Path Planning Algorithm for Automatic Parallel Parking from Arbitrary Initial Angle

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***Abstract*— This paper presents automatic parallel parking for car-like vehicle, with highlights on a path planning algorithm for arbitrary initial angle using two tangential arcs of different radii. The algorithm is divided into three parts. Firstly, a simple kinematic model of the vehicle is established based on Ackerman steering geometry; secondly, not only a minimal size of the parking space is analyzed based on the size and the performance of the vehicle but also an appropriate target point is chosen based on the size of the parking space and the vehicle; Finally, a path is generated based on two tangential arcs of different radii. The simulation results show that the feasibility of the proposed algorithm.**

Keywords- automatic parallel parking; path planning; arbitrary initial angle

I. INTRODUCTION

Nowadays, more and more vehicles are used to improve the living standard of people, but the more vehicles means the smaller parking space and higher parking maneuver. Consequently, parking might be damaging for a vehicle and stressful for a driver. Therefore, the automatic parking assistant system is the key to increase the security and comfort of driver.

Path planning, which has been widely studied, is an important issue to be considered in the automatic parking assistant system. There are several path planning algorithms for the automatic parallel parking system.

The fuzzy logic algorithm [1, 2] is demonstrated using the experiences of the driver. Although the fuzzy logic algorithm can provide path planning in real time, they are limited to human experts' knowledge and difficult to generalize the experiences of the driver. Different reference functions are used to generate the path. Bezier curve [3] and fifth degree polynomial [4] can make a continuous-curvature path; Composite function [5], which combined with arctangent function and polynomial function, minimize the orientation angle of the vehicle at the parking point. Some geometric curves are combined to generate the path. In [6], the parking in one or several maneuvers in tiny spots using two arcs of the same minimum radius; the combination of straight lines and two arcs of the same minimum radius are proposed in [7]; in [8], two arcs of different radii are used in the intermediate state to the target state. But few researchers make discussion on the path planning from arbitrary initial angle, several algorithms require the initial state to be parallel to the parking space or only to have a smaller deflection angle to complete the parallel parking.

In this paper, after considering the actual initial parking state, which always has a deflection angle to the parking space, a path planning algorithm is proposed for parallel parking from arbitrary initial angle. The path is generated based on two tangential arcs of different radii. And the feasibility of the proposed algorithm is verified on the MATLAB.

II. THE VEHICLE KINEMATIC MODEL

The vehicle is running at low speed when parking, so it is assumed to move with non-sliding. The vehicle structure mentioned in this paper is the Ackerman steering structure. The vehicle kinematic model is illustrated in Fig.1.

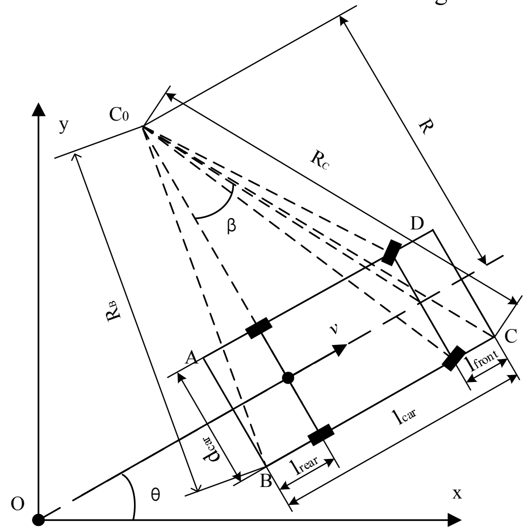

Figure 1. The vehicle kinematic model

In the reference coordinate system, the vehicle rotates with a certain radius at the center C_0, which is the intersection of three perpendiculars of the direction of the front wheels and the vehicle. R represents the distance between the midpoint of the rear wheel and the center. R_B represents the distance between point B and the center. R_C represents the distance between point C and the center. β is defined as the steering angle. θ is defined as the orientation angle according to global coordinate system. v represents the constant movement speed of the vehicle.

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As shown in Fig.1, the geometric relationships between R, R_B and R_C are presented as follows:

$$\begin{cases} R = (l_{car} - l_{rear} - l_{front})/\tan\beta \\ R_B = \sqrt[2]{{l_{rear}}^2 + (R + d_{car}/2)^2} \\ R_C = \sqrt[2]{(l_{car} - l_{rear})^2 + (R + d_{car}/2)^2} \end{cases} \quad (1)$$

Because of the vehicle structure constraints, the vehicle will rotate with the minimum radius when the front wheel gets the maximum steering angle. The minimum radius and the maximum steering angle are defined as R_{min} and β_{max} respectively. Simultaneously, the minimum radius of R_B and R_C, which are defined as $R_{B_{min}}$ and $R_{C_{min}}$ can be obtained.

