Autonomous Parking System Development and Evaluation Using CARLA

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Abstract

This report presents the development, testing, and evaluation of an autonomous parking system using the CARLA simulator. The focus was on assessing vehicle behavior in various parking scenarios, including parallel parking, parking behind other vehicles, and parking in crowded parking environments. The system integrated perception modules, planning algorithms, and execution strategies to perform parking maneuvers autonomously. Test results demonstrate that the system achieves high success rates in standard parking tasks, while challenges arise when parking in crowded environments. The findings provide valuable insights into current system limitations and future enhancement directions.

1. Introduction

Autonomous parking is an essential functionality for next-generation intelligent vehicles, aimed at enhancing convenience and safety in urban environments. Unlike basic parking assist features, full autonomous parking systems require the integration of real-time perception, robust planning under uncertainty, and precise vehicle control. This project evaluates the performance of an autonomous parking system developed and tested using the CARLA simulator, focusing on various parking scenarios, particularly parking within crowded environments.

The primary objective is to validate the system's ability to detect available parking spaces, plan an appropriate path, and execute parking maneuvers autonomously, even in complex, dynamic conditions. The insights obtained are crucial for refining autonomous vehicle systems for real-world deployment.

2. Methodology

2.1 Test Setup

The tests were performed in the CARLA simulator (Town04), offering realistic parking lot layouts and urban road configurations. The key test scenarios included:

- Parallel Parking: Parking between two vehicles along the curb.
- Behind Parking: Parking directly behind another vehicle.
- Crowded Parking Environments: Parking lots densely occupied by other vehicles.

Vehicles were equipped with simulated RGB cameras and semantic segmentation sensors. A YOLOv8-based server was utilized for real-time object detection via ZeroMQ communication, aiding parking spot identification.

2.2 Testing Procedures

Each test followed a structured procedure:

1. Initialize the CARLA simulation world and spawn the ego vehicle.
2. Attach sensor packages for environmental perception.
3. Utilize YOLOv8 object detection to identify parking spaces.
4. Execute maneuvering algorithms for parking:
   - Approach trajectory planning.
   - Reverse steering control.
   - Final position adjustment.
5. Record vehicle behavior using CARLA's video capture and logging tools.
6. Repeat each scenario multiple times for statistical reliability.

Test videos recorded

Table 1" Tools and Configurations"

Tool	Configuration
CARLA Simulator	**Version 0.9.x, Town04 map**
Python API	**Vehicle and sensor control**
YOLOv8 Model	**Object detection of cars and parking spots**
ZeroMQ	**Communication between detector server and vehicle controller**
Hardware	**I7-9700k, 2080 GPU, 16GB RAM**

3. Results

3.1 Test Observations

Parallel Parking

- The vehicle successfully aligned and performed parallel parking maneuvers.
- Minor corrections were needed in tight spaces.

Figure 1 Vehicle executing a parallel parking maneuver."

Behind Parking

- The system consistently detected appropriate spaces and reversed into position.
- Occasional slight misalignment required multi-move adjustments.

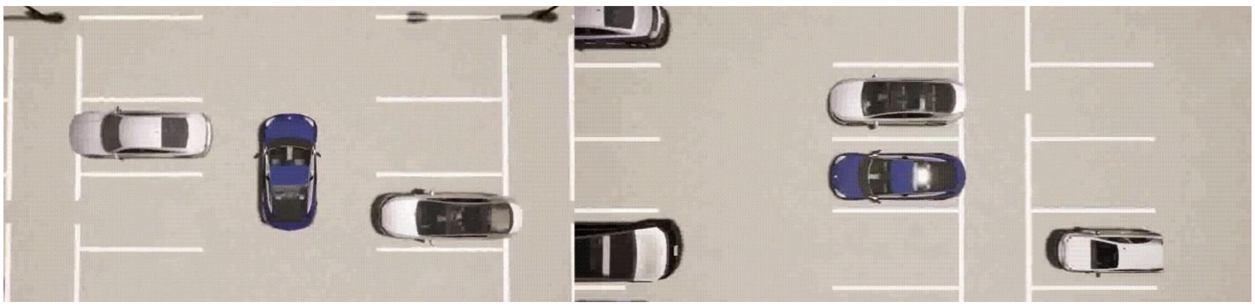

Figure 2 "Vehicle parking behind a stationary car."

