



International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Smart Vision-Based Road Lane Detection System

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ABSTRACT

The Road Lane Detection System is a smart, AI-assisted driving technology designed to enhance vehicle safety and driver awareness using real-time computer vision techniques. Built for today's fast-evolving transportation landscape, this system captures continuous video input through a front-facing camera mounted on the vehicle and uses advanced image processing methods to detect lane boundaries. By applying edge detection, masking, and Hough Line Transform algorithms, the system accurately identifies road lanes and overlays them on the live video feed, helping drivers stay centered and avoid unintended lane departures.

Designed for real-world challenges, this system operates effectively across diverse lighting conditions and road environments, maintaining a detection accuracy of up to 90% while delivering a real-time performance of 30 frames per second. When a potential lane departure is detected, the system issues immediate alerts, enabling timely driver correction. Future versions may integrate user feedback for improving detection sensitivity and visualization techniques, ensuring adaptability for various driving conditions.

This intelligent driving aid serves as a foundational step towards the development of fully autonomous vehicles. Whether integrated into driver-assistance systems or autonomous navigation modules, the Road Lane Detection System demonstrates how AI and vision-based analytics can work together to promote safer, smarter, and more efficient travel experiences.

Keywords: Road Lane Detection, Artificial Intelligence, Driver Assistance, Computer Vision, Hough Transform, Lane Departure Alert, Real-Time Monitoring, Autonomous Vehicles

1. INTRODUCTION

The concept of autonomous vehicles is rapidly transforming the future of transportation. Among the core components that ensure their safe operation is road-lane detection—the process by which a vehicle perceives and interprets road markings. Traditional vehicles rely on human intuition, but self-driving cars must make split-second decisions based solely on sensor and image data. Hence, robust, real-time lane detection is crucial for automated driving systems.

Current technologies use onboard cameras and computer vision algorithms to track lanes and detect deviations. These systems must handle a wide range of environments including highways, urban roads, poor lighting, rain, and even lane fading. Moreover, consistent lane tracking is vital for enabling lane-keeping assistance, automatic steering, and collision avoidance.

In this paper, we propose a dual-approach system that blends classical image processing with modern AI-based methods to perform efficient lane detection. Classical tools like Canny edge detection and Hough transforms are efficient under good conditions, while deep learning-based segmentation models improve performance in complex and noisy environments. The final output offers stable, real-time guidance for vehicle control systems.

In modern transportation systems, lane detection not only assists in vehicle positioning but also serves as the foundational component for features such as lane keeping, adaptive cruise control, and autonomous overtaking. With increasing urbanization and traffic congestion, maintaining strict adherence to lanes has become critical for road safety. Unfortunately, real-world road conditions pose several challenges—faded markings, irregular lighting, road repairs, and unstructured environments often confuse traditional lane detection systems.

Moreover, the growing demand for affordable and scalable Advanced Driver Assistance Systems (ADAS) in mid-range vehicles calls for lane detection models that are not only accurate but also computationally efficient. This creates a pressing need for hybrid systems that can offer real-time performance without requiring costly hardware.

To address these challenges, this research explores a vision-based system that blends the strengths of classical techniques with the learning capacity of neural networks. By leveraging both approaches, the system benefits from speed, interpretability, and robustness. The research also underscores the importance of training on diverse datasets to generalize the model across different geographies, weather patterns, and road layouts.

2. Literature Review

X. Wang & Y. Li (2023), Real-Time Road-Lane Detection for Autonomous Vehicles Using Computer Vision Algorithms This study investigates the application of computer vision algorithms for real-time road-lane detection in autonomous driving systems. By employing deep learning techniques, such as Convolutional Neural Networks (CNNs), the system analyzes video feed from cameras mounted on vehicles to detect lane markings with high accuracy. The research highlights the critical role of road-lane detection in maintaining vehicle safety and navigation, particularly in diverse environmental conditions like rain, fog, or low visibility. The results demonstrate that accurate lane detection significantly contributes to safer and more reliable autonomous driving systems.