There have been many researches about the Ackerman steering structure of the vehicle [9], and the vehicle kinematic model is shown as follows

$$\begin{cases} \dot{x} = v * cos\theta \\ \dot{y} = v * sin\theta \\ \dot{\theta} = \frac{v*tan\theta}{l_{car}-l_{rear}-l_{front}} \end{cases} \quad (2)$$

III. The Minimum Parking Space And Target Point

To prevent that the vehicle collide with the parking line during the parking process, the parking space should not be too small. Obviously, the size of the parking space must be larger than the size of the vehicle. But when parking in one maneuver, the accurate size of parking space must be analyzed according to the performance of the vehicle and several collisions avoidance conditions.

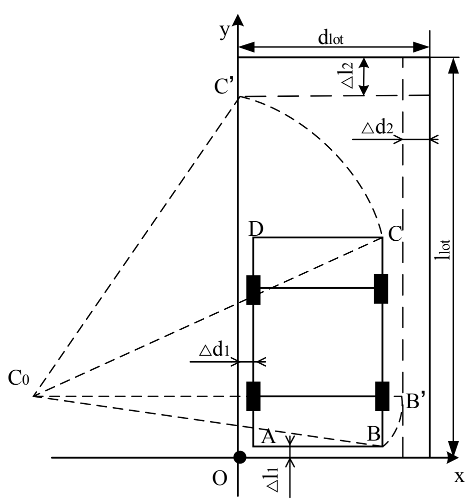


Figure 2. The relative position between parking space and vehicle

The relative position between parking space and vehicle and the collision points are shown in Fig.2. The left front vertex of the parking space and the right front vertex C of the vehicle may collide at point C′. The left front vertex of the parking space and the right front vertex C of the vehicle may collide at point C′. The right side of the parking space and the right rear vertex B of the vehicle may have a collision at point B′. The distances between the vehicle contour and the parking boundary on each direction are defined as Δd_1, Δd_2, Δl_1 and Δl_2 respectively.

The length and width of the parking space are presented as follows:

$$\begin{cases} d_{lot} = R_B - R + \frac{d_{car}}{2} + \Delta d_1 + \Delta d_2 \\ l_{lot} = \sqrt{{R_C}^2 - \left(R - \frac{d_{car}}{2}\right)^2} + l_{rear} + \Delta l_1 + \Delta l_2 \end{cases} \quad (3)$$

By Eq. (1), $R_{B_{min}}$ and $R_{C_{min}}$ can be obtained when $R = R_{min}$, Therefore the minimum size of the parking space can be calculated when $\Delta d_1 = 0, \Delta d_2 = 0, \Delta l_1 = 0, \Delta l_2 = 0$ and $R = R_{min}$, then define as $d_{lot_{min}}$ and $l_{lot_{min}}$.

The distance of Δd_1 and Δl_1 depends on the target point of the vehicle. In Fig.2, we take the lower left corner of the parking space as the origin of the global coordinate system and define the midpoint of the rear wheel as target point (x_2, y_2). The relationships between Δd_1, Δl_1 and (x_2, y_2) are shown as follows:8/++

$$\begin{cases} \Delta d_1 = x_2 - d_{car}/2 \\ \Delta l_1 = y_2 - l_{rear} \end{cases} \quad (4)$$

The following path planning for automatic parallel vehicle based on the minimum size of the parking space, so $\Delta d_1 = 0$ and $\Delta l_1 = 0$, then we can get the target point of the vehicle as follows:

$$\begin{cases} x_2 = d_{car}/2 \\ y_2 = l_{rear} \end{cases} \quad (5)$$

IV. Path Planning

In most cases, the initial direction of the vehicle axis is not parallel to the parking space, so we propose an algorithm for automatic parallel parking from arbitrary initial angle. The parallel parking path planning is to generate a geometric path composed of two tangential arcs of different radii. Given a barrier-free environment, the path of the vehicle can be expressed in Fig.3.

