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IOT-Enabled Smart Blind Curve Collision Avoidance System using Hybrid Sensor Fusion and Solar Energy for Mountain Roads

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Abstract—

Road accidents in mountainous and curved road regions continue to increase due to poor visibility, blind turns, and delayed driver response. Conventional traffic warning systems are often ineffective in remote areas because of limited infrastructure and lack of real-time monitoring. This paper proposes an IoT-enabled smart blind curve collision avoidance system that combines radar sensing, ultrasonic detection, GSM communication, and solar-powered embedded control to improve road safety in hilly environments. The proposed system utilizes hybrid sensor fusion techniques for accurate vehicle detection under varying weather and visibility conditions. An ATmega328P microcontroller processes real-

INTRODUCTION

Transportation safety remains one of the major global concerns due to the increasing number of road accidents occurring every year. In mountainous and ghat road regions, accidents are more frequent because drivers face sharp curves, narrow roads, poor lighting conditions, fog, rainfall, and limited visibility. Blind turns prevent drivers from observing approaching vehicles from the opposite side, resulting in severe collisions and traffic congestion.

Existing road safety systems mainly depend on signboards, convex mirrors, or manual traffic control mechanisms, which are insufficient during low visibility or high-speed conditions. Advanced Driver Assistance Systems (ADAS) used in modern vehicles improve safety but are often expensive and unavailable in rural or hilly regions. Therefore, there is a need for an intelligent, low-cost, and energy-efficient system capable of providing real-time warnings in remote mountain environments.

time sensor data and activates warning indicators, buzzer alerts, and remote GSM notifications whenever a vehicle approaches a blind curve. A piezoelectric sensor is additionally integrated for landslide and vibration monitoring. Experimental evaluation demonstrates a detection accuracy of 98% within a range of 2–10 meters, with an average response delay below 1.5 seconds. The solar-powered design ensures energy-efficient operation in remote locations without dependency on grid power. The proposed system provides a low-cost, scalable, and reliable solution for educing collision risks on mountain roads and improving intelligent transportation safety systems.

Keywords— AtMega328P, GSM, ADAS, Sensor Fusion.

The proposed research introduces a smart blind curve monitoring system based on hybrid radar and ultrasonic sensing combined with GSM communication and solar energy harvesting. The system continuously monitors vehicle movement near blind turns and provides early alerts through LED indicators and buzzer signals. The integration of GSM technology enables remote warning transmission even in areas with limited internet connectivity. Additionally, solar-powered operation ensures uninterrupted functionality in isolated locations.

The major contributions of this research include:

- Development of a hybrid sensor fusion-based vehicle detection mechanism
- Real-time blind curve monitoring using embedded processing
- GSM-enabled remote warning communication
- Solar-powered energy-efficient operation
- Landslide and vibration monitoring using piezoelectric sensing
- Experimental validation under simulated hilly road conditions.

I. LITERATURE REVIEW

Blind spot detection and collision avoidance systems have become important components in intelligent transportation systems, especially for mountainous and curved road environments where driver visibility is significantly reduced. Radar-based vehicle monitoring systems are widely used because they provide reliable object detection under adverse weather conditions such as fog, rainfall, and low-light environments. Kim et al. developed a radar-assisted blind spot monitoring system that improved vehicle detection reliability and reduced collision probability in dynamic traffic environments [1]. Millimeter-wave radar technology has also been adopted in advanced driver assistance systems (ADAS) due to its long-range detection capability and high-speed object tracking performance.

Texas Instruments introduced an mmWave radar-based blind spot monitoring reference design capable of accurately detecting vehicles up to 120 meters away under complex road conditions [2].

Ultrasonic sensor-based detection systems are commonly used as low-cost alternatives for obstacle detection and short-range monitoring applications. These systems calculate distance using time-of-flight principles and are effective for narrow roads and compact vehicle systems [3]. Researchers have also integrated radar and ultrasonic sensors together to improve detection accuracy and minimize false alarms caused by environmental noise and signal reflection [4].

Recent advancements in artificial intelligence and deep learning have enabled the implementation of convolutional neural network (CNN)-based blind spot detection systems. These systems analyze vehicle movement patterns and improve classification accuracy in complex traffic conditions [5]. However, AI-based systems require high computational resources and are often unsuitable for low-cost rural deployment.

Embedded systems using Arduino and ATmega microcontrollers are widely used in intelligent transportation applications because of their low power consumption, flexibility, and ease of sensor integration [6]. GSM-enabled communication modules are also increasingly integrated into accident prevention systems to provide real-time alerts and emergency notifications in remote regions where internet connectivity is limited [7]. Researchers have additionally explored renewable-energy-powered transportation monitoring systems.

Solar-powered embedded systems provide sustainable operation in isolated mountainous environments and reduce dependency on external electrical infrastructure [8].

