Islamia College Peshawar (Public Sector University)

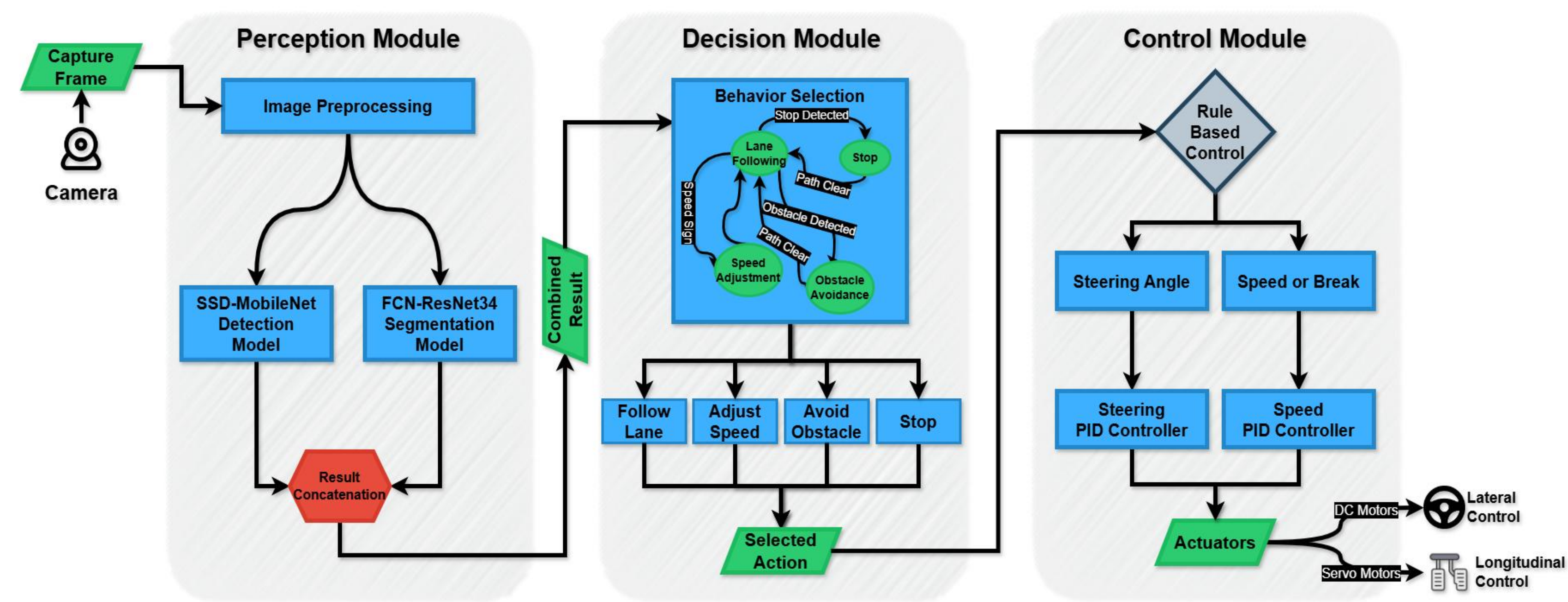
DIGITAL IMAGE PROCESSING LAB

Democratizing Autonomous Driving Research via Economical Hardware

Imran Nawar
Wajahat Ullah

GitHub Repository

Autonomous driving research often relies on expensive hardware, limiting participation. We present a cost-effective autonomous driving framework using affordable, energy-efficient hardware to democratize research in the area of autonomous driving. Built from scratch, the framework uses the NVIDIA Jetson Nano as the core computing unit, integrated with a monocular camera, motor control modules, and custom hardware assembly. Our modular architecture integrates optimized deep learning models for object detection and road segmentation, achieving competitive performance despite resource constraints.



System Architecture

PROBLEM STATEMENT

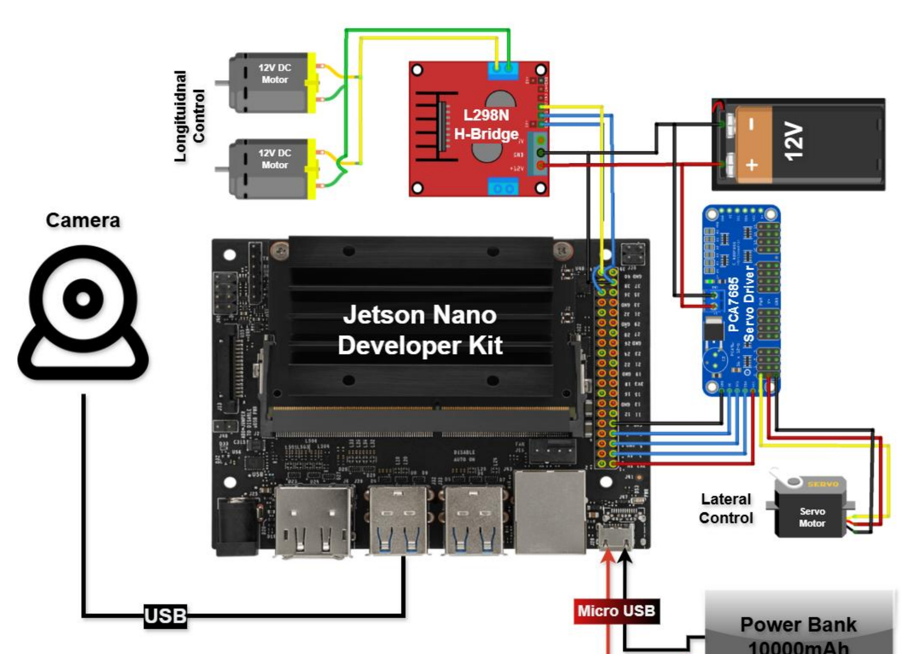
- Autonomous driving research often depends on expensive hardware setups, creating barriers for researchers in resource-constrained environments.
- High-performance systems typically require advanced sensors, high-end GPUs, and high power consumption, making them impractical for low-cost, small-scale deployments.
- There is a need for an affordable, energy-efficient framework capable of providing core autonomous navigation functions without relying on costly sensor suites.
- The design of such a system requires integrating optimized perception models with low-cost hardware while maintaining competitive accuracy and real-time performance.

