STM JOURNALS

Research & Reviews: Journal of
Embedded System & Applications

https://journals.stmjournals.com/rrjoesa

ISSN: 2395-6712 (Online)
ISSN: 2321-8533 (Print)
Volume 14, Issue 1, 2026
January–April
DOI (Journal): 10.37591/RRJoESA

Review RRJoESA

VERONICA: AI-Driven Edge System for Comprehensive Bike Safety and Assistance Through Multi-Source Data Fusion

Sanket Khandu Sadgir[1], Aditya Sanjay Salve[2,*], Vaibhav Savliram Bodke[3], Sahil Jaimal Pathania[4], Ranjana P. Dahake[5]

Abstract

Road safety for bike riders remains a significant concern, with accident rates highlighting the need for advanced solutions to ensure rider protection and awareness. This paper presents "VERONICA: AI-Driven Edge System for Comprehensive Bike Safety and Assistance Through Multi-Source Data Fusion", a voice-activated, continuously operating assistance system designed to provide real-time, intelligent solutions for various riding scenarios. VERONICA integrates accident detection, low-traffic route navigation, traction control advisories, and weather updates into a single, user-friendly platform. By leveraging advanced voice recognition, natural language understanding (NLU) and Internet of Things (IoT) technologies, VERONICA delivers proactive guidance and timely alerts tailored to user needs. The system employs robust architecture, including microcontrollers, sensors, and APIs, to monitor and respond to environmental conditions. This paper explores the technical challenges, architecture, and implementation strategies involved in creating VERONICA, with a focus on ensuring reliability, responsiveness, and scalability for practical deployment in real-world scenarios. The results demonstrate that VERONICA significantly enhances rider safety and convenience, making it a transformative step forward in biking technology.

Keywords: Accident detection, low-traffic route navigation, NLU, updates VERONICA, weather

INTRODUCTION

Road accidents involving motorcycles are a major global concern, with millions of fatalities and injuries reported every year. Traditional safety measures, such as helmets and protective gear, are insufficient to address the dynamic challenges faced by the riders. The need for real-time, hands-free assistance has never been more critical than it is today. This study introduces VERONICA, an advanced riding assistance system, designed to enhance rider safety and convenience through innovative technologies.

VERONICA integrates voice-activated controls, natural language understanding (NLU), and advanced sensors to provide features such as emergency alerts, low-traffic navigation, and weather updates for the visually impaired. Unlike general-purpose virtual assistants, VERONICA consolidates these functionalities into a single, user-friendly interface, minimizing distractions and enhancing safety. The system leverages cutting-edge hardware and software, including microcontrollers, sensors, and application programming interfaces (APIs), to monitor and respond to environmental and vehicle conditions. Its

***Author for Correspondence**
Aditya Sanjay Salve
E-mail: assalve3838@gmail.com

[1–5]Assistant Professor, Department. of Computer Engineering, MET Institute of Engineering, Nashik, Maharashtra, India
[2–4]Student, Department. of Computer Engineering, MET Institute of Engineering, Nashik, Maharashtra, India

Received Date: June 16, 2025
Accepted Date: September 08, 2025
Published Date: November 18, 2025

Citation: Sanket Khandu Sadgir, Aditya Sanjay Salve, Vaibhav Savliram Bodke, Sahil Jaimal Pathania, Ranjana P. Dahake. VERONICA: AI-Driven Edge System for Comprehensive Bike Safety and Assistance Through Multi-Source Data Fusion. Research & Reviews: Journal of Embedded System & Applications. 2026; 14(1): 9–17p.

voice-activated, hands-free design ensures that riders can stay focused on the road while accessing critical assistance features.

