

Optimization Based Trajectory Planning of Parallel Parking with Multiple Constraints

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ABSTRACT

The reference path played a very important role in the parking schemes. In this paper, an arc tangent like polynomial trajectory model is proposed, and an optimal trajectory is obtained for automatic parallel parking based on genetic algorithm, which ensures that the vehicle does not collide with obstacles or other vehicles during parking. The proposed algorithm has strong robustness because of that all the parameters of the vehicle and the parallel parking spaces are parameterized. Using the trajectory model with the vehicle and parking space parameters, a cost function with multi-constraints, were established for path planning. The start and end points of the planning trajectory are the actual starting point and the desired final parking point of the vehicle by choosing three parameters of the trajectory model appropriately. Simulation results illustrate the effectiveness of the proposed algorithm.

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INTRODUCTION

With the popularity of private cars, parking space in cities is becoming more crowded than ever before, which significantly increases the difficulty of parking task of drivers. Therefore, more and more drivers are expecting that vehicles could have the functionality of automatic parking or semi-automatic parking assistance. The automatic parking techniques are attracting great attention of researchers in both automotive industry and academia. In [1], automatic parking was transformed into a tracking control problem by adding a predefined virtual trajectory and obtained solution for nonholonomic mobile robots. In [2], a fuzzy gain scheduling strategy was proposed for parallel automatic parking, which introduced a combination of a local path tracking controller and fuzzy rule based path planning techniques. In [3] a neuro-fuzzy model was developed for autonomous parallel parking of a car-like mobile robot and the training data was generated by a fifth order polynomial reference path model. In [4], the parking situation was captured by an arrangement of pre-calculated vector fields of feasible nonholonomic paths, by which the vehicle is controlled toward a desired goal configuration inside a parking bay.

The planning of reference path played a very important role in developing parking techniques. The process of parallel parking is that, choosing a feasible and executable trajectory, the vehicle reaches to a desired end position in the parallel parking space from the start

position. Different trajectory will give different parking quality, e.g. taking an unfit parking trajectory, collisions with the obstacles or other vehicles may occur during the parking process or the body of the vehicle is not parallel to the parking space at the end position. Planning a reasonable parking trajectory is necessary for parallel parking and the quality of the planning trajectory will directly affect the parking result. Regard to trajectory planning, many well-known path planning algorithms were proposed for the parking problem in recent years. In [7], based on the back-stepping method, a switching algorithm of two set of steering laws was proposed for the multi-chain systems and applied to automatic parking systems, but the parking trajectory would vary with the different driving velocity. Geometry-based model [8] and polynomial model [3] are the main types of trajectory descriptions. In [8], a shortest path was given for a car with a given minimum turning radius between the starting and ending point without considering the potential collisions. In [9], the parking assist system planed an optimal path according to driver's selection, and then tracked the reference path by a PID controller with limited error. In [10], based upon recursive subdivision of a reference path, a fast and exact motion planner was obtained for a car-like robot, but the planned trajectory sometimes cannot be used in practical application because of the ignoring the motion constraints when generating the reference path. A perfect planned parking path should be continuous, smooth, collision-free and satisfy the constraints of the vehicle motion.

In this paper, an arc tangent liked polynomial trajectory model is proposed according to the characteristics of the practical parallel parking path. The constraints function is established base on the proposed model and the parameters of the parking space and vehicle. Using the genetic algorithm, the optimal trajectory was numerically computed for parallel parking with considering the constraints of initial and desired ending points, collision-free and the vehicle motion constraints etc. Simulation results illustrate the effectiveness of the proposed method.

PARALLEL PARKING TRAJECTORY PLANNING

In the following, we will use three subsections to expound the parallel parking trajectory model, constraints of the trajectory and parallel trajectory planning algorithm respectively.

