

IoT-Enabled Lane Departure Detection with Intelligent Vehicle Lighting and Wiper Control

P. Sujatha^{1*}, B. Rama Krishna¹, Kethavath Vikas¹, Thanniru Mahesh¹, Bakka John Samuel¹, Erragolla Anil Kumar¹

¹Department of Electronics and Communication Engineering, Kommuri Pratap Reddy Institute of Technology, Ghanpur, Ghatkesar, 501301, Telangana, India.

*Correspondence: P. Sujatha

Abstract

The rapid advancement of intelligent transportation systems has significantly influenced modern vehicle safety technologies. Historically, vehicle safety relied on manual control and basic mechanical systems, which often lacked real-time responsiveness and predictive capabilities. With increasing road congestion and accident rates, there is a growing need for automated and connected safety solutions. Traditional vehicle systems provide limited assistance, such as basic warning indicators, but they fail to integrate multiple safety parameters or offer real-time monitoring and remote data access. These systems also suffer from delayed response, lack of adaptability, and minimal driver support in critical situations. To address these challenges, this project proposes an IoT-based smart vehicle automation and safety monitoring system using an ESP32 microcontroller. The system integrates multiple sensors, including infrared sensors for lane detection, an ultrasonic sensor for obstacle detection, an LDR for automatic headlight control, an RPS sensor for speed monitoring, and a vibration sensor for accident detection. A servo motor enables automated mechanical responses, while a buzzer provides immediate alerts during unsafe conditions. Real-time sensor data is displayed on an LCD, and a GPS module ensures continuous vehicle tracking and location sharing during emergencies. The proposed system offers a cost-effective and efficient solution by combining automation, real-time monitoring, and IoT connectivity. Its significance lies in improving driver awareness, reducing accident risks, and enabling intelligent vehicle control. This integrated approach enhances overall road safety and represents a scalable foundation for future smart transportation systems.

Keywords: Internet of Things (IoT), Intelligent Transportation Systems (ITS), Vehicle Safety, Lane Departure Detection, Obstacle Detection, Automatic Headlight Control.

1. Introduction

The evolution of connected technologies has transformed the way modern vehicles approach safety and automation. With the increasing complexity of road environments and rising accident rates, there is a strong demand for intelligent systems that can assist drivers in making quicker and safer decisions. The integration of sensing devices, embedded controllers, and wireless communication has enabled the development of smart vehicle systems that can monitor conditions continuously and respond in real time. This research presents a compact and efficient vehicle automation model built using the ESP32 microcontroller as its core processing unit. Due to its high processing capability, integrated Wi-Fi support, and flexibility in handling multiple inputs and outputs, the ESP32 serves as a reliable platform for implementing real-time safety features. The system combines several functional modules designed to enhance both driver awareness and vehicle responsiveness. A lane monitoring mechanism is implemented to detect unintended vehicle drift and provide timely alerts, helping maintain proper

alignment on the road. An automatic lighting system adjusts the vehicle's headlights based on surrounding brightness levels, ensuring optimal visibility without driver intervention. To further strengthen safety, the system incorporates mechanisms for detecting sudden impacts and identifying obstacles in areas not directly visible to the driver. These features work together to simulate key aspects of modern driver assistance technologies in a simplified and cost-effective manner. The system demonstrates how embedded electronics and IoT capabilities can be utilized to build practical solutions for safer and more intelligent transportation systems.

2. Literature Survey

A. Al-Fuqaha et al. [1] proposed an advanced Internet of Vehicles (IoV) architecture that combines IoT, edge computing, and cloud platforms to support intelligent transportation systems. Their model is designed to handle large-scale vehicular data efficiently while ensuring minimal delay in communication. A key strength of their approach lies in achieving ultra-low latency, which is critical for time-sensitive safety applications such as collision avoidance. The integration of edge computing allows data processing closer to the source, reducing dependency on centralized systems. This helps vehicles respond quickly to dynamic road conditions. The architecture also supports seamless communication between vehicles and infrastructure, enabling cooperative decision-making. It enhances scalability by efficiently managing multiple connected devices. Reliability is improved through distributed processing and redundancy. The framework provides a strong foundation for real-time vehicle monitoring and smart mobility solutions.

