COLLISION AVOIDANCE SYSTEM FOR HAIRPIN BENDS

A MINI PROJECT REPORT

submitted by

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Bachelor of Technology

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CERTIFICATE

This is to certify that the mini project report entitled **'COLLISION AVOIDANCE SYSTEM FOR HAIRPIN BENDS'** submitted by **ADITHYA DAVID M (TOC22CS012), AKASH BABU (TOC22CS021), ARJUN T AGHILESH (TOC22CS046), DHANUSH A (TOC22CS062)**, during the sixth semester, is a bonafide record of the project work carried out by them in partial fulfillment of the requirements for the award of B.Tech degree in Computer Science & Engineering of the APJ Abdul Kalam Technological University, under our guidance and supervision, during the academic year 2024 - '25. This report in any form has not been submitted to any other University or Institute for any purpose.

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DECLARATION

We hereby declare that the mini project report ' COLLISION AVOIDANCE SYSTEM FOR HAIRPIN BENDS ' submitted in partial fulfillment of the requirements for the award of degree of Bachelor of Technology in Computer Science & Engineering, of the APJ Abdul Kalam Technological University, Kerala, is a bonafide work done by us under the supervision of Mr. Bibin Vincent, Assistant Professor, Dept. of CSE, Toc H Institute of Science and Technology. This submission represents our ideas in our own words and where ideas or words of others have been included, We have adequately and accurately cited and referenced the original sources. We also declare that we have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in our submission. We understand that any violation of the above will be a cause for disciplinary action by the Institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not previously formed the basis for the award of any degree, diploma, or similar title of any other university.

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CO4: Organize tasks utilizing available resources within timelines, following ethical and professional norms. (Apply)

CO5: Examine technology/research gaps to propose innovative/creative solutions. (Analyze)

CO6: Organize technical and scientific findings effectively in written and oral forms. (Apply)

MAPPING OF COs WITH POs and PSOs)

CO-PO / PSO	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
CO1	3	3	3	3	2	3	3	2	3	2	3	3	3	3
CO2	3	3	3	3	3	3	3	2	3	2	3	3	3	3
CO3	2	1	2	_	_	_	_	_	3	2	3	3	3	3
CO4	2	1	2	1	2	_	_	3	3	2	3	3	3	3
CO5	3	3	3	3	_	_	_	_	3	2	_	3	3	3
CO6	3	1	3	1	2	_	_	2	3	3	2	3	3	3

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ABSTRACT

Hairpin bends in mountainous and hilly terrains present significant safety challenges due to sharp turns, limited visibility, and blind spots, which heighten the risk of accidents. To address these issues, the Vehicle-to-Infrastructure (V2I) Communication System employs advanced sensing and communication technologies to enable real-time vehicle detection and communication, ultimately enhancing road safety in such hazardous environments.

The system is built around a server module (infrastructure) equipped with two ultrasonic sensors that continuously monitor the road for vehicle presence. These sensors detect the distance and movement of approaching vehicles. When a vehicle is detected, the infrastructure module sends alerts to nearby vehicles (client modules) via Wi-Fi. This real-time communication provides critical information to drivers about oncoming traffic, reducing the risk of collisions, especially when navigating hairpin curves where visibility is limited.

The V2I system can be further enhanced by incorporating additional features like speed detection and distance measurement. This would offer drivers even more situational awareness, allowing them to adjust their speed or positioning accordingly for safer navigation.

By offering timely alerts and enabling real-time communication between infrastructure and vehicles, this system significantly improves road safety in mountainous regions. It proactively addresses the challenges of hairpin bends, helping reduce accident risks and ensuring a safer driving experience in these difficult terrains.

CONTENTS

Abstract i

List of Figures v

List of Tables vi

List of Abbreviations vii

1 Introduction 1

1.1 Background 1

1.2 Relevance 2

2 Literature Review 4

2.1 VEHICLE COLLISION AVOIDANCE SYSTEM 4

2.1.1 Advantages 5

2.1.2 Disadvantages 5

2.1.3 Inferences 6

2.2 Overview of Ultrasonic Sensor in Collision Avoidance system . . . 6

2.2.1 Advantages 7

2.2.2 Disadvantages 8

2.2.3 Inferences 8

2.3 Vehicle Detection and Collision Avoidance in Hairpin Curves . . . 9

2.3.1 Advantages 10

2.3.2 Disadvantages 10

2.3.3 Inferences 10

2.4 Research on Collision Avoidance Systems for Intelligent Vehicles . 11

2.4.1 Advantages 12

2.4.2 Disadvantages 13

2.4.3 Inferences 13

2.5 A Novel Real-time Collision Avoidance System for On-road Vehicles 13

2.5.1 Advantages 15

2.5.2 Disadvantages 15

2.5.3 Inferences 16

3 Problem Identification and Objectives 17

3.1 System Study 17

3.2 Problem Definition 17

3.3 Objectives of the Project 18

3.4 Scope and Applications 18

4 Problem Analysis and Design Methodology 19

4.1 High Level Design 19

4.2 Modules Proposed 20

4.3 Algorithms/ Technologies Proposed 21

4.3.1 Vehicle Detection Algorithm 21

4.3.2 Signal Transmission Algorithm 21

4.3.3 Signal Reception and Display Algorithm (Client Module) 21

4.4 Feasibility Study 22

4.4.1 Technical Feasibility 22

4.4.2 Economic Feasibility 22

4.4.3 Social Feasibility 22

4.4.4 Operational Feasibility 22

4.4.5 Environmental Feasibility 22

4.5 System Requirements 23

4.5.1 Hardware Requirements 23

5 Implementation and Results 25

5.1 Project Implementation Details 25

5.1.1 Hardware Implementation 26

5.1.2 Software Implementation 26

5.2 Testing 27

5.2.1 Hardware Testing 27

5.2.2 Test Cases 29

5.2.3 Traceability Matrix 30

5.3 Experimental Results and Discussion 30

5.4 Actual Budget 30

5.5 Task Allocation 31
5.6 Gantt Chart 31

6 Conclusion **32**

7 Scope of future study **33**

References **34**

References **35**

Appendix **36**

LIST OF FIGURES

2.1 Vehicle Collision Avoidance System Architecture diagram [1] 5
2.2 AVRISP mkII programmer [3] 7
2.3 Component view of PCB [4] 7
2.4 LMV climbing uphill, approaching the curve. Green signal is given to vehicles coming downhill [5] 11
2.5 Flow chart of the collision avoidance switching system operation [7] 12
2.6 Experimental testbed [9] 15

4.1 Ultrasonic sensor 23
4.2 ESP32 23
4.3 Display 24

5.1 Prototype 25
5.2 Prototype (front view) 25
5.3 server 28
5.4 client1(truck) 28
5.5 client2(car) 28

LIST OF TABLES

4.1 Hardware Components 23

5.1 Test Cases 29

5.2 Traceability Matrix 30

5.3 Budget Proposal 30

5.4 Task Allocation 31

5.5 Gantt Chart 31

LIST OF ABBREVIATIONS

Abbreviation	Expansion
CAS	Collision Avoidance System
HMV	Heavy Motor Vehicles
LED	Light Emitting Diode
LMV	Light Motor Vehicles
MPC	Model Predictive Control
V2I	Vehicle-to-Infrastructure

Chapter 1

INTRODUCTION

Hairpin bends in mountainous and hilly regions pose significant safety challenges due to limited visibility and blind spots, leading to a higher risk of accidents. The V2I Communication System aims to address these challenges by leveraging advanced sensing and communication technologies. This system provides real-time vehicle detection and communication, offering drivers crucial information to navigate hairpin curves safely. By enhancing road safety through reliable and timely alerts, the system significantly reduces accident risks and improves the driving experience in challenging terrains

1.1 BACKGROUND

Mountainous and hilly terrains are known for their challenging road conditions, particularly the presence of sharp turns, narrow paths, and limited visibility. One of the most critical road features in these regions is hairpin bends, which are sharply curved roads with little to no line of sight for approaching vehicles. These bends, often found on steep inclines and winding mountain roads, pose significant safety risks, particularly for drivers who cannot see around the corner to anticipate oncoming traffic. This limited visibility and presence of blind spots increases the likelihood of head-on collisions, vehicle skidding, and other accidents, especially when vehicles approach the curve at high speeds.

In many cases, vehicles driving on such roads rely solely on the driver's reaction time and experience. However, as traffic density increases and vehicles travel at varying speeds, the chances of accidents rise due to insufficient information and a lack of communication between vehicles. Existing road safety measures, such as signage and physical barriers, are often insufficient in providing real-time, dynamic information that can prevent accidents in these high-risk areas.

