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An IoT-Based Smart Helmet for Real Time Rider Safety Monitoring and Emergency Response System

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ABSTRACT: Two-wheeler accidents contribute significantly to road fatalities due to delayed emergency response and lack of real-time safety monitoring. This paper presents Techmet, an IoT-based smart helmet system designed to enhance rider safety through automated detection and alert mechanisms. The system is divided into four modules: sensing, processing and decision, communication, and control and alert. Sensors such as accelerometer, gyroscope, alcohol sensor, and IR sensor collect real-time data. The processing module analyzes this data to detect accidents, alcohol consumption, and helmet non-compliance. The communication module enables GPS-based location tracking and data transmission, while the control module triggers emergency alerts and manages vehicle ignition. A mobile application provides real-time monitoring and notifications. The system demonstrates improved response time, reliable performance, and a scalable approach to reducing accident-related fatalities.

KEYWORDS: IoT, Smart Helmet, Rider Safety, Accident Detection, Emergency Alert System, GPS Tracking, Sensor Integration, Real-Time Monitoring, Techmet

I. INTRODUCTION

Road accidents are one of the leading causes of death globally, with two-wheeler riders being particularly vulnerable. Factors such as delayed medical assistance, lack of safety compliance, and absence of intelligent monitoring systems significantly increase fatality rates. Traditional helmets provide passive protection but do not offer active safety monitoring or emergency communication. Recent advancements in IoT and embedded systems have enabled the development of intelligent safety solutions. However, many existing systems focus only on isolated functionalities such as accident detection or GPS tracking, lacking a unified and integrated approach to address these challenges, Techmet is proposed as a comprehensive smart helmet system that integrates sensing, decision-making, communication, and control functionalities into a single platform. The system ensures real-time monitoring of rider conditions, enforces safety compliance, and provides immediate emergency response.

II. LITERATURE SURVEY

Recent advancements in smart helmet systems have focused on enhancing rider safety through the integration of IoT, sensor technologies, and embedded systems.
Sneha A. M., Spandana S., Mariyam N., Zaiba Khanum, and Rudresha S. J. [1] proposed an IoT-based smart helmet system that integrates alcohol detection, helmet usage verification, and accident detection. Their system prevents vehicle ignition under unsafe conditions and sends emergency alerts using GPS. This work highlights the importance of combining multiple safety features into a unified system.

D. Tamizhmalar, A. T. M. Athif, N. S., and K. S. [2] developed an AI-based helmet detection system that focuses on identifying helmet usage using intelligent algorithms. While the system improves enforcement of helmet compliance, it mainly relies on external monitoring and does not provide integrated rider-level safety mechanisms.

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M. Rafiq H and C. V. Gowdar [3] introduced an intelligent IoT-integrated smart helmet for real-time rider safety monitoring. Their system includes GPS tracking and accident detection features, enabling real-time communication. However, it lacks strong decision-making and control mechanisms such as ignition control.

D. R. Kiran Babu, P. Thirupathi Reddy, S. Inderjeet Singh, V. Sahith Kumar, G. Mahibabu, and M. Amani [4] proposed an IoT-based smart helmet with real-time communication for accident detection and prevention. Their system emphasizes fast emergency response but primarily focuses on accident detection without incorporating comprehensive rider condition monitoring.

S. M. Simi, A. S. Vaishnavi, R. S. Saira Bhanu, S. Diya, and S. Liyana Shibu [5] developed a smart helmet system integrating accident detection and alcohol monitoring. Their work demonstrates that combining multiple sensors improves safety; however, it lacks a structured architecture for decision-making and control.

G. Rajasekaran, A. Mohamed Sybudheen, S. Kizar Hussain, U. Gomathi, M. Mohamed Sameer Ali, S. Suman Rajest, and R. Regin [6] presented an integrated smart helmet system with drowsiness detection, accident monitoring, and alcohol detection. Although the system incorporates multiple features, it increases system complexity and lacks a clearly defined modular architecture.

III. PROBLEM STATEMENT

Road accidents involving two-wheeler riders remain a major cause of fatalities, mainly due to delayed emergency response and lack of safety compliance such as improper helmet usage and alcohol consumption. Conventional helmets provide only passive protection and do not support real-time monitoring or accident detection, leading to delays in reporting accidents and receiving medical assistance. Existing smart helmet systems address individual features like tracking or detection but lack an integrated approach. Therefore, there is a need for a unified system that can monitor rider safety, detect accidents, enforce safety conditions, and provide immediate emergency alerts, which is addressed by the proposed Techmet IoT-based smart helmet system.

