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Deterministic Real-Time Lane Detection Via Roi- Gated Edge Refinement

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Abstract: *Lane detection is a fundamental component of Advanced Driver Assistance Systems (ADAS) and autonomous driving applications, where real-time performance, accuracy, and computational efficiency are critical. This paper presents a deterministic real-time lane detection framework based on Region of Interest (ROI) gated edge refinement to achieve robust lane extraction under varying road and illumination conditions. The proposed method reduces computational overhead by dynamically restricting image processing to a predefined ROI corresponding to the probable lane region. Edge features are extracted using gradient-based operators and further refined through adaptive filtering and morphological enhancement to suppress noise and irrelevant road artifacts. A deterministic processing pipeline ensures predictable execution latency, making the system suitable for embedded automotive platforms with strict real-time constraints. The refined edge map is subsequently processed using probabilistic Hough transformation to accurately identify lane boundaries. Experimental evaluation on urban and highway driving datasets demonstrates improved detection stability, reduced false positives, and faster processing speed compared with conventional full-frame edge detection techniques. The proposed approach achieves reliable lane localization while maintaining low computational complexity, making it an efficient solution for real-time intelligent transportation and autonomous navigation systems.*

Key Words: *Lane Detection, Real-Time Systems, Region of Interest (ROI), Edge Refinement, Advanced Driver Assistance Systems (ADAS), Autonomous Vehicles, Computer Vision, Hough Transform, Embedded Systems, Image Processing.*

I.INTRODUCTION

Advanced Driver Assistance Systems (ADAS) and autonomous vehicles require accurate real-time lane detection, object detection, and object tracking for safe navigation and collision avoidance. Conventional vision-based methods often suffer from high computational complexity, increased delay, and reduced accuracy under varying road and lighting conditions, affecting real-time performance.

To address these challenges, this paper proposes a deterministic real-time lane detection framework based on ROI gated edge refinement integrated with object detection and tracking. The proposed method reduces computational overhead by processing only the Region of Interest (ROI) containing probable lane and object areas. Edge features are extracted and refined using adaptive filtering and morphological operations to remove noise and improve detection accuracy. Object detection and tracking techniques are used to identify and monitor surrounding vehicles and obstacles in real time.

The refined edge information is processed using the Hough Transform method for accurate lane boundary detection. Experimental results demonstrate improved detection accuracy, reliable object tracking, reduced false detections, and faster processing speed compared to conventional approaches, making the proposed system suitable for ADAS and autonomous driving applications.

II.PROBLEM STATEMENT

Conventional lane detection and object tracking systems suffer from high computational complexity and increased processing delay due to full-frame image processing. Variations in lighting conditions, shadows, road noise, and moving obstacles further reduce detection accuracy and system reliability. These limitations affect the real-time performance required in ADAS and autonomous vehicles. Therefore, an efficient system is needed to achieve accurate lane detection, object detection, and tracking with reduced computational overhead. The proposed ROI gated edge refinement approach aims to provide fast, reliable, and deterministic real-time performance for intelligent transportation applications.

III.OBJECTIVES

- To develop a real-time lane and object detection using YOLOv11.

- To accurately detect lane boundaries and road objects in different driving conditions.
- To improve detection accuracy using ROI-Gated edge refinement techniques.
- To reduce computational complexity and achieve faster real-time processing.
- To enhance road safety and support ADAS and autonomous vehicle applications.

IV.LITERATURE SURVEY

Several research works have been proposed for lane detection and object detection in ADAS and autonomous vehicles. Traditional methods using edge detection and Hough Transform suffer from reduced accuracy under varying road and lighting conditions. Recent deep learning models such as YOLO provide faster and more accurate object detection for real-time applications. Researchers also introduced ROI-based processing and edge refinement techniques to reduce computational complexity and improve detection performance. However, existing systems still face challenges in achieving accurate and deterministic real-time performance. Therefore, the proposed system integrates YOLOv11 with ROI-Gated edge refinement to improve lane and object detection accuracy with faster processing speed.

