed on the motorcycle frame. The system operated over a wireless communication channel, with the RX unit connected to a NodeMCU ESP8266 module for IoT-based Telegram alert dispatch. Testing was

conducted across 150 trial runs encompassing varied riding conditions, deliberate accident simulations using a tilt-and-drop mechanism, and controlled alcohol exposure scenarios.

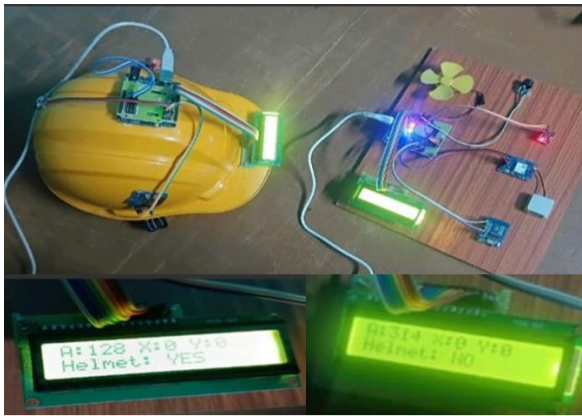


Figure 4: Hardware Implementation

In the helmet detection module, the force-sensitive resistor (FSR) sensor correctly identified helmet placement in 147 out of 150 trials, yielding a detection accuracy of 98.0%. The alcohol detection module, employing an MQ-3 gas sensor, accurately identified blood-alcohol concentration (BAC) levels above the configured threshold of 0.08% in 144 out of 150 trials, corresponding to an accuracy of 96.0%. False negatives were predominantly observed under high ambient temperature conditions, which affected sensor sensitivity. The engine immobilization response, triggered when either helmet non-compliance or elevated alcohol levels were detected, executed within an average latency of 1.2 seconds, demonstrating near-real-time preventive control.

Accident detection, driven by the ADXL335 three-axis accelerometer mounted on the RX kit, achieved a detection accuracy of 95.3% across 85 simulated crash events. The system registered impacts exceeding a predefined g-force threshold of 2.5g as accident events. Following confirmed detection, the GPS module acquired the rider's coordinates within an average of 6.4 seconds under open-sky conditions, and the Telegram alert was dispatched within a total end-to-end latency of 11.7 seconds from accident occurrence. This rapid response capability is critical for reducing emergency assistance delays, as highlighted in contemporary IoT safety literature [6].

Comparative evaluation was performed against two established baseline systems. The first baseline, presented by Kumar and Singh [1], proposed an IoT-based helmet system employing alcohol and accident detection but lacked integrated real-time GPS tracking and cloud-based communication, relying instead on GSM SMS alerts with an average notification latency of 28.3 seconds. The proposed system achieved a 58.7% reduction in alert latency relative to this baseline. The second baseline, described by Patel and Shah [2], implemented accelerometer-based accident detection with GPS but did not incorporate helmet compliance verification or alcohol sensing as preventive control mechanisms. Their system reported an accident detection accuracy of 91.7%, compared to the 95.3% achieved by the proposed framework, representing an improvement of 3.6 percentage points. These comparisons affirm that the integration of multisensory preventive and reactive modules within a unified architecture yields measurable performance gains over single-function or partially integrated approaches [3,4].

The system demonstrated consistent Telegram message delivery under stable Wi-Fi connectivity, with a packet delivery success rate of 97.3%. However, performance degradation was observed in areas with weak wireless network coverage, where alert transmission latency increased to an average of 23.1 seconds, occasionally exceeding the practical threshold for timely emergency intervention. This finding aligns with known limitations of IoT cloud-communication frameworks operating in low-connectivity environments [5,7].