IV. METHODOLOGY

The Techmet system follows a modular architecture consisting of four primary modules: sensing module, processing and decision module, communication module, and control and alert module.

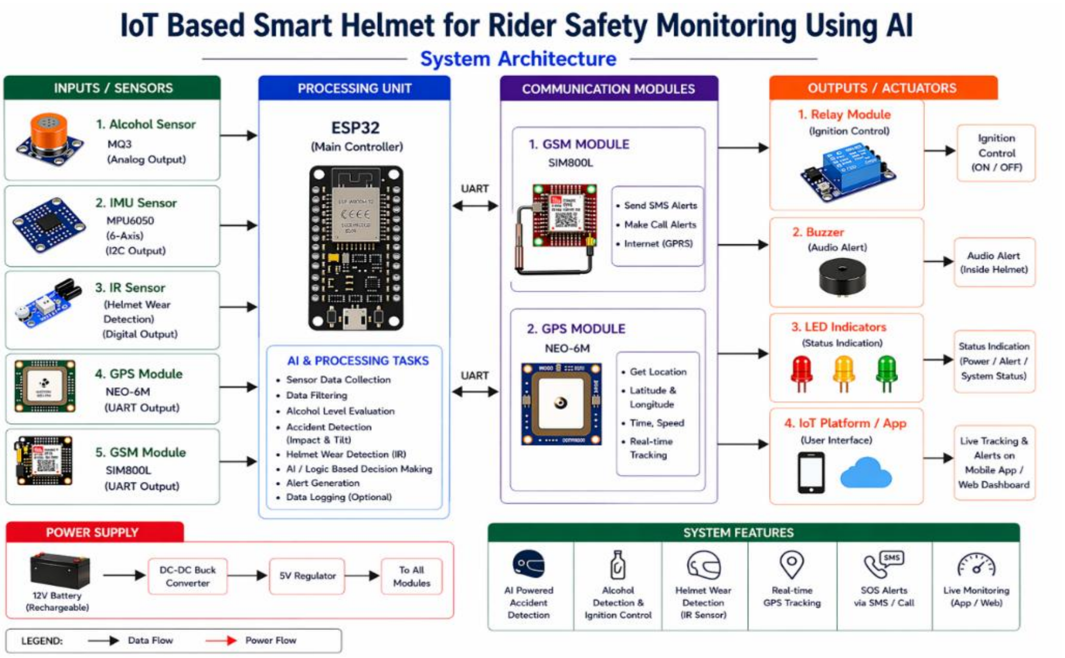

Fig.1 System Architecture For Smart Helmet System

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The sensing module continuously collects real-time data from various sensors embedded within the helmet. This includes motion data, alcohol levels, and helmet usage status. The collected data is transmitted to the processing and decision module. The processing and decision module acts as the core unit, where all incoming data is analyzed using predefined logic and threshold-based evaluation. It identifies unsafe conditions such as accidents, alcohol consumption, and absence of helmet usage. Once a decision is made, the communication module is activated to retrieve the rider's real-time location and transmit relevant data to external systems, including mobile applications and emergency contacts.

Mathematical Model of the System

System input:

$$S(t) = \{A(t), G(t), H(t), L(t)\}$$

Where:
* S(t) represents the sensor inputs at time t
* A(t) → Accelerometer data
* G(t) → Gyroscope data
* H(t) → Helmet status
* L(t) → Alcohol level

This represents all real-time data collected from the sensing module.

Acceleration magnitude & Angular Motion:

$$|A| = \sqrt{(A\_x^2 + A\_y^2 + A\_z^2)}$$

These equations calculate the magnitude of acceleration and angular motion. High values indicate sudden movement, which may correspond to an accident.

$$|G| = \sqrt{(G\_x^2 + G\_y^2 + G\_z^2)}$$

Helmet detection:

$$H(t) = 1 \quad \text{(helmet worn)}$$
$$H(t) = 0 \quad \text{(helmet not worn)}$$

This function checks whether the rider is wearing a helmet.

Alcohol condition:

$$L(t) > L\_th$$

Where L_{th} is the threshold value.

If this condition is true, the rider is considered unsafe.
Accident detection:

$$D(t) = \alpha|A| + \beta|G|$$
$$D(t) > D_{th}$$

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This model combines acceleration and angular motion to detect accidents. If the value exceeds the threshold, an accident is assumed.

