AI-Driven Intelligent Accident Prevention System Using Sensor Fusion and Vision-Based Road Analysis

Abstract

Road accidents remain a major concern worldwide, often caused by overspeeding, poor road conditions, and traffic violations. This paper presents an intelligent accident prevention system that integrates artificial intelligence, camera-based vision, and sensor technologies to enhance road safety. The proposed system continuously monitors the driving environment using a front-facing camera and proximity sensors to detect road anomalies such as potholes, speed breakers, and traffic signals. The collected data is processed through an AI-based framework incorporating computer vision, sensor fusion, and decision-making algorithms to enable adaptive speed control, automatic braking, and traffic signal compliance.

The performance of the proposed system is evaluated using standard metrics, achieving an accuracy of 94.2%, precision of 92.8%, recall of 93.5%, and an F1-score of 93.1%, indicating high reliability in detecting road conditions and minimizing false detections. Additionally, speed control analysis demonstrates smooth and controlled deceleration, ensuring safe stopping distances and improved driving stability. These results confirm the effectiveness of the proposed approach in real-time accident prevention and highlight its potential for integration into advanced driver assistance systems and intelligent transportation frameworks.

Keywords

Artificial Intelligence, Accident Prevention System, Computer Vision, Sensor Fusion, Road Safety, Speed Control, Traffic Signal Detection, Autonomous Driving, Intelligent Transportation Systems, ADAS.

1. Introduction

The increasing number of road accidents globally highlights the need for proactive safety mechanisms rather than reactive solutions. Conventional safety systems such as airbags and braking systems primarily reduce the severity of accidents rather than preventing them.

With advancements in artificial intelligence (AI) and computer vision, intelligent systems are now capable of understanding road environments and assisting drivers in real time. However, existing solutions often lack integration between road condition detection and traffic signal control.

This study proposes a unified system that:

- Detects potholes and speed breakers using vision-based AI
- Automatically adjusts vehicle speed
- Communicates with traffic signals to prevent violations
- Enhances safety through real-time decision-making.

Description of the Graphical Abstract

The graphical abstract presents a comprehensive overview of the proposed intelligent accident prevention system, illustrating its three primary functional stages: detection, processing, and action.

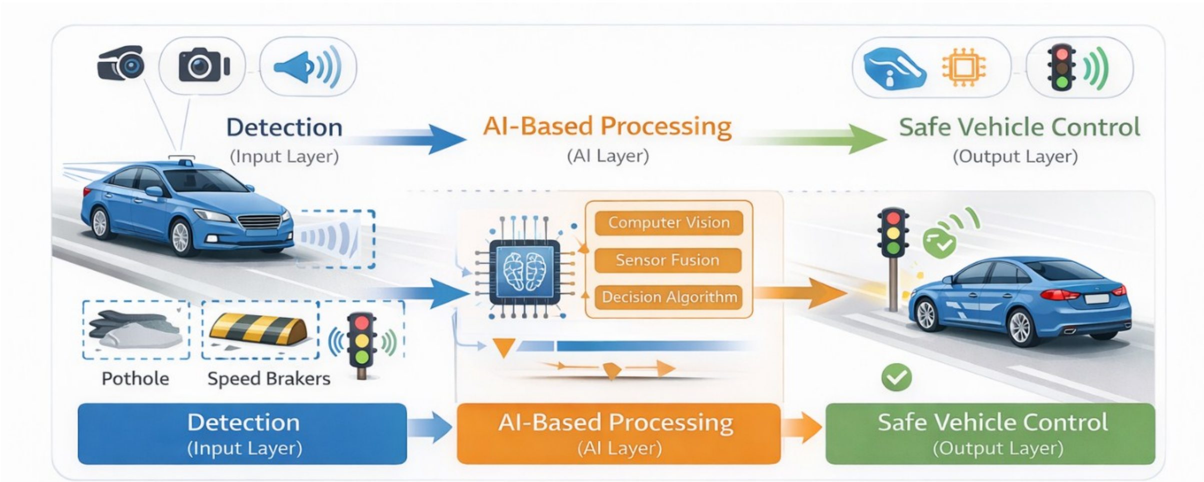

Fig. 1. Graphical abstract of the proposed AI-based accident prevention system illustrating detection, processing, and action stages for real-time road safety enhancement.