While accessing critical assistance features. This study delves into the technical architecture, implementation strategies, and challenges encountered during the development of VERONICA, highlighting its potential to redefine motorbike safety standards. The system represents a transformative step forward in biking technology, combining safety, convenience, and innovation into a seamless solution. By integrating real-time accident detection, voice-activated controls, and environmental monitoring, VERONICA enhances rider safety and provides a personalized and intuitive user experience. The system's ability to deliver proactive alerts and context-aware assistance ensures that riders are better prepared to handle dynamic road conditions, thereby reducing the risk of accidents. Furthermore, the modular design of VERONICA allows for scalability and future enhancements, such as integration with smart city infrastructure and advanced machine learning models for predictive analytics. As the global push for safer roads intensifies, VERONICA stands out as a pioneering solution that bridges the gap between cutting-edge technology and practical real-world applications, paving the way for a safer and more efficient riding experience.

LITERATURE REVIEW

VERONICA, an advanced riding assistance system, addresses significant gaps in existing motorcycle safety systems by integrating real-time accident detection, voice-activated controls, and environmental monitoring into a single user-friendly platform. This survey examines prior work on accident detection systems, navigation tools, and Internet of Things (IoT)-based safety solutions to highlight unresolved challenges and unique contributions.

Related Work

Accident Detection Systems

Rodegast et al. addressed the limitations of passive safety for motorcycles, emphasizing the need for rapid and reliable collision detection. They developed a comprehensive simulation-based database to train machine learning models, such as decision trees, support vector machines, and neural networks. These models have demonstrated significant improvements in the detection of collisions in real-time scenarios compared to traditional threshold-based detection methods [1]. Md. Islam et al. designed a cost-effective accident detection system using sensors such as the MPU6050 gyroscope and accelerometer. Their system integrated modules such as SIM808, Raspberry Pi 3, and Arduino Uno. It triggers alerts during accidents, sending real-time messages with the victim's location to emergency contacts, including hospitals and police stations [2]. Rishi proposed an automatic message system (AMS) utilizing GPS/GSM and accelerometers for accident detection. This system successfully transmits location data to cloud servers and emergency contacts [3, 4].

Navigation and Route Optimization

Zhong et al. introduced SAFEBIKE, a bike-sharing route recommender system that integrates historical data to predict bike and dock availability. The system also utilizes crime statistics to suggest safer routes [5]. Li et al. developed an intelligent bike assistance system using GPS and G-sensors. The system monitors the rider's behavior and bike movements and analyzes the lean angles and pedaling patterns to assess risks [6–8].

IoT-Based Safety Solutions

Ch VR et al. presented a smart bicycle system equipped with IoT sensors, such as GPS, accelerometers, and gyroscopes, for accident detection and real-time location tracking [9]. Jia et al. proposed an IoT-based bicycle theft detection system. This system uses motion sensors to detect unauthorized movement or tampering, triggering an alarm and sending real-time location updates via GPS [10]. Fang et al. focused on enhancing bicycle safety and efficiency using IoT technology. Their system monitors tire pressure, brake performance, fuel levels, and engine temperature, and issues an alert for maintenance or safety concerns [11].

Previously Non-Existent Solutions

This paper introduces several groundbreaking solutions that address the limitations of existing tools.

Unified Safety Platform

Existing systems often focus on a single aspect of rider safety, such as accident detection and navigation. VERONICA consolidates multiple safety features (e.g., accident detection, weather updates, and low-traffic navigation) into a single, user-friendly platform, significantly reducing the need for multiple devices or applications [1–3].

Real-Time Accident Detection and Alerts

Unlike traditional systems that rely on manual intervention, VERONICA employs real-time sensor data analysis to detect accidents and automatically triggers emergency alerts. This ensures timely assistance in critical situations, addressing the inefficiencies of passive safety systems [4, 5].

Voice-Activated Controls

While existing systems require manual interaction, VERONICA integrates voice-activated controls and NLU to provide hands-free assistance. This minimizes distractions and enhances rider safety, particularly in high-traffic or hazardous conditions [6, 7].

PROPOSED APPROACH

This system comprises multiple layers and modules, making it a comprehensive platform for enhancing rider safety and convenience. A detailed description of each component is provided in the following sections.