S. Sharma et al. [2] designed a smart vehicle monitoring and safety system using IoT technologies combined with embedded sensors and wireless communication modules. Their system continuously tracks vehicle conditions and detects abnormal situations such as sudden impacts or unsafe driving patterns. By integrating real-time sensing, the system can immediately notify users or authorities during emergencies. This rapid detection mechanism helps in reducing response time and improving safety outcomes. The use of wireless communication ensures that alerts are transmitted without delay. The system also contributes to driver awareness by providing timely warnings. It is capable of monitoring multiple parameters simultaneously, making it versatile for practical use. The implementation is cost-effective and suitable for real-world deployment. Overall, it provides a reliable solution for enhancing vehicle safety through continuous monitoring. M. A. Javed et al. [3] introduced a cooperative hazard awareness system that enables vehicles to share safety-related information using vehicle-to-vehicle (V2V) communication. In this approach, vehicles exchange real-time data about road conditions, obstacles, and potential hazards. This cooperative mechanism helps drivers receive early warnings about dangers beyond their immediate line of sight. The system is particularly useful in dynamic traffic environments where conditions change rapidly. It ensures fast dissemination of information across multiple vehicles. The communication framework is designed to be reliable even under high mobility scenarios. By sharing hazard data, the system reduces the likelihood of accidents. It also improves coordination among vehicles, leading to smoother traffic flow. This approach strengthens the concept of connected driving environments.

S. E. Li et al. [4] presented an extensive review of connected and automated vehicle technologies with a strong focus on improving safety and traffic efficiency. Their work highlights how modern vehicular systems utilize sensors, communication networks, and automation to enhance driving performance. The analysis demonstrates that IoT-enabled vehicle systems significantly reduce accident risks by enabling faster decision-making. The authors discuss various levels of automation and their impact on road safety. They also explain how real-time data exchange contributes to better traffic management. The

integration of intelligent systems helps in minimizing human errors. Their work provides valuable insights into future transportation trends. It emphasizes the importance of connectivity in modern vehicles. The discussion supports the development of safer and more efficient mobility solutions. Kumar et al. [5] developed an intelligent vehicle safety system that uses IoT technology along with embedded sensors for real-time monitoring. Their system focuses on detecting obstacles and identifying potential accident scenarios. By continuously analyzing sensor data, it provides immediate alerts to the driver. This helps in avoiding collisions and maintaining safe driving conditions. The system is designed to operate efficiently in various environments. It enhances situational awareness by providing accurate and timely information. The use of IoT allows remote monitoring and data sharing. It also supports integration with other smart systems. The design is simple yet effective for practical applications. This approach improves overall driving safety and reliability.

R. Patel et al. [6] examined security vulnerabilities present in automotive IoT environments, focusing on risks associated with vehicular communication systems. Their work highlights how connected vehicles are exposed to cyber threats due to increased data exchange between devices. They identified several potential attack points within vehicle networks that could compromise safety-critical operations. To address these challenges, they proposed security mechanisms aimed at protecting communication channels and internal system components. Their approach emphasizes the need for encryption and authentication in vehicular systems. By strengthening security layers, the reliability of connected vehicles can be improved. The work also stresses the importance of designing secure architectures from the initial development stage. Ensuring data integrity is crucial for maintaining trust in smart vehicle systems. This contribution supports safer deployment of IoT-enabled transportation technologies. N. Wong et al. [7] focused on trust management and security in connected vehicle networks, addressing the challenges of reliable communication. Their approach ensures that data exchanged between vehicles is authentic and free from malicious interference. They introduced mechanisms to evaluate trust levels among communicating entities. This helps in filtering out unreliable or compromised data sources. The system also incorporates intrusion detection techniques to identify abnormal network behavior. Maintaining communication integrity is essential for safety applications. Their work enhances confidence in real-time vehicular communication systems. It also reduces the chances of incorrect decision-making due to false data. The proposed model improves both security and performance. This contributes to the development of dependable connected vehicle ecosystems.