Safety condition:

$$\text{Safe}(t) = 1 \quad (H(t) = 1 \text{ and } L(t) < L\_th)$$
$$\text{Safe}(t) = 0 \quad (\text{otherwise})$$

The rider is safe only if the helmet is worn and alcohol level is below the limit.

Control:

$$C(t) = \text{ON} \quad (\text{Safe}(t) = 1)$$
$$C(t) = \text{OFF} \quad (\text{otherwise})$$

This determines whether the vehicle ignition is enabled or disabled.

Alert:

$$\text{Alert}(t) = 1 \quad (D(t) > D\_th)$$
$$\text{Alert}(t) = 0 \quad (\text{otherwise})$$

Finally, the control and alert module executes appropriate actions such as disabling ignition, sending emergency alerts, and notifying users. This structured approach ensures efficient data flow, quick response, and system reliability.

1. Sensing
2. Processing and Decision
3. Communication
4. Control and Alert

1. Sensing

The sensing module is responsible for acquiring real-time data from the rider and environment. It includes multiple sensors such as accelerometer and gyroscope for motion detection, alcohol sensor for detecting alcohol levels, and IR sensor for helmet usage
verification. This module continuously monitors rider conditions and forwards raw data to the processing unit.

2. Processing and Decision

This module acts as the central processing unit of the system. It receives input data from the sensing module and performs analysis using predefined algorithms. It detects accidents by identifying abnormal motion patterns and evaluates safety conditions such as alcohol presence and helmet usage. Based on these evaluations, it generates decisions that determine system actions.

3. Communication

The communication module is responsible for transmitting data between the system and external entities. It retrieves real-time GPS location data and sends it along with alert messages to emergency contacts. It also communicates with the mobile application to provide live tracking and status updates.

4. Control and Alert

This module executes actions based on decisions received from the processing module. It controls vehicle ignition to prevent unsafe riding and triggers emergency alerts during accidents. Notifications are sent to users through the mobile application, ensuring timely awareness and response.

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V. RESULTS

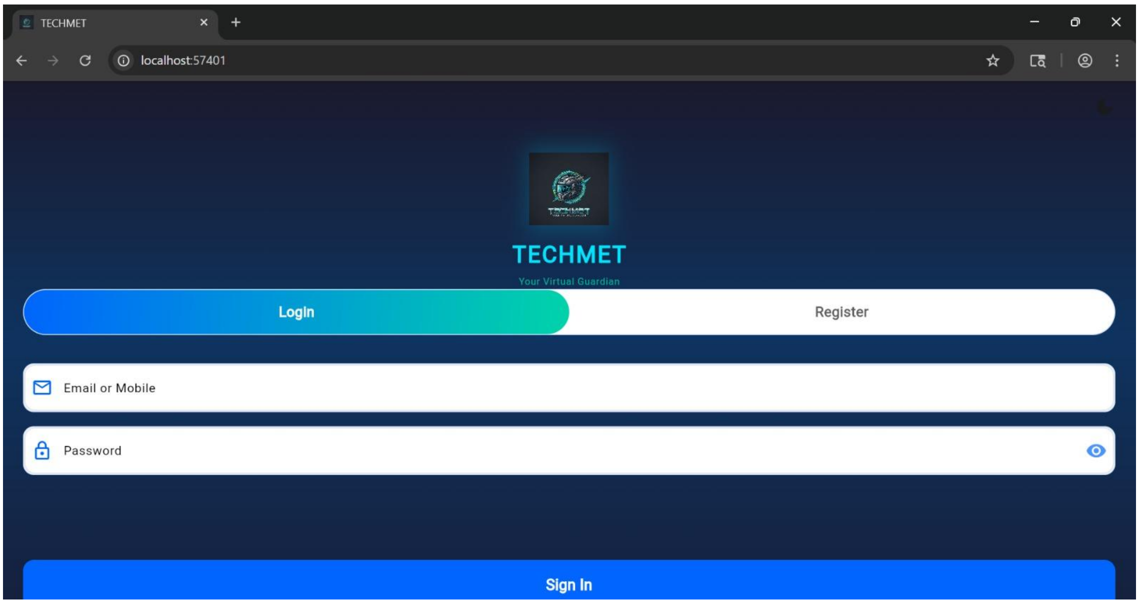

Fig.2 Login Page

The Fig.2 shows the login page of the TECHMET web application running on a browser at localhost. The interface has a modern dark blue gradient background with the TECHMET logo displayed at the top center. Below the logo, there is a toggle section for Login and Register, with the Login tab currently selected in a blue-green gradient style. The page contains two input fields for Email or Mobile and Password, with icons placed beside each field. At the bottom, a large blue Sign In button is provided for user authentication.