Platform Integration

The VERONICA, an advanced riding assistance system, will be developed using a robust and scalable technology stack, including microcontrollers (Arduino UNO), single-board computers (Raspberry Pi), and IoT-enabled sensors (MPU6050 gyroscope and accelerometer). The platform integrates voice-activated controls, real-time data processing, and external APIs for weather forecasting, traffic monitoring, and GPS-based navigation. By leveraging message queuing telemetry transport. (MQTT) for lightweight communication and REST APIs for external service integration, VERONICA ensures seamless connectivity and real-time response. The system also features a mobile application interface for user interaction, providing a unified platform for all functionalities.

Accident Detection and Emergency Alerts

The accident detection module analyzes data from the MPU6050 gyroscope and accelerometer to monitor the orientation and movement of the bike. Using advanced algorithms, the system detects sudden changes in the tilt angle or acceleration, flagging potential accidents. If an accident is detected, the SIM808 module triggers emergency alerts by sending the rider’s GPS coordinates and accident details to predefined contacts via SMS. This feature ensures timely assistance in critical situations, even when the rider is incapacitated.

Voice-Activated Controls

VERONICA integrates NLU and voice recognition technologies to enable hands-free operation. Riders can use voice commands to access features such as navigation, weather updates, and system control. The voice processing module uses a Speech-to-Text API and custom NLU models, ensuring high accuracy even in noisy environments [4–12]. This minimizes distractions and enhances safety by allowing riders to focus on the road.

Real-Time Environmental Monitoring

The system continuously monitors environmental conditions using IoT sensors and external APIs. For example:

- *Weather updates*: The system fetches real-time weather data from APIs such as OpenWeatherMap to provide alerts about rain, storms, or extreme temperatures.
- *Traffic monitoring*: Integration with Google Maps API will enable real-time traffic updates and suggest low-traffic routes for safer navigation.
- *Voice interaction*: VEROINCA will be engaged and respond to the rider's commands, even if the rider asks any real-world questions.

Scalability and Performance Optimization

VERONICA is designed to scale effortlessly as user demand grows. The system employs load balance and efficient API integration to ensure responsiveness, even during peak usage. The modular architecture allows the addition of new features, such as predictive maintenance alerts or integration with smart city infrastructure, without significant changes to the core system.

User Notifications and Interface

Once the system detects an accident or identifies a potential hazard, users receive real-time notifications via a mobile application or helmet-mounted audio system. The user-friendly interface allows riders to:

- View navigation directions and safety alerts on a user interface.
- Audio feedback was received for hands-free interaction. Settings, such as alert sensitivity and notification preferences, can be customized to suit user needs.

Work Aims to Achieve the Following Objectives

- *Unified safety platform*: A comprehensive system that integrates accident detection, navigation assistance, and environmental monitoring into a single platform, eliminating the need for multiple devices or applications.
- *Real-time accident detection and alerts*: Implementation of a robust accident detection system that uses sensor data and AI algorithms to identify crashes and trigger emergency alerts in real time.
- *Voice-activated controls*: Enable hands-free operation through voice recognition and NLU, minimizing distractions and enhancing rider safety.
- *Real-time environmental monitoring*: Provides weather updates, traffic alerts, and road condition warnings to help riders make informed decisions during their journeys.
- *Continuous improvement*: Establish a feedback loop to incorporate user suggestions and the latest advancements in AI and IoT technologies to ensure that the platform remains cutting-edge and user centric.
- *Enhanced rider safety*: Proactive safety alerts (e.g., collision warnings and lane departure alerts) are provided to help riders avoid potential hazards. The rider's health metrics (e.g., fatigue levels and heart rate) are monitored using wearable devices, and alerts are provided if unsafe conditions are detected.
- *Integration with smart infrastructure*: Collaborate with smart city initiatives to integrate VERONICA with traffic lights, parking systems, and public transportation networks to enable vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication to improve coordination and reduce the risk of accidents.