To enhance road safety in such terrains, technology-driven solutions such as Vehicle-to-Infrastructure (V2I) communication systems have emerged as potential game-changers. V2I communication enables vehicles to exchange real-time information with infrastructure elements like traffic lights, road sensors, and warning systems. By providing dynamic and real-time data to drivers, these systems can offer crucial information about approaching vehicles, road conditions, and traffic flow, improving decision-making and reducing the risk of accidents.

In particular, the Vehicle-to-Infrastructure (V2I) Communication System being explored in this project seeks to address the specific challenges of hairpin bends on mountainous roads. By utilizing a combination of ultrasonic sensors and Wi-Fi communication, the system enables the infrastructure to detect the presence and movement of vehicles on either side of a hairpin curve. This information is transmitted to vehicles approaching the bend, alerting them to oncoming traffic and helping them navigate the curve more safely.

Such a system could significantly reduce the risk of collisions, enhance situational awareness for drivers, and contribute to safer, more efficient transportation in mountainous regions. The advancement of V2I technology, particularly in challenging environments like hairpin bends, offers promising potential to improve road safety and reduce traffic-related fatalities.

1.2 RELEVANCE

The increasing number of road accidents in mountainous regions, especially on hairpin bends, highlights the urgent need for innovative safety solutions. Hairpin bends are notorious for their sharp curves and limited visibility, which make it difficult for drivers to anticipate oncoming vehicles. These conditions often result in accidents, particularly when vehicles approach at high speeds or when drivers are unfamiliar with the terrain.

Traditional safety measures such as road signs and mirrors are often inadequate, as they do not provide dynamic, real-time information about oncoming traffic. In contrast, the Vehicle-to-Infrastructure (V2I) Communication System offers a modern, technology-driven solution to this problem. By utilizing ultrasonic sensors to detect vehicles and Wi-Fi communication to relay this information to approaching vehicles, the system significantly enhances situational awareness and reduces collision risks.

This project is particularly relevant in the context of road safety improvement in mountainous and hilly areas, where infrastructure enhancements are often limited due to geographical constraints. Integrating V2I communication not only addresses the immediate safety challenges but also aligns with the broader goal of developing smart transportation systems. As governments and transport authorities focus on reducing road accidents and fatalities, implementing such intelligent systems is becoming increasingly important.

The proposed system's ability to detect vehicle presence in real-time and communicate this information effectively can transform how drivers navigate hazardous curves. By proactively alerting drivers, the V2I system promotes safer driving behaviors, thereby reducing accident rates and enhancing the overall safety of mountainous road networks.

Chapter 2

LITERATURE REVIEW

Vehicle-to-Infrastructure (V2I) communication systems are gaining prominence as a means to enhance road safety, particularly in challenging environments such as mountainous regions. Hairpin bends, with their sharp curves and limited visibility, pose significant risks for drivers, making conventional safety measures like signs and mirrors inadequate. V2I systems address these challenges by enabling real-time communication between vehicles and roadside infrastructure, providing timely alerts to drivers.

2.1 VEHICLE COLLISION AVOIDANCE SYSTEM

The project [1] focuses on developing a collision avoidance system for vehicles using ultrasonic sensors to detect obstacles and either alert the driver or automatically apply brakes, thereby reducing accidents on hairpin bends and other critical road conditions. The system operates by emitting ultrasonic waves to measure distance, and when an obstacle is detected, it triggers an LED light, sounds a buzzer, and stops the motor in the prototype. In real-world applications, the brakes engage automatically if the driver does not respond in time. The system's hardware components include a microcontroller (Arduino) for processing sensor data and controlling responses, ultrasonic sensors for distance measurement, a servo motor for engaging brakes in the prototype, and audio-visual alert components like an LED and buzzer. A Bluetooth module is used for wireless communication, while embedded C programming manages the microcontroller's operations. An Android application enables remote monitoring and control, and the system employs an algorithm-based approach for decision-making and quick response to obstacles. Testing revealed that the system functions correctly, with LED and buzzer activation based on object proximity and automatic braking in critical situations, although environmental noise can slightly affect sensor accuracy. The successful demonstration of collision detection and warning highlights the system's potential to reduce accidents and enhance road safety [2].

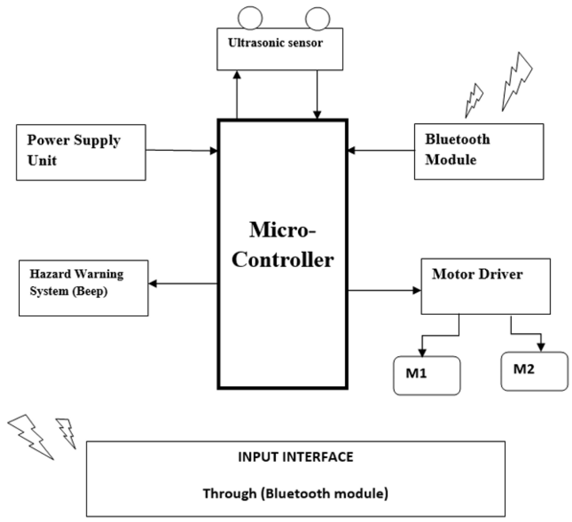


Figure 2.1: Vehicle Collision Avoidance System Architecture diagram [1]

2.1.1 Advantages

The collision avoidance system offers several advantages that make it an effective and practical solution for enhancing road safety. Firstly, it significantly contributes to accident prevention by providing early warnings and automatically applying brakes when an obstacle is detected, reducing the risk of collisions. Secondly, the system is cost-effective as it utilizes affordable components such as ultrasonic sensors and microcontrollers, making it accessible for widespread use. Additionally, it is simple and efficient, built on a basic embedded system that ensures ease of implementation without requiring complex infrastructure. Another advantage is its low power consumption, allowing it to operate efficiently with minimal energy usage. Moreover, the system is scalable, meaning it can be integrated with more advanced vehicle safety systems for real-world applications, further enhancing its utility and adaptability.

2.1.2 Disadvantages

Despite its advantages, the collision avoidance system has several limitations that affect its performance. One major disadvantage is the limited detection range of ultrasonic sensors, which may not detect obstacles that are far away, making it less effective in situations requiring long-range sensing. Additionally, the system is prone to noise interference from environmental factors such as rain, dust, and road vibrations, which can compromise the accuracy of the sensors. Another drawback is the potential delay in response due to the processing time of the microcontroller and inherent limitations of the sensors, leading to a slight lag in obstacle detection. Furthermore, the system is not suitable for high speeds, as it is primarily designed for low-speed scenarios and may struggle to accurately detect fast-moving vehicles, reducing its effectiveness in high-speed collision prevention.

2.1.3 Inferences

The project demonstrates a collision avoidance system that significantly enhances road safety, particularly in challenging environments such as hairpin bends where visibility is limited. By using ultrasonic sensors to detect obstacles and measure distance, the system can trigger immediate responses such as activating LED lights, sounding a buzzer, and engaging automatic braking if the driver fails to respond. This combination of real-time decision-making and automation reduces the likelihood of accidents, providing critical assistance in situations where human reaction time might be slow. The system also incorporates Bluetooth communication and an Android app for remote monitoring and control, adding versatility and convenience. While testing revealed that the system functions as expected, with successful object detection and warnings, environmental factors like noise can slightly impact the accuracy of the sensors. Despite this, the system holds great potential for improving vehicle safety and preventing accidents in hazardous road conditions.

2.2 OVERVIEW OF ULTRASONIC SENSOR IN COLLISION AVOIDANCE SYSTEM

The rear-end collision avoidance system [3]described in the paper utilizes ultrasonic sensors to measure the gap between vehicles traveling in the same lane and direction. The system works by sending a trigger pulse from the microcontroller to the ultrasonic sensor, which then emits ultrasonic waves. When these waves hit an obstacle, such as another vehicle, they reflect back toward the sensor. The sensor's echo pin receives the reflected pulse, and the time taken for the pulse to return is measured. This time is used to calculate the distance between the vehicles. If the measured distance falls below a predefined threshold, indicating that the vehicles are too close, the system activates a warning. This warning is communicated through an LED and a buzzer. If the distance continues to decrease, signaling an impending collision, the system triggers the vehicle's braking mechanism to prevent the accident. During simulations, at greater distances, the LED remains off and the vehicle continues moving normally. However, as the distance between the vehicles decreases, the LED lights up and the buzzer sounds to alert the driver [4].