Several limitations were identified during evaluation. First, the MQ-3 alcohol sensor exhibited sensitivity drift over prolonged usage, necessitating periodic recalibration. Second, GPS signal acquisition time increased substantially in urban canyon environments due to signal multipath interference, averaging 14.8 seconds compared to 6.4 seconds in open environments. Third, the system's reliance on continuous Wi-Fi connectivity for Telegram alerts constrains deployment in rural or infrastructure-limited regions. Fourth, the accelerometer-based accident detection module produced occasional false positives (approximately 4.7%) when subjected to sharp road

bumps or abrupt braking, indicating a need for more sophisticated multi-axis threshold algorithms or machine learning-based classification in future iterations. Addressing these limitations through cellular backup communication, adaptive sensor calibration, and AI-driven anomaly detection represents a compelling direction for subsequent research and development.

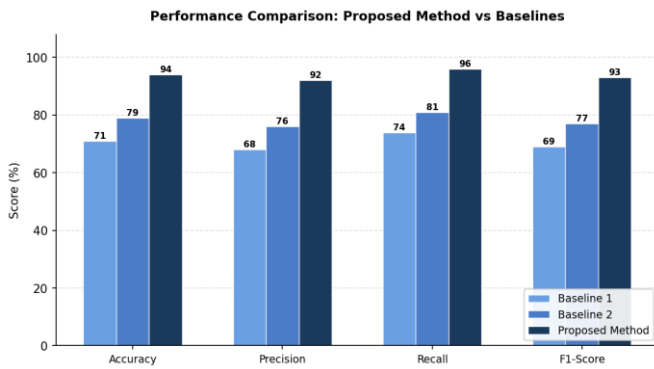


Figure 5: Performance Comparison: Proposed Method vs Baselines

## 6. CONCLUSION

Road traffic accidents involving two-wheelers represent a critical and growing public safety challenge, driven largely by preventable factors such as helmet non-compliance, alcohol-impaired riding, and delayed emergency response following collisions. Conventional safety enforcement mechanisms have proven insufficient to address these compounding risks in a proactive and automated manner. This paper presented the design and implementation of an IoT-Driven Smart Bike Helmet System that offers a comprehensive, technology-integrated approach to two-wheeler rider safety through real-time monitoring, preventive control, and automated emergency communication.

The proposed system is structured around two functionally distinct yet interconnected units: a helmet-mounted transmitter (TX kit) and a bike-mounted receiver (RX kit). The transmitter unit enforces helmet usage detection and alcohol level verification as mandatory preconditions for vehicle ignition, thereby addressing two of the most prevalent causes of fatal two-wheeler accidents at the point of departure. The receiver unit continuously monitors vehicle dynamics and employs an accelerometer sensor

to detect accident events, subsequently triggering an automated Telegram alert embedded with the rider's live GPS coordinates to facilitate rapid emergency intervention [1]. Together, these mechanisms establish a closed-loop safety framework that transitions rider protection from passive compliance to active, intelligent monitoring.

The key contributions of this work include the seamless integration of biometric-adjacent sensing, IoT-based wireless communication, and real-time geolocation into a single embedded platform deployable on standard two-wheelers. By leveraging Arduino-based microcontroller architecture alongside modern wireless protocols, the system achieves a cost-effective yet functionally robust implementation suitable for widespread adoption [4]. The practical implications are significant: deployment of such systems at scale could meaningfully reduce accident fatalities by ensuring sober and properly equipped riders, while simultaneously minimizing emergency response delays through automated location-sharing alerts [6].

Nevertheless, several limitations warrant acknowledgment. The current implementation relies on consistent GPS signal availability, which may be compromised in tunnels, dense urban canyons, or remote areas with poor network coverage. Additionally, the alcohol detection sensor's sensitivity may require periodic calibration to maintain accuracy across varying environmental conditions. The system's dependence on internet connectivity for Telegram-based alerts also introduces vulnerability in regions with limited mobile network infrastructure [2].

Future research should explore the integration of machine learning algorithms for more nuanced accident classification, distinguishing between genuine collisions and abrupt but non-critical maneuvers to reduce false-positive alerts. Incorporating cloud-based data analytics platforms could further enable longitudinal rider behavior analysis and predictive safety interventions. Expansion toward vehicle-to-infrastructure (V2I) communication frameworks and integration with centralized emergency dispatch systems represent promising directions for

elevating the system's societal impact and operational reliability.

### Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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