Parallel Parking Trajectory Model

It has been shown in [14] that the shortest path for a car-like vehicle is arcs of circle (with minimum turning radius) connected with straight line segments. But the problem about this path is that the curvature profile is discontinuous between arcs and straight lines, so that the vehicle has to stop at each discontinuity point at line-arc transition to reorient the front wheels. Since instantaneous changes in steering mechanisms are physically impossible, to overcome this problem, several authors have proposed continuous-curvature path planners using differential mathematical polynomial models.

Modeling is generally divided into two steps: the first step is to determine the model structure and the second step is to identify the model parameters. Establish the model structure is very important, because the model structure mainly determines the descriptive ability of the model. Trajectory model is a mathematical function described the characteristics of the parking trajectory. In parallel parking process, the trajectory curve has similar characteristics of the arctangent function with different amplitude and curvature [14]. But a single arctangent model cannot fully describe the trajectory characteristics considering the trajectory constraints as indicated in the next section. Then a perturbation is needed. Since both the parking trajectory curve and arctangent function have nonlinear characteristics, it would be better to choose a nonlinear perturbation. In a two-dimensional coordinate (X,Y), the trajectory curve of both a third degree polynomial and an arctangent function are mainly in the first and third quadrants or second and fourth quadrants, but the trajectory curve of a two degree polynomial is mainly in the first and second quadrants or third and fourth quadrants. Comparing with a two degree polynomial, it should be better to choose a third degree polynomial as a perturbation of the parallel parking trajectory model for the more similarity between a third degree polynomial and arctangent function and that a second-order perturbation is a special case of the third-order perturbation. But the trajectory model will be more complex, which will increase the amount of calculation and the difficulty of the model parameter identification, if we choose a four or higher order degree perturbation. Therefore, we choose the mathematical function with similar structure of the arctangent function with a third degree polynomial perturbation as parallel parking trajectory model:

$$y = c_1 \arctan(c_2 x + c_3) (c_4 x^3 + c_5 x^2 + c_6 x + c_7) + c_8 \quad (1)$$

where (x, y) is the coordinate of the vehicle parking trajectory as shown in Figure 1, x is the lateral coordinate, y is the longitudinal coordinate and $c_i, i = 1, 2, \dots, 8$ are constant parameters for the trajectory model.

Trajectory Constraints

The process of the vehicle parallel parking was shown in Figure 1.

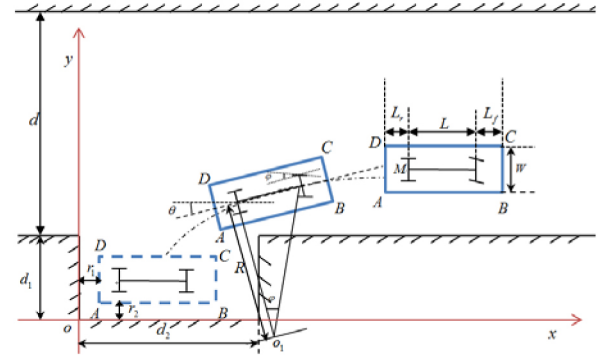


Figure 1. Parallel parking process.

In Figure 1, the parking vehicle was simplified as a rectangular frame and A, B, C and D representing the four outline vertices respectively. L is the wheel base, L_f is the length of the front overhang, L_r is the length of the rear overhang and W is the vehicle width. θ is the posture of the vehicle, φ is the steering angle and R is the turning radius. d is the width of the road, d_1 and d_2 denote the width and length of parking space. r_1 and r_2 are the desired distances of the vehicle to the left and bottom edge of the parking space after completing the parking process.

Let the coordinate of point M, the center of the rear wheel, is (x_M, y_M) , then

$$\theta = \arctan \left(\frac{dy_M}{dx_M} \right) \quad (2)$$

and

$$\rho = \frac{y_M'}{(1 + y_M'^2)^{3/2}} \quad (3)$$

where ρ is the curvature of the vehicle parking trajectory.

According to geometric principles, the coordinate of $A(x_A, y_A)$, $B(x_B, y_B)$, $C(x_C, y_C)$ and $D(x_D, y_D)$, are as follows