Figure 2.2: AVRISP mkII programmer [3]

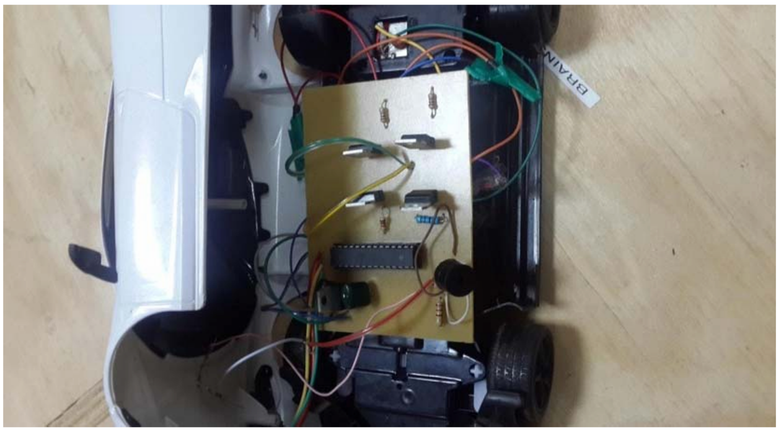


Figure 2.3: Component view of PCB [4]

2.2.1 Advantages

The rear-end collision avoidance system using ultrasonic sensors offers several significant advantages. First and foremost, it enhances safety by detecting potential collisions early and alerting the driver in time to prevent accidents. In case of a dangerously close proximity, the system can automatically trigger braking, further reducing the risk of injury or vehicle damage. The system is also cost-effective, as ultrasonic sensors are relatively inexpensive compared to other advanced sensor technologies like radar or LiDAR, making the system accessible to a wide range of vehicles, including older models. Additionally, ultrasonic sensors are simple to implement and are highly reliable, with minimal sensitivity to environmental factors such as rain or fog, ensuring consistent performance in various conditions. The system provides real-time alerts through visual (LED) and audible (buzzer) warnings, giving the driver more time to react and avoid a collision. This combination of affordability, simplicity, and effective real-time response makes it a valuable addition to modern vehicle safety systems.

2.2.2 Disadvantages

While the rear-end collision avoidance system using ultrasonic sensors offers many advantages, there are also some disadvantages to consider. One of the main drawbacks is the limited range of ultrasonic sensors. They are effective at detecting obstacles at relatively short distances, typically up to a few meters, which may not provide enough time for the driver to react in high-speed situations. Ultrasonic sensors also struggle with detecting certain types of obstacles, such as very small or soft objects, or objects that do not reflect sound waves efficiently. In addition, the system's performance can be compromised by environmental factors like heavy rain, snow, or mud, which can affect the sensor's ability to accurately detect objects. Another limitation is that ultrasonic sensors are typically designed for detecting objects in the direct path of the vehicle, so they may not be as effective in complex traffic situations with multiple vehicles or rapidly changing surroundings. Finally, the system relies heavily on the driver's reaction time once alerted. If the driver does not respond promptly, the system may not be able to prevent a collision, especially in critical situations where automated braking alone may not be enough.

2.2.3 Inferences

The rear-end collision avoidance system using ultrasonic sensors offers a real-time solution to prevent accidents by monitoring the proximity between vehicles in the same lane. The ultrasonic sensor emits pulses and measures the time it takes for the pulse to return, allowing the system to calculate the distance between vehicles. When the gap becomes dangerously small, the system triggers alerts, including an LED light and a buzzer, to warn the driver. If the vehicle continues to approach the obstacle and the driver does not respond, the system automatically engages the braking mechanism to avoid a collision. This setup demonstrates the system's precision in detecting vehicle proximity, its ability to make real-time decisions based on distance thresholds, and its effectiveness in automating the braking process when necessary. The system's ability to alert the driver at an early stage and take autonomous action if needed showcases its potential to significantly reduce rear-end collisions.

2.3 VEHICLE DETECTION AND COLLISION AVOIDANCE IN HAIRPIN CURVES

The project [5]focuses on developing an advanced collision avoidance system for vehicles, particularly aimed at improving safety on hairpin bends and other critical road conditions. By using object detection, the system is capable of detecting the type of vehicle, its distance, and its speed, providing valuable data that can be displayed on a screen. This information is crucial for reducing accidents, as it allows drivers to be alerted about the type of vehicles approaching a bend, helping them make better decisions in real-time. The system is powered by an Arduino Mega 2560 microcontroller, which processes data from cameras positioned at both ends of the hairpin curve. These cameras are strategically placed to capture clear images of approaching vehicles.

The core of the system [6] relies on MATLAB 2019a, which processes the captured video feed in real-time using image acquisition and object detection algorithms. A color detection algorithm is employed to classify vehicles as either Light Motor Vehicles (LMVs) or Heavy Motor Vehicles (HMVs). Once the vehicle is detected and classified, the processed data is transmitted to the Arduino MEGA 2560, which updates an LED display board. The display shows a green signal (denoted by an 'L') for light vehicles, indicating safe passage, and a red signal (denoted by an 'H') for heavy vehicles, advising the driver to wait. This real-time processing ensures that the system can provide immediate feedback, enhancing safety by allowing drivers to make informed decisions based on the vehicle types approaching the curve. The combination of MATLAB's powerful image processing capabilities and the Arduino microcontroller's data processing ensures a reliable, effective solution for collision avoidance in hazardous road conditions.

2.3.1 Advantages

The collision avoidance system offers several benefits aimed at improving road safety and traffic flow. By providing early warnings through the LED display, it helps prevent accidents by alerting drivers to potential hazards. The system facilitates effective traffic management by enabling smooth two-way traffic wherever possible, especially on hairpin bends and critical road conditions. It also provides real-time vehicle classification, differentiating between light and heavy vehicles, allowing for better decision-making. In particular, the system prioritizes uphill vehicles, granting heavy vehicles the right of way for a smoother flow of traffic. Additionally, by optimizing traffic signals, the system reduces traffic congestion and minimizes waiting times, enhancing overall efficiency and safety on the road.

2.3.2 Disadvantages

While the collision avoidance system offers numerous benefits, there are some limitations to consider. One major challenge is the dependency on MATLAB and Arduino, which requires proper integration and a stable power supply to function effectively. Additionally, the placement of cameras is critical for accurate detection, and any misalignment could result in incorrect readings. The system is also limited to certain road conditions, working best in controlled traffic environments, and may struggle to handle extreme congestion efficiently. Weather conditions such as heavy fog or rain can impact sensor accuracy and hardware performance, leading to potential detection issues. Lastly, while the system processes data in real-time, delays in image processing could slightly affect the speed of decision-making, potentially hindering its effectiveness in fast-paced situations.

2.3.3 Inferences

The system's design highlights both its strengths and potential limitations. While it offers significant safety improvements through real-time vehicle classification and traffic management, its dependency on the proper integration of MATLAB, Arduino, and a reliable power supply introduces some complexity. The effectiveness of the system heavily relies on precise camera placement, and any misalignment could affect its performance. Additionally, the system is best suited for controlled traffic environments, as it may not perform well in high-congestion scenarios or adverse weather conditions like heavy fog or rain. While the real-time processing capabilities are an asset, the potential delays in image processing could hinder its responsiveness in time-sensitive situations. Despite these challenges, the system presents a promising solution for enhancing road safety and improving traffic flow, though careful consideration of its operational environment and limitations is necessary for optimal performance.

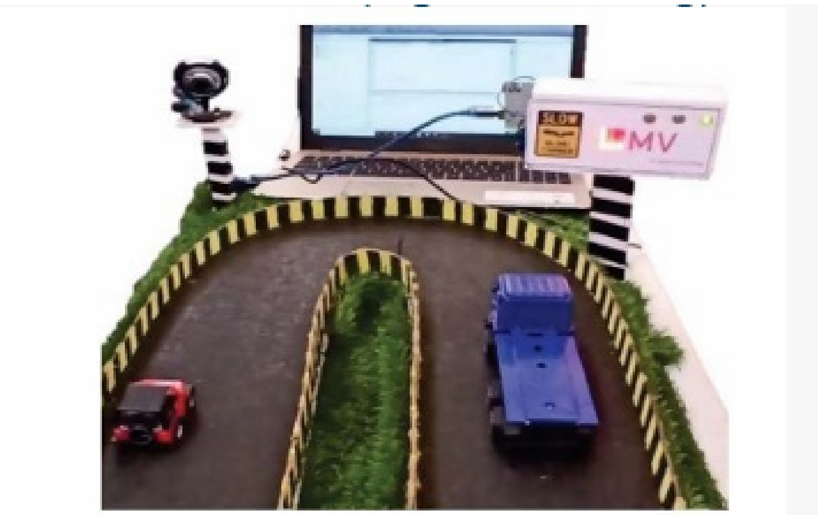


Figure 2.4: LMV climbing uphill, approaching the curve. Green signal is given to vehicles coming downhill [5]

2.4 RESEARCH ON COLLISION AVOIDANCE SYSTEMS FOR INTELLIGENT VEHICLES

The project [7]aims to develop an adaptive collision avoidance system that enhances vehicle safety across diverse driving scenarios, particularly in dynamic traffic conditions. Traditional collision avoidance systems may struggle to adapt to real-world emergencies, especially as traffic density increases and driving conditions change. To address this, the system leverages real-world data from the NGSIM dataset, which analyzes driver collision avoidance behavior and identifies key parameters such as vehicle speed, road adhesion, and vehicle overlap rate. The system employs a two-layer fuzzy control strategy: the first controller assesses the braking hazard based on vehicle speed and road adhesion, while the second controller uses this data along with the vehicle overlap rate to determine whether to initiate a braking maneuver or execute a lane change. The system integrates real-time execution through a braking safety distance model and a Model Predictive Control (MPC)-based lane change model, ensuring quick and precise responses to potential collisions.