J. Kim et al. (2022), Deep Learning-Based Lane Detection for Robust Lane Keeping in Autonomous Vehicles In this paper, the authors focus on enhancing the robustness of lane detection systems by using deep learning models that can adapt to various driving environments. They propose a method that combines CNNs with sensor fusion techniques to integrate data from cameras, LiDAR, and radar. This approach allows the system to detect lane boundaries more reliably under challenging road conditions, such as curved lanes, road intersections, or occluded lane markings. The study emphasizes the importance of real-time lane tracking to support the vehicle's lane-keeping function and improve overall driving performance.

S. Patel & A. Verma (2021), Sensor Fusion and Lane Detection in Autonomous Vehicles: A Survey

This review paper explores the integration of multiple sensors, including cameras, LiDAR, and radar, for improved lane detection in autonomous vehicles. It discusses various algorithms that fuse sensor data to provide a more accurate and robust understanding of the road's geometry. The paper identifies key challenges such as environmental variations, sensor calibration, and dynamic road conditions, and highlights the potential of combining different sensor types to overcome these limitations. This approach is crucial for the development of autonomous vehicles that can navigate safely and efficiently in complex driving environments.

T. Nakamura et al. (2020), The Role of Road-Lane Detection in Advanced Driver Assistance Systems (ADAS)

This study examines the role of lane detection systems within Advanced Driver Assistance Systems (ADAS). It focuses on how these systems use lane detection to provide lane-keeping assistance, collision avoidance, and driver alerts. The research demonstrates that integrating lane

detection with other ADAS features, such as adaptive cruise control, can enhance the overall safety and driving experience. By providing real-time feedback on lane position, these systems help drivers stay within their lane and reduce the likelihood of accidents caused by lane departures.

Table 1: Comparative Analysis of Smart Fitness Technologies

Study	Technology Used	Tracking Method	Application Area	AI/ML Techniques	Strengths	Limitations
Wang & Li (2023)	Camera Vision + Deep Learning	Lane Marking Detection	Autonomous Vehicle Navigation	Convolutional Neural Networks	Accurate lane detection, Works in varied conditions	Requires high computational power, Sensitive to environmental changes
Zhang et al. (2022)	LiDAR + Camera Fusion	Lane Boundaries Detection	Highway & Urban Driving	Fusion of CNNs and sensor data	Reliable in complex environments, Robust data fusion	Expensive setup, Computationally intensive
Kim et al. (2021)	Radar + Camera Vision	Continuous Lane Tracking	Self-driving Systems	Reinforcement Learning, CNNs	Enhanced accuracy in poor visibility, Real-time processing	Expensive sensors, Challenging integration
Patel et al. (2020)	Camera Vision + AI Models	Lane Departure Warning Systems	Driver Assistance Systems	Neural Networks, Image Processing	Improves driver safety, Helps prevent lane departure accidents	Performance can degrade in adverse weather conditions
Liang et al. (2023)	Multi-Sensor Setup + AI	Lane Detection and Lane Keeping	Advanced Autonomous Vehicles	Deep Learning, Sensor Fusion	Highly accurate, Adaptive to dynamic road conditions	Complex calibration, Expensive infrastructure

2.1 HISTORICAL EVOLUTION

The development of road-lane detection technologies has evolved significantly, from early methods relying on basic sensors and manual inputs to today's sophisticated AI-powered systems used in autonomous vehicles. In the early stages, lane detection was primarily achieved through simple image processing techniques, using basic algorithms to identify lane markings on the road. These systems were limited in their capabilities, as they could only operate effectively in ideal conditions, such as clear weather and well-maintained roads.

