OntarioTech Engineering & Applied Science

Autonomous Valet Parking System

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Problem Statement

Autonomous vehicle technologies face substantial challenges, particularly in autonomous parking. Traditional vehicles lack the inherent capability to autonomously navigate and park in complex, dynamic parking environments. This gap highlights a need for an advanced solution that integrates precise environmental perception, adaptability, and autonomous control to ensure safe navigation from point A to point B. Additionally, there exists a broader challenge for the autonomous vehicle research community, bridging the divide between theoretical algorithm development and practical application testing in controlled physical environments.

Solution

Addressing these challenges, our project introduces an Autonomous Valet Parking (AVP) System, leveraging sensor fusion, machine learning, and ROS to enhance autonomous parking capabilities. By integrating LiDAR, depth cameras, and IMUs, our system is able to navigate any pre-configured traffic environment. Utilizing Autoware for its autonomous driving stack, our system introduces dynamic path planning and vehicle control algorithms essential for precise parking. Recognizing the need for a scalable testing platform, the software was adapted to run on the ROSMASTER R2 model car, thus providing a Virtual-to-Reality Integration (VRI) System that allows for an accessible, cost-effective means for developers to test and refine their algorithms.

THE AUTOWARE FOUNDATION

YAHBOOM

Methodology

Our project started with the evaluation of various simulators to test our AVP system virtually before physical deployment. We assessed three simulators compatible with Autoware: Carla, AWSIM, and Godot. Carla was eliminated due to its lack of Autoware support, and Godot, despite its visual capabilities, lacked necessary sensing functionalities. Ultimately, AWSIM was selected for its integration with Autoware and available sensing features, providing a solid foundation for our AVP system's virtual testing and real-world implementation.

Figure 1. Carla Simulator

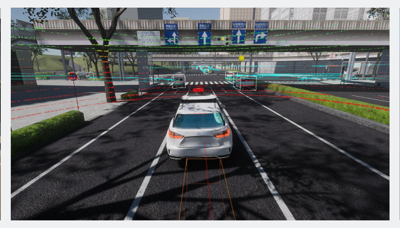

Figure 2. AWSIM Simulator

Figure 3. Godot Simulator

After successfully simulating the AVP system using AWSIM, we proceeded to develop a custom simulation environment. This involved generating a dense point cloud data file with Berkeley Localization and Mapping (BLAM) which only requires a LiDAR. This file establishes a detailed environment where lanes can be implemented using a tool called Vector Map Builder. The vehicle's localization within this custom environment uses the Normal Distributions Transform (NDT) method. NDT compares live LiDAR data against the point cloud ground truth, determining the vehicle's position and orientation for navigation and parking in the simulated city.

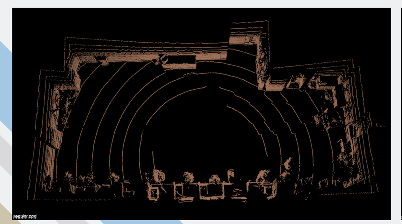

Figure 4. Raw Point Cloud Data

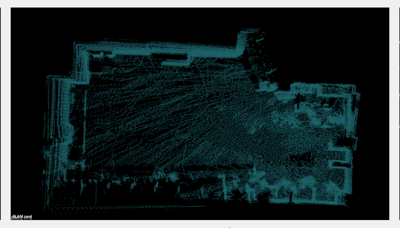

Figure 5. BLAM Implementation

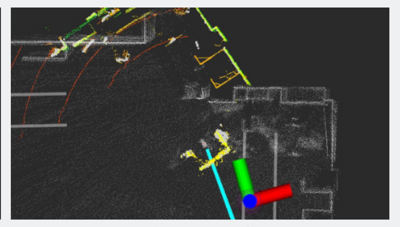

Figure 6. NDT Localization

Entering this project, we operated under the assumption that adapting Autoware for real-scaled vehicles to a smaller scale would primarily involve shrinking the environment and adjusting vehicle configurations. This assumption proved to be incorrect. Autoware is designed for mid to large-scale vehicles, lacking support for small-scale applications. Consequently, we faced the challenging task of reconfiguring Autoware's parameters in order to accommodate a small-scale vehicle. With hundreds of configuration files and a complex system architecture minimally documented and commented, understanding the functionality of each variable and how the entire system interconnects was challenging. Despite these obstacles, through an incremental approach, we managed to reconfigure Autoware to function effectively with small-scale vehicles. The figures below illustrate our journey from the initial out-of-the-box state of Autoware to our customized configuration, showcasing the significant adjustments made to facilitate its application on a smaller scale.