Piezoelectric sensors have also been investigated for vibration and landslide detection in hilly terrains, enabling early warning generation during slope instability events [9].

IoT-based intelligent transportation systems have recently gained significant attention due to their capability for remote monitoring, cloud integration, and real-time communication [10]. However, most existing systems focus either on urban traffic management or vehicle-mounted safety systems rather than roadside accident prevention in mountain regions. The literature survey indicates that hybrid sensor fusion, embedded processing, GSM communication, and renewable energy integration are key technologies for developing efficient accident prevention systems. However, limited research has addressed the combined implementation of radar sensing, ultrasonic detection, landslide monitoring, GSM communication, and solar-powered operation in a single integrated platform for blind curve safety applications. The proposed research attempts to bridge this gap by developing a low-cost and energy-efficient smart blind curve collision avoidance system specifically designed for hilly roads.

II. METHODOLOGY

The proposed smart blind curve collision avoidance system continuously monitors vehicle movement on both sides of a blind road section using radar and ultrasonic sensors. The sensor data is sent to the ATmega328P microcontroller, which analyzes the presence of approaching vehicles and detects abnormal ground vibrations through the vibration sensor. Based on the received information, the controller activates appropriate warning devices such as the red LED, green LED, buzzer, and GSM module to alert drivers and monitoring personnel about potential hazards. The LCD display provides real-time system status, while the gate control module can restrict vehicle entry during dangerous situations such as vehicle

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congestion or landslide occurrence. A dedicated power supply unit ensures uninterrupted operation of all modules, enabling reliable accident prevention and improved road safety in hilly and blind curve regions.

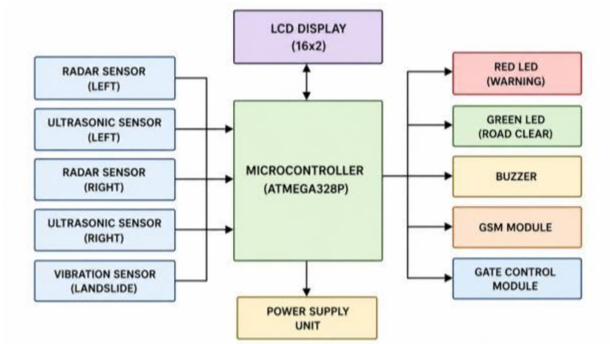

Figure 1. Block Diagram of Proposed system

III. MATHEMATICAL MODEL

The ultrasonic distance measurement is calculated using:
$d=(v\times t)/2$ where:
d = measured distance

• v = speed of sound

• t = echo return time

Radar signal reflection intensity is represented as:

$d=\frac{v\times t}{2}$ where:
• (P_r) = received power

• (P_t) = transmitted power

• (G_t, G_r) = antenna gains

• (R) = target distance

• () = radar cross section Detection accuracy is calculated as: $P_r=(P_t G_t G_r \lambda^2 \sigma)/((4\pi)^3 R^4)$

IV. EXPERIMENTAL RESULTS AND DISCUSSION

The prototype was tested under simulated mountainous road conditions including:

• Curved road sections

• Fog conditions

• Variable vehicle speeds

• Day and night operation.

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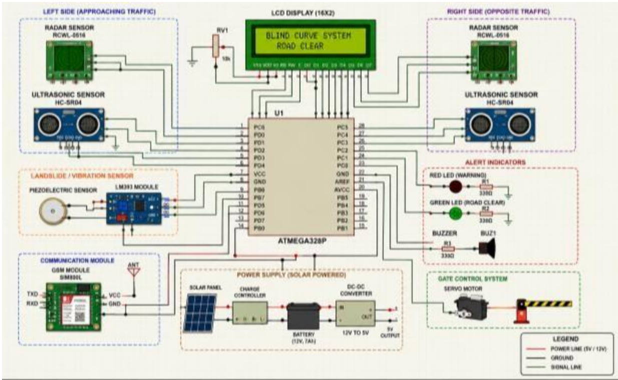

Figure 2. Circuit Diagram

Figure no. 2 represents the Proteus simulation circuit diagram. It is implemented and test the working of the this circuit and it is work accurately the test results are as follows,

5.1Detection Accuracy

The hybrid sensor fusion system achieved improved performance compared to single-sensor systems.

Distance (m)	Detection Accuracy (%)
2	98
5	97
10	96
15	93
20	91

The radar-ultrasonic fusion significantly reduced false detections caused by environmental noise and surface reflections.