F. Sakiz et al. [8] proposed a zero-trust security framework tailored for connected and autonomous vehicles. Their approach assumes that no device or user is inherently trusted, requiring continuous verification at every stage of communication. This model strengthens system security by preventing unauthorized access. It ensures that every interaction is authenticated before granting permissions. The framework is particularly effective against modern cyberattacks targeting vehicular networks. It also enhances resilience by isolating compromised components. Continuous monitoring plays a key role in maintaining system integrity. The approach supports secure communication across different network layers. It reduces vulnerabilities in highly connected environments. This model provides a robust solution for securing next-generation vehicle systems. H. Nassif et al. [9] discussed the challenges involved in validating safety and reliability in autonomous vehicle systems. Their work emphasizes the importance of testing and verification processes for safety-critical applications. They highlighted that real-world testing alone is insufficient due to the complexity of driving scenarios. Therefore, simulation-based validation methods are also necessary. The authors addressed regulatory requirements and industry standards for safety assurance. Their approach focuses on identifying potential system failures before deployment. Reliable validation ensures that automated systems perform correctly under

all conditions. This is essential for building trust in autonomous technologies. Their work supports the development of robust and dependable vehicle systems. It also encourages the adoption of structured testing methodologies.

N. Sharma et al. [10] introduced an IoT-enabled connected vehicle framework that supports real-time diagnostics and safety alerts. Their system continuously monitors vehicle performance and identifies potential issues. It provides instant notifications to drivers or service providers in case of abnormalities. This helps in preventing breakdowns and improving maintenance efficiency. The integration of IoT enhances communication between vehicles and external systems. It also contributes to traffic management by sharing relevant data. Real-time monitoring improves overall vehicle performance and safety. The system is designed to be scalable for large deployments. It supports intelligent decision-making through data analysis. This approach strengthens the concept of smart transportation systems. B. Lee et al. [11] explored various V2X communication technologies used in vehicular safety applications. Their work analyzed how vehicles interact with other vehicles, infrastructure, and networks. They focused on cooperative mechanisms that help in collision avoidance. Reliable communication is essential for transmitting safety messages without delay. The study highlights different protocols used for vehicular networking. It also discusses challenges such as signal interference and network congestion. Their analysis shows the importance of low-latency communication. Effective data exchange improves reaction time in critical situations. The work supports the development of advanced safety systems. It provides valuable insights into communication-based vehicle safety.

T. Zhang et al. [12] addressed privacy concerns in vehicular communication systems by introducing cryptographic solutions. Their approach ensures secure data sharing without exposing sensitive user information. They focused on maintaining a balance between privacy and system performance. The use of encryption techniques protects communication channels from unauthorized access. Their model allows vehicles to exchange data safely in real time. It also prevents misuse of personal or location data. Ensuring privacy is essential for user acceptance of connected vehicle technologies. The approach enhances trust among users and systems. It supports secure and efficient communication. This work contributes to privacy-aware vehicular networks. J. Santa et al. [13] analyzed IoT connectivity in transportation systems, focusing on vehicle data collection and communication. Their work highlights how telematics systems gather real-time information from vehicles. This data can be used for monitoring, analysis, and decision-making. The integration of IoT enables seamless communication with smart city infrastructure. It also supports traffic management and safety applications. Their approach enhances the efficiency of transportation systems. Real-time data helps in identifying issues quickly. The system supports scalable deployment across urban environments. It improves coordination between vehicles and external systems. This work strengthens the role of IoT in modern transportation.

A. Zanella et al. [14] discussed IoT architectures designed for smart city applications, with a focus on transportation systems. Their work explains how connected devices can improve urban mobility. They addressed communication challenges such as network scalability and data management. Efficient communication is necessary for handling large volumes of data. Their approach supports integration between vehicles and city infrastructure. It enhances traffic control and safety monitoring. The system enables better resource utilization in urban areas. Their work also highlights the importance of interoperability. It supports the development of intelligent transportation services. This contributes to smarter and more efficient cities.

3. Proposed system

The proposed methodology defines a structured and integrated framework for intelligent vehicle safety monitoring and automation using IoT-enabled embedded systems. The analytical flow begins with real-time data acquisition from multiple sensors embedded within the vehicle environment, followed by signal processing, condition evaluation, and automated response generation. The system is centered around an ESP32 microcontroller, which acts as the processing unit responsible for handling sensor inputs, executing control logic, and managing communication. The sensing layer captures various parameters such as lane position, obstacle proximity, ambient light conditions, vehicle motion, and environmental disturbances, as shown in figure 1. These inputs are processed to detect abnormal or unsafe conditions such as lane deviation, obstacle presence, low visibility, or sudden impact. Based on predefined thresholds and logic, the system generates alerts and triggers automated control mechanisms including lighting adjustment and mechanical actuation. Additionally, real-time data is displayed locally and transmitted to a remote server for monitoring and analysis. A communication module enables continuous connectivity, while location tracking enhances situational awareness. The system also supports periodic data updates and event-driven responses, ensuring timely decision-making.