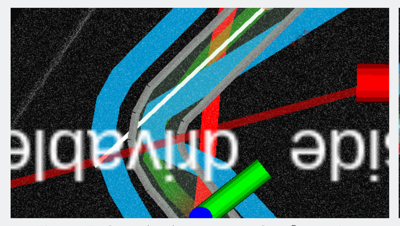

Figure 7. Standard Autoware Configuration.

Figure 8. Drivable Area Configured.

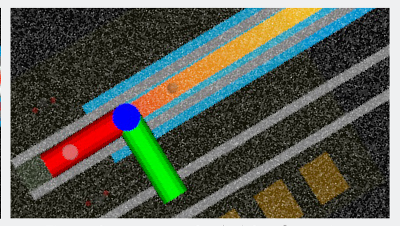

Figure 9. Autoware Scaled Configuration.

With Autoware tailored to function with small-scale vehicles, we began to automate the detection of parking spots. Using an overhead view of the parking lot, our system identifies available parking spots and communicates this information to the vehicle, enabling it to plan and execute a path to the spot. This component involves a custom-trained YOLOv8 model, designed to recognize other ROSMASTER R2 vehicles within the parking lot.

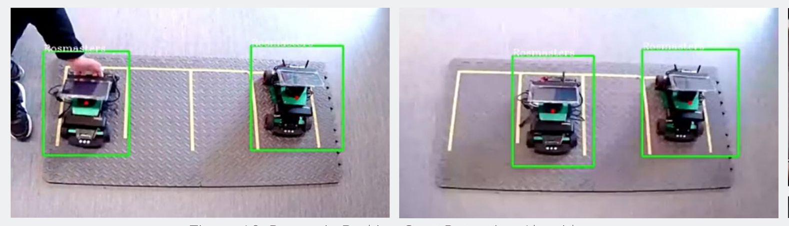

Figure 10. Dynamic Parking Spot Detection Algorithm.

Figure 11. Dynamic Path Rerouting

The system is able to dynamically adjust parking destination choices in real-time, should the initially selected spot become occupied. This ensures the vehicle can respond to changing parking lot conditions.

Detailed Autoware and R2Ware Communication

R2Ware sends positioning, sensor, and camera data to Autoware, which then processes this information and sends back control commands for the vehicle's gear, steering, and indicators. Autoware also receives feedback reports on the vehicle's status, ensuring synchronization between the vehicle's actual state and the autonomous driving system's commands.

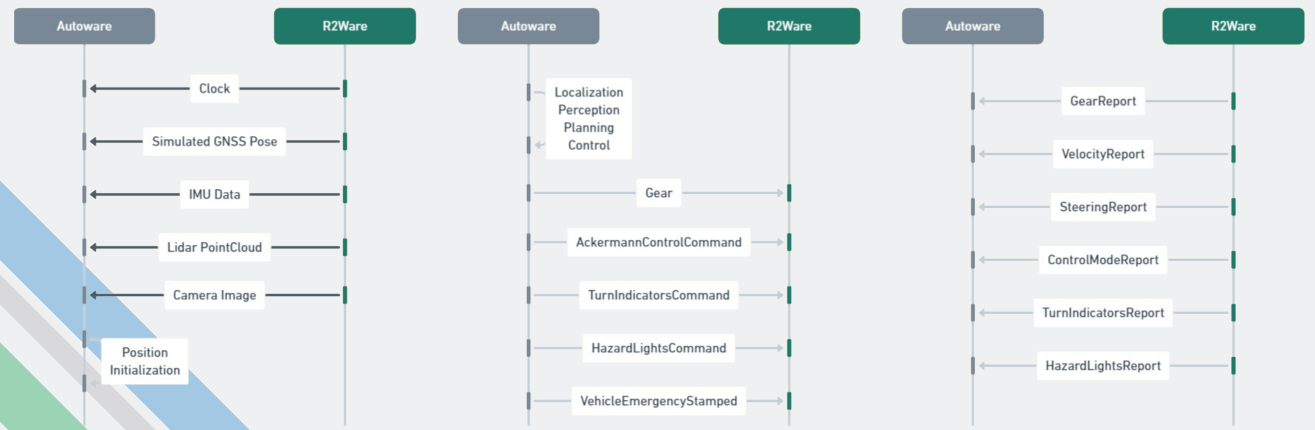

Figure 12. End-to-End Vehicle Control and Monitoring Sequence.