V.METHODOLOGY

The proposed system implements real-time lane detection, object detection, and object tracking using ROI-Gated edge refinement and YOLOv11 for ADAS and autonomous vehicles. Input images or video frames are preprocessed using resizing and camera calibration techniques. A Region of Interest (ROI) is selected to reduce computational complexity and improve processing speed. Lane features are enhanced using perspective transformation, adaptive thresholding, and edge refinement techniques, followed by Hough Transform for accurate lane boundary detection. Simultaneously, YOLOv11 is used to detect and track vehicles, pedestrians, and obstacles in real time. Finally, the detected lanes and objects are overlaid on the original frame to generate the final output. The proposed methodology provides improved detection accuracy, reduced false detections, and faster real-time performance for intelligent transportation applications.

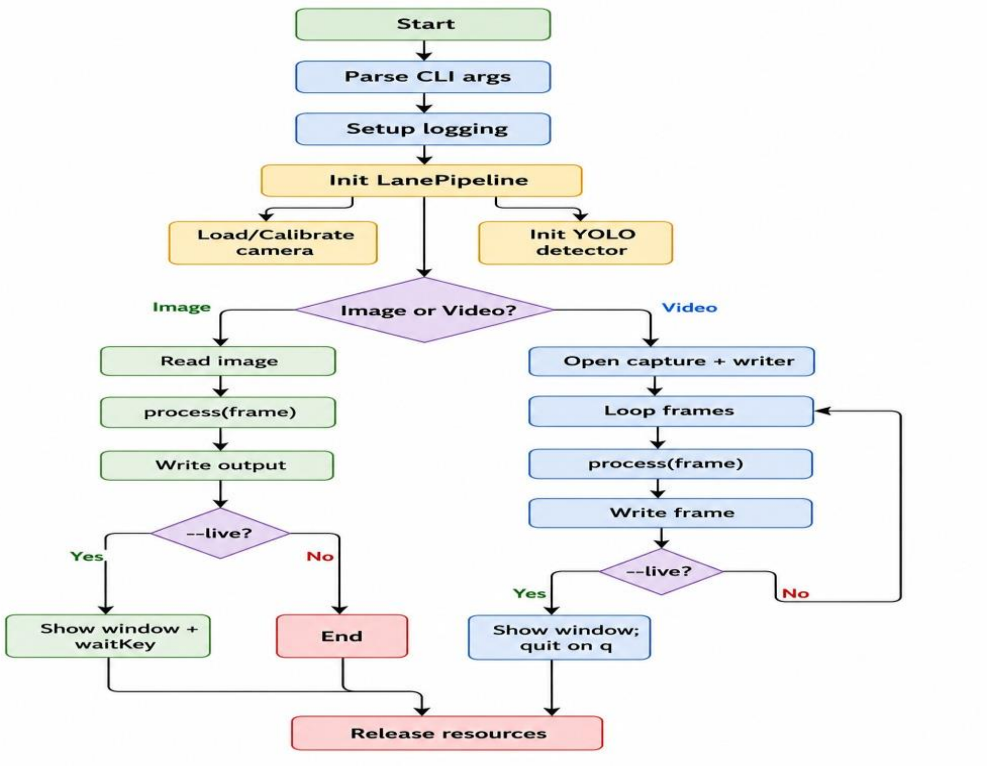

Figure 1: Flowchart of the Proposed Lane Detection and YOLO-Based Processing Pipeline

Figure 1 illustrates the overall workflow of the proposed real-time lane and object detection system. The system is designed to process both images and video streams for accurate lane identification and obstacle detection using the YOLO algorithm.

A. Initialization Stage

The execution begins with parsing command-line arguments and configuring the logging module for monitoring system operations. After initialization, the Lane Pipeline module is activated. During this stage, the camera calibration parameters are loaded to remove lens distortion and improve image quality. Simultaneously, the YOLO detector is initialized for real-time object detection.

B. Input Selection Stage

After initialization, the system checks whether the given input is an image or a video stream. Based on the input type, the corresponding processing pipeline is selected for further execution.

