

Modelling Autonomous Parallel Parking Procedure for Car-like Robot Avrora Unior in Gazebo Simulator

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Abstract

This paper focuses on implementation of path planning and control for Avrora Unior robot car that enable autonomous parallel parking. Path planning is based on existing geometrical approach, which was modified to fit specific kinematics of the robot shape and control geometry. Geometry and parking space size determine path key points: steering and counter-steering points. We implemented and tested the algorithm using Avrora Unior robot model in Gazebo simulator.

Keywords: autonomous parallel parking, Avrora Unior robot car, car-like robot, Gazebo, algorithm, modelling.

1. Introduction

Parallel parking is a hard problem for amateur drivers to perform and in some cases is challenging even for the experts. The parking process involves search for an empty spot and executing series of maneuvers in such a way that places a car in this spot without accidents, which are highly probable at narrow parking spots. Automobile manufacturers are independently developing specialized solutions (known as parking assistants¹) to help driver in those situations, e.g., Toyota's Intelligent Parking Assist, Ford's Active Park Assist, BMW's Parking Assistant, and Mercedes's Active Parking Assist.

We are working on a similar problem for a smaller fully autonomous vehicle by adapting existing algorithm to suit car-like robot constraints. Our work is based on Avrora Unior robot. The paper discusses parking path planning² and control tested for a simulated Avrora Unior robot, but our solution is easily transferable to a real Avrora Unior and other car-like robots³.

The paper is organized as follows: Section II describes car-like Avrora Unior robot and its relevant characteristics, Section III outlines generalized parking problem for non-holonomic vehicle; Section IV covers

necessary modifications that were made to the existing robot model⁴; Section V covers updates of the robot's control module. In Section VI we discuss experimental setup and results. Finally, we conclude in Section VII.

2. Avrora Unior robot

Car-like Avrora Unior mobile robot (Fig. 1) was developed by Russian company Avrora Robotics. Robot's main purpose was to become a main teaching platform for mobile robotics students, which affected the composition of its sensors. Relevant linear measurements for Avrora Unior robot are listed in the Table I.

Avrora Unior robot is driven by two rear wheels (each featuring individual DC brushless motor coupled with a fixed ratio gearbox) and steered by separate DC motor that turns the two front wheel linkage. Design of steering linkage is based on a Ackermann steering geometry⁵. Microsoft Kinect camera is installed in the front section. We also requested manufacturer to install Hokuyo laser rangefinder mounting plate in the front upper part of the robot. Avrora Unior is equipped with off-the-shelf parking sensor utilizing 8 ultrasonic transducers to determine the distance to obstacles; 4 are mounted on the front and 4 on the rear bumper.

Table 1. Avrora Unior’s Linear Dimensions.

Dimension	Dimension (mm)
Rim diameter	205
Wheel diameter	260
Wheel width	104
Wheelbase	700
Axle track	540
Body length	1120
Body height	570
Body width	650



Fig. 1. Avrora Unior robot.

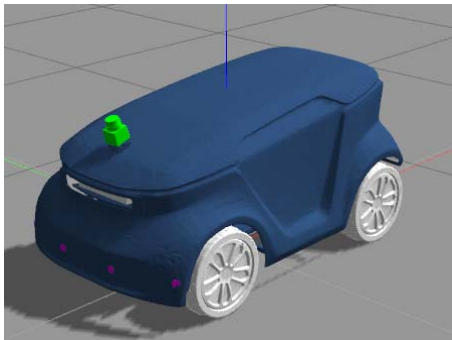


Fig. 2. Avrora Unior model in Gazebo.

To prevent unnecessary collisions and other accidents at this stage of research we are using robot model in a Gazebo⁶ simulation that was developed previously⁴ (Fig. 2). The model features and all sensors entirely replicate physical characteristics of the real Avrora Unior robot.

3. Problem specification

Adaptation of parallel parking algorithm for Avrora Unior robot involves solving two major issues. The first issue is implementation of non-holonomic control for Avrora Unior robot.

A. Non-holonomic vehicle control

To implement control for four-wheel mobile robot with rear driven wheels and front steering wheels we introduce two control variables (θ is a steering angle, v is a forward velocity); thus configuration space has 3 dimensions (x, y, θ). The vehicle motion is described through the following set of equations:

$$\begin{cases} \dot{x} = v \cos \phi \cos \theta \\ \dot{y} = v \cos \phi \sin \theta \\ \dot{\theta} = \frac{v}{L} \sin \phi \end{cases} \quad (1)$$

Equations (1) represents a system of non-holonomic constraints because they include derivative of vehicle’s coordinates variable and are not integrable⁷.

B. Parking Path Planning

For parallel parking path planning we modified path planning method based on geometrical approach⁸. This planning method can be used to precalculate all necessary trajectories for a given environmental parameters (distance to parked cars, length of available space), so we can generate trajectories for most common situations.