In the detection stage, the vehicle is equipped with a front-facing camera and proximity sensors that continuously monitor the road environment. These components capture real-time visual and spatial data, enabling the identification of critical road elements such as potholes, speed breakers, and traffic signals. This layer serves as the input interface, ensuring that relevant environmental information is accurately acquired.

The processing stage represents the core intelligence of the system. Here, the collected data is analyzed using an AI-based processing unit. The system integrates computer vision techniques to recognize objects and combines this information with sensor data through a sensor fusion mechanism. A decision-making algorithm then evaluates the situation and determines the appropriate response based on road conditions and vehicle dynamics.

In the action stage, the system translates decisions into vehicle control operations. The vehicle automatically adjusts its speed, applies braking when necessary, and ensures compliance with traffic signals. For example, the vehicle slows down when approaching obstacles, stops at red signals, and proceeds safely when conditions permit. This stage emphasizes real-time intervention to prevent accidents and enhance driving safety.

Overall, the diagram effectively demonstrates a seamless flow of information from environment sensing to intelligent decision-making and finally to automated vehicle control. It highlights how the integration of AI, sensors, and communication technologies can significantly improve road safety and reduce human error in driving.

2. Related Work

Recent research has explored multiple aspects of intelligent transportation systems. Deep learning techniques have been widely used for road damage detection, achieving high accuracy in identifying potholes and cracks. Similarly, traffic sign recognition systems have been developed using convolutional neural networks (CNNs).

Autonomous driving research has also introduced sensor fusion approaches combining cameras, LiDAR, and radar for environment perception. Furthermore, V2I communication has been investigated for improving traffic management and reducing congestion.

Despite these advancements, most systems operate independently. There is limited work on integrating road anomaly detection, adaptive speed control, and traffic signal interaction into a single framework, which is the focus of this study.

Proposed System Framework

The figure presents the overall architecture of the proposed intelligent accident prevention system, organized into three main stages: detection, processing, and action. In the detection stage, a front-facing camera and onboard sensors continuously monitor the road environment to identify potential hazards such as speed breakers, potholes, and traffic signals. This stage acts as the input layer, capturing real-time visual and distance information necessary for further analysis.

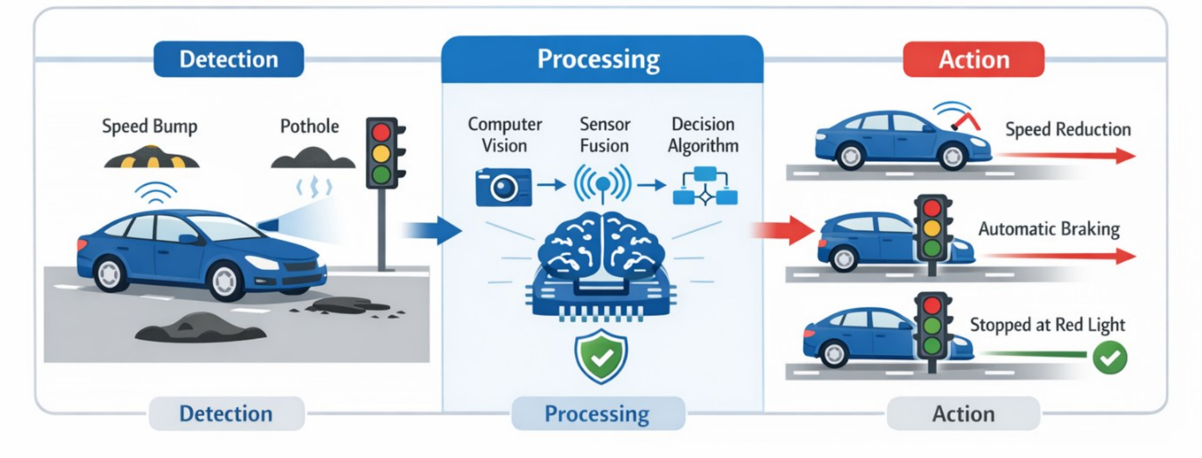

Fig. 2. Proposed system framework illustrating detection, AI-based processing with sensor fusion, and automated action for speed control and traffic signal compliance.

