

Research on optimal parking trajectory based on parking planning model

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Abstract. This paper mainly deals with the planning problem of unmanned vehicle parking path in parking lot. For each different parking problem and different parking constraints, a suitable parking model is established in this paper. First of all, the Ackman turned to the geometric model, and the original four -wheel car model was equivalent to a two -wheeled bicycle model, so that the two different corners of the front wheels were equivalent to a corner 6.462m. In the solution to the shortest distance, this article first establishes the shortest distance model of accelerating to the same maximum speed under any condition. The shortest distance required to solve the maximum limit of 20km/h is 5.561m. Lately, the vehicle motion equation model was established, and the change rate of the maximum curvature relative path length was 1.140m^{-2} . Aiming at problem 2: First, the turning process in parking is analyzed, and the minimum turning radius when the control point is located at the axisymmetric center of the rear wheel is recalculated to be 4.974m, which is used in the subsequent parking path planning. Finally, using the above analysis of the motion situation of the unmanned vehicle and the planning of the parking trajectory, the parking trajectory in each case and the relationship between the changes of each physical quantity over time are given.

Keywords: ackerman, unmanned vehicle, parking track, planning, optimal parking space.

1. Introduction

The automatic parking of unmanned vehicles refers to the process of realizing the automatic parking of cars in the parking lot. In big cities with limited parking space, it is a more practical function, which reduces the difficulty for drivers to drive vehicles into narrow spaces[1]. This study takes the Ackerman vehicle model as an example and requires us to implement the function of automatic parking in the parking lot [2]. When the unmanned vehicle drives to the designated position, how to identify the optimal target parking space in the parking lot, and how to quickly arrive and park safely according to the target parking space are the core issues of the automatic parking process [3]. At the same time, the parking process should be as short as possible while ensuring safety. In the case of limiting jerk and acceleration, the shortest distance required to accelerate to the maximum speed limit and give the parking trajectory and various physical parameters at each moment[4].

2. Construction And Solution of The Shortest Distance Model

2.1. Minimum turning radius

Based on the above Ackman steering principle, the four -wheel car model can be equivalent to one two -wheeled bicycle model, as shown in Figure 1:

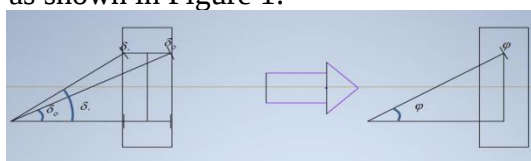


Figure 1. Equivalent diagram of the Ackerman car model

It can be seen from the above that the turning angle of the two front wheels is equivalently the turning angle φ at the midpoint of the front axle. At the same time, according to the Ackerman geometric principle, we can get:

$$\cot \delta_0 - \cot \delta_i = \frac{W}{L} \quad (1)$$

$$\cot \delta_i + \cot \delta_0 = 2 \cot \varphi \quad (2)$$

The formula for calculating the turning radius of the vehicle at this time can be obtained:

$$R = \frac{L}{\sin \delta_0} \quad (3)$$

When the front outer wheel angle reaches the maximum, there is a minimum turning radius $R_{\min}$ [5].

$$R_{\min} = \frac{L}{\sin \delta_{o\max}} \quad (4)$$

$$\delta_{o\max} = \text{arccot}(\cot \varphi_{\max} + \frac{W}{2L}) \quad (5)$$

Know the relationship between the steering wheel angle and the front wheel angle from the question

$$\varphi_{\max} = \frac{476^\circ}{16} = 29.375^\circ \quad (6)$$

Substitute into the above formula to get the minimum turning radius $R_{\min} = 6.462$ m.

2.2. Shortest distance to accelerate to maximum speed

Limit the maximum vehicle jerk to 20 m/s^3 , limit the maximum acceleration to 3 m/s^2 , accelerated to a maximum speed of 20 km/h :

$$s.t \begin{cases} j(t) \leq 0 \\ \int_0^{t_0} a(t) dt = \frac{50}{9} \\ a(t) \leq 3 \end{cases} \quad (7)$$

$$x = vt \quad (8)$$

Let the jerk $j_0 = 20$ of the unmanned vehicle during acceleration.