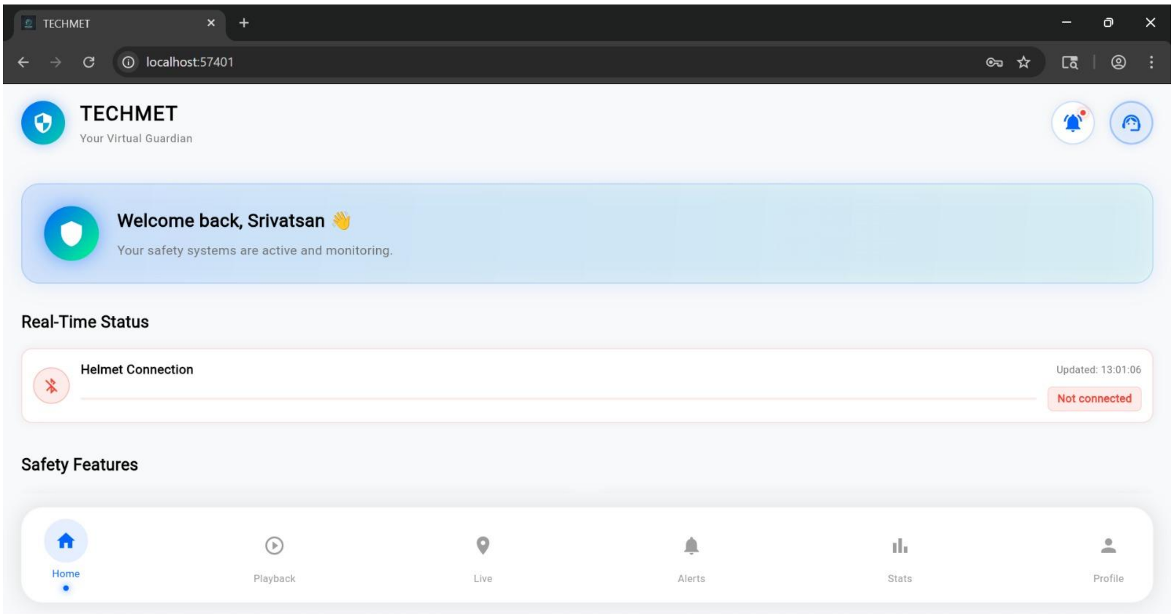

Fig.3 Dashboard Page

The Fig.3 displays the home dashboard of the TECHMET application running in a web browser. At the top, the TECHMET logo and title are shown along with notification and support icons. A welcome banner greets the user "Srivatsan" and indicates that the safety systems are active and monitoring. Below it, the real-time status section shows

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the helmet connection as not connected, and a bottom navigation bar provides access to Home, Playback, Live, Alerts, Stats, and Profile pages

