DEEP LEARNING ENABLED ADVANCED DRIVER ASSISTANCE SYSTEM (ADAS) ALIGNED FOR REAL TIME VEHICLE WARNING SYSTEM FOR COLLISION AVOIDANCE WITH OPTIMAL TRAJECTORY PLANNING

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Introduction:
Road accidents have become one of the leading causes of injury and death across the globe. Human errors such as distraction, fatigue, poor lane discipline, and wrong judgment during overtaking or lane changing are the main reasons for most accidents. Drivers often find it difficult to correctly judge the speed and distance of nearby vehicles, especially when visibility is poor or when another vehicle blocks their view. These challenges often result in collisions that could otherwise be avoided with better awareness and quick decision-making.
Although several safety systems such as mirrors, parking sensors, and radar-based assistance tools exist, they are often costly or provide limited environmental awareness. In this context, Advanced Driver Assistance Systems (ADAS) play a crucial role in improving driving safety by assisting drivers with better situational awareness and decision support. However, many ADAS solutions rely on expensive hardware, highlighting the need for a smarter, simpler, and camera-based solution that can provide real-time information to drivers without depending on costly equipment. Such improvements aim to make ADAS more accessible and efficient for everyday driving conditions.
The proposed Real-Time Vehicle Warning System for Collision Avoidance with Optimal Trajectory Planning fills this gap by using artificial intelligence (AI) and computer vision to analyse road scenes in real time. The system uses YOLOv8 for detecting vehicles and YOLOP for identifying lanes and drivable areas. Together, these models help in understanding the driving environment accurately, even in challenging situations such as traffic jams or poor lighting. The system continuously monitors the surroundings, tracks vehicle movement, and warns the driver about possible risks before a collision occurs. This approach is inspired by recent developments in trajectory planning, risk assessment, and deep learning-based driving systems.

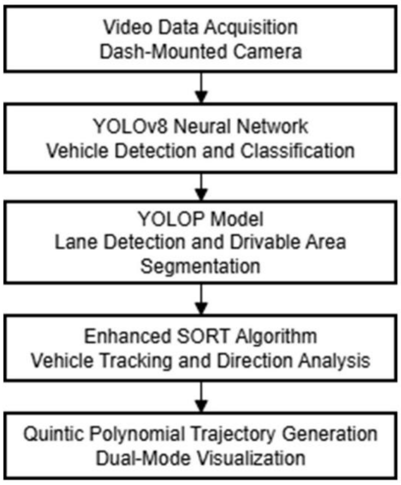

Figure 1: System Pipeline of the Proposed Collision Avoidance and Lane Detection System

Objectives:

1. To design and implement a deep learning model using YOLOv8 for accurate real-time vehicle detection and classification.
2. To integrate YOLOP for simultaneous lane boundary and drivable area segmentation.
3. To apply the Enhanced SORT tracking algorithm for assigning unique IDs and monitoring vehicle motion direction (oncoming or same-direction).
4. To estimate vehicle distance and generate real-time visual warnings indicating safe or dangerous overtaking conditions.
5. To develop quintic polynomial trajectory planning for smooth, safe lane-change and overtaking path generation.
6. To build a user-friendly dual-mode GUI displaying live dashcam overlays and top-view maps for better driver awareness.

Methodology:

The proposed system follows a sequential pipeline starting with video input from a front-facing dash-mounted camera, forming a key component of modern Advanced Driver Assistance Systems (ADAS). Each frame is preprocessed — resized, normalized, and gamma-adjusted — before being passed to the detection modules. YOLOv8 performs real-time multi-class vehicle detection producing bounding boxes, class labels, and confidence scores. Simultaneously, YOLOP performs lane and drivable area segmentation. Non-Maximum Suppression (NMS) refines the YOLOv8 detections to eliminate duplicate predictions.

The filtered detections are fed into the Enhanced SORT tracking algorithm, which uses Kalman filtering for motion prediction and the Hungarian algorithm for frame-to-frame vehicle association. Each vehicle is assigned a unique ID and classified by direction — oncoming, same-direction, or stationary — based on bounding box displacement analysis. This motion data, combined with lane occupancy information from YOLOP, is fed to the Trajectory Planning Module.

The Trajectory Planning Module uses quintic polynomial equations to generate smooth overtaking or avoidance paths:

$X(t) = a0 + a1t + a2t^2 + a3t^3 + a4t^4 + a5t^5$.

This ensures smooth transitions in position, velocity, and acceleration during lane changes. Lane position estimation is computed from YOLOP lane boundary outputs, and vehicle center from YOLOv8 bounding boxes. Based on traffic analysis, the system classifies adjacent lanes as Free, Blocked, or Oncoming and generates "SAFE TO OVERTAKE" or "DANGEROUS - ONCOMING VEHICLE" warnings displayed via a dual-mode visualization interface (dashcam overlay + top-view map). This decision-making capability enhances the effectiveness of ADAS by providing real-time collision avoidance assistance.

The YOLOv8 model was trained on a custom dataset of 22,789 annotated bounding-box instances covering seven vehicle categories: bicycle, bus, car, motorbike, rickshaw, truck, and van. The dataset was split 70% training (~15,950), 20% validation (~4,558), and 10% testing (~2,279) to prevent overfitting and ensure generalization. The model was evaluated under both daytime and nighttime conditions.

Result and Conclusion:

The implemented system achieves strong real-time performance on standard GPU hardware. YOLOv8-based vehicle detection achieved an average precision of 88.2% with a recall of 86.5% and an F1-score of 0.87 at 28 FPS. YOLOP lane and drivable area segmentation achieved 86.7% precision with an F1-score of 0.86. The Enhanced SORT tracker maintained consistency above 90% even with moderate occlusions. The overall combined pipeline achieved 87.5% average precision at 26 FPS, meeting the real-time requirement. A comparative study showed the proposed hybrid (YOLOv8 + YOLOP + Enhanced SORT) outperforms YOLOv5+SORT (82.3%) and YOLOv7+DeepSORT (85.6%) while maintaining competitive speed.

In conclusion, the system successfully demonstrates a real-time, camera-based ADAS capable of detecting and tracking multiple vehicles simultaneously, identifying lane boundaries and drivable regions, predicting motion direction, and generating safe, smooth overtaking paths through quintic polynomial trajectory planning. The system proves that deep learning and computer vision can deliver low-cost, efficient driver assistance without expensive sensor hardware like LiDAR or radar.

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Future Scope:

The future scope of this project includes:

- Add real-time webcam input for live on-road testing and integration with in-vehicle dashcam hardware.
- Enable GPU acceleration and model compression (quantization/pruning) for efficient deployment on embedded automotive systems.
- Integrate additional sensors such as LiDAR, radar, and ultrasonic for multi-modal depth perception and performance under adverse weather (fog, rain, night), further enhancing Advanced Driver Assistance Systems (ADAS) capabilities.
- Extend the system to detect pedestrians, cyclists, and other vulnerable road users for broader safety coverage.