When the acceleration of the unmanned vehicle increases to $a_0 = 3$, the required time is:

$$t = \frac{a_0}{j_0} = \frac{3}{20} = 0.15 \text{ s} \quad (9)$$

The speed of the unmanned vehicle at this time is:

$$v = \int_0^{t_1} j_0 t dt < \frac{50}{9} \text{ m/s} \quad (10)$$

When performing the final variable acceleration movement, it should be symmetrical with the variable acceleration movement of the first segment:

$$t_1 = t_3 = 0.15 \text{ s} \quad (11)$$

$$v_0 - v_2 = v_1 = 0.225 \quad (12)$$

In the uniform acceleration phase, the time used is:

$$t_2 = \frac{v_0 - 2v_1}{a_0} = \frac{\frac{50}{9} - 2 \times 0.225}{3} = 1.702s \quad (13)$$

The time required for the whole process is:

$$t_0 = t_1 + t_2 + t_3 = 2.002s \quad (14)$$

The lengths of the three paths are:

$$\begin{cases} x_1 = \int_0^{t_1} \frac{j_0 t^2}{2} dt = \frac{j_0 t_1^3}{6} = 0.01125m \\ x_2 = \int_0^{t_2} (v_1 + a_0 t) dt = 4.728m \\ x_3 = \int_0^{t_3} \left(v_2 + a_0 t + \frac{j_0 t^2}{2} \right) dt = 0.822m \end{cases} \quad (15)$$

The v-t diagram of the whole process is(Figure 2):

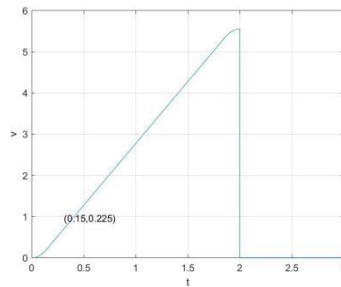


Figure 2. The v-t diagram of the unmanned vehicle during the forward acceleration process

In summary, we can get the shortest path length for the unmanned vehicle to accelerate to 20km/h:

$$x_0 = x_1 + x_2 + x_3 = 5.561m \quad (16)$$

2.3. Curvature change rate size limit

We establish a coordinate system to analyze the motion of the unmanned vehicle at any time(Figure 3):

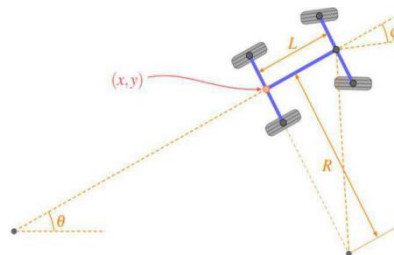


Figure 3. Unmanned vehicle motion equation model

We obtain three kinematic expressions describing the motion of the unmanned vehicle[6]:

$$\begin{cases} \frac{dx}{dt} = v \cos \theta \\ \frac{dy}{dt} = v \sin \theta \\ \frac{d\theta}{dt} = \frac{\tan \varphi}{L} \end{cases} \quad (17)$$

Let the arc length traversed by the unmanned vehicle be s , and the turning angle be s . According to the definition of curvature, we have:

$$K = \frac{d\theta}{ds} = \frac{1}{R} \quad (18)$$

From the meaning of the question, the rate of change of the curvature on the path relative to the path length is the derivative of the curvature to the path length[7].

