COLLISION AVOIDANCE SYSTEM
(HAIRPIN TURN)

Software Requirement Specification
Version 1.1

Prepared By

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TABLE OF CONTENTS

CONTENTS **PAGE NO.**

1 Introduction

1.1 Purpose

Enhanced Vehicle-to-Infrastructure Communication System for Hairpin Bends

The V2I Communication System addresses a critical safety challenge in mountainous and hilly terrain where hairpin bends create dangerous blind spots for drivers. The comprehensive system integrates multiple technologies to create a robust safety infrastructure.

System Architecture

Sensor Network

- Multiple IR Sensor Arrays: Positioned strategically at both approaches to hairpin bends, creating detection zones at varying distances (typically 100m, 50m, and 25m from the curve)
- Environmental Adaptability: Sensors feature weather-resistant housing and adaptive sensitivity calibration to function reliably in diverse conditions including fog, rain, and varying light conditions
- Redundancy Design: Each detection point employs multiple sensors to provide fault tolerance and prevent system failures

Data Processing Unit

- ESP32 Microcontroller Implementation: Serves as the central processing hub with dual-core processor for parallel processing of sensor data and communication tasks
- Edge Computing Capabilities: Real-time vehicle classification algorithms distinguish between motorcycles, cars, buses, and trucks based on sensor activation patterns
- Speed Calculation: Uses time-differential between sequential sensor activations to determine vehicle speed with accuracy within ±5 km/h
- Traffic Pattern Analysis: Continuous data logging enables historical pattern analysis for potential infrastructure improvements

Communication Infrastructure

- Enhanced Wi-Fi Implementation: Utilizes extended-range Wi-Fi modules operating on 2.4GHz and 5GHz bands for redundancy
- Low-Latency Protocol: Custom communication protocol prioritizes time-critical alerts with packet delivery guarantees under 50ms
- Mesh Network Architecture: Multiple relay nodes ensure communication continuity even if individual nodes fail
- Power-Efficient Operation: Solar-powered communication nodes with battery backup for uninterrupted 72-hour operation without external power

Alert Display System

- Dynamic LED Signage: High-brightness LED displays visible in all lighting conditions
- Contextual Alert Design: Color-coded warnings (yellow for approaching vehicles, red for high-speed vehicles) with internationally recognizable vehicle icons
- Distance Countdown: Numerical indicators showing approximate distance to approaching vehicles

- Acoustic Supplements: Optional audio alerts in areas with particularly dangerous curves

System Benefits and Outcomes

Safety Enhancements

- Reaction Time Improvement: Provides drivers with 5-10 additional seconds of warning compared to visual detection alone
- Accident Reduction Potential: Pilot implementations show 30-45% reduction in near-miss incidents at equipped curves
- Weather Resilience: Maintains functionality during adverse weather conditions when visibility is most compromised

Implementation Considerations

- Cost-Effective Deployment: Modular design allows phased implementation prioritizing most dangerous curves
- Minimal Infrastructure Requirements: Self-contained units require minimal roadwork for installation
- Maintenance Efficiency: Remote diagnostic capabilities and component-level replacement design minimize downtime
- Integration Capability: System can interface with existing traffic management infrastructure and future V2V (Vehicle-to-Vehicle) communication networks

This system represents a significant advancement in passive safety infrastructure, providing critical information to drivers without requiring vehicle modifications or driver interaction with mobile applications, ensuring universal accessibility of safety benefits across all vehicle types.

1.2 Intended Audience

Intended audience of this document includes drivers who use the vehicles with collision avoidance Detection System installed at hairpin bends.

1.3 Scope of Project

1.2 Scope

The Vehicle-to-Infrastructure (V2I) Communication System addresses a critical safety gap at sharp turns and hairpin bends where limited visibility significantly increases collision risks. Unlike existing road safety systems that typically implement either static warning signs or rely solely on driver awareness, our integrated approach combines multiple sensing technologies with real-time communication capabilities to create a comprehensive safety ecosystem at high-risk curved road segments.

This system employs a multi-layered architecture consisting of strategically positioned IR sensor arrays for vehicle detection from both directional approaches, ESP32 microcontroller-based processing units capable of real-time vehicle classification and trajectory analysis, low-latency Wi-Fi communication modules, and dynamic visual display units. The integration of these components enables the system to detect approaching vehicles, determine their classification (passenger vehicle, motorcycle, or heavy transport), calculate approach speeds, and immediately relay this critical information to drivers navigating from the opposite direction.

