An AI-Driven Unified Model for Traffic Sign and Lane Detection in Dynamic Road Environments

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Abstract— **This system is designed to enhance road safety by providing real-time driver assistance through the integration of lane detection, seat safety monitoring, and traffic sign recognition technologies. A camera mounted on the vehicle continuously captures road images, which are processed using advanced computer vision and deep learning techniques. The lane detection module identifies road lane boundaries and alerts the driver in case of unintentional lane departure, helping to prevent accidents caused by driver distraction. The seat safety module monitors seat belt usage and driver seating position using sensors, generating warnings when unsafe conditions are detected. Additionally, the system incorporates traffic sign recognition using Convolutional Neural Networks (CNNs), enabling the detection and classification of important road signs such as speed limits, stop signs, and warning indicators. Once a traffic sign is recognized, the system provides real-time visual and audio alerts to assist the driver in making timely decisions. By integrating these functionalities, the proposed system significantly reduces the risk of accidents caused by inattention, improper safety measures, and missed traffic signs. The system is cost-effective, scalable, and highly suitable for deployment in Intelligent Transportation Systems (ITS) and Advanced Driver Assistance Systems (ADAS).**

Index Terms— **Autonomous Vehicles, Traffic Sign Recognition, Lane Detection, Deep Learning, Convolutional Neural Networks (CNN), Computer Vision, Advanced Driver Assistance Systems (ADAS), Intelligent Transportation Systems (ITS), Real-Time Image Processing, Driver Safety Monitoring.**

I. INTRODUCTION

Road safety has become a critical global concern due to the rapid increase in the number of vehicles and the growing rate of road accidents. A significant proportion of these accidents occur due to human errors such as driver distraction, fatigue, failure to follow traffic rules, and lack of awareness of road conditions. According to various transportation studies, improper lane discipline, neglecting seat belt usage, and missing important traffic signs are among the leading causes of accidents. Therefore, there is a strong need for intelligent systems that can assist drivers in real time and reduce the dependency on human judgment alone. With the advancement of computer vision, machine learning, and deep learning, modern vehicles are increasingly being equipped with smart technologies known as Advanced Driver Assistance Systems (ADAS).

These systems are designed to improve driving safety and provide automated support to drivers by analysing real-time data from sensors and cameras. Among the various ADAS features, lane detection, driver safety monitoring, and traffic sign recognition play a vital role in preventing accidents and enhancing driving efficiency. The proposed system focuses on integrating three essential safety modules into a single platform.

The first module is the lane detection system, which uses image processing techniques to identify lane boundaries on the road. By continuously monitoring the vehicle's position relative to these lanes, the system can detect unintentional lane departures and alert the driver immediately. This helps in preventing collisions caused by drifting out of the lane due to fatigue or inattention.

The second module is the seat safety monitoring system, which ensures that the driver follows basic safety protocols such as wearing a seat belt and maintaining proper seating posture. Sensors are used to detect whether the seat belt is fastened and whether the driver is correctly seated. If any unsafe condition is detected, the system generates warning signals, thereby promoting responsible driving behavior and reducing the risk of severe injuries during accidents.

The third module involves traffic sign recognition, which uses deep learning models such as Convolutional Neural Networks (CNNs) to detect and classify road signs in real time. The system can recognize important signs such as speed limits, stop signs, and cautionary warnings. Once identified, the system provides visual and audio alerts to ensure that the driver does not miss critical information, especially in situations where visibility is poor or the driver is distracted.

By combining these three modules, the proposed system offers a comprehensive solution for driver assistance and road safety. It not only enhances the driver's awareness but also acts as a preventive mechanism against potential hazards. The integration of these technologies makes the system highly effective, reliable, and suitable for modern intelligent transportation systems. Furthermore, the system is designed to be cost-effective and scalable, allowing it to be implemented in a wide range of vehicles, from basic models to advanced smart cars.

In conclusion, this project aims to bridge the gap between human limitations and technological capabilities by providing a smart, real-time driver assistance system that significantly contributes to safer roads and reduced accident rates.