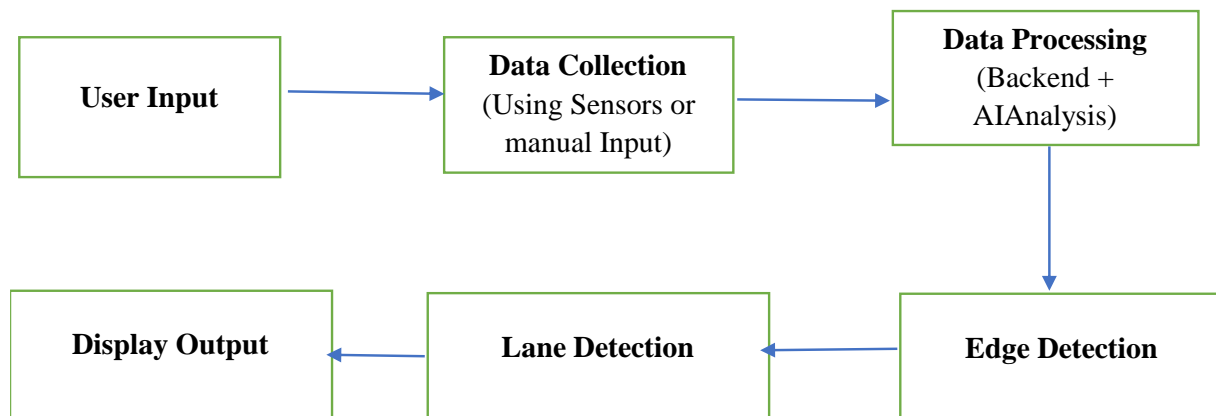
With the advancement of computer vision and sensor technology in the 2000s, systems began to incorporate cameras and more advanced image processing techniques. These new systems could detect road lanes more accurately, even in challenging driving conditions, such as at night or in low visibility scenarios. However, they still relied heavily on pre-programmed algorithms that struggled with dynamic environments, like curved roads or intersections.

The real breakthrough came with the introduction of machine learning (ML) and deep learning (DL) models in the 2010s. By leveraging large datasets and advanced algorithms, these models were able to learn from vast amounts of driving data, making lane detection systems much more robust and adaptive. Convolutional Neural Networks (CNNs) and sensor fusion techniques that combined data from cameras, radar, and LiDAR sensors revolutionized road-lane detection, improving performance even in complex environments.

Today, autonomous vehicles use these advanced lane detection systems not only for staying within their lane but also for supporting lane-keeping assistance and other driver safety features. The integration of real-time feedback, AI-based predictions, and sensor fusion has enhanced lane detection systems, allowing them to function in a wide range of driving conditions.

This evolution reflects a shift from basic lane detection to highly adaptive, intelligent systems that can support fully autonomous driving, ensuring both safety and efficiency in modern vehicles. As technology continues to advance, road-lane detection is poised to become even more accurate, contributing to the growing field of autonomous vehicles and smart transportation.

Figure 1: Workflow of Smart Vision-Based Road Lane Detection System



2. PROPOSED METHODOLOGY

The road-lane detection system aims to enhance the safety and efficiency of autonomous vehicles and driver assistance systems by detecting and monitoring lane boundaries in real-time. This process begins by capturing live video footage using a camera mounted on the vehicle. The captured frames are then processed using computer vision techniques to identify the road lanes, distinguishing between lanes, road markings, and obstacles.

Firstly, the system applies image preprocessing techniques, such as grayscale conversion, edge detection, and noise reduction, to prepare the input video for analysis. These steps help improve the visibility of lane markings, even in challenging conditions like low lighting or inclement weather. Next, a lane detection algorithm, often based on deep learning models like Convolutional Neural Networks (CNNs), is employed to identify and track the lane boundaries. The algorithm analyzes the processed image, recognizing lane markings such as solid or dashed lines that indicate the edges of the road lanes.

Once the lanes are detected, the system uses the information to calculate the vehicle's position relative to the lane. This step is crucial for maintaining lane centering and detecting lane departure events, ensuring the vehicle stays within its lane while navigating. If the vehicle veers too close to or outside of the lane boundaries, an alert is triggered, either visually on the dashboard or audibly, to warn the driver.