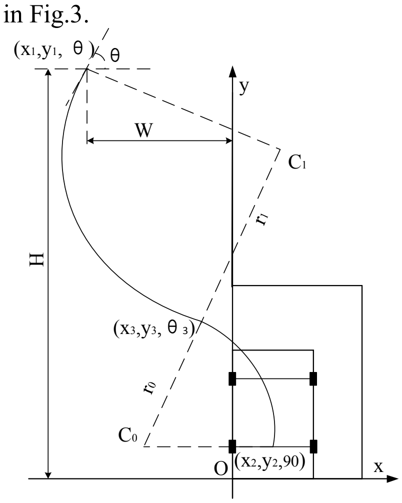


Figure 3. Path planning

The initial coordinate is (x_1, y_1, θ), the coordinate of the intersection of the two tangential arcs is (x_3, y_3, θ_3), and the target coordinate is $(x_2, y_2, 90)$. The center of two arcs are C_0 and C_1 respectively. The radii of two arcs are r_0 and r_1. By Eq. (3) (4) (5), $x_2 = d_{car}/2$, $y_2 = l_{rear}$ and $r_0 = R_{min}$ can be obtained. By the laser sensors and coordinate conversion, the initial coordinate can be determined that $x_1 = -W$ and $x_2 = H$. Then the center C_0, C_1, r_1 and the coordinate of the intersection can be calculated as follows:

$$\begin{cases} x_{C_0} = x_2 - r_0 \\ y_{C_0} = y_2 \end{cases} \quad (6)$$

$$\begin{cases} x_{C_1} = x_1 + r_1 * cos\theta \\ y_{C_1} = y_1 - r_1 * sin\theta \end{cases} \quad (7)$$

$$r_1 = \frac{(x_1 - x_{C_0})^2 + (y_1 - y_{C_0})^2 - r_0{}^2}{2[r_0 - (x_1 - x_{C_0})\sin\theta + (y_1 - y_{C_0})\cos\theta]} \quad (8)$$

$$\begin{cases} x_3 = \frac{r_0 * (x_1 - x_{C_0})}{r_0 + r_1} + x_{C_0} \\ y_3 = \frac{r_0 * (y_1 - y_{C_0})}{r_0 + r_1} + y_{C_0} \\ \theta_3 = \arctan(\frac{x_{C_0} - x_{C_1}}{y_{C_0} - y_{C_1}}) + 90^0 \end{cases} \quad (9)$$

Considering the vehicle performance constraint, the radius of the first arcs must satisfy that $r_1 \geq R_{min}$, so when the initial angle $\theta = 0$, the initial y coordinate must satisfy that $y_1 \geq 3R_{min} + l_{rear}$. The larger of the initial angle, the smaller the value of the initial y coordinate is, which can not be smaller than R_{min}.

V. SIMULATION

The automatic parallel parking path planning algorithm programming is implemented on MATLAB. The environment information is perceived by using all kinds of sensors, then the vehicle initial state, the parking space and other useful information are determined by integrating the data which obtained from sensors. Meanwhile, it generates the parallel path through the parallel parking path planning algorithm. The parameters of the vehicle and the smallest parking space are shown in Table Ⅰ. The parameters of simulation for different initial site are shown in Table Ⅱ.

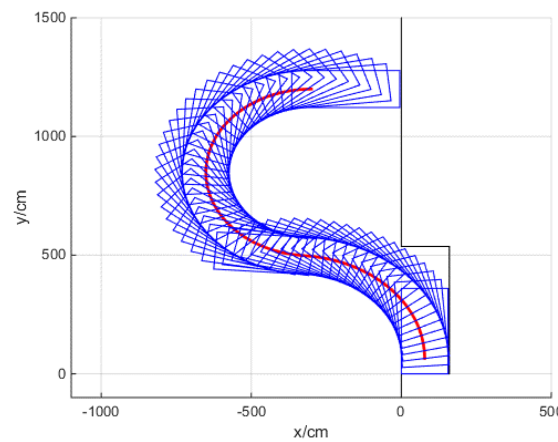
TABLE I. THE PARAMETERS OF THE VEHICLE AND THE SMALLEST PARKING SPACE

Parameters	Simulation value	Description
l_{car}/cm	360	Length of vehicle
d_{car}/cm	156	Width of vehicle
l_{front}/cm	80	The distance between the front axle and the front of the vehicle
l_{rear}/cm	65	The distance between the rear axle and the rear of the vehicle
β_{max}/º	26.34	The maximum angle of the steering
v/(km/h)	5.6	The speed of the vehicle
$l_{lot_{min}}$/cm	536	The minimum length of the parking space
$d_{lot_{min}}$/cm	160	The minimum width of the parking space