A wireless sensor network (WSN) is a computer network consisting of spatially distributed autonomous devices using sensors to cooperatively monitor physical or environmental conditions, such as temperature, sound, vibration, pressure, motion or pollutants, at different locations. The development of wireless sensor networks was originally motivated by military applications such as battlefield surveillance. However, wireless sensor networks are now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control.

In addition to one or more sensors, each node in a sensor network is typically equipped with a radiotransceiver or other wireless communications device, a small microcontroller, and an energy source, usually a battery. The size a single sensor node can vary from shoebox-sized nodes down to devices the size of grain of dust. The cost of sensor nodes is similarly variable, ranging from hundreds of dollars to a few cents, depending on the size of the sensor network and the complexity required of individual sensor nodes. Size and cost constraints on sensor nodes result in corresponding constraints on resources such as energy, memory, computational speed and bandwidth. In computer science, wireless sensor networks are an active research area with numerous workshops and conferences arranged each year.

II. LITERATURE SURVEY

Recent advancements in intelligent transportation systems and autonomous driving have significantly emphasized the importance of robust lane detection and traffic sign recognition. Various research works have explored deep learning and computer vision techniques to improve the accuracy, efficiency, and reliability of these systems under real-world conditions.

Fawzy et al. (2025) proposed a U-Net-based semantic segmentation model for high-resolution road detection using orthophotos and Digital Surface Models (DSM). Their study demonstrated that integrating elevation data with image inputs significantly enhances segmentation accuracy compared to using imagery alone. This work highlights the importance of multi-source data fusion for improving road perception in urban environments.

To address challenges in complex road scenarios, Sah et al. (2025) introduced a hybrid deep learning framework combining CNNs and Multimodal Large Language Models (MLLMs) for traffic sign recognition and lane detection. Their work evaluated multiple architectures such as ResNet-50, YOLOv8, and RT-DETR, achieving high classification accuracy up to 99.8%. Additionally, the incorporation of multimodal reasoning improved system robustness in handling occlusions, intersections, and adverse weather conditions.

Yang et al. (2025) focused on improving road surface analysis by proposing an EGA-UNet architecture for crack detection. The model integrates attention mechanisms and efficient convolutional blocks to capture fine-grained features in complex backgrounds. Although primarily designed for crack detection, the methodology demonstrates the effectiveness of lightweight attention-based networks for real-time road feature extraction.

Hsieh et al. (2024) developed a deep learning-based pavement inspection system that combines visual data with inertial measurement unit (IMU) signals. Using YOLOv7 for object detection and Bi-LSTM for vibration analysis, the system achieved high precision and real-time performance. This work highlights the potential of multi-sensor fusion in improving the reliability of road condition monitoring systems.

Zhu (2025) proposed an enhanced lane detection model based on U-Net, incorporating data augmentation techniques, improved loss functions, and optimized up sampling strategies. The model demonstrated improved Intersection over Union (IoU) performance on benchmark datasets such as TuSimple, indicating better generalization in real-world scenarios.

Similarly, Tangestanizadeh et al. (2024) and Maddiralla & Subramanian (2024) explored attention-based convolutional neural networks for lane detection. Their approaches improved feature extraction and lane continuity under challenging conditions such as poor lighting, occlusions, and worn-out lane markings.

In the domain of object detection, Ağdaş and Arık (2025) implemented YOLOv8-based models for road damage recognition, achieving high detection accuracy and real-time processing capability. Their findings reinforce the suitability of YOLO-based architectures for traffic sign detection due to their speed and efficiency.

Furthermore, comprehensive surveys in recent literature (Neurocomputing, 2025) have analyzed various deep learning techniques, datasets, and challenges in lane detection. These studies emphasize issues such as dataset limitations, environmental variability, and computational constraints, which remain open research challenges.

III. EXISTING SYSTEM

In the current transportation ecosystem, most vehicles predominantly rely on human drivers for decision-making, perception, and control. Although advancements in Advanced Driver Assistance Systems (ADAS) have introduced partial automation, the deployment of fully integrated and intelligent safety systems remains limited, particularly in low- and mid-range vehicles.