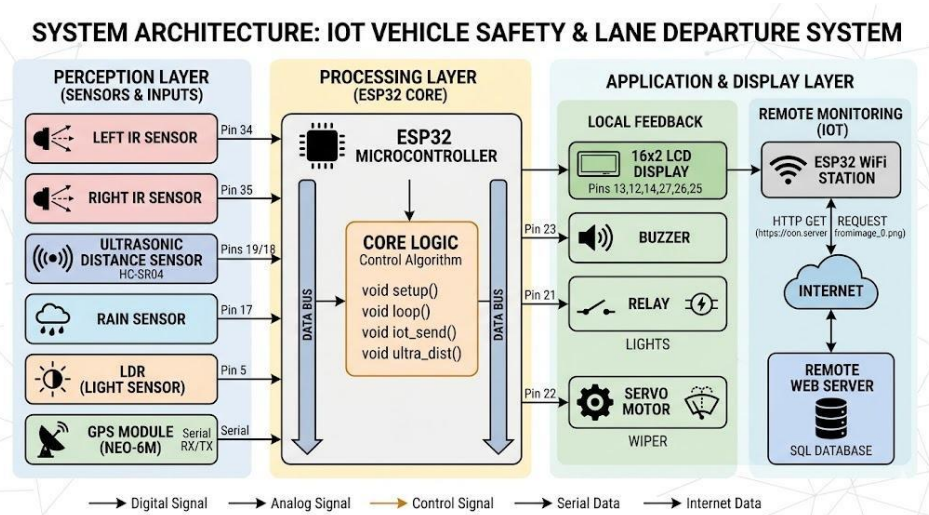


Figure. 1: System architecture.

User Interface (Display Module)

- The system provides a visual interface through an LCD module for real-time monitoring.
- It displays critical parameters such as lane status, obstacle distance, light conditions, and environmental alerts.
- The interface enables immediate feedback to the driver regarding vehicle safety conditions.
- All processed sensor outputs are continuously updated on the display unit.

ESP32 Microcontroller (Processing Unit)

- The ESP32 acts as the central control unit managing all operations within the system.
- It collects data from multiple sensors and processes it using embedded logic.
- The controller performs real-time decision-making based on sensor inputs.
- It also manages communication with external servers through Wi-Fi connectivity.

Sensor Layer (Data Acquisition Module)

- The system integrates multiple sensors to capture real-time environmental and vehicle data.
- Infrared sensors are used for lane detection and side obstacle identification.
- Ultrasonic sensors measure distance to nearby objects for collision avoidance.
- LDR sensors detect ambient light intensity for automatic headlight control.
- Rain sensors identify weather conditions to enable automated responses.

Lane Detection Mechanism

- Infrared sensors continuously monitor lane boundaries on both sides of the vehicle.
- Any deviation from the expected lane position is detected instantly.
- The system generates alerts when unsafe lane movement is identified.
- This mechanism helps maintain proper vehicle alignment and improves driving safety.

Obstacle Detection Module

- The ultrasonic sensor calculates the distance between the vehicle and nearby objects.
- It provides accurate short-range measurements for collision prevention.
- When an object is detected within a critical range, the system triggers warnings.
- This module enhances blind-spot awareness and reduces accident risks.

Automatic Headlight Control

- The LDR sensor measures surrounding light intensity.
- Based on light conditions, the system automatically switches headlights ON or OFF.
- This ensures proper visibility during night or low-light environments.
- It eliminates the need for manual headlight operation.

Rain Detection and Wiper Control

- The rain sensor detects the presence of water droplets on the surface.
- Upon detection, the system activates a servo motor to simulate wiper movement.
- The automated response improves visibility during rainy conditions.
- This feature enhances driver convenience and safety.