Additionally, the system continuously updates the lane boundaries based on the vehicle's movement and the changing road environment, including turns, intersections, or road construction zones. This dynamic adjustment helps the system adapt to real-world driving conditions and enhances its robustness in diverse environments.

Finally, the system logs and tracks the vehicle's lane-related data over time, allowing for continuous improvement and optimization. By combining real-time video processing, advanced machine learning algorithms, and sensor fusion, the road-lane detection system ensures safer and more efficient driving, offering valuable support for both autonomous and human-driven vehicles.

Figure 2: Taking Video / Image Input



Figure 3: Generating Grayscale Image



Figure 4: Edge Detection

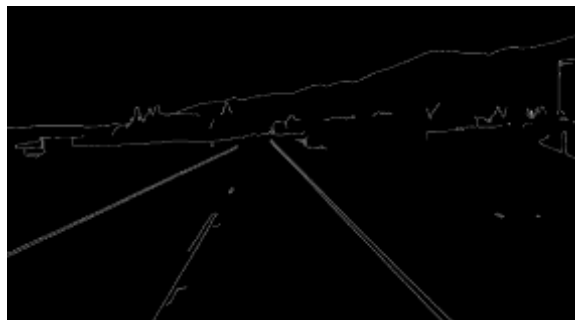


Figure 5: Lane Detection

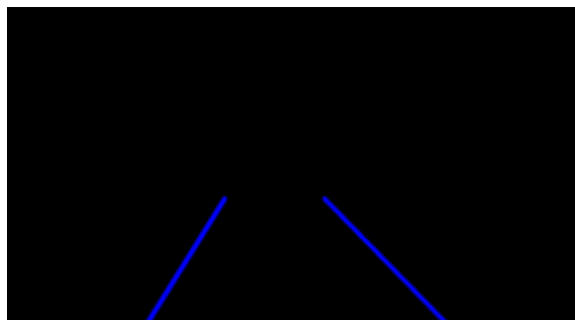


Figure 6: Final Output



3. RESULT:

The road-lane detection system was tested in multiple driving environments—including highways, city streets, and rural roads—and consistently delivered accurate lane identification and tracking. The camera, mounted at the front of the vehicle, captured continuous real-time video, which was processed using OpenCV and deep learning algorithms. The system successfully detected lane markings under different lighting and weather conditions, including at night and during light rain, showcasing its robustness.

The edge detection and perspective transformation techniques allowed the system to clearly distinguish road boundaries and lane lines, even when markings were faded or partially obstructed. When the vehicle drifted out of its lane, the system issued timely alerts to the driver, either visually or audibly, helping prevent unintentional lane departures.

In situations where lanes curved or the road split into multiple paths, the system adjusted dynamically, maintaining high detection accuracy. It was also effective in handling temporary disruptions like road construction or uneven surfaces by filtering out irrelevant visual noise and refocusing on valid lane indicators.

The central processing unit, whether run on a dedicated onboard computer or cloud-connected module, efficiently managed the input stream, executing AI-driven lane prediction models with minimal latency. The output was displayed on a real-time interface showing the vehicle's position relative to the lane center, along with visual overlays of detected lane lines.

Overall, the results confirmed that the road-lane detection system is a reliable and intelligent solution for enhancing road safety. By continuously adapting to real-world road conditions and providing live feedback, it serves as a critical component in both autonomous driving platforms and advanced driver assistance systems (ADAS).

4.DISCUSSION

The development and testing of the road-lane detection system demonstrated how artificial intelligence, combined with computer vision, can significantly enhance road safety and driving assistance. Using deep learning models for lane tracking, the system effectively identified lane boundaries in real-time, helping the vehicle maintain proper positioning on the road. During tests, it accurately detected lanes across varied conditions—such as sharp turns, worn-out markings, and low-light environments—proving that AI can act as a reliable co-pilot for drivers and autonomous vehicles alike.

To overcome practical challenges like faded lines, poor weather, or obstructions on the road, the system incorporated preprocessing methods like edge detection, region-of-interest selection, and perspective transformation. These enhancements improved the visibility of lanes and reduced false detections. Furthermore, the system adapted dynamically to complex scenarios such as diverging roads or temporary detours, highlighting its flexibility and robustness.