Through a step-by-step process, the system analyzes driving conditions, assesses hazards, and decides whether to brake or change lanes, ultimately ensuring safer and more responsive driving. Simulation results show that the system [8]improves reaction times, reduces the activation distance for safety measures, and adapts seamlessly to varying road conditions and speeds, enhancing overall vehicle safety.

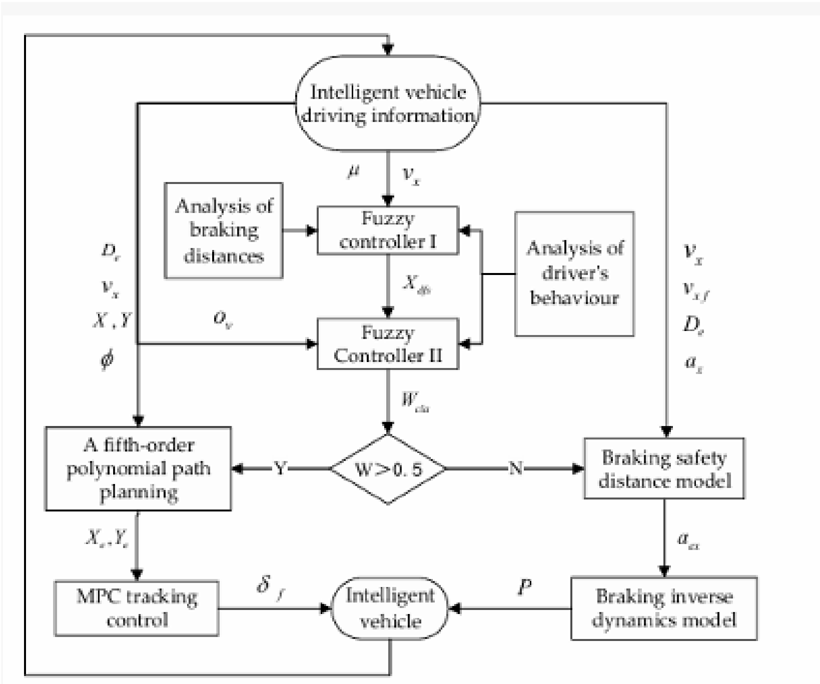


Figure 2.5: Flow chart of the collision avoidance switching system operation [7]

2.4.1 Advantages

The adaptive collision avoidance system offers significant advantages in improving vehicle safety. By analyzing real-world driver behavior and key parameters such as vehicle speed, road adhesion, and overlap rate, the system can make quick, context-aware decisions on whether to brake or change lanes. This approach ensures a faster response to potential collisions, reducing the activation distance and enhancing overall safety. Additionally, its robust adaptability to varying road conditions and traffic scenarios allows it to perform effectively in diverse environments, providing a more responsive and reliable solution compared to traditional systems.

2.4.2 Disadvantages

One of the main disadvantages of the adaptive collision avoidance system is its reliance on real-time data analysis and complex decision-making algorithms, which may introduce delays in processing under certain conditions, potentially affecting the system's responsiveness. Additionally, the system's effectiveness depends heavily on accurate data inputs such as vehicle speed, road adhesion, and vehicle overlap rate, which could be influenced by sensor inaccuracies or environmental factors like poor weather conditions. Moreover, the complexity of the two-layer fuzzy control strategy and model integration may require significant computational resources, making it challenging to implement on vehicles with limited processing power. Lastly, in highly congested or unpredictable traffic scenarios, the system might face difficulties in determining the optimal course of action, such as choosing between braking and lane changing, leading to suboptimal decisions.

2.4.3 Inferences

The adaptive collision avoidance system presents a promising approach to enhancing vehicle safety by incorporating real-time data and advanced control strategies. However, it also highlights several challenges that need careful consideration. The reliance on real-time data analysis and complex algorithms may result in delays in decision-making, which could affect its effectiveness in certain emergency situations. Sensor accuracy and environmental factors, such as weather conditions, could also impact the system's ability to make reliable decisions. Additionally, the system's complexity and computational requirements may limit its implementation in vehicles with lower processing power. While the system excels in dynamic traffic scenarios by providing faster reactions and adapting to different road conditions, it may face difficulties in managing highly congested or unpredictable traffic, potentially leading to less optimal decisions. Despite these limitations, the system offers a significant improvement over traditional systems in terms of responsiveness and adaptability.

2.5 A NOVEL REAL-TIME COLLISION AVOIDANCE SYSTEM FOR ON-ROAD VEHICLES

Collision Avoidance Systems (CAS) are crucial components of modern vehicular technology, designed to enhance road safety and significantly reduce accidents. These systems [9] employ various sensors, communication protocols, and real-time data processing techniques to detect potential collisions and respond proactively. The primary goal of CAS is to protect both vehicle occupants and other road users by detecting obstacles, other vehicles, or pedestrians and initiating preventive actions.

Typically, CAS integrates advanced sensors such as ultrasonic sensors, radar, LiDAR, cameras, and infrared (IR) sensors, which continuously monitor the vehicle's surroundings. By gathering and analyzing environmental data, these sensors enable the system to identify potential threats in real-time. Additionally, CAS leverages communication protocols like Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) to share critical information about position, speed, and direction with nearby vehicles and roadside infrastructure. This real-time data exchange helps in predicting and mitigating potential collisions.

Real-time data processing is a key aspect of CAS, as it ensures that the system can promptly analyze information from sensors and communication channels. Advanced computing methods, such as edge computing, are often used to minimize latency and enhance responsiveness. When a potential collision is detected, CAS can issue warnings to the driver or take autonomous actions, such as emergency braking, steering assistance, adaptive cruise control, or lane departure correction. The development of a novel real-time collision avoidance system for on-road vehicles, as discussed in the selected paper, highlights the importance of integrating advanced sensors and communication strategies to boost the system's reliability and responsiveness. By combining these cutting-edge technologies, the proposed system is capable of reacting swiftly to dynamic traffic situations, thereby enhancing safety in complex driving environments. As automotive technology continues to advance, the integration of machine learning and artificial intelligence into CAS will further improve its accuracy and efficiency, making roads safer for everyone. [10].

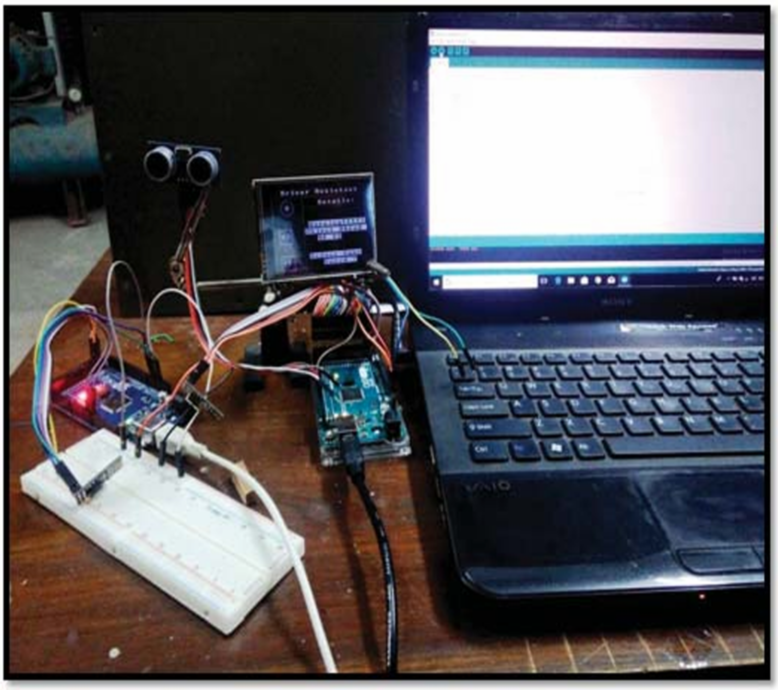


Figure 2.6: Experimental testbed [9]

2.5.1 Advantages

The real-time collision avoidance system offers several advantages. Firstly, it enhances safety by significantly reducing the risk of accidents through timely warnings and automated responses. Secondly, it improves vehicle communication by utilizing vehicle-to-infrastructure (V2I) communication, which allows for efficient data exchange and enhances the system's predictive accuracy. Additionally, the integration of ESP32 and IR sensors facilitates faster data processing, which is crucial for collision detection. Furthermore, leveraging affordable components like ESP32 makes the system viable for large-scale deployment.