Alert System (Buzzer Module)

- A buzzer is used to provide immediate audible alerts during unsafe conditions.
- It is activated during lane deviation, obstacle detection, or environmental hazards.
- The alert mechanism ensures quick driver response.
- It also serves as a warning signal to nearby surroundings.

IoT Communication Module

- The system uses Wi-Fi connectivity to transmit real-time data to a remote server.
- Sensor readings and system status are sent periodically or during critical events.
- This enables remote monitoring and data logging.
- The communication module supports integration with cloud-based platforms.

GPS Tracking Module

- The system includes location tracking functionality for real-time positioning.
- It provides latitude and longitude information for monitoring vehicle movement.
- This feature is useful during emergency situations or accident detection.
- It enhances situational awareness and tracking capabilities.

Data Processing and Decision Logic

- The system evaluates sensor inputs based on predefined thresholds.
- Logical conditions determine whether an event is normal or critical.
- Based on the analysis, appropriate actions such as alerts or automation are triggered.
- This ensures accurate and timely responses.

Output and Response Generation

- The system generates outputs in the form of alerts, display messages, and automated actions.
- Real-time data is shown on the LCD module for driver awareness.
- Critical events trigger buzzer alerts and IoT data transmission.
- The combined response improves overall vehicle safety.

Remote Monitoring and Data Transmission

- The architecture supports continuous data sharing with remote systems.
- External platforms can receive and analyze vehicle data.
- This enables tracking, monitoring, and future data-driven improvements.
- The system supports scalable IoT-based integration.

System Adaptability and Enhancement

- The framework allows integration of additional sensors and modules.
- It can be extended with advanced analytics or AI-based decision systems.
- Periodic updates improve system performance and accuracy.
- This adaptability ensures long-term usability and scalability.

4. Result and discussion

The results and discussion section presents the performance analysis of the developed intelligent vehicular safety framework under various operating conditions. The system was evaluated by testing different sensor modules such as lane detection, obstacle sensing, light adaptation, and environmental

monitoring in real-time scenarios. Observations focus on how effectively the system responds to dynamic inputs and generates appropriate alerts or automated actions. The integration of multiple sensing units with the processing module demonstrated reliable and timely decision-making. Communication with the remote server was also verified for consistent data transmission. The outcomes highlight the accuracy, responsiveness, and practical feasibility of the implemented design. This section further interprets the observed results to understand system behavior and its effectiveness in enhancing driving safety.

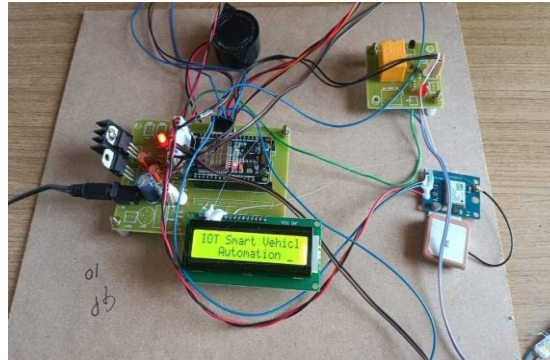


Figure. 2: Experimental setup of IoT-Enabled smart vehicle automation and safety system

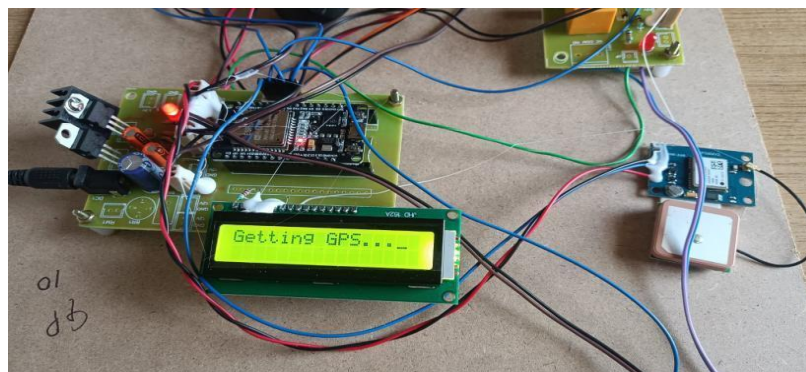


Figure. 3: GPS initialization and Real-Time data acquisition setup

Figure 3 depicts the operational state of the intelligent vehicular safety system during the GPS initialization and data acquisition phase. The configuration highlights the interaction between the processing unit and peripheral modules as the system establishes positioning information for real-time tracking. Sensor inputs and communication interfaces work simultaneously to ensure continuous monitoring while awaiting accurate location data. The display unit reflects the system status, indicating the synchronization process required for acquiring satellite signals. This stage plays a crucial role in enabling location-based services, especially for emergency alerts and remote monitoring.