INTRODUCTION

- Autonomous driving combines perception, decision-making, and control to achieve safe navigation.
- Current high-performance systems often rely on costly sensors and advanced computing hardware, limiting adoption in educational and low-budgeted research settings.
- Affordable, energy-efficient solutions can democratize autonomous driving research, making it more accessible for education, prototyping, and experimental platform.
- We present a low-cost framework, developed from the ground up, that employs the NVIDIA Jetson Nano, a monocular camera, and custom hardware to perform essential perception and navigation tasks in controlled environments.

Hardware Platform

- **Computing Unit:** NVIDIA Jetson Nano (4 GB)
- **Vision Sensor:** Logitech C270 HD webcam (720p)
- **Chassis:** 4WD robot car kit with DC motors
- **Motor Driver:** L298N dual H-bridge module
- **Steering**: PCA9685 PWM driver with SG90 servo motor
- **Power:** Power bank (10000 mAh, 22.5 W) + Li-ion battery pack (3×18650, 3.7 V each)



Hardware Setup

CONTRIBUTIONS

Modular Framework: We propose a modular autonomous driving framework optimized for real-time inference on resource-constrained hardware, integrating TensorRT and efficient deep learning architectures for controlled environments.

Optimized Perception Pipeline: An edge-deployable pipeline combining object detection (SSD-MobileNet, 0.69 mAP@0.5 at 30 FPS) and road segmentation (FCN-ResNet34, 0.93 mIoU at 20 FPS) on the Jetson Nano platform.

Complete System Integration: A fully functional prototype achieving 120ms latency and 8.5W power consumption.

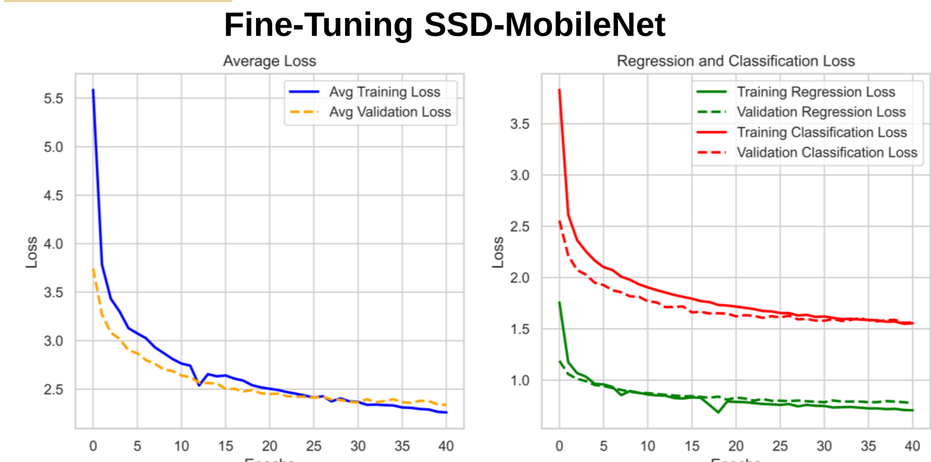
Research Democratization: Total system cost under $300, proving viability for educational and research applications.