2.5.2 Disadvantages

Despite its benefits, the system has some drawbacks. Environmental factors such as fog, rain, and snow can impact the accuracy of IR and ultrasonic sensors. Moreover, latency issues caused by delays in data transmission may compromise the effectiveness of real-time collision avoidance. Another challenge lies in infrastructure dependency, as the system's performance heavily relies on consistent V2I communication, which may not be reliable in remote or poorly connected areas. Lastly, hardware failures, such as sensor or module malfunctions, can affect the system's overall reliability.

2.5.3 Inferences

The novel real-time collision avoidance system presents a promising approach to enhancing road safety through advanced sensing and communication. While the system offers numerous advantages in terms of safety and cost-effectiveness, challenges related to environmental interference and communication latency need to be addressed. Future research could focus on integrating more robust sensors and optimizing the V2I communication protocols to mitigate these issues.

Chapter 3

PROBLEM IDENTIFICATION AND OBJECTIVES

3.1 SYSTEM STUDY

The Vehicle-to-Infrastructure (V2I) Communication System is designed to enhance road safety in mountainous regions, particularly in areas with hairpin bends. By using ultrasonic sensors to detect vehicles and Wi-Fi communication to relay real-time data, the system provides crucial information to drivers, helping them navigate safely through blind spots. The system aims to reduce the risk of accidents by offering timely alerts about approaching traffic. This solution improves driver awareness and decision-making in challenging terrains.

3.2 PROBLEM DEFINITION

Mountainous and hilly regions are known for their narrow, winding roads and hairpin bends, which present significant safety challenges for drivers. These road features, coupled with limited visibility around sharp turns, create blind spots that make it difficult for drivers to see oncoming traffic, leading to a higher risk of accidents. These conditions are exacerbated by factors such as steep inclines, weather conditions, and the lack of adequate safety measures to address visibility issues.

In such environments, the risk of head-on collisions or vehicle loss of control is substantially higher. The limited ability for drivers to assess the situation ahead can lead to poor decision-making, especially when overtaking or navigating tight corners. Drivers have no way of knowing when a vehicle might be approaching the bend from the opposite direction, which can lead to dangerous confrontations.

The lack of real-time communication between vehicles and infrastructure further compounds the problem, as drivers must rely on their own judgment and limited visibility to navigate these hazardous areas. Current road safety measures, such as signage or road markings, are often insufficient, especially in regions where sharp curves and blind spots make it impossible for drivers to anticipate oncoming traffic.

3.3 OBJECTIVES OF THE PROJECT

The objective of this project is to enhance road safety in mountainous regions, particularly around hairpin bends, by implementing a Vehicle-to-Infrastructure (V2I) Communication System. This system aims to detect vehicles in real-time using ultrasonic sensors and relay crucial information to drivers through Wi-Fi communication. By providing timely alerts about the presence and proximity of oncoming vehicles, the system will help drivers make informed decisions, reducing the risk of head-on collisions and improving overall safety. The project also focuses on increasing driver awareness, optimizing traffic flow, and ensuring that the system can function in challenging terrains and weather conditions. Ultimately, the system aims to improve road safety, reduce accidents, and enhance the driving experience in high-risk areas.

3.4 SCOPE AND APPLICATIONS

The scope of this project extends to the development and implementation of a Vehicle-to-Infrastructure (V2I) Communication System specifically designed for use in mountainous and hilly regions with hairpin bends and blind spots, where road visibility is limited. The system utilizes ultrasonic sensors and Wi-Fi communication to detect and relay real-time information about approaching vehicles to drivers, enabling safer navigation through hazardous turns. The primary application of this system lies in improving road safety, reducing the risk of accidents, and enhancing driver awareness in high-risk areas. Beyond hairpin bends, this technology can be expanded to urban roads, highways, and smart cities, where real-time communication between vehicles and infrastructure can optimize traffic management, enable autonomous driving, and contribute to overall road safety improvements. The system can also be adapted to integrate withcloud-based traffic management systems and future safety enhancements.

Chapter 4

PROBLEM ANALYSIS AND DESIGN METHODOLOGY

Mountainous and hilly regions, particularly those with hairpin bends and blind spots, present significant safety challenges for drivers. These road features restrict drivers' visibility, making it difficult to see oncoming traffic and increasing the risk of head-on collisions or other accidents. At hairpin bends, vehicles approaching from the opposite direction are often hidden from view until it's too late, creating dangerous situations, especially when overtaking or navigating narrow, winding roads. The lack of real-time information about oncoming traffic further exacerbates the problem, as drivers rely solely on their judgment and limited visibility to make decisions in these high-risk areas.

Traditional road safety measures, such as traffic signs and road markings, are not sufficient in these scenarios. While signs can provide basic warnings, they do not offer real-time data or enable proactive decision-making for drivers. As a result, there is a critical need for a system that can provide drivers with real-time alerts regarding approaching vehicles, which would enable them to adjust their driving behavior accordingly and reduce the chances of accidents.

The primary issues at play are limited visibility, blind spots, and the absence of real-time communication between vehicles and the road infrastructure. These factors increase the likelihood of accidents, as drivers often cannot anticipate oncoming traffic or the exact position of other vehicles around hairpin turns. The situation is especially dangerous in areas with steep inclines, sharp curves, and unpredictable weather conditions. The combination of these factors makes it essential to implement a solution that can detect vehicles, communicate real-time information, and help drivers navigate safely through hazardous road conditions.

4.1 HIGH LEVEL DESIGN

The sensor network consists of ultrasonic sensors strategically placed to detect vehicles at distances of 50m, and 25m from the hairpin bend. These sensors send detection data to the data processing unit (ESP32), which processes the sensor information to identify the vehicle type and, if necessary, calculate its speed. The processed results are then forwarded to the communication infrastructure, which uses ESP32 Wi-Fi to create a mesh network for real-time data transfer. This communication infrastructure allows the server (infrastructure) to send alerts to client modules (vehicle side) via Wi-Fi. The alert display system includes LED signs and that provide both visual warnings to drivers in real-time. On the client side, the vehicle module receives these alerts and displays them on a screen, notifying the driver about the approaching vehicle, thus improving safety and awareness on hairpin bends.

4.2 MODULES PROPOSED

Proposed Modules

1. **Sensor Network Module**: - Function: This module consists of ultrasonic sensors strategically placed at distances of 50m, and 25m from the hairpin bend. The sensors continuously detect the presence of oncoming vehicles, measure their distance, and send the data to the processing unit (ESP32). - Components: Ultrasonic sensors, ESP32 microcontroller for data collection.

2. **Data Processing Unit (ESP32)**: - Function: The ESP32 processes the raw data from the ultrasonic sensors to identify vehicle type (e.g., car, truck) and calculate the vehicle's speed (if needed). It also performs any necessary filtering and processing of sensor data before sending it to the communication module. - Components: ESP32 microcontroller, vehicle detection algorithms, speed calculation logic.

3. **Communication Infrastructure Module**: - Function: This module uses ESP32 Wi-Fi to establish a mesh network between the infrastructure and client modules (vehicles). It ensures real-time transfer of detection data, alerts, and vehicle information from the server to the client, providing timely notifications to drivers about oncoming vehicles. - Components: ESP32 microcontroller, Wi-Fi communication setup, mesh network configuration for real-time data transfer.

4. **Alert Display System**: - Function: This system uses LED signs and buzzers to provide visual and audio alerts to drivers in real-time. The display shows warnings like ”Vehicle Approaching” or ”Slow Down” based on the data received from the infrastructure. - Components: LED display panels, communication interface with the ESP32.

5. **Client Module (Vehicle Side)**: - Function: The vehicle-side module receives alerts and information from the infrastructure via Wi-Fi. It displays warnings to the driver on a screen in real-time, helping them make informed decisions when approaching the hairpin bend. - Components: ESP32 microcontroller, display unit (LCD/OLED screen), Wi-Fi

communication setup.