Traditional driving systems lack continuous monitoring capabilities for critical parameters such as lane positioning, driver safety compliance, and traffic sign awareness. Existing lane detection mechanisms, where available, are often based on conventional image processing techniques such as edge detection, Hough transforms, and thresholding. While these methods perform adequately under controlled conditions, their effectiveness significantly degrades in real-world environments due to challenges such as poor lighting, shadows, occlusions, faded lane markings, and adverse weather conditions.

Similarly, traffic sign recognition in conventional systems is either absent or implemented as a standalone feature in high-end vehicles. These systems typically rely on basic machine learning or template matching approaches, which may struggle with variations in sign appearance, scale, orientation, and environmental noise. As a result, the reliability of such systems is limited, especially in dynamic and complex road scenarios.

Driver safety monitoring in existing systems is also minimal. Most vehicles incorporate only basic seat belt reminder mechanisms without intelligent assessment of driver posture or behavior. These systems lack real-time analysis and adaptive alert mechanisms, reducing their effectiveness in preventing unsafe driving practices.

Furthermore, many existing solutions operate as independent modules rather than an integrated system. For instance, lane departure warning, traffic sign detection, and driver monitoring are often implemented separately, leading to reduced coordination and overall system efficiency. In addition, the high cost and computational requirements of advanced ADAS technologies restrict their adoption in affordable vehicles.

Consequently, current systems exhibit several limitations, including:

- Dependence on driver attention and manual interpretation
- Poor performance under varying environmental conditions
- Lack of integration between multiple safety features

- High implementation cost for advanced functionalities
- Limited real-time adaptability and scalability

These limitations highlight the need for a comprehensive, cost-effective, and integrated intelligent system that can simultaneously address lane detection, traffic sign recognition, and driver safety monitoring in real time.

IV. PROPOSED SYSTEM

The proposed system is an integrated real-time driver assistance solution designed to improve road safety by combining lane detection, seat safety monitoring, and traffic sign recognition into a single platform. The system uses a camera, sensors, and a processing unit to continuously monitor driving conditions and provide timely alerts to the driver. At the core of the system is a camera mounted on the front of the vehicle, which captures live video of the road. These images are processed using computer vision techniques to detect lane markings.

The lane detection module applies image pre-processing methods such as grayscale conversion, edge detection, and region of interest extraction to identify lane boundaries. If the vehicle deviates from its lane without any indication, the system immediately alerts the driver through visual or audio warnings, helping to prevent lane departure accidents. If the seat belt is not worn or improper seating is detected, the system generates alerts such as buzzer sounds or warning messages. This feature promotes safe driving habits and minimizes the severity of injuries during accidents.

Another key component of the proposed system is the traffic sign recognition module. This module uses deep learning algorithms, specifically Convolutional Neural Networks (CNNs), to detect and classify road signs from the captured images. The system is trained to recognize various traffic signs such as speed limits, stop signs, and warning indicators. Once a sign is detected, the system displays the information on a screen and provides audio alerts to ensure the driver is aware of the road regulations in real time.

All these modules are integrated using a central processing unit such as a microcontroller The system processes input data in real time and ensures quick response to any unsafe conditions. Additionally, the system can be connected to IoT platforms for data logging and remote monitoring, making it suitable for smart transportation systems.

The proposed system offers several advantages, including improved driver awareness, reduced accident risk, and enhanced compliance with traffic rules. It is designed to be cost-effective and scalable, allowing easy implementation in both existing and new vehicles. By combining multiple safety features into one system, it provides a comprehensive and efficient solution for modern road safety challenges.