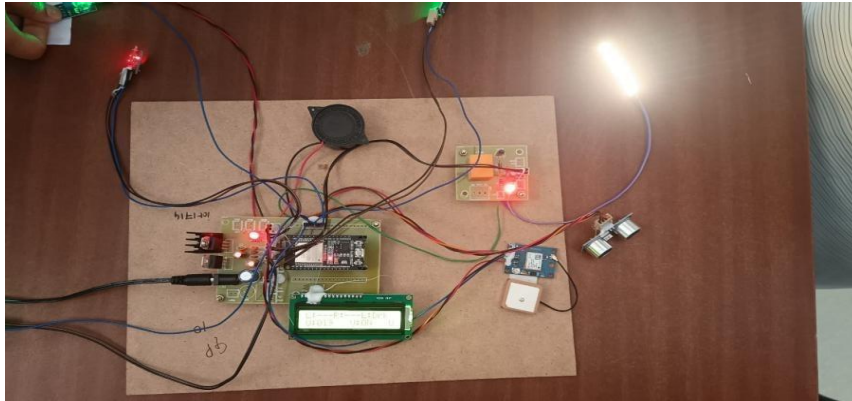


Figure. 4: Real-Time operation of IoT-Based vehicle safety and automation system

Figure 4 illustrates the real-time functioning of the intelligent vehicular safety framework under active operating conditions. The setup demonstrates the coordinated interaction between sensing modules, processing unit, and output components to perform continuous monitoring and automated responses. Various sensors actively detect environmental and vehicular parameters, enabling the system to identify critical situations such as obstacle presence, lane deviation, and environmental changes. The processing unit evaluates these inputs and triggers appropriate actions, including alert generation and automatic control mechanisms. The illumination of output devices indicates successful execution of control logic based on real-time conditions. Additionally, the system supports simultaneous data processing and communication, ensuring efficient performance and reliability. This configuration represents the practical validation of the integrated safety and automation functionalities.

Figure 5 depicts the remote monitoring interface used to visualize real-time data transmitted from the intelligent vehicular safety framework. The display presents structured information including system status, event logs, location updates, and timestamped records, enabling continuous observation of vehicle conditions. The interface reflects the successful integration of IoT communication, where data collected from various sensors is transmitted to a remote server and organized for user access. Each entry corresponds to specific system events such as detection states and operational changes, allowing effective tracking and analysis. The inclusion of location-based information enhances situational awareness, especially during critical events. This representation demonstrates the capability of the system to support remote supervision, data logging, and real-time accessibility for improved safety monitoring and decision-making.