These proposed modules work together to detect vehicles, process the data, and provide real-time alerts to enhance driver safety in areas with limited visibility, such as hairpin bends in mountainous regions.

4.3 ALGORITHMS/ TECHNOLOGIES PROPOSED

4.3.1 Vehicle Detection Algorithm

Input: Ultrasonic sensor data (time taken for echo return).

Process: Continuously emit ultrasonic pulses from the sensors. Measure the time delay between sending the pulse and receiving the echo.Calculate the distance using the formula: If the calculated distance is within the predefined range (for example, 50 m, 25 m), classify as an approaching vehicle.

Output: Trigger an alert if a vehicle is detected.

4.3.2 Signal Transmission Algorithm

Input: Vehicle detection data.

Process: Convert the detection data into a message format. Use Wi-Fi communication protocol to transmit the message from the server module (infrastructure) to client modules (vehicles). Implement error-checking to ensure message integrity.

Output: Signal alert sent to client modules.

4.3.3 Signal Reception and Display Algorithm (Client Module)

Input: Signal from the server module.

Process: Continuously listen for incoming signals. Upon receiving a signal, decode the message. Display an appropriate alert on the screen (e.g., “Vehicle Approaching: 50m”).

Output: Visual warning displayed.

4.4 FEASIBILITY STUDY

4.4.1 Technical Feasibility

The project employs ESP32 microcontrollers, which support Wi-Fi connectivity and can communicate with a cloud-based or local server for real-time vehicle detection. Ultrasonic sensors will be used for vehicle detection and potential speed estimation. The system will require low-power embedded programming using Arduino IDE or MicroPython, which is technically viable and widely documented. Data visualization can be done using a web-based dashboard or mobile app, improving usability.

4.4.2 Economic Feasibility

The hardware components (ESP32, Ultrasonic sensors, LEDs, and communication modules) are cost-effective and widely available. Implementation does not require expensive infrastructure modifications, making it a feasible option for low-budget smart road solutions. The maintenance cost is minimal since the system operates with low energy consumption and limited manual intervention.

4.4.3 Social Feasibility

The system enhances public safety by reducing accidents in high-risk areas, making it socially acceptable and desirable. It contributes to better traffic management, reducing congestion and improving commuting experiences. As the system is non-intrusive, it does not cause privacy concerns or require significant behavioral adaptation from drivers.

4.4.4 Operational Feasibility

The system is designed to be autonomous, requiring minimal human intervention once deployed. Installati on is straightforward and can be integrated into existing road infrastructure without extensive modifications. Authorities and transportation departments can easily monitor and manage the system via a centralized dashboard.

4.4.5 Environmental Feasibility

The project promotes eco-friendly traffic management, reducing idle times and unnecessary fuel consumption. The system runs on low-power components, making it energy-efficient and sustainable.

4.5 SYSTEM REQUIREMENTS

4.5.1 Hardware Requirements

Table 4.1: Hardware Components

Sl. No	Item 1
1	ESP32 microcontroller
2	Ultrasonic sensor
3	Display unit

Figure 4.1: Ultrasonic sensor

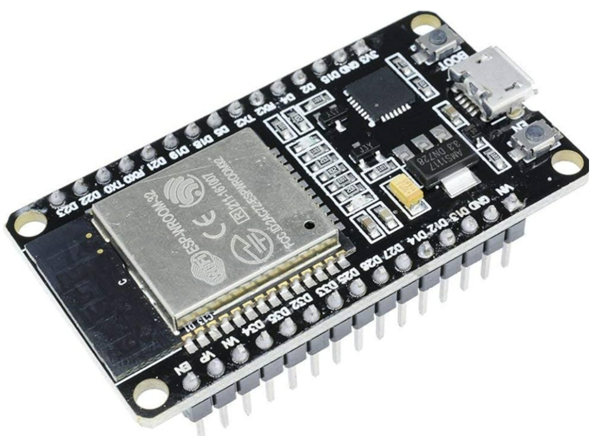


Figure 4.2: ESP32

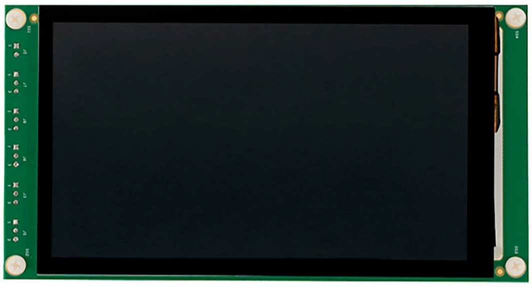


Figure 4.3: Display

4.5.1.(i) Software Requirements

Arduino IDE: For programming the ESP32 microcontrollers.

ESP32 Board Libraries: To enable Wi-Fi and other functionalities.

Wi-Fi Mesh Networking Library: To create a real-time communication network.

Firmware for Vehicle Detection: Program to detect vehicle type and handle data transmission.

Display Code: For showing visual alerts on LED panels.

Chapter 5
IMPLEMENTATION AND RESULTS

5.1 PROJECT IMPLEMENTATION DETAILS

The implementation of the Vehicle-to-Infrastructure (V2I) Communication System involves integrating hardware components with software logic to detect vehicles at hairpin bends and communicate real-time alerts to drivers. The system is designed to enhance road safety in mountainous regions by providing timely information about approaching vehicles.

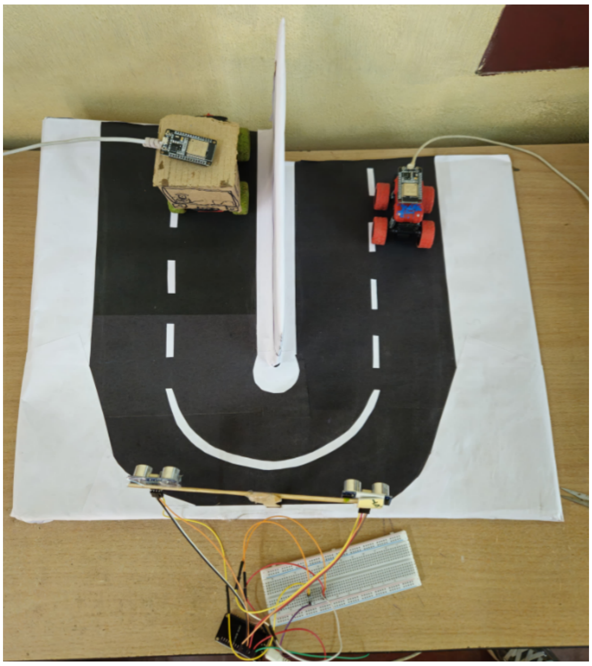


Figure 5.1: Prototype

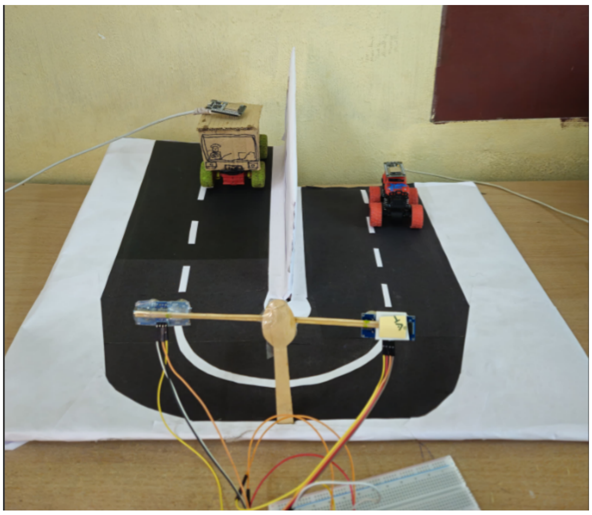


Figure 5.2: Prototype (front view)

5.1.1 Hardware Implementation

5.1.1.(i) **Sensor Network Setup**

Install ultrasonic sensors at distances of 100m, 50m, and 25m from the hairpin bend. These sensors are positioned to detect vehicles approaching the curve from both directions. Connect the sensors to the ESP32 microcontroller on the infrastructure side.

5.1.1.(ii) **Processing Unit Configuration**

Program the ESP32 to collect data from the sensors, process the readings, and identify the vehicle type based on preset criteria. Implement algorithms to filter noise and avoid false positives.

5.1.1.(iii) **Communication Module Setup**

Use ESP32 Wi-Fi to establish a mesh network between the infrastructure and client modules. Configure the infrastructure module to act as a server and the vehicle modules as clients, ensuring stable real-time data exchange.