METHODOLOGY

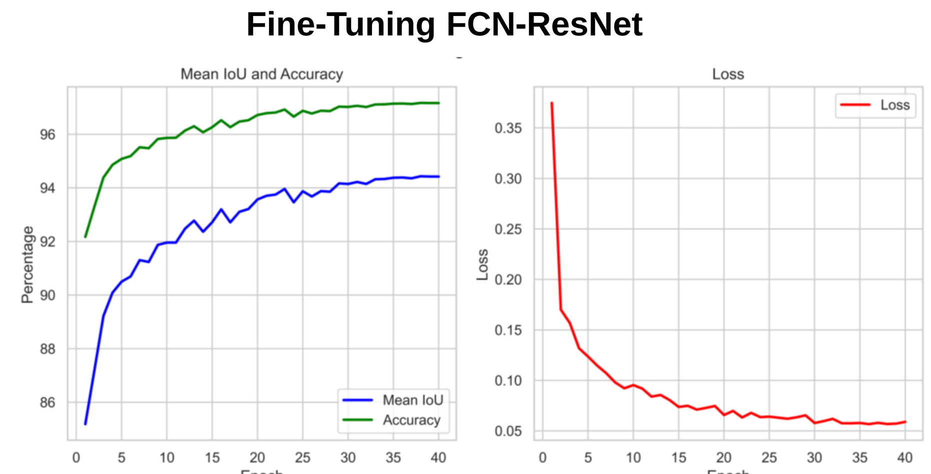
- **System Architecture:** Four-module pipeline: sensor → perception → decision-making → control, optimized for the Jetson Nano.
- **Perception Pipeline:** Parallel, TensorRT-optimized models: SSD-MobileNet for object detection (9 classes) and FCN-ResNet34 for road segmentation.
- **Decision Logic:** Rule-based hierarchical state machine processing perception outputs for traffic sign compliance and obstacle avoidance.
- **Control System:** PID controller regulating steering (servo motor) and speed (DC motors) for precise vehicle navigation.

RESULTS

Fine-Tuning SSD-MobileNet

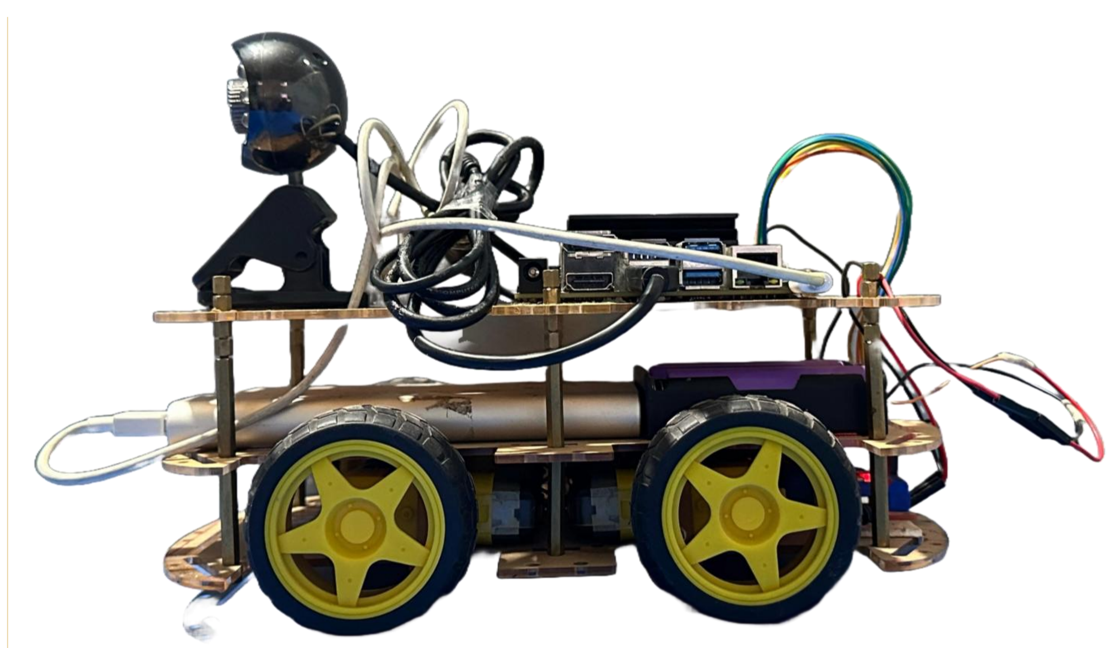


Fine-Tuning FCN-ResNet



System Performance Metrics

Metric	Value
End-to-End Latency	**120 ms**
Inference Rate	**9 FPS**
Power Consumption	**8.5 W**
Total Hardware Cost	**$293**
Object Detection Accuracy	**0.69 mAP@0.5**
Road Segmentation Accuracy	**0.93 mIoU**



BACKGROUND

- State-of-the-art autonomous driving platforms often rely on LiDAR, high-end GPUs, and custom-built computing hardware, with system costs frequently exceeding US $100k.
- These costs create high entry barriers, limiting research and educational adoption.
- There is a clear need for low-cost, energy-efficient platforms that enable prototyping and teaching, thereby democratizing autonomous driving research.

CONCLUSION

- Our research shows that reliable autonomous driving capabilities are achievable on the NVIDIA Jetson Nano platform through optimized deep learning models, delivering a complete system under $300.
- Controlled-environment testing validates performance across traffic-sign recognition, obstacle detection, and path-following tasks, achieving 120 ms end-to-end latency at 8.5 W power consumption.
- Full-scale autonomous vehicle platforms used in research can cost over $100,000. Our $300 prototype offers a low-cost alternative for controlled-environment experimentation. This enables broader participation by educational institutions and smaller research teams, fostering innovation across diverse communities.
- Future work will focus on enhancing perception via sensor fusion, strengthening decision-making for complex scenarios, and improving safety mechanisms, while maintaining cost-effectiveness to support wider adoption.

Real-time detection and segmentation output