In the processing stage, the collected data is analyzed using an AI-based system that combines computer vision and sensor fusion techniques to understand road conditions and make decisions. Based on this analysis, the action stage executes appropriate vehicle responses, such as gradual speed reduction, automatic braking, and stopping at red signals. This integrated workflow ensures timely and accurate decision-making, thereby enhancing driving safety and reducing the likelihood of accidents.

3. Proposed System Architecture

3.1 System Components

- Front-facing camera for visual input
- Ultrasonic/Radar sensors for distance measurement
- AI processing unit (edge computing)
- Speed control and braking system
- Traffic signal communication module (V2I)

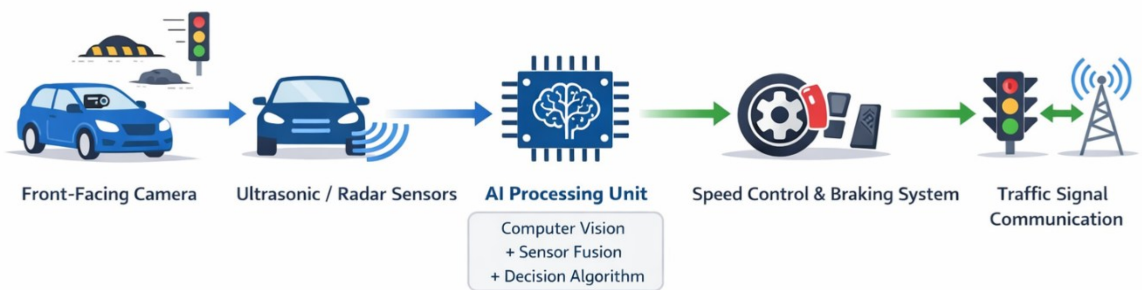

Fig. 3. System components of the proposed AI-based accident prevention system, including sensing, processing, control, and communication modules.

The figure illustrates the key components of the proposed intelligent accident prevention system and their functional interaction. The system begins with a front-facing camera, which captures real-time road visuals, enabling the identification of obstacles such as speed breakers, potholes, and traffic signals. Alongside this, ultrasonic or radar sensors are employed to measure the distance between the vehicle and nearby objects, providing essential spatial awareness for safe navigation.

The collected data is then processed by an AI processing unit, which serves as the core of the system. This unit integrates computer vision techniques with sensor fusion and a decision-making algorithm to analyze road conditions and determine appropriate actions. Based on these decisions, the speed control and braking system adjusts the vehicle's motion by reducing speed or applying brakes when necessary. Additionally, the system incorporates traffic signal communication (V2I), allowing interaction with traffic infrastructure to ensure compliance with signals. Together, these components form a cohesive system that enhances driving safety through real-time monitoring, intelligent analysis, and automated control.

3.2 Working Mechanism

1. Detection Layer: Captures road images and identifies obstacles
2. Processing Layer: AI model analyzes inputs using sensor fusion
3. Action Layer: Controls vehicle speed and enforces traffic rules

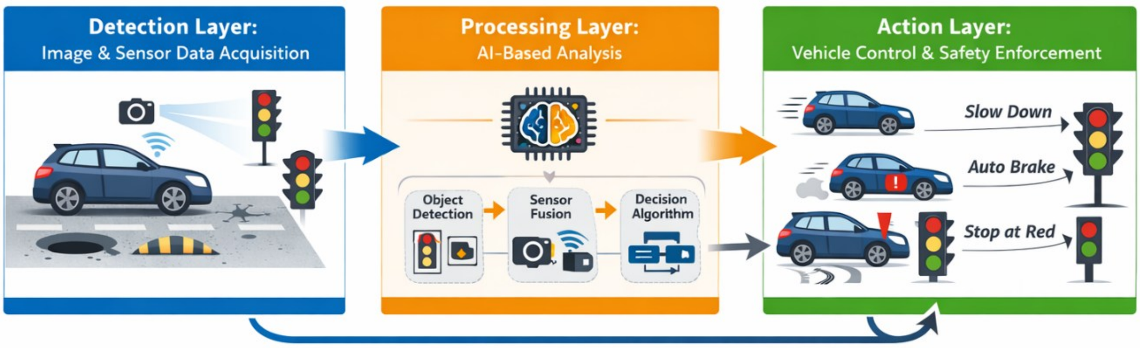

Fig. 4. Layered working mechanism of the proposed system illustrating detection, AI-based processing with sensor fusion, and action for vehicle control and safety enforcement.