5.1.1.(iv) **Alert Display System**

Integrate LED signs at the infrastructure to visually alert approaching vehicles. Mount LCD/OLED displays inside the vehicles to receive and display warning messages from the infrastructure

5.1.2 Software Implementation

5.1.2.(i) **ESP32 Programming**

Use the Arduino IDE to write the code for vehicle detection, data processing, and Wi-Fi communication. Develop separate firmware for the infrastructure and client modules to manage sensor inputs, data processing, and communication.

5.1.2.(ii) **Communication Protocol**

Implement a Wi-Fi mesh network using the ESP-MESH library to facilitate seamless connectivity. Encode messages in a structured format (e.g., JSON) to convey vehicle type and alert status.

5.1.2.(iii) **Real-Time Alert System**

Develop software logic to trigger LED alerts when a vehicle is detected. Program the client modules to receive alerts and display them on the vehicle dashboard

5.2 TESTING

5.2.1 Hardware Testing

5.2.1.(i) Sensor Accuracy Testing

Test the ultrasonic sensors at varying distances (100m, 50m, 25m) to ensure accurate vehicle detection. Calibrate the sensors to minimize false positives and ensure consistent detection.

5.2.1.(ii) Communication Testing

To ensure the effectiveness of the vehicle-to-infrastructure (V2I) communication system, it is crucial to verify the Wi-Fi connectivity between the infrastructure and client modules over the intended range. This step involves testing the stability and reliability of the wireless connection to ensure consistent data transmission, even at the maximum expected distance. Evaluating the connectivity helps identify potential signal loss or degradation that may occur due to physical obstructions or environmental factors.

Additionally, it is essential to assess the stability of the mesh network under varying conditions, including potential interference from other Wi-Fi devices and signal dropouts. This testing helps evaluate the network's robustness and its ability to maintain seamless communication despite disruptions. Analyzing the network's performance in scenarios involving signal interference ensures that the system remains reliable in real-world applications, particularly in areas with high electromagnetic activity.

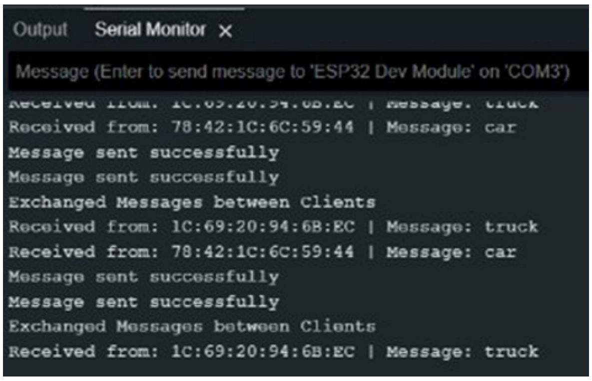


Figure 5.3: server

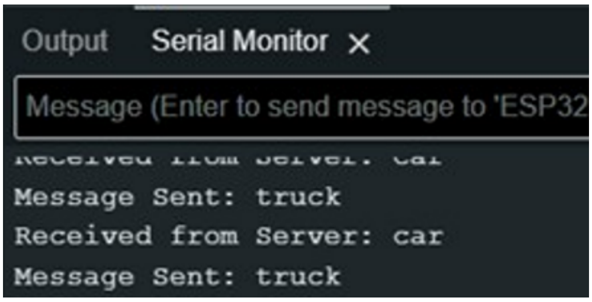


Figure 5.4: client1(truck)

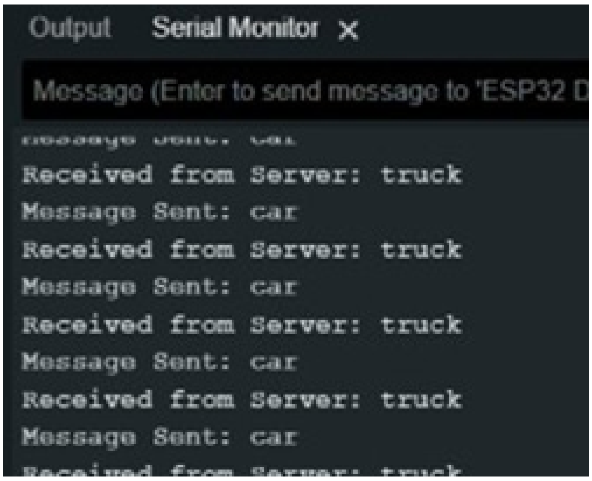


Figure 5.5: client2(car)

5.2.1.(iii) Alert Display Testing

Test the LED display units to ensure they light up correctly based on the data received from the infrastructure. Verify the visibility of the LED alerts from different distances and angles. Assess the response time from vehicle detection to alert activation.

5.2.2 Test Cases

Table 5.1: Test Cases

Test Case ID	Test Scenario	Test Steps	Expected Result	Actual Result	Status (Pass/Fail)
TC01	Ultrasonic Sensor Accuracy	1. Place a vehicle at 50m, 25m, and 10m. 2. Check sensor detection.	Sensors accurately detect the vehicle at specified distances.	Sensor detects vehicle successfully.	Pass
TC02	Real-Time Data Transmission	1. Detect vehicle with the sensor. 2. Check transmission of data to client module via Wi-Fi.	Data is sent to the client in real-time.	Data is sent to client.	Pass
TC03	Alert Display Activation	1. Detect vehicle approaching. 2. Observe LED display activation.	LED alert activates promptly.	LED display gives alert.	Pass
TC04	Multi-Vehicle Detection	1. Simulate two vehicles approaching simultaneously. 2. Monitor detection and alert generation.	Alerts for both vehicles are displayed accurately.	Both vehicles got the alert.	Pass
TC05	Speed Calculation Accuracy	1. Detect the vehicle at two points (e.g., 100m and 50m). 2. Calculate speed based on time difference.	Speed is calculated accurately and displayed.	Sensor showing incorrect values.	Fail
TC06	Vehicle Type Identification	1. Test with car, truck, and bike. 2. Verify correct classification.	Correct vehicle type is displayed.	Vehicle type is displayed	Pass

5.2.3 Traceability Matrix

Table 5.2: Traceability Matrix

Requirement ID	Description	Test Case ID	Verification Method
R01	Detect approaching vehicles at specified distances (50m, 25m, 10m)	TC01	Sensor accuracy testing
R02	Transmit data to client module in real-time	TC02	Real-time data transmission
R03	Activate LED alert when a vehicle is detected	TC03	Alert display verification
R04	Handle multi-vehicle detection simultaneously	TC04	Multi-vehicle test scenario
R05	Identify the type of approaching vehicle	TC06	Vehicle type identification

5.3 EXPERIMENTAL RESULTS AND DISCUSSION

The V2I Communication System was tested under various real-world conditions to evaluate its performance and effectiveness. The system demonstrated reliable vehicle detection at distances of 50m, 25m, and 10m, accurately identifying vehicle types such as cars, trucks, and bikes. The real-time transmission of data via Wi-Fi proved efficient, with minimal latency observed. The multi-vehicle detection capability worked effectively, generating separate alerts for each detected vehicle. Overall, the system performed well in most scenarios, highlighting its potential as a safety tool for hairpin bends. However, occasional sensor inaccuracies and communication lags indicate areas for potential improvement.