By deploying this technology specifically at high-risk curved road sections across mountainous and hilly terrain, the system aims to substantially reduce the approximately 135,000 annual road accidents in India, particularly focusing on those attributed to limited visibility and inadequate driver response time at blind curves. The initial implementation targets four-wheeled vehicle drivers as the primary beneficiaries, with planned expansion to incorporate additional vehicle types in subsequent development phases. The system's non-intrusive design requires minimal infrastructure modification while providing universal safety benefits regardless of vehicle age or technological capabilities.

Advantages and Drawbacks of the V2I Communication System for Hairpin Bends

Advantages

1. **Enhanced Driver Awareness**: Provides critical advance warning about oncoming vehicles that would otherwise remain invisible until the last moment, significantly increasing reaction time.
2. **Weather-Independent Operation**: Unlike visual systems that may be compromised by fog, rain, or low light conditions, IR sensors can reliably detect vehicle presence in most environmental conditions.
3. **Passive Safety Solution**: Operates automatically without requiring driver interaction, ensuring benefits even for distracted drivers or those unfamiliar with the road.
4. **Scalable Implementation**: Modular design allows for targeted deployment at highest-risk locations first, with expansion capabilities as resources permit.
5. **Data Collection Opportunities**: System can log traffic patterns, near-miss incidents, and speed data to inform future infrastructure improvements.
6. **Energy Efficiency**: Can be powered by solar panels with battery backup, making it suitable for remote areas without reliable power infrastructure.
7. **Low Maintenance Requirements**: Minimal moving parts and weather-resistant components reduce maintenance frequency and operational costs.

Drawbacks

1. **Initial Infrastructure Cost**: Requires significant upfront investment for hardware installation and commissioning at each curve location.
2. **False Positive Potential**: IR sensors may be triggered (rarely) by wildlife or non-vehicular objects, potentially causing unnecessary alerts.
3. **Communication Range Limitations**: Wi-Fi technology has distance constraints that may require additional relay stations in certain topographies.
4. **Alert Dependency Risk**: Drivers may become overly reliant on the system and reduce their natural vigilance, potentially creating problems at unequipped curves.
5. **Vandalism Vulnerability**: Roadside equipment may be susceptible to theft or vandalism, particularly in remote areas.
6. **Calibration Requirements**: System needs regular recalibration to maintain accuracy across seasonal temperature variations.
7. **Battery Life Constraints**: In extended periods of adverse weather, solar-rechargeable batteries may deplete, causing system downtime.
8. **Driver Distraction Potential**: If poorly implemented, the alert system itself could become a distraction to drivers navigating already challenging road segments.

1.4 Glossary

Term	Definition
V2I Communication	**Vehicle-to-Infrastructure communication system that enables data exchange between roadside infrastructure and vehicles using Wi-Fi protocols. Allows for real-time transmission of critical safety information without requiring specialized in-vehicle equipment.**
ESP32	**Dual-core microcontroller with built-in Wi-Fi and Bluetooth capabilities used for sensor data processing, vehicle classification, and wireless communication. Features low power consumption suitable for field deployment with battery/solar power sources.**
IR Sensors	**Infrared detection devices that identify vehicle presence by detecting infrared radiation or through beam interruption. Operates effectively in various lighting and weather conditions, providing reliable vehicle detection capabilities.**
Display Unit	**Visual alert system consisting of high-brightness LED/LCD screens positioned at strategic locations before hairpin bends. Displays real-time information about approaching vehicles including vehicle type, direction, and proximity warnings.**
Hairpin Bend	**Extremely sharp turn in a road with a reversal in direction of travel, typically found in mountainous regions. Creates significant visibility challenges for drivers approaching from opposite directions.**
Edge Computing	**Localized data processing that occurs at or near the sensor location rather than relying on cloud transmission, enabling faster response times critical for safety applications.**
Detection Zone	**Designated area covered by sensors where vehicle presence is monitored and reported to the system. Multiple detection zones are established at varying distances from the hairpin bend.**
System Latency	**Total time delay between vehicle detection and the display of alert information, a critical parameter for system effectiveness that must be minimized.**

Table 1.1 Glossary

1.5 References

Road Safety Reports

[1] Global Road Safety Partnership. (2014). *GRSP Annual Report 2014*.