SYSTEM ARCHITECTURE

The system architecture of the VERONICA, an advanced riding assistance system, integrates several interconnected modules, including sensors, communication components, a core processing unit, user interfaces, and external services. Each module works together seamlessly to deliver intelligent and responsive functionalities tailored to the needs of bike riders, as shown in Figure 1.

Sensors

The primary input devices for gathering real-time data from the environment and motorcycles. Key sensors include:

- *Accident detection sensors*: Monitors sudden impacts, skidding, or abrupt changes in velocity.
- *Basic sensors:* Collect essential metrics like speed, temperature, and environmental data.

Communication Module

Connects the system to external entities and devices. It comprises:

- *Emergency messaging*: Sends automated alerts to predefined contacts during accidents.
- *Bluetooth/Wi-Fi connectivity*: Facilitates wireless connectivity with devices such as smartphones and helmet-mounted audio systems.

Core System

Processes incoming data and governs the system's logic. It includes:

- *Voice processing*: Allows riders to interact with the system using natural language commands.
- *System logic*: Analyzes sensor data, interprets voice commands, and integrates information from external application programming interfaces (APIs).

User Interface

The user interface provides a platform for interaction between the rider and the system. It is designed to prioritize safety and convenience and has the following features:

Display (Optional)

Shows critical information such as navigation directions, safety alerts, and system status

Kept minimal to avoid rider distraction.

Audio Output

- Delivers verbal updates on navigation, system status, and alerts.
- Ensure riders can receive information without taking their eyes off the road.

Voice Command Input

- Captures and processes the rider's spoken commands.
- Allows for seamless and hands-free interaction with the system.

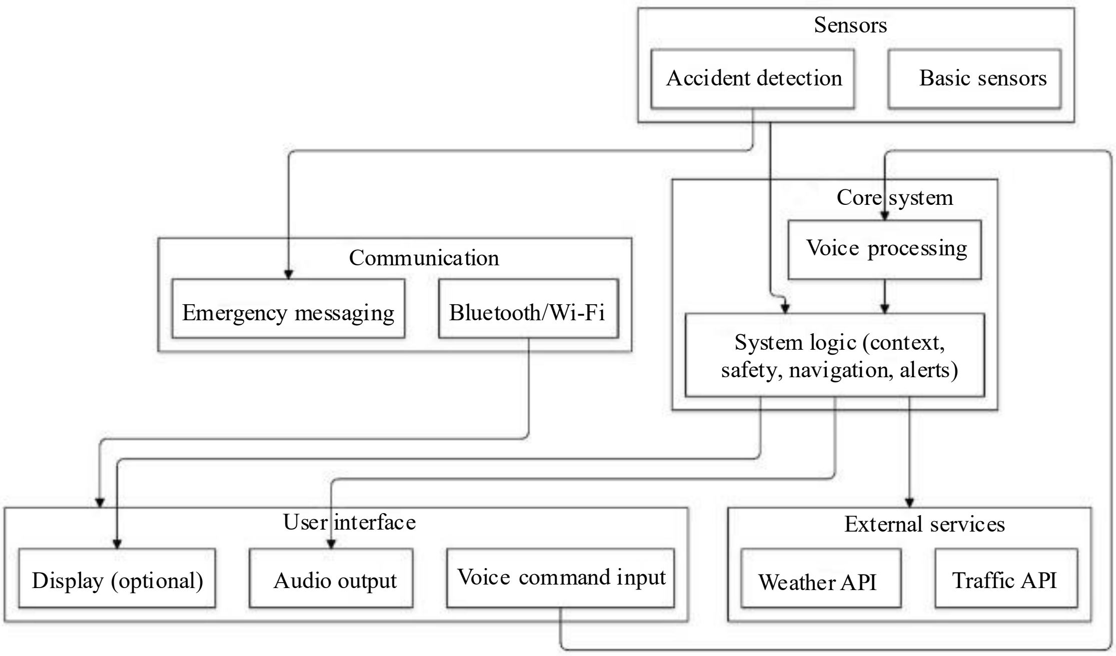

Figure 1. System architecture.