C. Image Processing Stage

If the input source is an image, the image is first read from the specified location and passed to the process(frame) function. In this stage, preprocessing, lane detection, and object detection operations are performed. The detected lane boundaries and objects are annotated on the frame, and the processed output image is generated. If live mode (--live) is enabled, the output image is displayed in a visualization window using the wait Key function.

D. Video Processing Stage

If the input source is a video, the video capture and video writer modules are initialized. The system then processes video frames continuously in a loop. Each frame undergoes preprocessing, lane detection, and YOLO-based object detection through the process (frame) function. The processed frames are written into the output video file. When live mode is enabled, the processed video is displayed frame by frame, and the execution can be terminated by pressing the 'q' key.

E. Output and Resource Management

After completion of image or video processing, the final annotated output is generated and saved. All allocated resources, including video capture objects, writers, and display windows, are released properly to ensure efficient memory utilization and smooth system termination.

The proposed workflow provides efficient real-time lane detection and object detection suitable for intelligent transportation systems, ADAS, and autonomous driving applications.

VI.IMPLEMENTATION

The proposed real-time lane and object detection system was implemented using Python, OpenCV, and YOLOv11 for Advanced Driver Assistance Systems (ADAS) and autonomous vehicle applications. The implementation process involved image preprocessing, lane detection, object detection, real-time video processing, and performance verification. The system was developed and tested using computer vision libraries and deep learning frameworks to achieve accurate and fast real-time detection.

The implementation process started with preprocessing techniques such as image resizing, camera calibration, and image undistortion to improve image quality and reduce computational complexity. ROI-Gated edge refinement, adaptive thresholding, and perspective transformation were then implemented for accurate lane boundary extraction. The lane detection module was integrated with YOLOv11-based object detection and tracking to identify vehicles, pedestrians, and road obstacles in real time. Functional testing and performance analysis were carried out using different road and lighting conditions.

A. Image Preprocessing and Lane Detection

Python and OpenCV libraries were used to implement preprocessing and lane detection operations. The input frames were resized to the required pipeline size, and camera calibration techniques were applied to remove distortion effects. Perspective transformation generated a Bird's Eye View (BEV) of the road for efficient lane analysis. ROI-Gated edge refinement and adaptive thresholding techniques were applied to enhance lane markings and suppress unwanted noise. The Hough Transform method was used to accurately detect lane boundaries and calculate lane curvature and vehicle offset information.

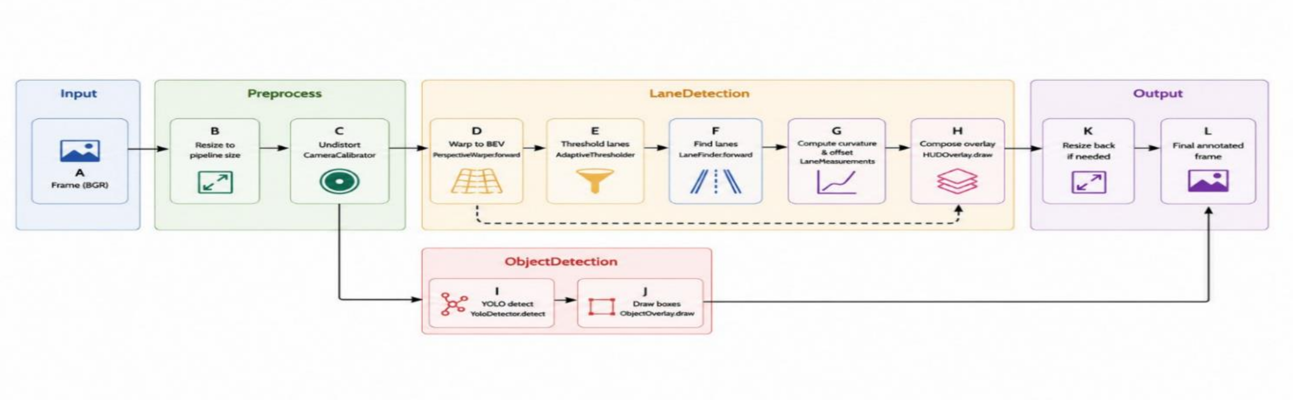

Figure 2: Preprocessing and Lane Detection Architecture

Figure 2 shows the preprocessing and lane detection stages used in the proposed system. The architecture includes image resizing, thresholding, edge refinement, and lane boundary detection blocks responsible for accurate lane extraction.