When φ and $\frac{d\varphi}{dt}$ reaches the maximum at the same time, the curvature relative path length changes, the rate of change of curvature relative to the path length has a maximum value:

$$\varphi_{\max} = 29.375^\circ, \frac{d\varphi}{dt_{\max}} = \frac{400}{16} = 25^\circ / s, v = 20 \text{ km} / h \quad (19)$$

The maximum value of the rate of change of the curvature relative to the path length can be obtained as:

$$\frac{dK}{ds_{\max}} = 1.140 \text{ m}^{-2} \quad (20)$$

3. Construction And Solution of Parking Process Planning Model

3.1. Vertical parking trajectory

The vertical direction of D on the left side of the origin establishes a coordinate system for the Y axis(Figure 4):

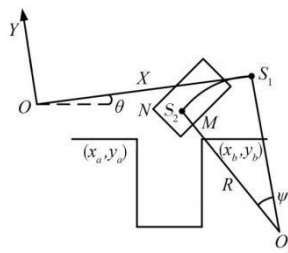


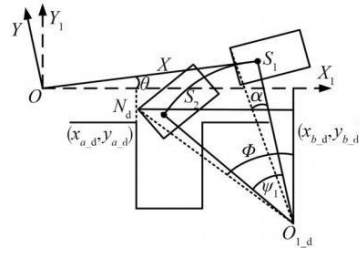
Figure 4. Schematic diagram of the first stop point of vertical parking

(1) Parking start point S1 coordinates:

The coordinates of the starting point S1 are:

$$\begin{cases} x_{s1} = x_{O1} \\ y_{s1} = 0 \end{cases} \quad (21)$$

(2) Parking point S2 coordinates(Figure 5):



. Change of heading angle of multi-step path

The coordinates of point S2 are:

$$\begin{cases} x_{s2} = x_{O1,d} - R \sin(\psi_1 + \theta) \\ y_{s2} = y_{O1,d} + R \cos(\psi_1 + \theta) \end{cases} \quad (22)$$

Advance point S3 coordinates(Figure 6):

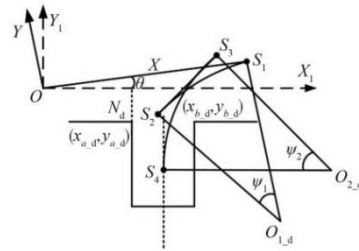


Figure 6. Vertical parking multi-step parking into the garage

The coordinates of the S3 point are obtained as:

$$\begin{cases} x_{s3} = x_{s2} + L_b \cos(\psi_1 + \theta) \\ y_{s3} = y_{s2} + L_b \sin(\psi_1 + \theta) \end{cases} \quad (23)$$

The coordinates of the S4 point are obtained as:

$$\begin{cases} x_{s4} = x_{O2,d} - R \\ y_{s4} = y_{O2,d} \end{cases} \quad (24)$$

3.2. Parallel parking trajectory

Establish a parking path planning right -angle coordinate system(Figure 7).

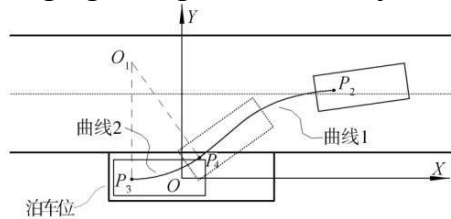


Figure 7. Schematic diagram of parking trajectory planning

Considering the relevant constraints in the driving process of the vehicle, a fifth-order polynomial is used to solve the unknown curve in this paper. curve1 is a quintic polynomial curve, its role is to connect the pose of points P2 $(x_{p2}, y_{p2}, \theta_{p2}, \varphi_{p2})$ and P4 $(x_{p4}, y_{p4}, \theta_{p4}, \varphi_{p4})$.

The process trajectory of parallel parking is:

$$y = \begin{cases} y_{P3} - R_{\min} - \sqrt{R_{\min} - (x - x_{P3})^2} & x_{P3} \leq x \leq x_{P4} \\ k_5 x^5 + k_4 x^4 + k_3 x^3 + k_2 x^2 + k_1 x + k_0 & , x_{P4} < x \leq x_{P2} \end{cases} \quad (25)$$

3.3. Inclined Parking Trajectory

The trajectory planning of inclined parking is similar to the above-mentioned vertical parking trajectory, except that the angles of the two arcs are different from it. Therefore, the trajectory planning of inclined parking will not be repeated in this paper[8].