External Services

The system integrates with external services to enhance its functionality and provide real-time updates.

Weather API

- It fetches real-time weather data to provide alerts about rain, storms, or extreme temperatures.
- Help riders prepare for changing weather conditions.

Traffic API

- It provides real-time traffic updates and suggests low-traffic routes for safer navigation.
- Ensures riders can avoid congested or hazardous areas.

Data Flow

The overall data flow of the system follows a streamlined pathway in which sensors capture real-time data from the motorcycle and its surroundings. The core system processes the data, analyzes them, and makes decisions based on predefined logic. The communication module transmits alerts and updates to external entities (e.g., emergency contacts and traffic APIs). The user interface delivers feedback to the rider via audio output or an optional display screen.

Scalability and Performance Optimization

The architecture is designed for scalability, ensuring that the system can handle increasing user demands without compromising performance.

ALGORITHM AND OVERALL FUNCTION OF THE SYSTEM

The VERONICA system integrates multiple hardware components and algorithms to ensure real-time accident detection, emergency alerts, and hands-free interaction. The system relies on a combination of gyroscope, accelerometer, and GPS sensors, processed by Arduino and Raspberry Pi, to detect abnormal riding behaviors and send emergency notifications when necessary. The tilt angle calculation was performed using accelerometer and gyroscope data, combining angular velocity and acceleration to compute orientation changes using the following formula:

$$\theta = arctan\left(\frac{a_y}{\sqrt{a_x^2 + a_z^2}}\right)$$

Where, ax, ay, and az are the acceleration components along the respective axes. The accident detection algorithm flags incidents when the tilt angle exceeds a threshold (e.g., 45°) for more than two seconds or when sudden deceleration is detected, calculated as:

$$a = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

and impact force is determined by:

$$Fimpact = ma$$

where m denotes the system mass. GPS coordinates were extracted using the SIM808 module, embedding latitude and longitude in emergency alert messages using

$$lat, lon = SIM808.get\ GPS$$

Upon confirming an accident, the system triggers an SMS alert to emergency contacts containing accident details, GPS coordinates, and a timestamp, with a five-second window for cancellation if mistakenly triggered. The VERONICA system also integrates weather and traffic data using APIs to provide real-time updates, where the weather monitoring algorithm fetches current atmospheric conditions such as temperature, humidity, and precipitation probability through

$Weather\ data = API.get\ weather\ (location)$

and traffic updates are retrieved using GPS-based traffic density analysis:

$Traffic\ status = API.get\ Traffic\ (location)$

This ensures that riders can make informed decisions about route selection and safety precautions. VERONICA, the built-in voice assistant, enables hands-free interaction using natural language processing (NLP), capturing voice input with:

$Command = speech\ recognizer.listen$

which is then processed through:

$parsed\ command = NLP.process\ (command)$

Providing spoken feedback to keep the rider informed without distraction. The navigation module leverages GPS and mapping APIs to offer optimized route guidance, where the shortest and least congested path is computed using Dijkstra's algorithm.

$Shortest\ path = Dijkstar\ (G, source\ destination)$

Where, G represents the road-network graph. The system dynamically updates navigation based on real-time traffic data to ensure efficient routing and minimal travel time. Additionally, the VERONICA system supports music playback through voice commands, allowing the rider to control the music hands-free. The voice command for music playback was captured using the following:

$music\ command = speech\ recognizer.listen$

The system can play, pause, or skip tracks as per the rider's request (Figure 2).