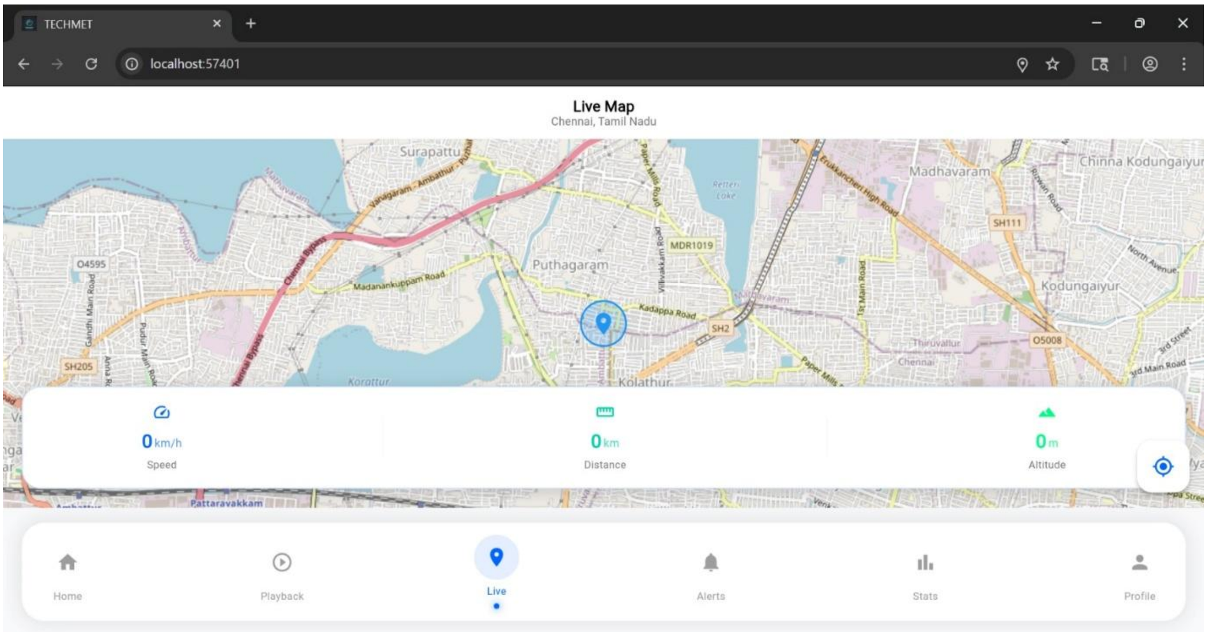

Fig.4 Live Maps Page

The Fig.4 shows the Live Map page of the TECHMET application running in a web browser. A map centred on Chennai, Tamil Nadu is displayed with a blue location marker indicating the current position of the rider or vehicle. Below the map, a status panel shows real-time metrics such as speed, distance travelled, and altitude, all currently at zero. At the bottom, a navigation bar highlights the Live section, with additional tabs for Home, Playback, Alerts, Stats, and Profile.

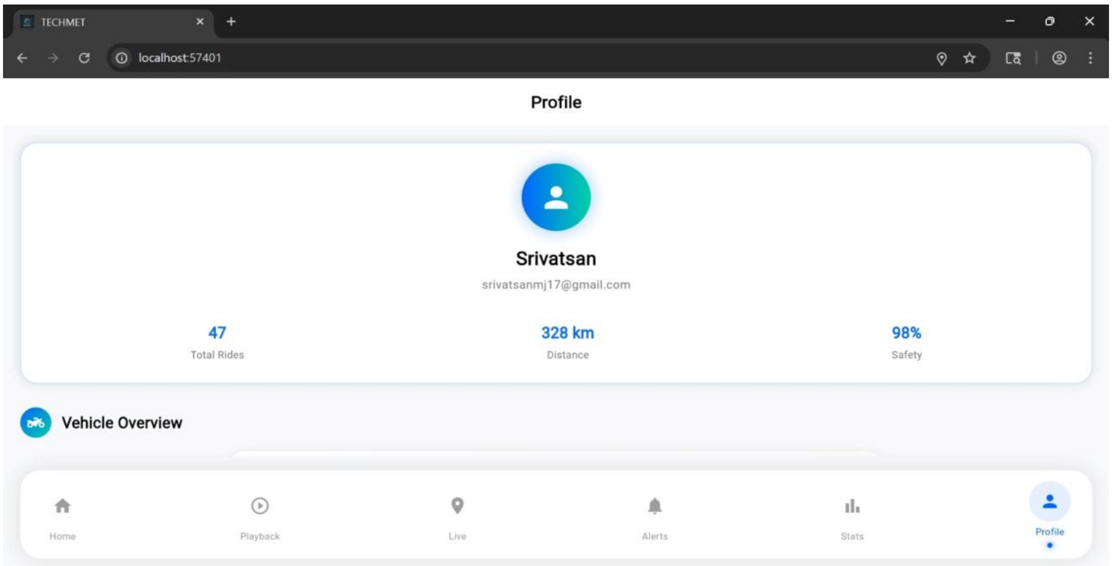

Fig.5 Profile Page

The Fig.5 displays the Profile page of the TECHMET application in a web browser. It shows the user profile of Srivatsan with a profile icon, email address, and personal statistics such as total rides, distance traveled, and safety score. A section titled Vehicle Overview is visible below the profile card for displaying vehicle-related details. At the

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bottom, a navigation bar highlights the Profile tab, with other options including Home, Playback, Live, Alerts, and Stats.