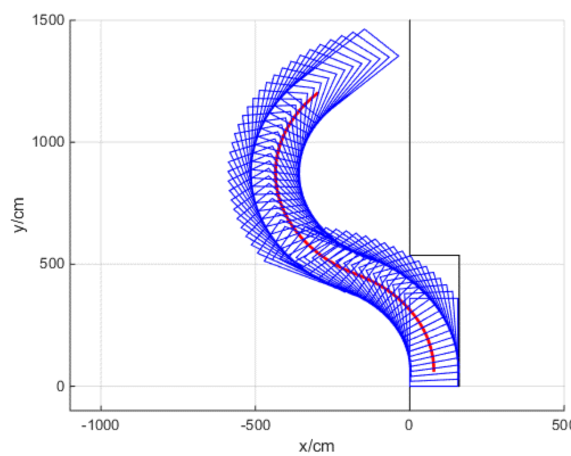
TABLE II. THE PARAMETERS OF SIMULATION FOR DIFFERENT INITIAL STATE

initial angle/º	initial x coordinate /cm	initial y coordinate /cm
0	-300	1200
45	-300	1200
90	-300	1200
135	-800	1000
180	-800	800

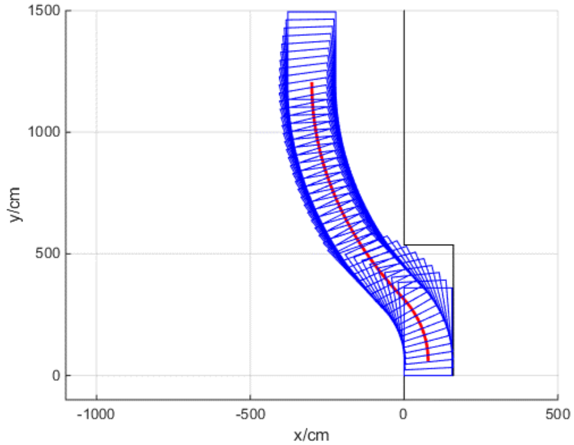
Given a barrier-free environment, the results of simulation are shown in Fig.4. It can be obtained even if the initial angle is too small or too big, the proposed algorithm can generate the parallel parking path successfully.



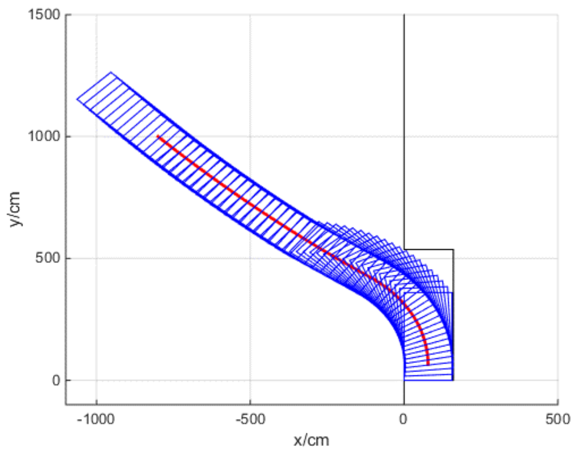
(a) Initial angle =0



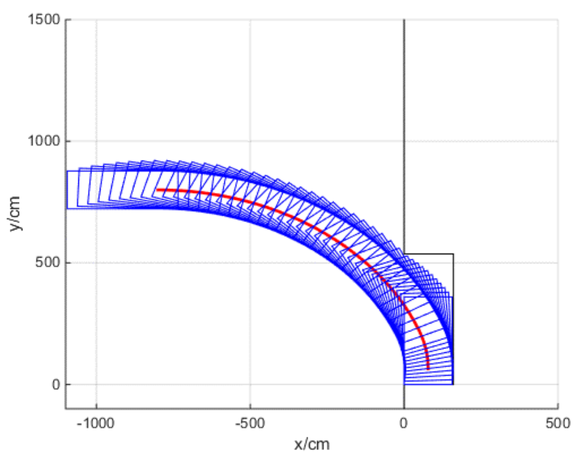
(b) Initial angle =45º



(c) Initial angle =90º



(d) Initial angle =135º



(e) Initial angle =180º

Figure 4. Simulation results

VI. Conclusion

Considering that the initial angle of the vehicle is not parallel to the parking space, a path planning algorithm for parallel parking from arbitrary initial angle is proposed in this paper. A simple Ackerman steering kinematic model of the vehicle is used to analyze the minimal size of the parking space and get the proper target point. Then a geometric path is generated composed of two tangential arcs of different radii. The simulation results show that the algorithm can generate the parallel parking path successfully of the vehicle from arbitrary initial angle.

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