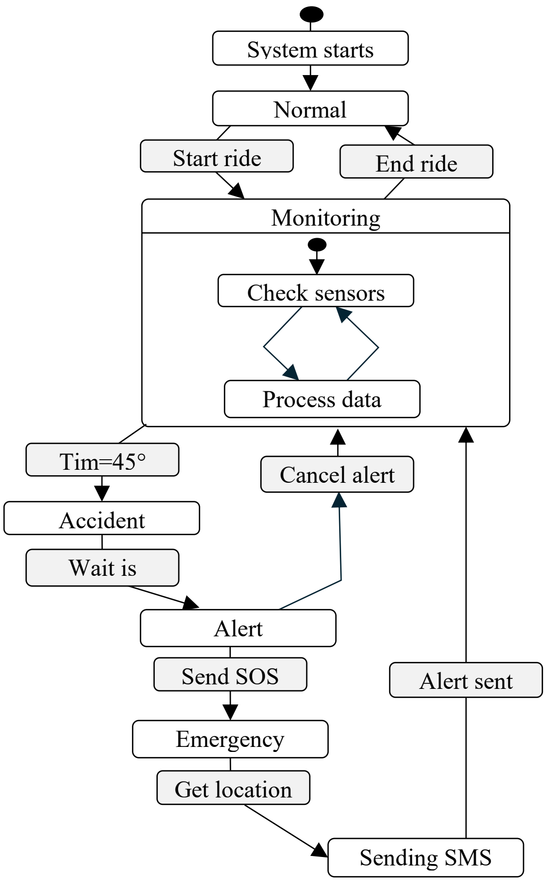

Figure 2. Flow of the accident detection system.

DISCUSSION AND RESULTS

The advanced riding assistance system is designed to provide motorcycle riders with real-time assistance, enhancing safety and convenience during their journeys. Key outcomes include:

- *Voice recognition system*: Our system demonstrated high accuracy in interpreting commands, even in noisy environments.
- *Weather and traffic alerts*: Real-time data were successfully fetched from APIs, providing reliable weather and low-traffic navigation recommendations.
- *Accident detection system*: It can reliably detect collisions during simulated crash scenarios and promptly trigger emergency response functionality.
- *User interaction and feedback*: The voice-activated interface significantly reduces the need for manual interaction, contributing to a safer riding experience.

CONCLUSION

The VERONICA, an advanced riding assistance system, represents a significant step forward in enhancing rider safety and convenience. By integrating real-time accident detection, navigation assistance, and voice command features, the system provides a practical and user-friendly solution for everyday cycling. Through extensive testing and optimization, this project demonstrated its potential to revolutionize the riding experience, ensuring better safety, control, and peace of mind for users.

The accident detection module, powered by advanced sensor data analysis and AI algorithms, has proven to be highly effective in identifying crashes and triggering emergency alerts within seconds. This ensures that riders receive timely assistance in critical situations, even if they are incapacitated. Additionally, the voice-activated controls and NLU capabilities minimize distractions, allowing riders to focus on the road while accessing essential features such as navigation, weather updates, and system controls.

The system's integration with external APIs for weather forecasting and traffic monitoring further enhances its utility, providing riders with real-time updates and proactive alerts to help them navigate safely. The modular and scalable architecture ensures that VERONICA can adapt to future advancements, such as predictive maintenance, augmented reality (AR) navigation, and integration with smart city infrastructure. In conclusion, VERONICA is not just a technological innovation but a transformative solution that bridges the gap between cutting-edge technology and real- world applications. By addressing the unique challenges faced by bike riders, VERONICA sets a new standard for rider safety and convenience, paving the way for a safer and more enjoyable riding experience for all.

FUTURE SCOPE

The VERONICA, an advanced riding assistance system, is set to revolutionize rider safety with cutting-edge cybersecurity AI and smart connectivity. Future enhancements will include blockchain-based security, encrypted communication, and AI-powered anomaly detection to prevent hacking and unauthorized access. Advanced anti-theft measures, such as remote immobilization and geofencing, further enhance security.

Additionally, AI-driven predictive analytics can help prevent accidents, and AR-integrated helmets can provide real-time hazard alerts. Vehicle-to-vehicle (V2V) communication enables seamless interaction between autonomous vehicles and smart city infrastructure. Biometric authentication, wearable health monitoring, and edge computing ensure secure and efficient performance, even offline.