Crowded Parking Environments

- Increased difficulty due to limited maneuvering space.
- Some failures to fully complete the parking maneuver without readjustments.

Figure 3 "Attempted parking in a crowded lot."

Driving Failures

- Failures were recorded primarily when detecting tight spaces too late, leading to maneuver aborts.

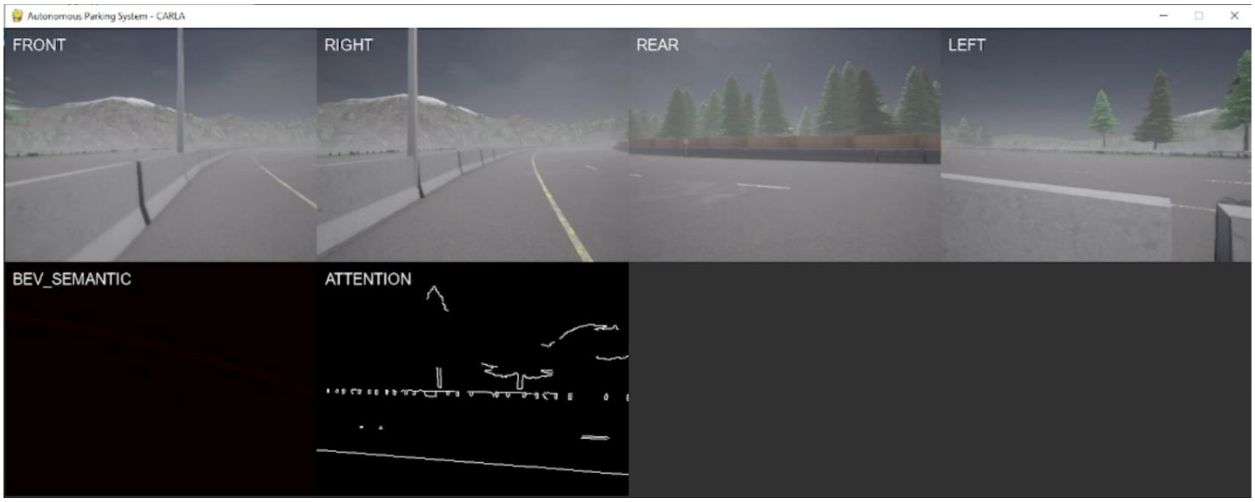

Figure 4 "Example of maneuver failure due to late detection."

Table 2 Results Summary

Scenario	Success Rate	Observations
Parallel Parking	**90%**	**Minor steering corrections needed**
Behind Parking	**85%**	**Occasional minor misalignment**
Crowded Parking	**70%**	**Frequent need for multi-move adjustments**

4. Analysis and Discussion

The autonomous system demonstrated strong performance in structured parking environments, particularly in parallel and behind parking. However, crowded environments exposed limitations in perception and path planning.

Factors contributing to reduced performance in crowded settings include:

- Limited Margin for Error: Tight spaces reduced allowable maneuvering flexibility.
- Detection Latency: The YOLOv8-based detection system occasionally lagged in identifying viable spots in dynamic environments.
- Motion Prediction Deficiency: Lack of predictive modeling for surrounding vehicle behavior complicated decision-making.

Improved approaches could involve enhancing perception robustness (e.g., sensor fusion) and incorporating real-time predictive path planning algorithms.

5. Conclusion

The project successfully demonstrated an autonomous parking system's capability within a simulation environment, achieving high success rates in standard scenarios. The challenges identified in crowded parking environments point toward necessary future improvements, particularly in perception accuracy, dynamic planning, and motion prediction.

These insights are valuable for the continued advancement of autonomous vehicle systems, aiming toward deployment in real-world, dynamic urban settings.

6. References

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