3.4. Solution of Vertical Parking Trajectory

According to the above model, we get the following trajectory for the vertical parking of the unmanned vehicle(Figure 8):

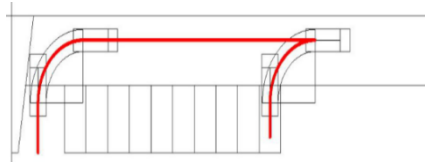


Figure 8. Vertical parking trajectory of unmanned vehicle

The specific physical parameters at each moment are as follows (Figure 9-12):

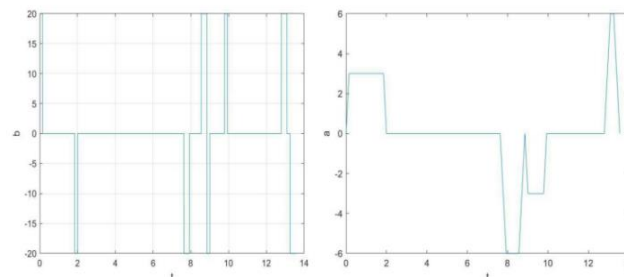


Figure 9. Jerk, acceleration versus time

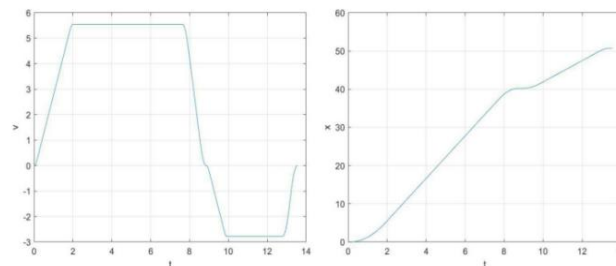


Figure 10. Variation of speed and path length with time

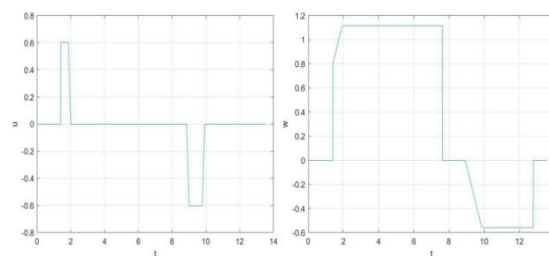


Figure 11. Angular acceleration and angular velocity change with time

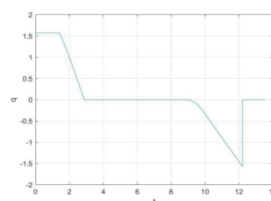


Figure 12. Changes in body orientation angle with time

3.5. Solving the Parallel Parking Trajectory

According to the above model, we get the trajectory of the following unmanned vehicle level parking (Figure 13):

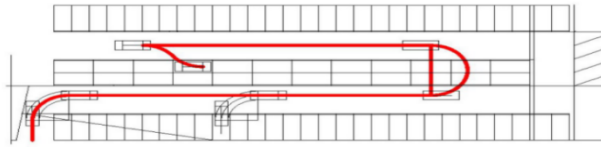


Figure 13. Unmanned vehicle horizontal parking trajectory

The specific physical parameters at each moment are as follows:

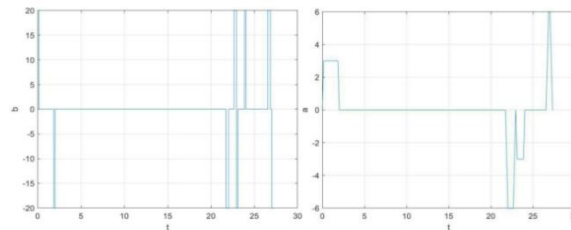


Figure 14. Jerk, acceleration versus time

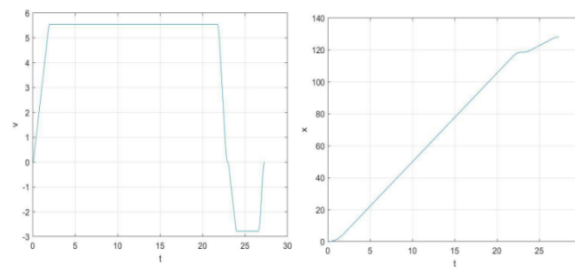


Figure 15. Velocity, path length versus time

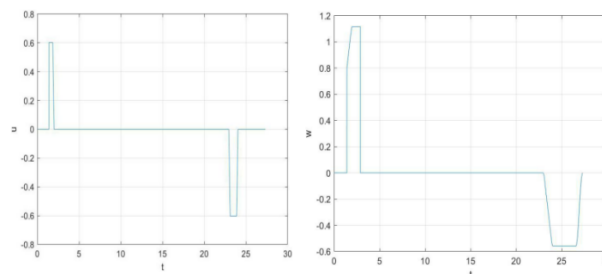


Figure 16. Angular acceleration and angular velocity change with time

3.6. The solution of inclined parking trajectory

According to the above model, we get the trajectory of the unmanned vehicle inclined parking, as shown in the Figure 17:

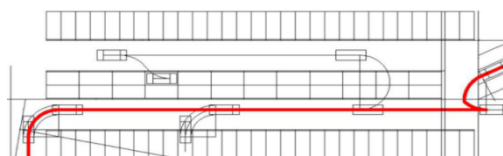


Figure 17. Unmanned vehicle inclined parking trajectory

The specific physical parameters at each moment are as follows(Figure 18-20):

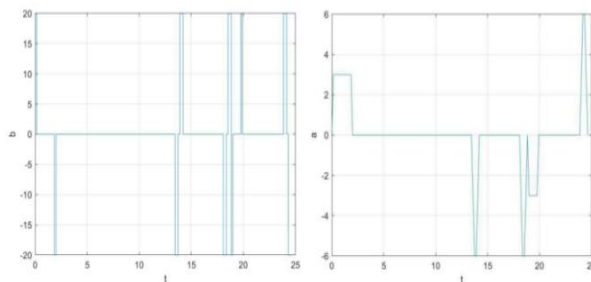


Figure 18. Jerk, acceleration versus time

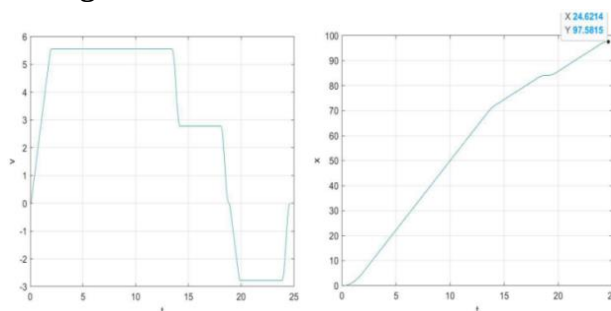


Figure 19. Velocity, path length versus time

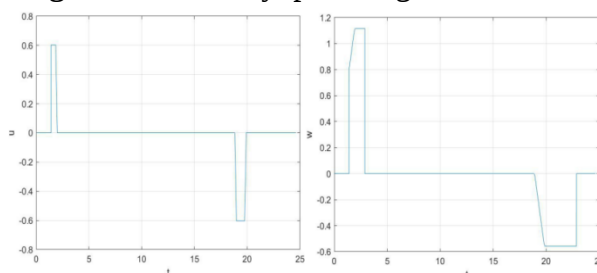


Figure 20. Angular acceleration and angular velocity change with time

4. conclusions

This paper mainly focuses on the automatic parking process of unmanned vehicles, and the model can be extended to the parking process of vehicles in real life. The driver only needs to control the steering angle of the steering wheel and give the vehicle a suitable speed, and then the vehicle can be parked in different parking spaces with the established trajectory and time in the model, which greatly improves the efficiency and accuracy of parking.

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