TARA - Tracking Adaptive Road Autonomous Vehicle

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Introduction

TARA is an autonomous ground vehicle developed to enhance intelligent transportation and road safety. It integrates multiple Advanced Driver Assistance System (ADAS) features, including Lane Keeping Assist (LKA),Traffic Sign Recognition (TSR), Adaptive Cruise Control (ACC), and Automatic Emergency Braking (AEB), utilizing Raspberry Pi 4B and ESP32 microcontrollers. The system employs computer vision and sensor fusion techniques for real-time perception and decision-making. The architecture includes perception, feature extraction, and ADAS management modules that collaboratively enable autonomous operation. This project is a scalable prototype for testing ADAS technologies and advancing the field of autonomous mobility.

Objectives

The objective of this work is to develop an autonomous vehicle capable of navigating road environments using camera and sensor data for real-time perception and control. The system incorporates Lane Keeping Assist (LKA) through live video processing and OpenCV, complemented by traffic sign detection and classification using advanced machine learning models. Ultrasonic and IMU sensors ensure obstacle avoidance and vehicle stability, while an ESP32-based control unit governs motor and steering actuation. The goal is to achieve real-time decision-making and safe autonomous navigation through integrated perception and control, thereby contributing to intelligent transportation development.

Methodology

The methodology involves the systematic integration of simulation, perception, and control modules to facilitate efficient system design and validation. The framework, illustrated in Figure 1, represents the overall system architecture of TARA, showcasing the interaction between the perception layer, ADAS feature modules, and the control logic. The CARLA Simulator provides a realistic virtual environment with accurate vehicle dynamics, road conditions, and sensor modeling to test various driving scenarios. The ADAS Manager incorporates key functionalities such as Adaptive Cruise Control (ACC), Automatic Emergency Braking (AEB), Forward Collision Warning (FCW), Lane Departure Warning (LDW), Blind Spot Detection (BSD), and Traffic Sign Recognition (TSR). The Scenario Manager executes predefined driving conditions, including lane changes, braking events, and object detection tests, ensuring the comprehensive validation of system performance under varying traffic environments.