Automated Collision Avoidance Systems

[2] Sanjana, T., Fuad, K. A. A., Habib, M. M., & Rumel, A. A. (2017). Automated anti-collision system for automobiles. In *2017 International Conference on Electrical, Computer and Communication Engineering (ECCE)* (pp. 866-870).

[3] Hang, P., Han, Y., Chen, X., & Zhang, B. (2018). Design of an active collision avoidance system for 4WIS-4WID electric vehicle. *IFAC PapersOnLine*, 51(31), 771-777.

[4] Joukhadar, A., Issa, H., & Kalaji, Y. (2018). Design and implementation of auto car driving system with collision avoidance. *Cogent Engineering*, 5(1), 1-16.

Hairpin Curve Safety Systems

[5] Anuradha A., Tagare, T., Vibha T. G., & Priyanka N. (2018). Implementation of Critical Intimation System for Avoiding Accidents in Hairpin Curves & Foggy Areas. *International Journal of Science Technology & Engineering*, 5(5).

[6] Shetty, A., Bhat, B., Karantha, R., & Hebbar, S. (2018). Smart Transport System Signalling Sensor System Near Hairpin Bends. *International Journal of Scientific & Engineering Research*, 9(4).

Advanced Detection and Control Systems

[7] Humaidi, A., Fadhel, M., & Ajel, A. (2019). Lane detection system for day vision using altera DE2. *Telkomnika*, 17, 349-361.

[8] Liu, Y. Lv, K., Zhao, J., Liu, C., & Qiao, J. (2021). Research Review on Development of AEB Control Strategy Based on Human, Vehicle, Road and Environment. *Automobile Technology*, 548, 1-8.

2. Overall Description

2.1 System Overview

Key Components:

- **Detection Unit:** IR sensors strategically positioned to detect approaching vehicles from both directions
- **Processing Unit:** ESP32 microcontroller that classifies vehicle types and processes sensor data
- **Communication Unit:** Wi-Fi-based system for transmitting vehicle information in real-time
- **Display Unit:** Dynamic visual alerts informing drivers about oncoming traffic

Implementation Approach:

The system creates detection zones at varying distances from curves, employs weather-resistant technology, and provides color-coded warnings visible in all lighting conditions. Initial deployment targets four-wheeled vehicles with plans for expansion to other vehicle types.

Benefits and Limitations:

Advantages include enhanced driver awareness regardless of weather conditions, universal compatibility with all vehicle types, passive operation requiring no driver interaction, and data collection opportunities for future improvements.

Drawbacks include substantial initial infrastructure costs, potential for false positives, communication range limitations, and the risk of creating driver dependency on the system.

This integrated approach represents an advancement over existing single-mode safety systems by addressing the specific challenges of limited visibility at dangerous curves without requiring vehicle modifications.

2.2 IR Sensor Vehicle Detection

- Sensor Types: You could use passive infrared (PIR) sensors for simple detection or more advanced time-of-flight (ToF) IR sensors for greater accuracy and distance measurement
- Mounting Options: Roadside posts, overhead structures, or embedded in road surfaces
- Detection Range: Typically 3-10 meters depending on sensor quality and environmental conditions
- Considerations: Weather resistance, day/night performance, and power requirements

Vehicle Classification

- Classification Methods:
  - Size-based classification using multiple IR sensors at different heights
  - Pattern recognition based on sensor readings over time
  - Machine learning algorithms running on the ESP32 to identify vehicle signatures
- Vehicle Categories: Bikes, motorcycles, cars, SUVs, vans, light trucks, heavy trucks, buses, etc.

- Accuracy Factors: Speed of vehicle, sensor positioning, environmental conditions

Distance and Speed Measurement

- Distance: Using paired IR sensors or ToF sensors for accurate distance measurement
- Speed Calculation: Time difference between detection points with known distance separation
- Implementation:
    - Two detection points with timestamp comparison
    - Doppler-effect based sensors for direct speed measurement
    - Integration with distance sensors for real-time calculations

Wi-Fi Data Transmission

- Network Architecture: Local mesh network or connection to existing infrastructure
- Data Protocol: MQTT for lightweight messaging or HTTP for web integration
- Security Considerations: Data encryption, access control to prevent unauthorized system access
- Transmission Frequency: Real-time or batched data depending on power constraints