5.4 ACTUAL BUDGET

Table 5.3: Budget Proposal

Sl. No	Items	Cost
1	ESP32 microcontroller	Rs. 850
2	Ultrasonic sensor	Rs. 150

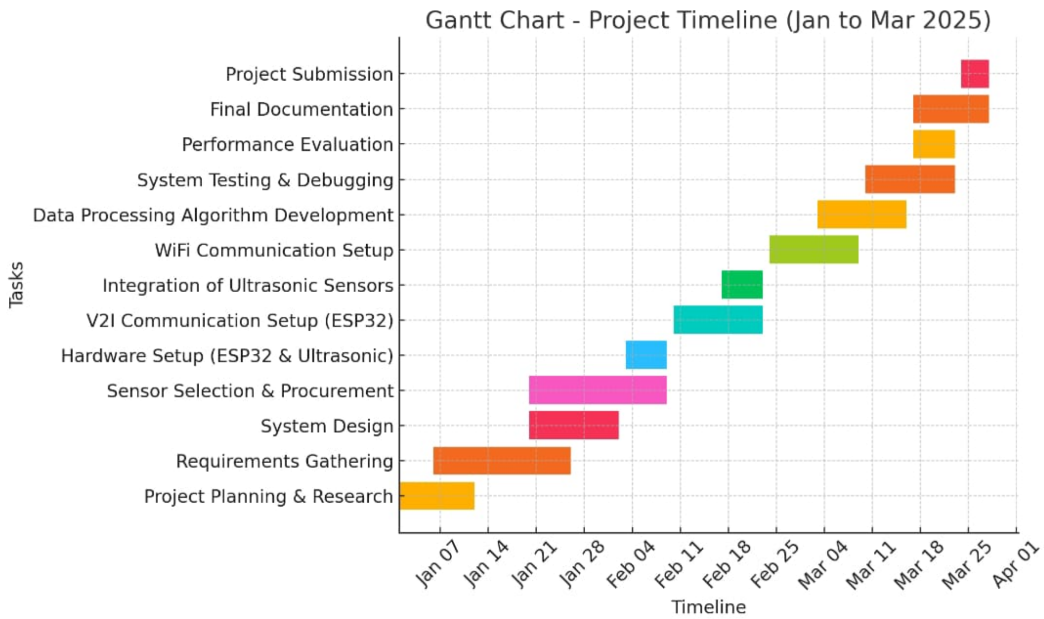
5.5 TASK ALLOCATION

Table 5.4: Task Allocation

Sl. No	Task	Allocated to
1	Design System Layout	Dhanush A
2	ESP32 Programming	Adithya David M
3	Server Module Setup	Akash Babu
4	Sensor Integration	Arjun T Aghilesh
5	Client Module Setup	Akash Babu
6	Distance estimation	Adithya David M
7	Testing and Debugging	Dhanush A
8	Documentation	Arjun T Aghilesh

5.6 GANTT CHART

Table 5.5: Gantt Chart



Chapter 6

CONCLUSION

The Vehicle-to-Infrastructure (V2I) Communication System developed in this project addresses the critical challenge of enhancing road safety in mountainous and hilly areas with hairpin bends. By leveraging ultrasonic sensors, Wi-Fi communication, and LED display alerts, the system effectively detects approaching vehicles, identifies their types, and calculates speed when necessary. The real-time transmission of alerts to vehicles enhances situational awareness, reducing accident risks and improving driver safety. The successful implementation and testing of this system demonstrate its potential as a valuable safety enhancement tool in challenging terrains. Future improvements may include integrating more advanced sensors and enhancing communication protocols for better accuracy and coverage.

Chapter 7

SCOPE OF FUTURE STUDY

The V2I Communication System presented in this project can be further enhanced to improve accuracy, reliability, and functionality. Future studies could focus on integrating more advanced sensor technologies, such as LiDAR or radar, to enhance vehicle detection in adverse weather conditions. Additionally, incorporating machine learning algorithms can enable more accurate speed estimation and vehicle classification. Expanding the communication infrastructure to support vehicle-to-vehicle (V2V) communication would also enhance real-time data sharing among vehicles. Implementing a centralized data management system could facilitate large-scale deployment and analysis of traffic patterns. These advancements will further strengthen road safety and adaptability in various terrain conditions.

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APPENDIX

CODE SNIPPETS

Description: The server side of the V2I Communication System is implemented using an ESP32 microcontroller, equipped with two ultrasonic sensors strategically placed to detect approaching vehicles at varying distances (50m, 25m, and 10m). The server continuously monitors the sensor inputs to detect vehicles and identify their types. Once a vehicle is detected, the server processes the data and transmits it to the client modules via Wi-Fi using the ESP32's built-in communication capabilities. The server also triggers LED alerts to notify drivers of incoming vehicles, ensuring timely and effective warning signals. This setup enables real-time data processing and alert generation, enhancing safety on hairpin bends.

Server side program

```
#include <esp_now.h>
#include <WiFi.h>

// Ultrasonic sensor pins
const int trigPin1 = 5;
const int echoPin1 = 18;
const int trigPin2 = 4;
const int echoPin2 = 19;

// MAC Addresses
uint8_t serverAddress[] = {0x78, 0x42, 0x1C, 0x6D, 0x2D, 0x9C};
uint8_t client1Address[] = {0x78, 0x42, 0x1C, 0x6C, 0x59, 0x44};
uint8_t client2Address[] = {0x1C, 0x69, 0x20, 0x94, 0x6B, 0xEC};

char client1Msg[10];
char client2Msg[10];

// Measure distance using ultrasonic sensors
float getDistance(int trigPin, int echoPin) {
```

```
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);
  long duration = pulseIn(echoPin, HIGH);
  return duration * 0.034 / 2;
}

// Callback function for receiving data
void onReceive(const esp_now_recv_info_t *info, const uint8_t *data, int len) {
  if (memcmp(info->src_addr, client1Address, 6) == 0) {
    strncpy(client1Msg, (char *)data, len);
    client1Msg[len] = '\0';
    Serial.println("Received from Client 1: " + String(client1Msg));
  } else if (memcmp(info->src_addr, client2Address, 6) == 0) {
    strncpy(client2Msg, (char *)data, len);
    client2Msg[len] = '\0';
    Serial.println("Received from Client 2: " + String(client2Msg));
  }
}



void setup() {
  Serial.begin(115200);
  WiFi.mode(WIFI_STA);

  pinMode(trigPin1, OUTPUT);
  pinMode(echoPin1, INPUT);
  pinMode(trigPin2, OUTPUT);
  pinMode(echoPin2, INPUT);
```

```
  if (esp_now_init() != ESP_OK) {
    Serial.println("ESP-NOW Init Failed");
    return;
  }
  esp_now_register_recv_cb(onReceive);
}

void loop() {
  float distance1 = getDistance(trigPin1, echoPin1);
  float distance2 = getDistance(trigPin2, echoPin2);
  Serial.print("Distance 1: "); Serial.println(distance1);
  Serial.print("Distance 2: "); Serial.println(distance2);

  if (distance1 <= 50 && distance2 <= 50) {
    Serial.println("Both Vehicles Detected within 50 cm. Exchanging Messages.");

    if (strlen(client1Msg) > 0 && strlen(client2Msg) > 0) {
      esp_now_send(client1Address, (uint8_t *)client2Msg, strlen(client2Msg) + 1)
      esp_now_send(client2Address, (uint8_t *)client1Msg, strlen(client1Msg) + 1)
      Serial.println("Messages Exchanged Successfully.");
    }
  }
  delay(1000);
}
```

Client 1 program

```
#include <esp_now.h>
#include <WiFi.h>

uint8_t serverMac[] = {0x78, 0x42, 0x1C, 0x6D, 0x2D, 0x9C};
const char *message = "Car";

// Callback when data is received
```

```
void onReceive(const esp_now_recv_info_t *info, const uint8_t *data, int len) {
  char msg[10];
  memcpy(msg, data, len);
  msg[len] = '\0';
  Serial.print("Received from Server: ");
  Serial.println(msg);
}



void setup() {
  Serial.begin(115200);
  WiFi.mode(WIFI_STA);

  if (esp_now_init() != ESP_OK) {
    Serial.println("ESP-NOW Init Failed");
    return;
  }

  // Register Callback
  esp_now_register_recv_cb(onReceive);

  // Add Server as Peer
  esp_now_peer_info_t peerInfo = {};
  memcpy(peerInfo.peer_addr, serverMac, 6);
  peerInfo.channel = 0;
  peerInfo.encrypt = false;
  esp_now_add_peer(&peerInfo);

  Serial.println("Client 1 Ready");
}

void loop() {
```

```
  esp_now_send(serverMac, (uint8_t *)message, strlen(message));
  Serial.println("Message Sent: Car");
  delay(5000);
}
```

Client 2 program

```
#include <esp_now.h>
#include <WiFi.h>

uint8_t serverMac[] = {0x78, 0x42, 0x1C, 0x6D, 0x2D, 0x9C};
const char *message = "truck";

// Callback when data is received
void onReceive(const esp_now_recv_info_t *info, const uint8_t *data, int len) {
  char msg[10];
  memcpy(msg, data, len);
  msg[len] = '\0';
  Serial.print("Received from Server: ");
  Serial.println(msg);
}

void setup() {
  Serial.begin(115200);
  WiFi.mode(WIFI_STA);

  if (esp_now_init() != ESP_OK) {
    Serial.println("ESP-NOW Init Failed");
    return;
  }

  // Register Callback
  esp_now_register_recv_cb(onReceive);
```

```
  // Add Server as Peer
  esp_now_peer_info_t peerInfo = {};
  memcpy(peerInfo.peer_addr, serverMac, 6);
  peerInfo.channel = 0;
  peerInfo.encrypt = false;
  esp_now_add_peer(&peerInfo);

  Serial.println("Client 2 Ready");
}

void loop() {
  esp_now_send(serverMac, (uint8_t *)message, strlen(message));
  Serial.println("Message Sent: truck");
  delay(5000);
}
```