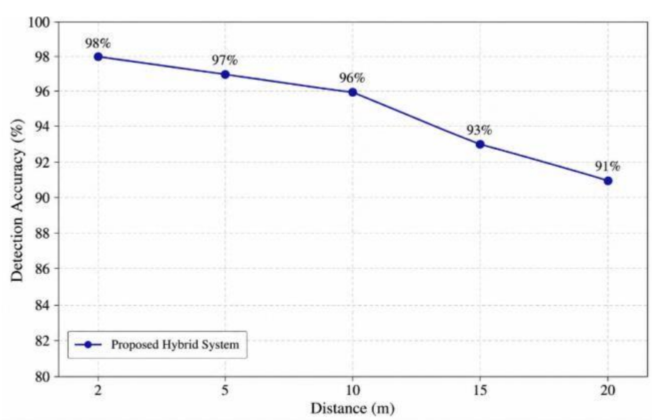

Figure 3. Accuracy Vs Distance

5.2Response Time Analysis

Table I: Distance Vs System Response Time

Distance (m)	System Response Time (s)
2	0.8
5	0.9
10	1.1
15	1.3
20	1.5

The system maintained near real-time operation with response delays below 1.5 seconds, making it suitable for practical road safety applications.

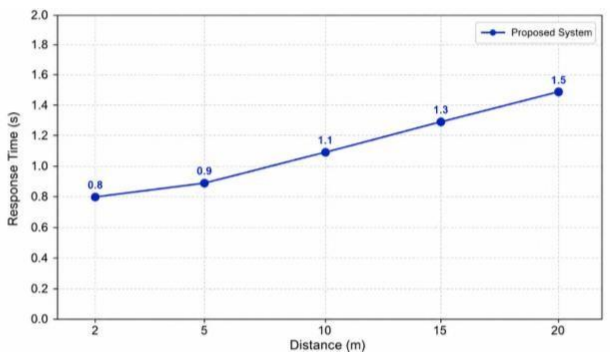

Figure 4. Accuracy Vs Response Time

5.3Power Consumption Analysis

Table 2: Operating Mode Vs Power Consumption

Operating Mode	Power Consumption (W)
Idle Mode	1.8
Detection Mode	3.2
GSM Transmission	4.5

The solar-powered design provided stable operation for continuous monitoring without external electrical infrastructure.

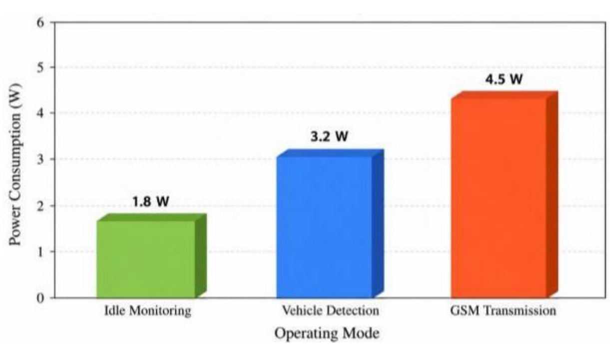

Figure 5. Power Consumption Analysis

5.4Comparative Performance

Table 3: Power Efficiency

System Type	Accuracy (%)	Cost	Power Efficiency
Ultrasonic Only	86	Low	Medium
Radar Only	92	High	Medium
Proposed Hybrid System	98	Moderate	High

The proposed system outperformed conventional single-sensor approaches in terms of detection accuracy and operational reliability.

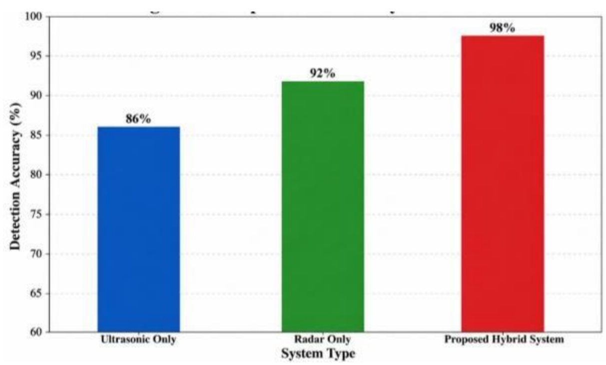

Figure 6. Comparative Performace

The Figure 7 is the actual implementation of the proposed system in that there is mountain at the center and hilly road in made in oval shape near the mountains whenever there is vehicle in range it will generate an alarm.

Figure 7. Actual Implementation

V. CONCLUSION

This research presented an IoT-enabled smart blind curve collision avoidance system designed specifically for mountain and hilly road environments. The integration of radar sensors, ultrasonic sensing, GSM communication, and solar-powered embedded control significantly improved road safety by providing real-time vehicle detection and warning generation.

Experimental analysis demonstrated high detection accuracy, low response time, and energy-efficient operation under challenging environmental conditions. The proposed system offers a practical and scalable solution for deployment in accident-prone mountainous regions where conventional traffic monitoring infrastructure is unavailable. Future work may include artificial intelligence-based traffic prediction, cloud-based monitoring platforms, and vehicle-to-vehicle communication technologies to further enhance intelligent transportation safety systems.

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