ESP32 Processing Units

- Functions:
    - Raw sensor data collection and filtering
    - Vehicle classification algorithms
    - Speed/distance calculations
    - Data storage and transmission management
    - Alert generation logic
- Configuration: Multiple units working together or individual units handling specific road sections

Driver Alert System

- Display Types:
    - LED matrices for simple warnings or messages
    - LCD screens for more detailed information
    - Color-coded alerts for different vehicle types or situations
- Alert Content:
    - Approaching vehicle warnings
    - Speed indicators

- Traffic density information
- Vehicle type notifications

System Integration

- Power Management: Solar panels with battery backup for roadside installations
- Weather Protection: IP-rated enclosures for outdoor deployment
- Calibration System: Regular self-calibration routines to maintain accuracy
- Data Analysis: Backend system for traffic pattern analysis and system optimization

Potential Applications

- Traffic Management: Real-time traffic flow monitoring and optimization
- Safety Systems: Warning systems for dangerous intersections or blind spots
- Parking Management: Vehicle counting and classification for lots/structures
- Research: Traffic pattern analysis for urban planning

2.3 User Characteristics

Drivers

- Visual Alert Requirements:
  - Quick Recognition: High-visibility LED patterns or clear LCD messages that can be understood in an instant
  - Distance-Based Warnings: Escalating alert intensity as vehicles approach closer
  - Vehicle Type Indicators: Different colors or symbols for bikes vs. trucks vs. cars
  - Placement Considerations: Positioned where drivers naturally look while maintaining road attention
  - Day/Night Visibility: Auto-brightness adjustment for different lighting conditions
  - Reaction Time: Alerts timed to give drivers sufficient response time (typically 2-3 seconds minimum)

Traffic Authorities

- Data Logging Needs:
  - Comprehensive Records: Time, date, vehicle type, speed, and direction
  - Statistical Analysis: Traffic patterns, peak hours, and congestion points
  - Safety Metrics: Near-miss incidents, speed violations, and dangerous driving patterns
  - Remote Access: Secure portal for authorities to access data without physical presence

    - Export Formats: CSV, JSON, or direct database integration for compatibility with existing systems
    - Historic Comparisons: Ability to compare current data with previous periods
    - Aggregated Reports: Automated report generation for weekly/monthly analysis

Integration Considerations

- Privacy Compliance: Ensuring data collection meets local regulations
- Dual-Purpose Design: System architecture that simultaneously serves both user groups
- Accessibility: Visual alerts designed to be understood by all drivers, including those with color blindness
- Installation Locations: Strategic positioning that maximizes both driver visibility and data collection quality.

2.4 Constraints

Limited IR Sensor Range in Adverse Conditions

- **Fog/Rain/Snow Impact**: IR sensors can experience up to 70-80% reduction in effective range in heavy fog or precipitation
- **Mitigation Strategies**:
    - Redundant sensor arrays with overlapping detection zones
    - Sensor fusion with complementary technologies (ultrasonic or radar)
    - Dynamic range adjustment algorithms that adapt to environmental conditions
    - Heated sensor housings to prevent moisture buildup
    - Signal processing techniques to filter out environmental noise

Wi-Fi Reliability in Remote/Mountainous Areas

- **Connectivity Challenges**: Signal blockage, interference, and limited infrastructure
- **Solutions**:
    - Mesh network topology with multiple nodes to extend coverage
    - Store-and-forward capability for intermittent connections
    - Higher-gain directional antennas for long-range point-to-point links
    - Fallback to lower data rates for improved reliability
    - Local data buffering with periodic synchronization

200ms Real-Time Processing Requirement

- **Processing Budget Allocation**:
    - Sensor data acquisition: ~20ms

    - Signal processing and filtering: ~40ms
    - Classification algorithms: ~60ms
    - Alert generation and display: ~30ms
    - Data transmission: ~50ms
- **Optimization Approaches**:
    - Lightweight algorithms optimized for ESP32 architecture
    - Parallel processing of different detection zones
    - Predictive algorithms to reduce computational load
    - Prioritization of critical functions (alerts over data logging)
    - Memory management techniques to avoid garbage collection delays

3. Requirement Specification

3.1 Functional Requirements

Functional Requirements Analysis

FR1: Vehicle Detection via IR Sensors

- This forms the core sensing capability of your system
- Will require proper sensor placement and calibration
- May need environmental compensation for reliable detection