B. YOLOv11 Object Detection and Tracking

The YOLOv11 deep learning algorithm was integrated into the system for real-time object detection and tracking. The model detects vehicles, pedestrians, and obstacles present in the driving environment. Bounding boxes and labels are generated around detected objects for identification and monitoring purposes. Object tracking is performed continuously across video frames to improve detection stability and road awareness.

Figure 3: YOLOv11 Object Detection Output

Figure 3 shows the object detection results generated using the YOLOv11 model. The detected vehicles and road objects are highlighted using bounding boxes with corresponding labels.

C. Functional Verification and Real-Time Processing

Functional verification was carried out using real-time video streams and recorded driving datasets. Different driving scenarios and lighting conditions were tested to evaluate lane detection accuracy, object detection performance, and processing speed.

Figure 4: Real-Time Detection Output

Figure 4 shows the final annotated output containing detected lane boundaries and surrounding objects. The implementation successfully demonstrated improved lane detection accuracy, reliable object tracking, reduced computational complexity, and efficient real-time performance suitable for ADAS and autonomous driving applications.

VII.RESULTS AND DISCUSSION

The proposed real-time lane and object detection system was evaluated under different driving conditions to analyse processing speed, lane curvature, and vehicle offset. The obtained results demonstrate the efficiency and stability of the proposed ROI-Gated edge refinement and YOLOv11-based framework.

A. FPS Performance Analysis

The FPS versus frame graph shows that the proposed system achieved stable real-time processing between 8 FPS and 12 FPS for most video sequences. Minor fluctuations occurred due to varying road complexity and object density, but the system maintained efficient real-time performance suitable for ADAS applications.

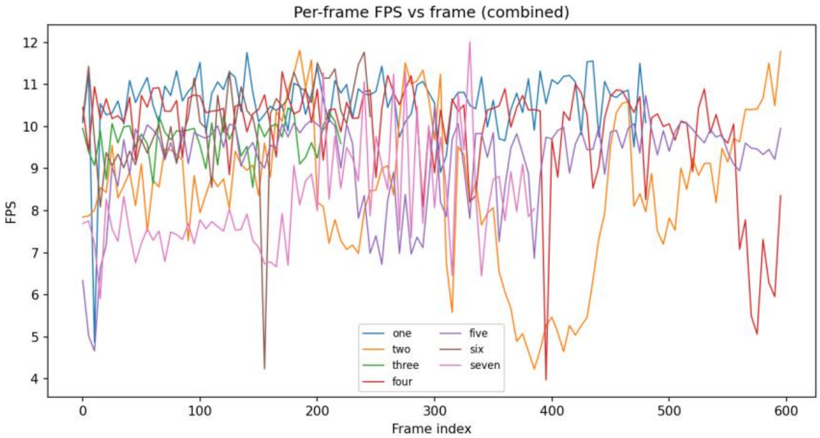

Figure 5: FPS Performance Analysis of the Proposed Real-Time Detection System

B. Lane Curvature Analysis

The average curvature versus frame graph represents the curvature estimation of detected lane boundaries. The system accurately detected both straight and curved lanes under different driving conditions. Curvature variations mainly occurred during sharp turns and complex road structures.