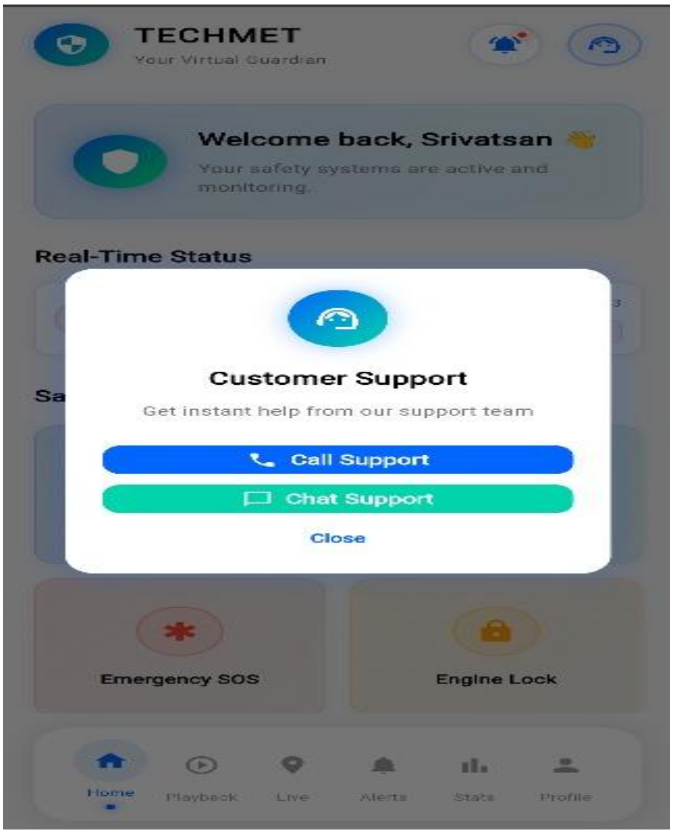

Fig.6 Customer Support Page

The Fig.6 shows the TECHMET application home screen with a customer support popup displayed at the center. The popup provides quick assistance options including Call Support and Chat Support, along with a Close button. In the background, the dashboard shows a welcome message, real-time status section, and safety features such as Emergency SOS and Engine Lock. A bottom navigation bar is visible with tabs for Home, Playback, Live, Alerts, Stats, and Profile.

The Techmet system was evaluated under multiple scenarios to verify its performance. The sensing module accurately detected helmet usage and alcohol presence. The processing module successfully identified abnormal motion patterns representing accidents.

The communication module provided real-time location tracking with minimal delay. Emergency alerts were transmitted successfully to predefined contacts. The control module effectively prevented ignition under unsafe conditions.

The mobile application displayed real-time data, including alerts and tracking information. Overall, the system demonstrated reliable performance and improved emergency response efficiency.

VI. CONCLUSION AND FUTURE ENHANCEMENTS

The proposed TECHMET Smart Helmet System provides an effective solution for improving rider safety using IoT and AI technologies. The system integrates multiple sensors to monitor helmet usage, alcohol consumption, fatigue, and accident conditions in real time. The ESP32 microcontroller processes the data and enables automatic decision-making, including ignition control and emergency alert generation. In case of an accident, the system sends a real-time alert with GPS location details to predefined contacts, reducing response time and improving the chances of timely assistance. By combining monitoring, prevention, and emergency response in a single system, TECHMET enhances

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overall rider safety and reduces accident-related risks. In addition, the system improves rider awareness by providing timely warnings and safety notifications during travel. The integration of a mobile application allows users to access live tracking, ride history, and emergency features in a convenient manner. TECHMET also demonstrates how smart technologies can be applied to everyday transportation for safer mobility. The proposed system is cost-effective, practical, and suitable for real-world implementation. Overall, TECHMET represents a significant step toward intelligent road safety solutions for modern riders.

The proposed TECHMET system can be improved by adding advanced features to enhance performance and usability. Future developments may include the use of advanced Artificial Intelligence for more accurate fatigue prediction, rider behavior analysis, and accident detection. TECHMET-to-TECHMET communication can be introduced to share instant alerts and hazard warnings between nearby riders for improved road awareness. Cloud storage facilities can be implemented for continuous data monitoring, trip history management, and predictive analysis. Integration with traffic management and emergency response systems can further improve accident handling efficiency. The mobile application can be enhanced with more real-time features, smart notifications, and remote monitoring capabilities. Better battery efficiency and intelligent power management techniques can increase device reliability and usage time. High-speed communication technologies such as 5G can provide faster and more stable data transmission. In addition, voice assistance and hands-free controls can be added to improve rider convenience and reduce distractions while driving. Future versions may also support smartwatch connectivity for instant alerts and quick emergency actions. The system can further be expanded with weather-based risk warnings and route safety recommendations to provide a smarter riding experience. Overall, these enhancements can make TECHMET a more advanced, reliable, and intelligent rider safety solution.

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