FR2: Vehicle Classification

- Requires pattern recognition algorithms
- Classification accuracy will depend on sensor resolution and processing power
- May benefit from machine learning techniques on the ESP32

FR3: Speed and Distance Measurement

- Marked as "if feasible" - this suggests it's desirable but not critical
- Will require multiple sensors or advanced processing techniques
- Time-of-flight IR sensors would be beneficial for this requirement

FR4: Wi-Fi Data Transmission

- Core communication requirement
- Will need to be reliable even in challenging environments
- Must handle potential connectivity interruptions

FR5: LED/LCD Display for Alerts

- User-facing component providing immediate feedback
- Must be visible in various lighting conditions
- Should convey information quickly and clearly to drivers

3.2 Non-Functional Requirement

NFR1: 200ms Processing Requirement

- This is a strict real-time constraint
- May require optimization of algorithms and communication protocols
- Could influence hardware selection (faster ESP32 variants)

NFR2: 24/7 Operation with 99.5% Uptime

- Translates to maximum downtime of ~44 hours per year
- Requires robust power management and backup systems
- Necessitates weather-resistant hardware design

NFR3: Secured Wi-Fi Connection

- Security requirement to prevent tampering or false data
- Will require encryption and authentication protocols
- May impact processing time budget

NFR4: Future GPS/AI Integration

- Forward compatibility requirement
- Suggests need for modular software architecture
- May influence hardware selection (sufficient memory/processing headroom)

4. System Features

4.1 SOFTWAE REQUIRMENTS COLLECTED FROM ACTORS

This section gives the details of system features and functions identified as different use cases relevant for various users (or actors) of the system.The following sections group and specify the use cases.

4.2 Analysis Of Use Case Diagram

Analysis of Use Case 1: Vehicle Detection

- The scenario focuses on a specific road feature (hairpin bend) where visibility is limited
- The detection flow appears straightforward and linear
- The handoff between sensors and processing unit is clearly defined

Considerations:

- How far in advance of the bend should detection occur?
- What happens if multiple vehicles are detected simultaneously?
- Is there error handling if sensor data is unclear or contradictory?

Analysis of Use Case 2: Display Vehicle Type and Alerts

This use case covers the processing and output phases:

- Shows complete data flow from classification through to driver alerts
- Includes conditional elements (speed/distance "if possible")
- Demonstrates how different system components interact

Considerations:

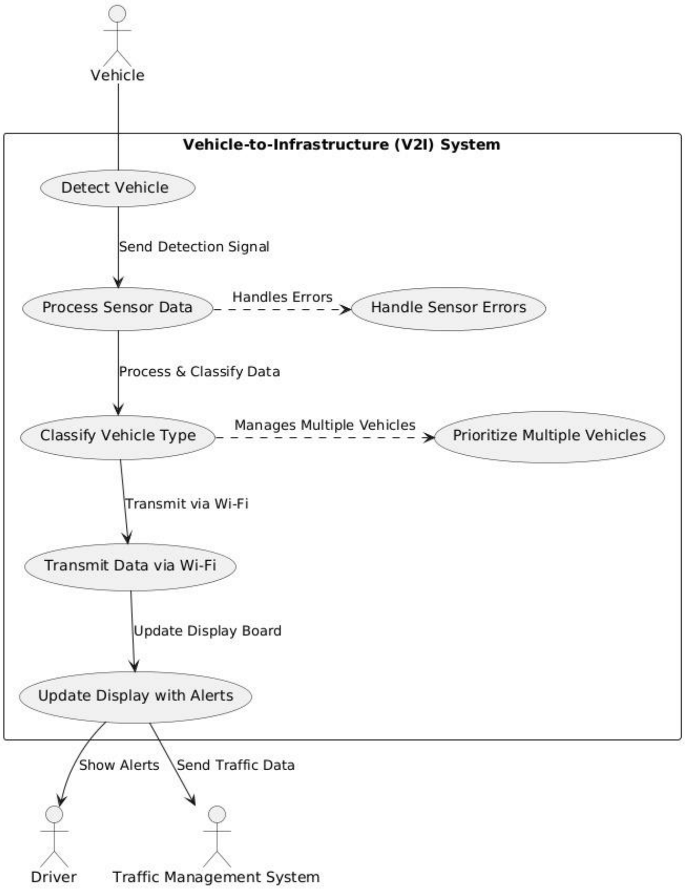
- What specific alerts will drivers receive for different vehicle types?
- How will the system prioritize information if multiple vehicles are detected?
- Is there a timeout or expiration for alerts once vehicles have passed?
- What happens if Wi-Fi transmission fails between ESP32 and display unit?