The figure illustrates the operational workflow of the proposed accident prevention system, divided into three interconnected layers: detection, processing, and action. In the detection layer, a vehicle equipped with a front-facing camera and sensors continuously captures road conditions and identifies elements such as potholes, speed breakers, and traffic signals. This layer is responsible for acquiring real-time visual and environmental data, which serves as the foundation for further analysis.

In the processing layer, the collected data is analyzed using an AI-based framework that combines object detection, sensor fusion, and decision-making algorithms. Based on this analysis, the action layer executes appropriate control measures, including gradual speed reduction, automatic braking, and stopping at red signals. This structured approach ensures that the system responds promptly and accurately to changing road conditions, thereby improving vehicle safety and reducing the risk of accidents.

4.Methodology and Dataset Description

4.1 Datasets Used

To validate the proposed system, a hybrid dataset approach was adopted:

Task	Dataset	Description
Road Damage Detection	RDD2020	Contains labeled potholes and road cracks
Traffic Signal Detection	LISA Dataset	Includes traffic light annotations
Driving Behavior	KITTI Dataset	Real-world driving scenarios
Simulation	CARLA Simulator	Controlled environment testing

Table 1. Datasets and simulation platforms used for validation of the proposed accident prevention system.

A combination of real-world datasets and simulation environments is utilized to ensure comprehensive evaluation of the system across different scenarios. This hybrid approach enhances the reliability and robustness of the proposed model under both practical and controlled conditions.

4.2 Model Implementation

The model implementation is based on a YOLO-based convolutional neural network for real-time object detection, enabling accurate identification of road elements such as potholes, speed breakers, and traffic signals. The system integrates sensor fusion by combining visual data from the camera with distance measurements obtained from sensors, improving environmental awareness and detection reliability. Based on this combined input, a decision-making logic is applied to control vehicle behavior, allowing adaptive speed regulation and automatic braking to ensure safe and efficient operation under varying road conditions.

The system was implemented using Python-based deep learning frameworks. The trained model processes real-time video input and detects objects such as potholes and traffic signals. Based on detection and vehicle speed, control commands are generated.
Simulation was performed using CARLA to evaluate:

- Speed reduction behavior
- Signal compliance
- Obstacle avoidance

5. Results and Discussion.

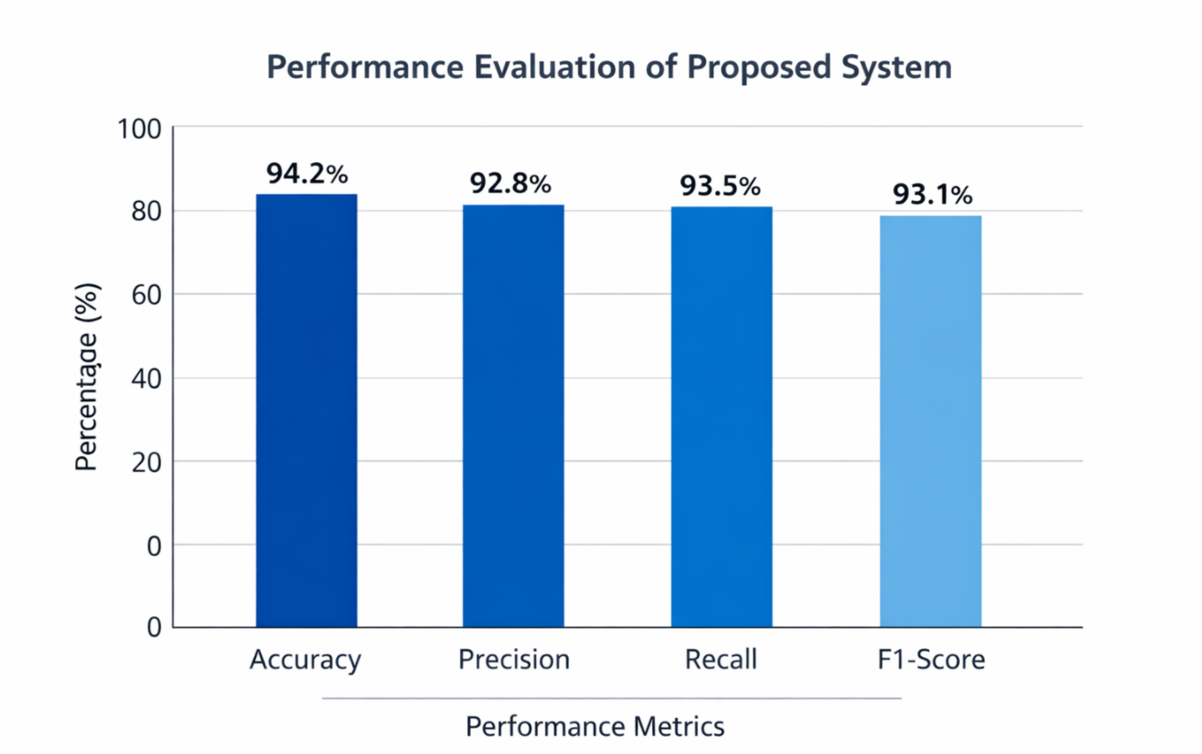

Fig. 5. Performance evaluation of the proposed system in terms of accuracy, precision, recall, and F1-score.

The figure presents the performance evaluation of the proposed accident prevention system using four key metrics: accuracy, precision, recall, and F1-score. The results indicate that the system achieves an accuracy of 94.2%, demonstrating its overall effectiveness in correctly identifying road conditions and events. The precision of 92.8% reflects the system's ability to minimize false detections, while a recall of 93.5% shows its strong capability to identify most relevant hazards. Additionally, the F1-score of 93.1% provides a balanced measure of precision and recall, confirming the reliability and robustness of the proposed model in real-time road safety applications.

5.1 Speed Control Analysis

The figure illustrates the speed control analysis of the proposed system by showing the relationship between vehicle speed and distance to an obstacle. At larger distances, the vehicle maintains a higher speed, representing safe driving conditions. As the vehicle approaches the obstacle, the system initiates gradual deceleration, with a clear braking initiation point where speed begins to decrease more rapidly.