Before parking, the robot calculates a set of key points where steering and counter-steering trajectories should be executed. Calculation of those key points is based on the following vehicle parameters: maximum steering angle (β), wheelbase (e), front and rear overhang (p), body width (w) and vehicle length (L)⁸. A trajectory for a single try parallel parking could be calculated only if available parking spot length is larger than L_{min} ⁸; otherwise more than one trial (series of steering-countersteering trajectories) are calculated to successful park a vehicle.

4. Algorithm implementation

This work is based upon implementation of geometry-based algorithm that have been made available by Rohith Krishnan⁹. However, due to a critical difference in selection of a target coordinate frame used in calculations of key points (centered not at the vehicle center, but at the rear axle center) the original package did not generate appropriate trajectories for Avrora Unior parking. Nevertheless, the original paper formulas were successfully adjusted in order to resolve this issue.

4.1. Robot Control

The algorithm was adapted to comply with the control system of Avrora Unior model. Implemented parallel parking module tracking vehicle’s position in relation to calculated key points. Changes in key points

speed = 0 and steering angle = 0) to ‘junior car/cmd’ velocity control topic (Fig. 6). Time that takes the vehicle to stop starting from the moment of message being sent and ending when the vehicle reaches velocity 0, is taken as a full stop time. In average it takes about 40 seconds for a full stop. Measuring required time for full steering was performed while the vehicle was suspended. In this experiment AckermannDriveStamped message with speed = 0 and steering angle = β is sending onto topic ‘junior car/cmd’. Three seconds are required for a full steering.

6. Experimental validation

Parking experiments were performed in a completely known environment. A virtual world¹¹ experiment consisted in defining an initial position of the vehicle and selection of a parking spot with a goal position.

For example, we describe sample experiment where a point (0.206, 0.325) is considered as a goal position and (2.5, 1.5) — as an initial one. Area of a parking spot is easily calculated for a goal position (for the rear axle) using $p = 0.206$ m, $w = 0.65$ m and $L_{min} = 1.7243$ m.

Gazebo simulation with experiment configuration was created (Fig. 7). Validation of our implementation was made by checking trajectories followed when the robot passes through key points to a goal point. Avroa Unior robot model successfully went through all points although its trajectories were not perfect (Fig. 3). Errors were related to an imperfect stopping process. Average displacement with regard to OX axle was about 0.06 m and with regard to OY axle was about 0.013 m relatively to the goal point; the displacements were estimated in series of experiments.



Fig. 7. Parking space in Gazebo

7. Conclusions and future work

We have implemented an algorithm of parallel parking that is based on a geometrical approach. Current implementation of the algorithm has an obvious disadvantage, which is its dependency on the initial robot orientation with regard to a goal position.

We currently keep working on a solution for this problem by using dynamic coordinate frame. Moreover, PID controller has a direct influence on accuracy of turns in key points. After addressing this issue the algorithm will be validated on a real Avroa Unior robot. Our future work is focused on development of fully autonomous parking system of level 4 according to SAE J3016 standard.

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References

1. Jung, H. G., et al. Parking slot markings recognition for automatic parking assist system. *IEEE Intelligent Vehicles Symposium* (2006), pp. 106-113.
2. Lavrenov, R. Smart Spline-Based Robot Navigation on Several Homotopies: Guaranteed Avoidance of Potential Function Local Minima. *International Conference on Artificial Life and Robotics* (2018), pp.407-410.
3. Shabalina, K., Sagitov, A., Magid, E. Comparative Analysis of Mobile Robot Wheels Design. In *11th International Conference on Developments in eSystems Engineering* (IEEE, 2018), pp. 175-179.
4. Shabalina, K., Sagitov, A., Su, K.L., Hsia, K.H., Magid, E. Avroa Unior car-like robot in Gazebo environment, *International Conference on Artificial Life and Robotics* (2019), pp. 116–119.
5. Mitchell W. C., et al. Analysis of Ackermann steering geometry. *SAE Technical Paper*, №. 2006-01-3638.
6. Lavrenov, R., Zakiev, A. Tool for 3D Gazebo map construction from arbitrary images and laser scans. In *2017 10th International Conference on Developments in eSystems Engineering* (IEEE, 2017), pp. 256-261.
7. Latombe J.-C., *Robot motion planning*. 124 (Springer Science & Business Media, 2012).
8. Sungwoo, C., Boussard, C., & d’Andrea Novel, B., Easy path planning and robust control for automatic parallel parking, *IFAC Proceedings Volumes*, 44(1) (2011), pp. 656–661.
9. “Rohith-k/autonomous-parallel-parking-car-like-robot-gazebo-ros,” <https://github.com/Rohith-K/Autonomous-Parallel-Parking-Car-likeRobot-Gazebo-ROS>, accessed: 2019-04-11.
10. Saveliev, A., Malov, D., Edemskii, A., & Pavliuk, N. Proactive Localization System Concept for Users of Cyber-Physical Space. In *International Conference on Interactive Collaborative Robotics* (Springer, Cham, 2018), pp. 233-238.
11. Simakov, N., Lavrenov, R., Zakiev, A., Safin, R., & Martinez-Garcia, E.A., Modeling USAR maps for the collection of information on the state of the environment. *International Conference on Developments in eSystems Engineering* (IEEE, 2019).