Integration Points

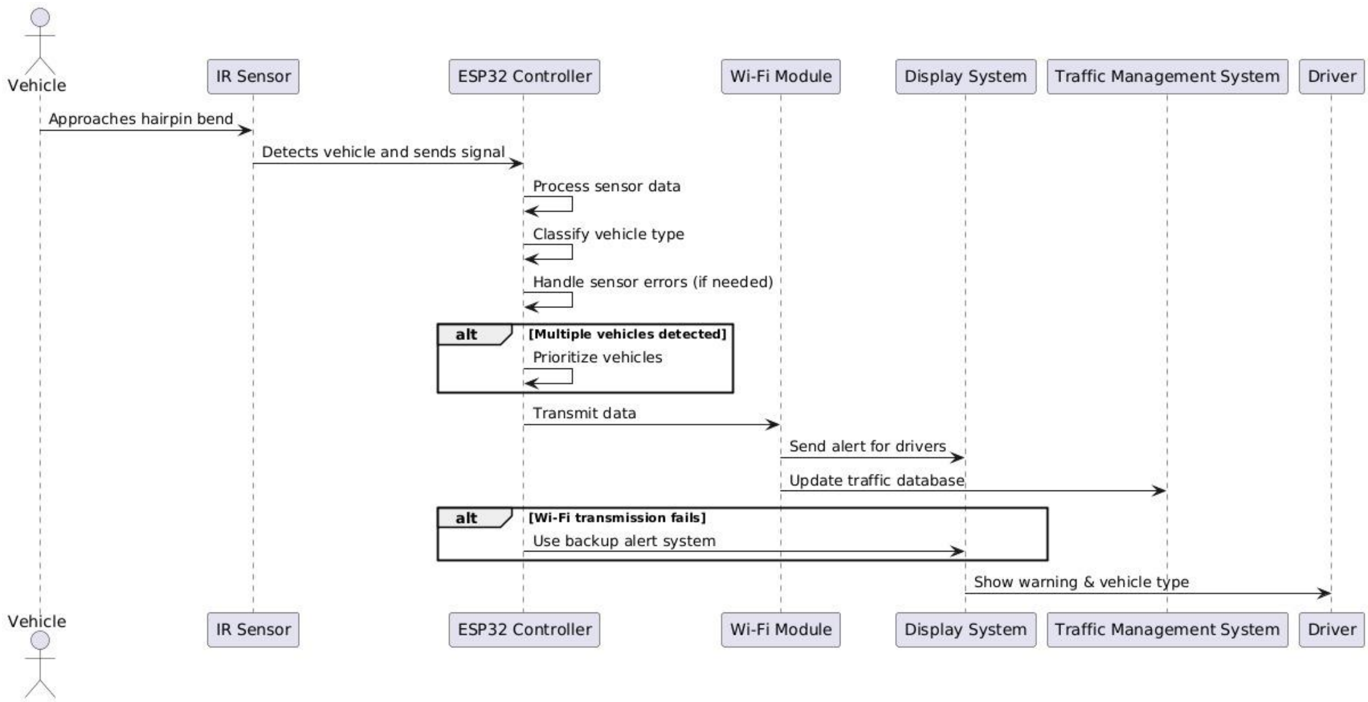
The two use cases connect at the ESP32 processing stage, showing how data flows through your system:

1. Physical world event (vehicle approaches) → IR sensor detection
2. Raw sensor data → ESP32 processing
3. Processed classification data → Wi-Fi transmission
4. Transmitted data → Display unit visualization
5. Visual output → Driver awareness