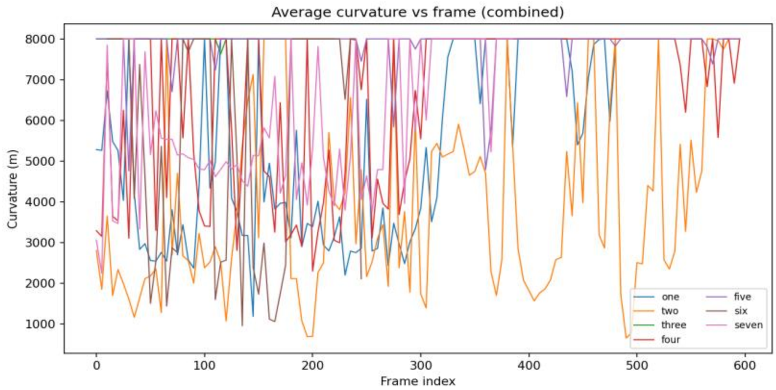

Figure 6: Lane Curvature Estimation under Different Driving Conditions

C. Vehicle Offset Analysis

The vehicle offset versus frame graph shows the lateral position of the vehicle relative to the lane center. The results indicate stable vehicle positioning with minimal deviation for most frames. Sudden variations occurred mainly during lane transitions and curved road conditions.

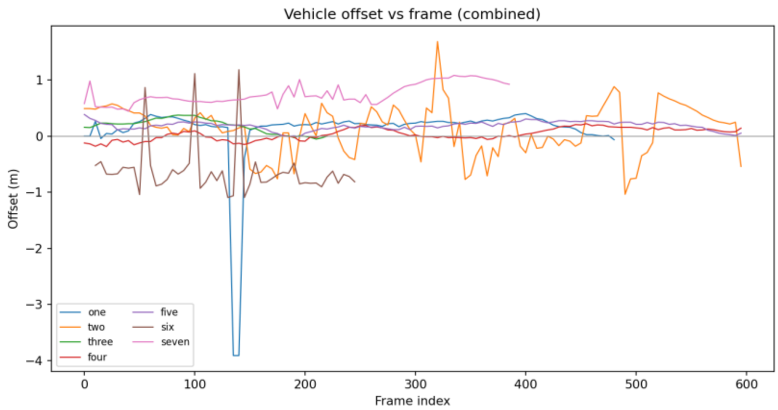

Figure 7: Vehicle Offset Analysis Relative to Lane Center

D. Overall Discussion

The experimental results demonstrate that the proposed system achieved reliable lane detection, accurate object detection, reduced computational complexity, and stable real-time performance. The integration of ROI-Gated edge refinement and YOLOv11 improved detection accuracy and enhanced driving safety for ADAS and autonomous vehicle applications.

VIII.ADVANTAGES

The proposed real-time lane and object detection system improves detection accuracy and real-time performance while reducing computational complexity and processing delay through ROI-Gated edge refinement and YOLOv11 integration.

- Reduced computational complexity Improved lane detection accuracy
- Efficient object detection and tracking
- Reduced false detections
- Reliable performance under varying road conditions

IX.APPLICATIONS

The proposed lane and object detection framework can be applied in several intelligent transportation and real-time automotive applications.

- Lane departure warning systems
- Collision avoidance systems
- Real-time vehicle tracking applications
- Advanced Driver Assistance Systems (ADAS)

X.FUTURE SCOPE

The proposed real-time lane and object detection system can be further enhanced by integrating advanced deep learning and sensor fusion techniques to improve detection accuracy under challenging weather and lighting conditions. Future work can include the use of LiDAR, RADAR, and GPS data for improved environmental perception and autonomous navigation. The system can also be optimized using hardware accelerators such as FPGA and GPU for higher processing speed and low-power real-time implementation. Additionally, advanced object tracking and driver behaviour analysis techniques can be incorporated to improve road safety and intelligent transportation applications.

XI.CONCLUSION

This paper presented a real-time lane and object detection system using ROI-Gated edge refinement and YOLOv11 for ADAS and autonomous vehicle applications. The proposed system achieved accurate lane detection, reliable object tracking, reduced computational complexity, and stable real-time performance under different driving conditions. Experimental results demonstrated improved detection accuracy, faster processing speed, and enhanced road safety, making the system suitable for intelligent transportation and autonomous driving applications.

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