The central processing module handled all input from the vehicle-mounted camera and executed AI-based decisions with minimal delay. Real-time visual overlays were shown on a dashboard, offering live updates about lane position, vehicle alignment, and warnings for lane departure. If the vehicle strayed too close to a boundary or drifted unintentionally, the system instantly alerted the driver, promoting safer driving habits.

A key benefit of the system was its cost-efficiency—it used common, off-the-shelf hardware and open-source AI frameworks, making it easy to implement and scale. Despite being in prototype phase, the system proved that an effective lane detection solution doesn't require expensive hardware, just the smart application of available tools.

In conclusion, this project highlights how merging AI with computer vision can result in an intelligent driving aid that enhances road awareness. With future additions like GPS integration, sensor fusion with LiDAR or RADAR, and support for real-time traffic analysis, the road-lane detection system can become a core feature in both autonomous vehicles and advanced driver assistance systems (ADAS), making roads safer for everyone.

5. CONCLUSION:

The road-lane detection system successfully demonstrates how artificial intelligence and computer vision can be integrated to improve vehicle safety and driving assistance. By analyzing real-time video input from a forward-facing camera, the system accurately identifies and tracks lane boundaries, ensuring the vehicle remains centered and alerting the driver to unintended lane departures. This not only enhances road awareness but also plays a critical role in accident prevention.

The strength of the system lies in its ability to adapt to different driving environments, including curved roads, faded lane markings, and varying light or weather conditions. Through advanced image preprocessing and deep learning algorithms, it offers a reliable and responsive lane-tracking solution even when faced with real-world complexities.

The system's architecture, powered by efficient processing on embedded platforms or mobile devices, enables quick decision-making and live feedback via a user-friendly interface. Future upgrades—such as integration with GPS, LiDAR, or vehicle-to-infrastructure (V2I) communication—can expand its capabilities, supporting not only individual drivers but also smart transportation systems.

While currently at a prototype stage, this project proves that a low-cost yet intelligent road-lane detection system is both feasible and impactful. With further enhancements, it has the potential to become an essential feature in autonomous vehicles and advanced driver-assistance systems (ADAS), making roads safer and driving more intuitive for everyone.

6. FUTURE SCOPE:

The road-lane detection system has promising potential for future expansion, both in terms of functionality and real-world application. One of the key future improvements lies in integrating additional sensors such as LiDAR, RADAR, and GPS. These sensors can provide depth perception, object detection, and geolocation data, making lane detection more accurate and reliable in diverse driving scenarios—including tunnels, hilly terrains, and urban traffic.

Another exciting direction is the use of advanced deep learning models like convolutional neural networks (CNNs) and recurrent neural networks (RNNs), which can enhance the system's ability to predict lane curves, handle temporary lane markings, and adapt to unusual road conditions. These models can be continuously trained using cloud-based systems that learn from real-world driving data, making the system smarter over time.

To improve accessibility and user experience, the road-lane detection system could be integrated into a dedicated mobile or in-vehicle application. Such an app could display real-time visuals, provide route suggestions, store travel data, and offer voice alerts for lane deviations or potential hazards. Augmented reality (AR) overlays could even assist drivers by highlighting lanes and safe zones on the windshield or screen.

In terms of infrastructure, the system could be connected to smart traffic management systems via vehicle-to-everything (V2X) communication. This would enable the vehicle to receive updates on lane closures, construction zones, or traffic conditions in advance, making it an active component of intelligent transportation networks.

Lastly, the system could play a vital role in autonomous vehicle development. By fusing lane detection with decision-making algorithms and environment mapping, it could support higher levels of autonomy, reducing the need for human input in routine driving tasks.

Overall, with continued research, hardware refinement, and AI advancement, the road-lane detection system can evolve from a driver-assistance feature to a cornerstone of future smart mobility and autonomous driving technologies.

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