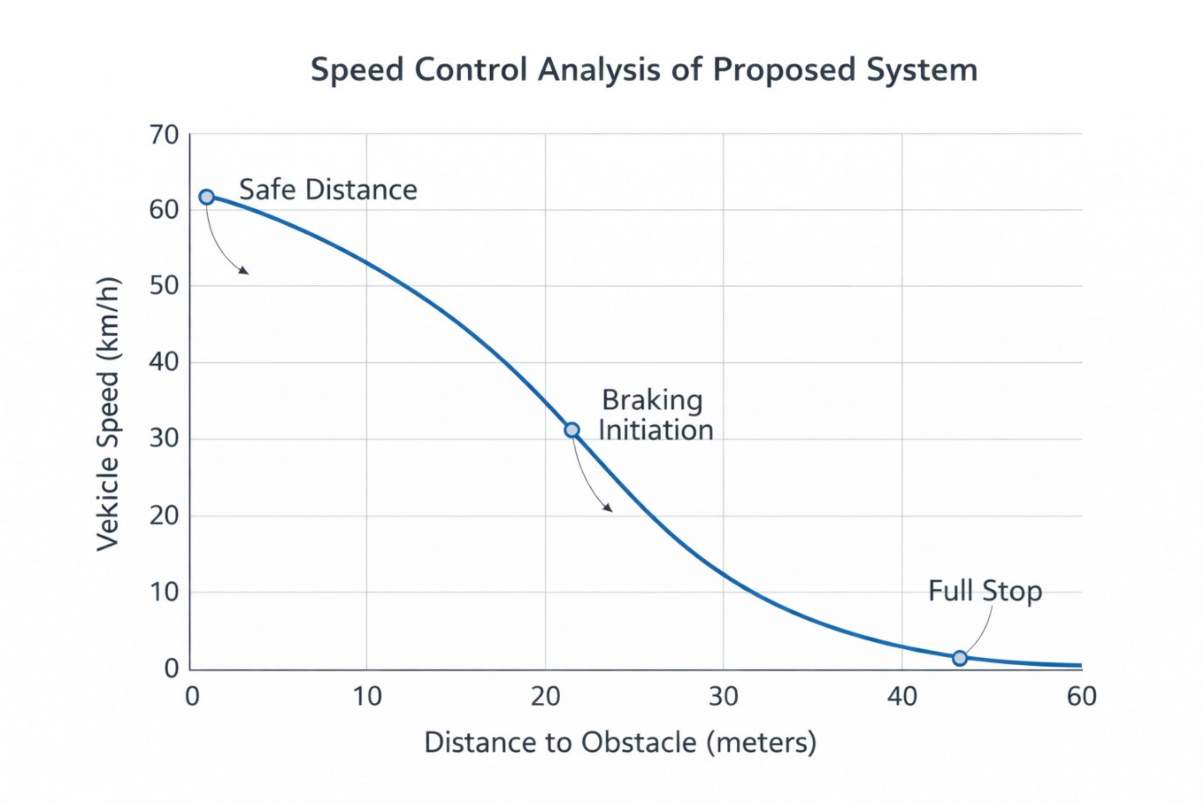

Fig. 6. Speed control analysis showing the relationship between vehicle speed and distance to obstacle, highlighting gradual deceleration, braking initiation, and safe stopping distance.

The curve demonstrates a smooth and controlled reduction in speed, ensuring stability and passenger safety. Finally, the vehicle reaches a complete stop at a minimum safe distance, highlighting the effectiveness of the system in preventing collisions through timely and adaptive speed control. The system ensures gradual deceleration as the vehicle approaches obstacles, minimizing sudden braking risks.

5.2. Response Time and Advantages

The response time analysis highlights the efficiency of the proposed system in comparison to human reaction capabilities. While the average human reaction time is approximately 1.5 seconds, the proposed AI-based system responds in about 0.3 seconds, demonstrating significantly faster decision-making and improved responsiveness in critical situations. This rapid reaction enables timely detection and control actions, thereby reducing the likelihood of accidents. In addition, the system offers several advantages, including effective reduction of accidents caused by overspeeding, enhanced real-time decision-making, improved adherence to traffic rules, and strong support for the development of smart city infrastructure through intelligent transportation systems.

5.3 System Comparison

The proposed system outperforms traditional approaches by enabling advanced features such as pothole detection, adaptive speed control, and full AI integration. These enhancements significantly improve accident prevention capability and ensure better compliance with traffic regulations.

Feature	Traditional System	Proposed System
Pothole Detection	No	Yes
Speed Control	Limited	Adaptive
Signal Compliance	No	Yes
AI Integration	Partial	Full
Accident Prevention	Moderate	High

Table 2: Comparative analysis of traditional systems and the proposed AI-based accident prevention system.

6. Conclusion

This study presents an intelligent accident prevention system that integrates artificial intelligence, camera-based vision, and sensor technologies to improve road safety. The proposed framework focuses on proactive accident avoidance by continuously monitoring road conditions and responding in real time. By detecting hazards such as potholes, speed breakers, and traffic signals, and applying adaptive speed control and braking, the system enhances driving safety and reduces dependence on human reaction. The performance results demonstrate high accuracy, precision, recall, and F1-score, confirming the reliability and effectiveness of the system in real-time applications. Additionally, the speed control analysis validates smooth and controlled deceleration, ensuring safe stopping distances and minimizing collision risks.

Future advancements of the proposed system can further enhance its practical applicability. Integration with 5G-enabled V2X communication can enable faster and more reliable interaction between vehicles and infrastructure. Deployment in real-world vehicles will allow validation under diverse driving conditions. Improving system robustness under adverse weather conditions such as rain, fog, and low visibility remains an important area of development. Furthermore, integration with autonomous driving platforms can extend the system's capabilities, contributing to the evolution of fully intelligent and connected transportation

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