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 assistants[1]) 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 planning[2] and control tested for a simulated Avrora Unior robot, but our solution is easily transferable to a real Avrora Unior and other car-like robots[3].

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 model[4]; 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 geometry[5]. 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.

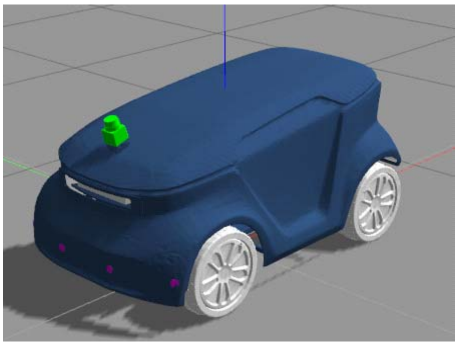

Fig. 2. Avrora Unior model in Gazebo.

To prevent unnecessary collisions and other accidents at this stage of research we are using robot model in a Gazebo[6] simulation that was developed previously[4] (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 integrable[7].

B. Parking Path Planning

For parallel parking path planning we modified path planning method based on geometrical approach[8]. 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 Lmin[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 Krishnan[9]. 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 calculation were only subtractions of displacement about OX from a rear axle location. More complex transformation were made for calculation of counter-steering point because it includes both rotation and translation.

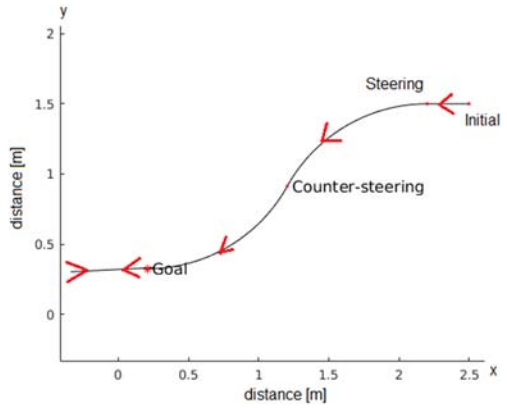

Fig. 3. Parking trajectory.

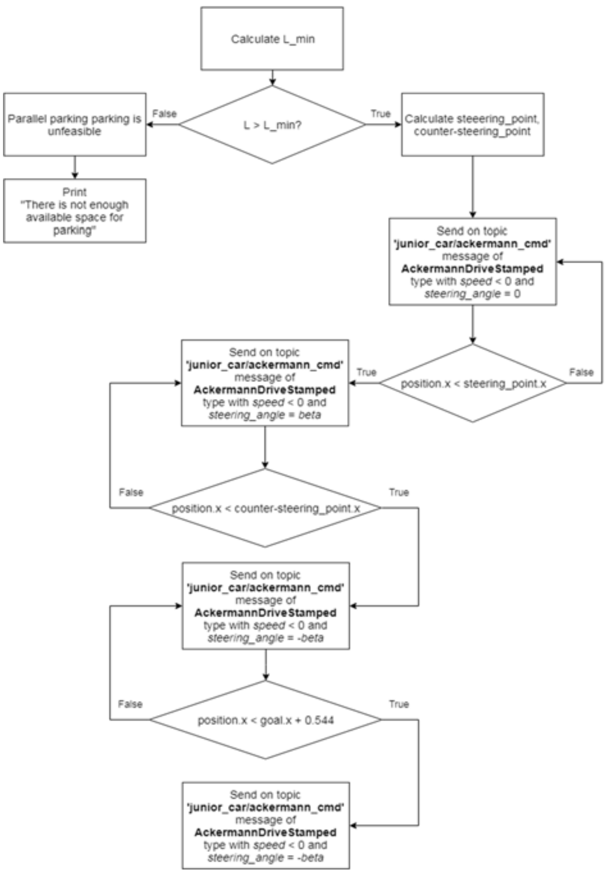

Fig. 4. Control algorithm diagram.

As Avrora Unior robot (and subsequently it's model) does not feature active braking system, we stop it in advance to the target point using only engine braking. We made measurements that determine the time required for a full stop and time it takes to turn steering for a full interval[10], and used those measurements to implement the final control algorithm, which is presented in Fig. 4.

4.2. Key Points

The first step is calculating a counter-steering point for the center of the vehicle. For calculation of a new counter-steering point, the coordinate frame {1} of the old one is used. The coordinate frame in the center of counter-steering point 1 is rotated by angle β relative to global coordinate frame {0} (a steering angle)[8] and further displaced by e/2 (Fig. 5). A separate ROS service was implemented for calculation of angle β from an input steering angle. The diagram of vehicle control architecture in Gazebo simulation is presented in Fig. 6.

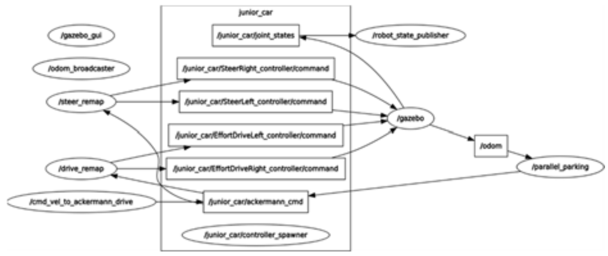

Fig. 5. Parking control system.

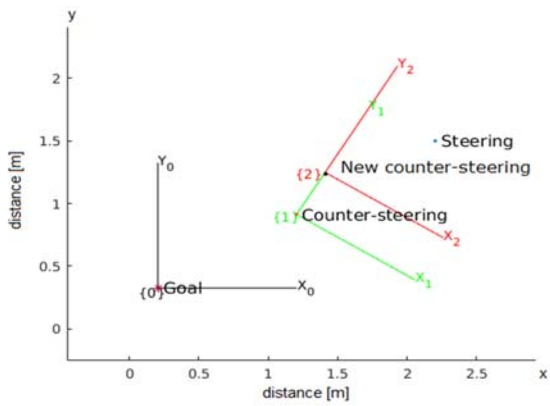

Fig. 6. Coordinate frames.

5. Avrora Unior model dynamic characteristics

We measured time required for a full stop by performing a series of experiments. After robot was accelerated to a predefined velocity (parking velocity) we engage a passive breaking (by sending ROS[10] AckermannDriveStamped message with parameters 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 world[11] 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 Lmin = 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. Avrora 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 Avrora Unior robot. Our future work is focused on development of fully autonomous parking system of level 4 according to SAE J3016 standard.

Acknowledgements

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