Design and Implementation

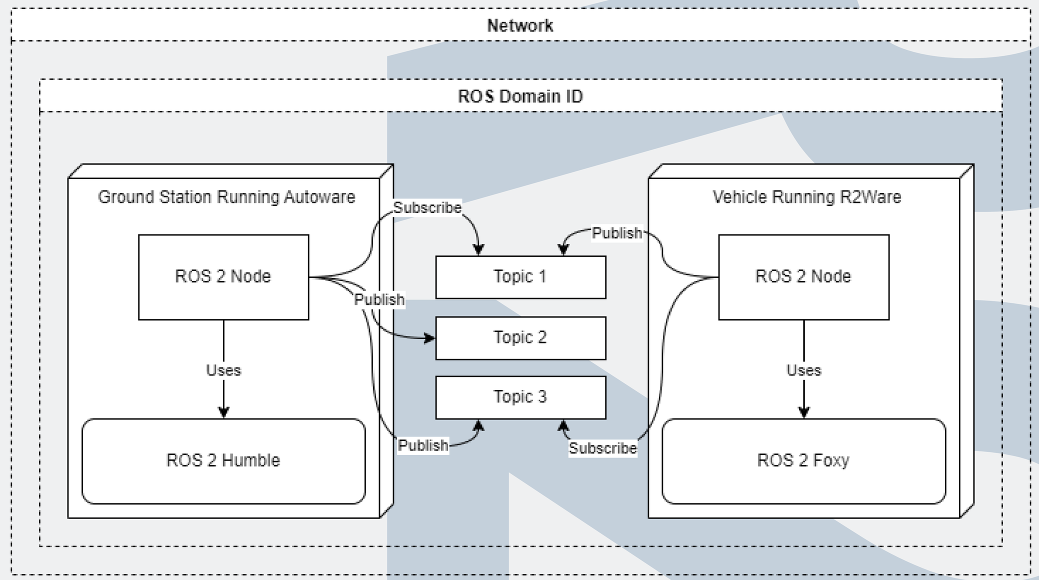

Figure 13. Autonomous Valet Parking System Multi-Machine Deployment Diagram.

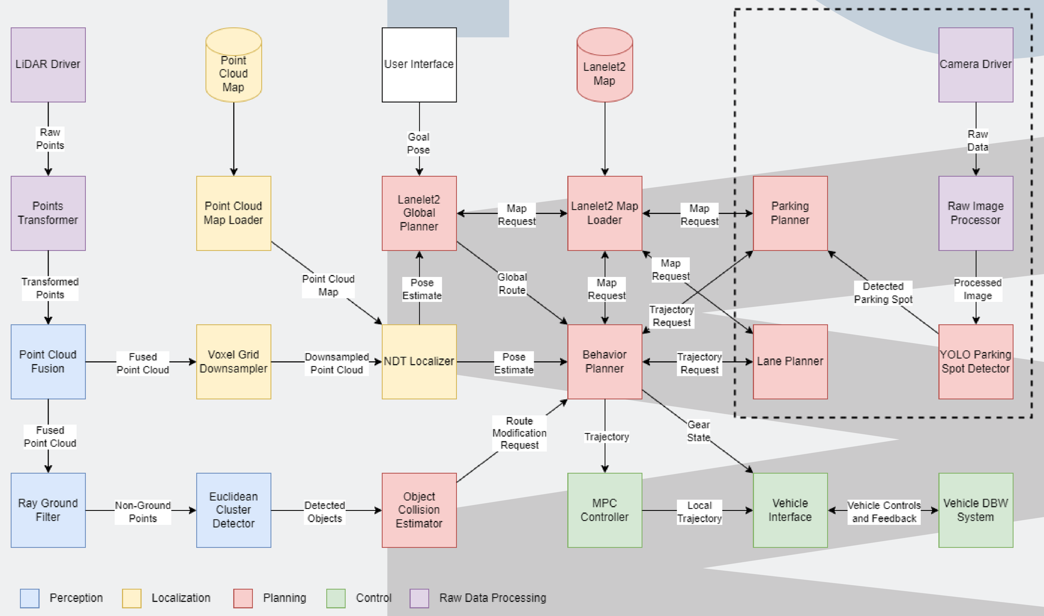

Figure 14. Structural and Relational Model of the AVP Autoware-Based Solution.

Conclusion and Future Works

Our project successfully adapted Autoware for small-scale vehicles and developed an automated parking spot detection system, showcasing the versatility and potential of autonomous vehicle technologies. This project not only addressed technical challenges but also set a foundation for future innovations in autonomous driving.

Looking ahead, our goals are to refine the object detection model for broader scenarios, test scalability across diverse environments, enable use of the 2D LiDAR, and encourage open-source collaborations to advance autonomous vehicle research. Additionally, implementing our system on a full-scale vehicle is the next step, aiming to bridge the gap between small-scale experimentation and real-world application, further validating our advancements in autonomous driving technology.

We extend our deepest gratitude to all individuals and organizations whose invaluable support and insights have led to the success of this project.