Figure 2: CARLA Simulation Environment

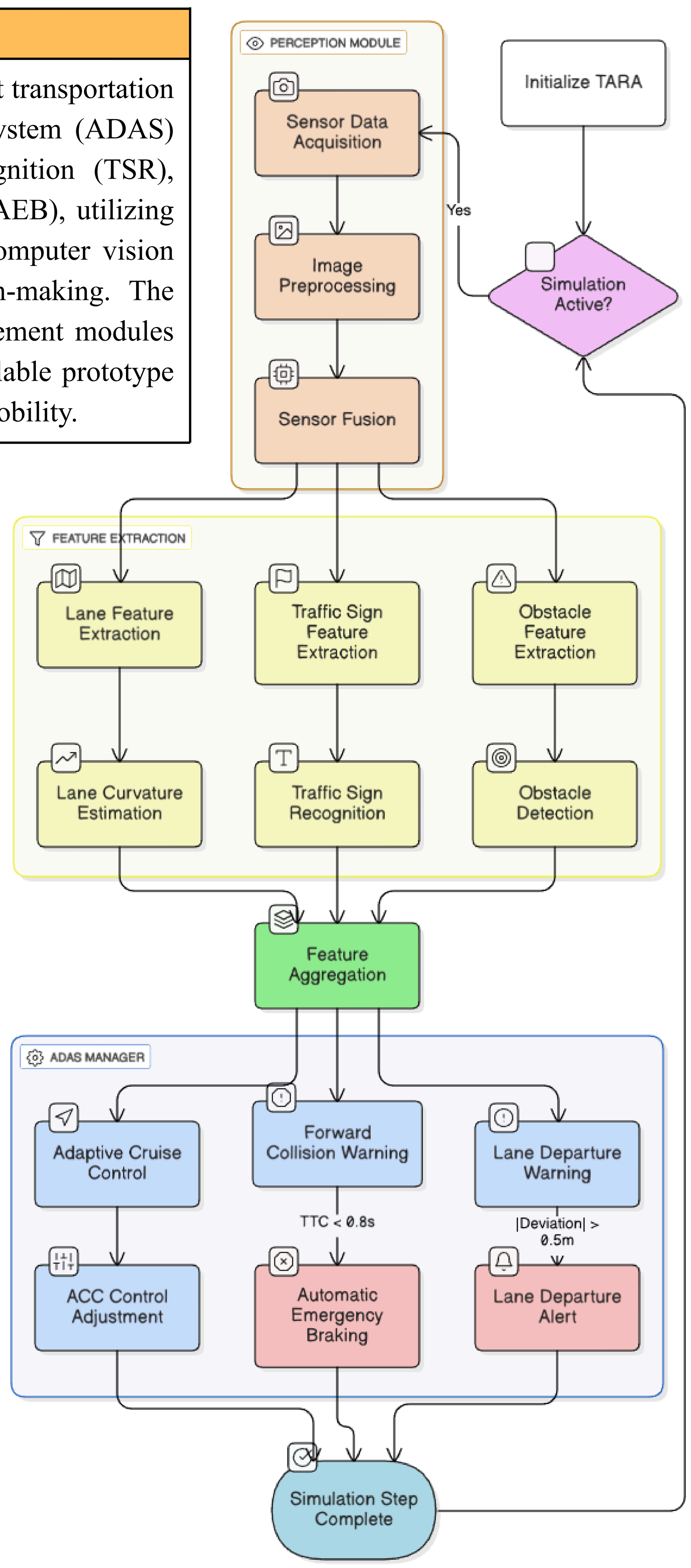

Figure 1: System Architecture of TARA

Figure 3: QR Code

Implementation Details

The system implementation is carried out within the CARLA Simulator using Python, NumPy, and OpenCV for perception and control integration. The simulation environment and HUD interface, presented in Figure 2, provide a complete testing platform for semi-autonomous driving functions. The Forward Collision Warning (FCW) subsystem computes Time-to-Collision (TTC) based on real-time distance and velocity estimates, triggering alerts below 2 seconds and critical warnings below 1 second. Automatic Emergency Braking (AEB) is activated to prevent collisions. Adaptive Cruise Control (ACC) dynamically adjusts throttle to maintain a constant following distance, while the Lane Departure Warning (LDW) system monitors lateral offsets beyond 0.5 meters. Traffic Sign Recognition (TSR) applies deep learning-based classification to identify signs up to 30 meters ahead. These modules are interconnected through a perception-decision-control feedback loop that ensures reliable, responsive, and adaptive behavior during simulated driving. The integration demonstrates how embedded systems and computer vision can jointly enable near-real-time automation capabilities.

Results and Discussion

TARA successfully demonstrates the operation of multiple ADAS features under realistic simulation conditions. The system effectively interprets radar and LiDAR data for object tracking, maintains lane discipline, and executes adaptive speed and braking control. The detected lane curvature estimation are in Figure 4, highlighting the robustness of the perception module. These results validate the robustness and effectiveness of the integrated ADAS framework in simulating realistic driving conditions and improving vehicle safety performance. For additional demonstration videos and simulation outputs, the QR code provided in Figure 3 offers direct access to recorded validation results and visual proof of system functionality.

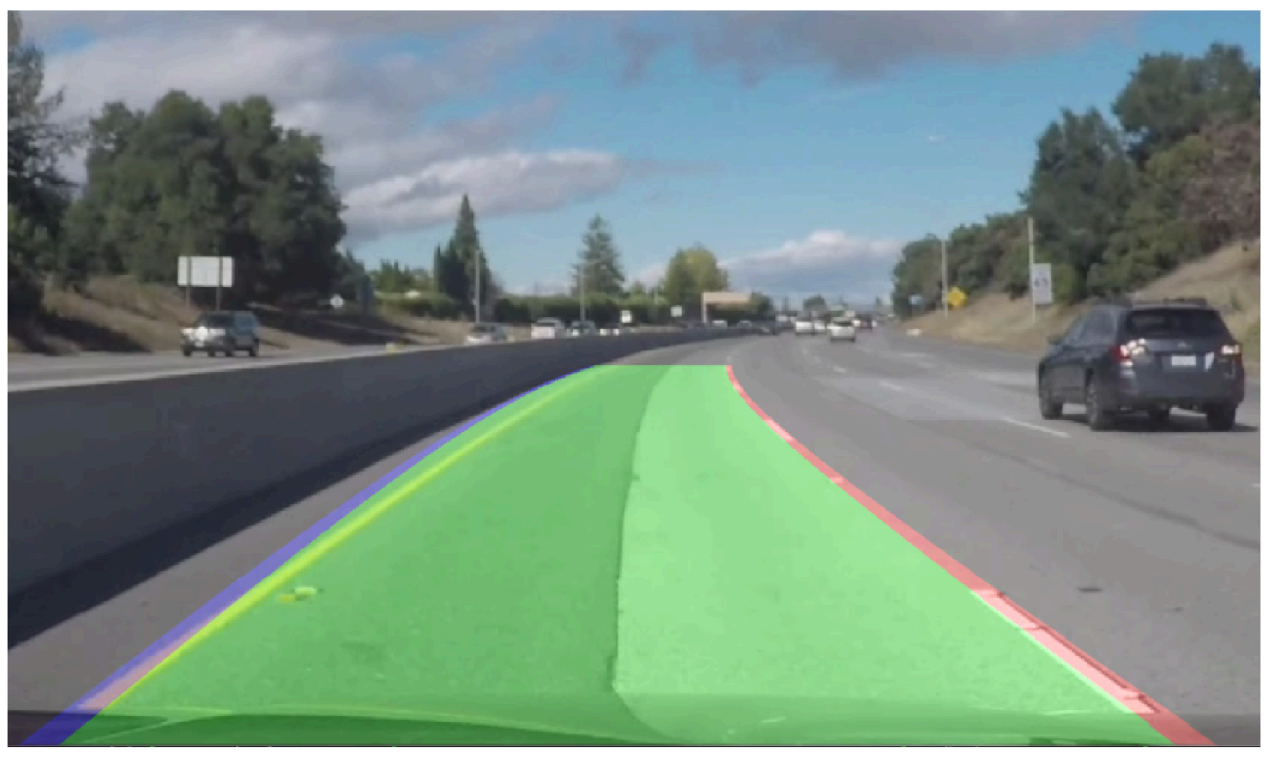

Figure 4: Lane Detection Output

Conclusion and Future Work

The developed prototype, TARA – Tracking Adaptive Road Autonomous Vehicle, effectively demonstrates real-time vision processing and sensor-based control for semi-autonomous navigation. Utilizing Raspberry Pi 4B for data processing and ESP32 for actuation, the system performs lane detection, traffic sign recognition, and obstacle avoidance with precision. This work highlights the potential of integrating computer vision with IoT-enabled control systems to advance intelligent transportation technologies. Future enhancements will focus on incorporating Adaptive Cruise Control (ACC), Automatic Emergency Braking (AEB), a Predictive Pavement Condition Warning System, GPS-based navigation, and cloud connectivity to further elevate the performance and reliability of autonomous driving systems.

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