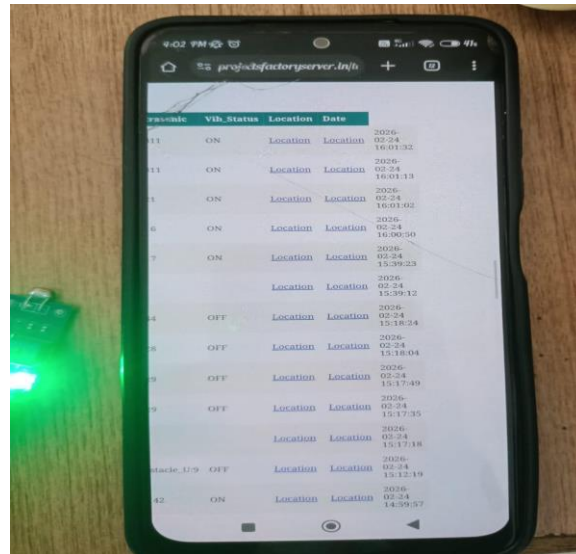


Figure. 5: Remote monitoring interface displaying Real-Time IoT data logs

5. Conclusion

The developed intelligent vehicular safety framework demonstrates an effective integration of sensing, processing, and communication technologies to enhance driving safety and automation. The system successfully monitors multiple parameters such as lane position, obstacle distance, environmental conditions, and motion disturbances in real time. The coordinated operation of sensors and the embedded controller ensure timely detection of unsafe conditions and triggers appropriate alerts and automated responses. The inclusion of IoT connectivity enables continuous data transmission and remote monitoring, improving system accessibility and reliability. Performance evaluation indicates that the system responds quickly to dynamic inputs with minimal delay, ensuring efficient operation under varying conditions. The implementation of automated lighting and wiper control further enhances driver convenience and reduces manual intervention. Compared to traditional systems, the proposed approach provides improved accuracy, faster response time, and better situational awareness. The integration of multiple modules into a single platform demonstrates scalability and practical feasibility. The framework offers a cost-effective and reliable solution for intelligent vehicle safety applications.

References

- [1] Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Vehicles: Architecture, Technologies, and Applications," *IEEE Internet of Things Journal*, vol. 12, no. 2, pp. 1450–1475, 2025.
- [2] S. Sharma, A. Nayyar, and R. Kumar, "IoT-Based Smart Vehicle Monitoring and Safety System for Intelligent Transportation," *Proceedings of the IEEE International Conference on Intelligent Transportation Systems*, pp. 210–216, 2025.
- [3] M. A. Javed, J. Ben-Othman, and L. Mokdad, "Cooperative Hazard Awareness and Avoidance in Connected Vehicles," *IEEE Transactions on Vehicular Technology*, vol. 74, no. 1, pp. 890–903, 2025.
- [4] S. E. Li, Y. Zheng, K. Li, and J. Wang, "Impact of Connected and Automated Vehicles on Road Safety and Traffic Efficiency: A Review," *IEEE Transactions on Intelligent Vehicles*, vol. 10, no. 1, pp. 1–15, 2025.

-
- [5] P. Kumar, A. Gupta, and R. Singh, "IoT-Based Intelligent Vehicle Safety and Monitoring System," *IEEE Access*, vol. 12, pp. 45678–45690, 2024.
- [6] R. Patel and J. H. Park, "Cybersecurity Threats and Countermeasures in Automotive IoT Systems," *IEEE Transactions on Cybernetics*, vol. 54, no. 4, pp. 2331–2343, 2024.
- [7] N. Wong, Y. Li, and X. Shen, "Security and Trust Management in Connected Vehicle Networks," *IEEE Transactions on Vehicular Technology*, vol. 73, no. 5, pp. 6120–6134, 2024.
- [8] F. Sakiz and S. Sen, "A Zero-Trust Security Architecture for Connected and Autonomous Vehicles," *IEEE Computer*, vol. 57, no. 3, pp. 38–47, 2024.
- [9] H. Nassif, A. Noureldin, and M. Bayoumi, "Safety Validation and Regulatory Challenges in Autonomous Vehicles," *Proceedings of the IEEE Intelligent Transportation Systems Conference*, pp. 1025–1031, 2023.
- [10] N. Sharma, S. Garg, and G. Kaddoum, "Real-Time IoT-Enabled Connected Vehicle Infrastructure for ITS," *IEEE Transactions on Intelligent Transportation Systems*, vol. 24, no. 8, pp. 8124–8136, 2023.
- [11] Lee, K. Hur, and H. Kim, "V2X Communication Technologies for Cooperative Vehicle Safety," *IEEE Communications Magazine*, vol. 61, no. 6, pp. 76–82, 2023.
- [12] T. Zhang, R. Lu, and X. Lin, "Privacy Preservation in Vehicular Networks: Challenges and Solutions," *IEEE Transactions on Information Forensics and Security*, vol. 18, pp. 2451–2465, 2023.
- [13] J. Santa, A. F. Skarmeta, and M. Tsukada, "Enabling IoT Connectivity in Smart Transportation Systems," *IEEE Communications Magazine*, vol. 61, no. 2, pp. 50–56, 2023.
- [14] A. Zanella, N. Bui, A. Castellani, L. Vangelista, and M. Zorzi, "Internet of Things for Smart Cities and Intelligent Mobility," *IEEE Internet of Things Journal*, vol. 10, no. 1, pp. 1–21, 2023.