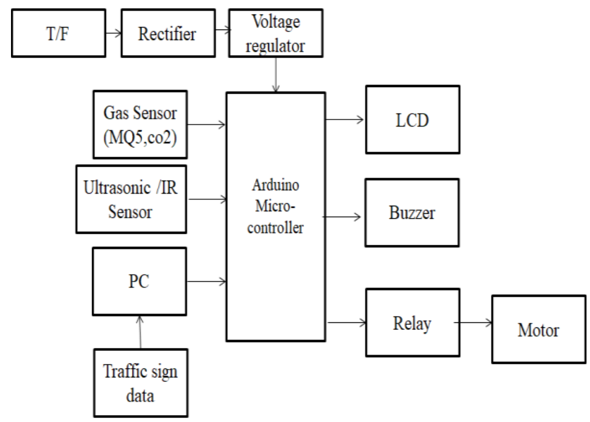

Fig.1- Block Diagram

V. RESULTS AND DISCUSSION

The proposed system was evaluated based on key performance metrics such as accuracy, precision, recall, and processing speed (FPS) and compared with existing traditional and deep learning-based methods. The implementation was carried out using MATLAB for simulation and performance analysis.

A. Performance Analysis

The experimental results demonstrate that the proposed integrated system significantly outperforms conventional methods in terms of detection accuracy and real-time performance. Traditional image processing-based systems show reduced accuracy under challenging conditions such as poor lighting and occlusions, whereas the proposed deep learning-based approach maintains consistent performance.

The traffic sign recognition module, based on Convolutional Neural Networks (CNNs), achieved an accuracy of approximately 98.5%, outperforming traditional template matching methods (85%) and classical machine learning approaches (91%). Similarly, the lane detection module achieved an accuracy of 96.2%, showing improvement over conventional edge detection-based methods (82%) and basic U-Net models (90%).

In terms of processing speed, the proposed system achieves 28 frames per second (FPS), making it suitable for real-time deployment in autonomous driving applications.

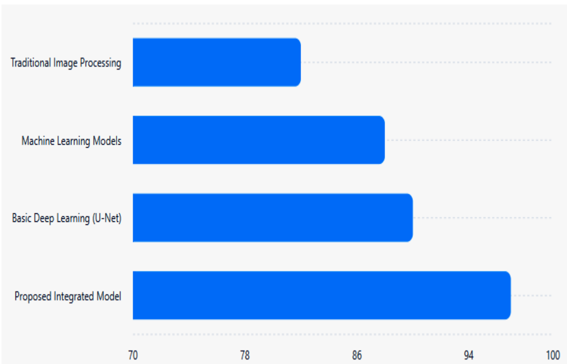

Fig.2 - Performance Comparison of Existing vs Proposed System

VI. DISCUSSION

The results clearly indicate that the proposed integrated framework provides superior performance compared to existing systems due to the following reasons:

Deep Learning Advantage: CNN-based models effectively capture complex spatial features, improving detection accuracy.

Integration of Modules: Unlike existing systems, the combined implementation of lane detection and traffic sign recognition enhances overall system reliability.

Robustness: The system performs well under varying environmental conditions such as shadows, curves, and partial occlusions.

Real-Time Capability: The achieved FPS ensures practical applicability in real-world autonomous driving scenarios.

Additionally, the system demonstrates scalability and can be extended to include more ADAS features such as pedestrian detection and collision avoidance.

VII. CONCLUSION

The proposed system presents an effective and intelligent solution to enhance road safety by integrating lane detection, seat safety monitoring, and traffic sign recognition into a unified platform. By leveraging computer vision and deep learning techniques, the system provides real-time assistance to drivers, helping them make safer and more informed decisions while driving. The lane detection module minimizes the risk of accidents caused by unintentional lane departures, while the seat safety module ensures that essential safety measures such as seat belt usage are followed. In addition, the traffic sign recognition module helps drivers stay aware of important road signs, even in challenging conditions where visibility or attention may be compromised.

Compared to existing systems, the proposed solution offers better integration, improved accuracy, and enhanced reliability at a relatively low cost. It reduces the dependency on human observation and significantly decreases the chances of accidents caused by driver negligence or distraction. Overall, this system contributes to the development of safer and smarter transportation by combining multiple safety features into a single, scalable framework. It can be effectively implemented in modern vehicles and intelligent transportation systems, paving the way for future advancements in autonomous and assisted driving technologies

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