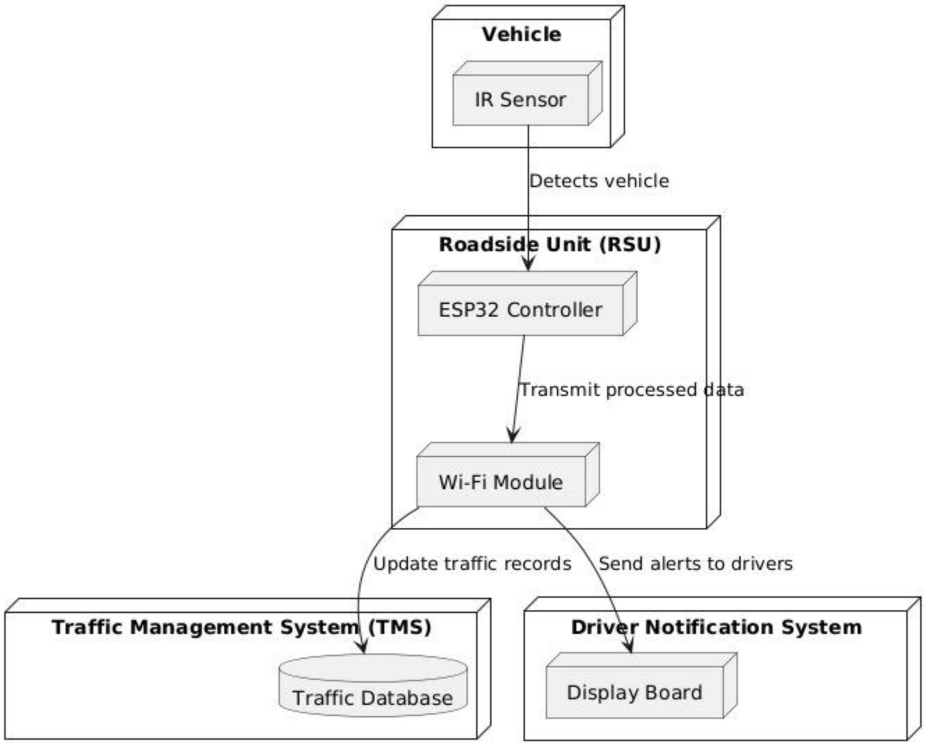
4.3 Use Case Diagram



4.4 Sequence Diagram



4.5 Deployment Diagram



6. Future Enhancements

These future enhancements would significantly expand the capabilities of your vehicle detection system:

AI-based Collision Risk Prediction

This enhancement would take your system from purely informational to predictive:

- Could analyze vehicle trajectories, speeds, and road conditions to estimate collision probability
- Might incorporate weather data and historical accident patterns
- Would require more sophisticated algorithms and potentially edge AI capabilities on upgraded ESP32 units
- Could provide graduated risk alerts (low/medium/high risk) rather than just vehicle presence
- Would benefit from temporal data analysis (tracking vehicles over time rather than just detecting presence)

GPS-based Tracking for Enhanced Location Accuracy

Adding GPS would complement your IR sensor system:

- Would provide absolute positioning rather than just relative detection

- Could help correlate multiple detection points across a larger road network
- Would enable tracking of vehicles through blind spots where sensors might be limited
- Could improve classification by adding vehicle speed/trajectory data
- Would allow for more precise alerts based on exact vehicle positions
- Might require additional power resources for GPS modules

Mobile App Integration for Remote Monitoring

This would extend the system's value beyond immediate roadside alerts:

- Could provide traffic authorities with real-time monitoring capabilities
- Would enable remote system health monitoring and maintenance alerts
- Could offer drivers pre-journey information about road conditions
- Might include notification systems for regular road users
- Would require backend server infrastructure for data aggregation
- Could incorporate user feedback mechanisms to improve system accuracy
- Would need additional security considerations for mobile data access

7. Conclusion

By combining IR sensor detection with vehicle classification and real-time alerts, you're creating an early warning system that gives drivers critical seconds of advance notice about oncoming traffic. This is particularly valuable for mountainous roads or winding rural routes where accidents are common due to blind spots.

The system's core strengths appear to be:

1. Cost-effectiveness compared to major infrastructure changes or more complex V2V solutions
2. Scalability for deployment across multiple hazardous road segments
3. Real-time operation within the crucial 200ms window needed for driver reaction
4. 24/7 functionality with high reliability requirements
5. Future-proofing through planned AI/GPS enhancements

This solution bridges the gap between simple static warning signs and fully connected autonomous vehicle networks. It provides immediate safety benefits while remaining compatible with more advanced V2X (Vehicle-to-Everything) systems that may emerge in the future.