Acknowledgement

I sincerely thank the authors of the reference papers for their invaluable contributions, which greatly informed and guided my research. I am also deeply grateful to the principal and staff of the Mumbai Educational Trust (MET) Institute of Engineering for their support and encouragement throughout the study. Their assistance was instrumental in the successful completion of this study.

REFERENCES

1. Rodegast P, Maier S, Kneifl J, Fehr J. On using machine learning algorithms for motorcycle collision detection. Discov Appl Sci. 2024;6:326. doi:10.1007/s42452-024-06014-w.
2. Islam MM, Ridwan AEM, Mary MM, Siam MF, Mumu SA, Rana S. Design and implementation of a smart bike accident detection system. 2020 IEEE Region 10 Symposium (TENSYMP), Dhaka, Bangladesh. 2020. p. 386–389. doi:10.1109/TENSYMP50017.2020.9230656.
3. Rishi R, Yede S, Kunal K, Bansode NV. Automatic messaging system for vehicle tracking and accident detection. 2020 International Conference on Electronics and Sustainable Communication Systems (ICESC), Coimbatore, India. 2020. p. 831–834. doi:10.1109/ICESC48915.2020.9155836.
4. Yang CY, Wu CT. Using on-bicycle rider assistant device while cycling: a hazard perception assessment. In: Stephanidis C, editor. HCI International 2011 – Posters' Extended Abstracts. Berlin: Springer Berlin Heidelberg; 2011. p. 85–89. doi:10.1007/978-3-642-22095-1_18.
5. Zhong W, Chen F, Fu K, Lu CT. SAFEBIKE: a bike-sharing route recommender with availability prediction and safe routing [preprint]. 2017. arXiv:1712.01469. doi:10.48550/arXiv.1712.01469.
6. Isaksson-Hellman I. A study of bicycle and passenger car collisions based on insurance claims data. Ann Adv Automot Med. 2012;56:3–12. PMID: 23169111.
7. Desai VJ, Nawale SP, Kokane SR. Design and implementation of GSM and GPS based vehicle accident detection system. Int J Technol Sci. 2014;1(2):8–11.Li K, Chen T, Luo Y, Wang J. Intelligent environment-friendly vehicles: concept and case studies. IEEE Trans Intell Transp Syst. 2012;13(1):318–328. doi:10.1109/TITS.2011.2170680.
8. Ch VR, Chegondi S, Myla K, Murala S, Myla SS, Kalava DR. IoT based smart helmet for bike rider safety. 2023 7th International Conference on Electronics, Communication and Aerospace Technology (ICECA), Coimbatore, India. 2023. p. 1445–1448. doi:10.1109/ICECA58529.2023.10394802.
9. Jia C. Design of intelligent bicycle anti-theft system based on Internet of Things and computer technology. J Comput Electron Inf Manag. 2025;18(3):19–22. doi:10.54097/xte64j23.
10. Fang CY, Hsu WH, Ma CW, Chen SW. A vision-based safety driver assistance system for motorcycles on a smartphone. 17th International IEEE Conference on Intelligent Transportation Systems (ITSC), Qingdao, China. 2014. p. 328–333. doi: 10.1109/ITSC.2014.6957712.
11. Bedmutha D, Yawalkar PM. A review on user privacy preserving and auditing for secure data storage system in cloud. Int J Comput Appl. 2014;97(5):8–12.
12. Dabhade V, Alvi AS. Malicious node detection and prevention for secured communication in WSN. In: Pandian AP, Fernando X, Haoxiang W, editors. Computer Networks, Big Data and IoT: Proceedings of ICCBI 2021. Singapore: Springer Nature Singapore; 2022. p. 121–136. doi:10.1007/978-981-19-0898-9_10.
13. Dabhade V, Alvi AS. An energy efficient approach for secure data communication using pairwise key encryption in WSN. NeuroQuantology. 2022;20(15):6311–6321. doi:10.48047/NQ.2022.20.15.NQ88632.

