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A PARKING PATH PLANNING METHOD BASED ON CIRCULAR ARCS AND LINES

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ABSTRACT: In recent years, there has been a shortage of parking spaces in many areas as the number of vehicles. Moreover, the parking space for each car may be narrowed, due to increase the number of parking spaces. As a result, parking spaces become narrower and accidents in the parking lot caused by inexperienced drivers are increasing. Thus, driving assistance functions such as automatic parking systems that perform parking tasks on behalf of the driver have recently become widespread. Facilities such as shopping malls and coin-operated parking lots have small parking spaces and are difficult to park. It is expected that the number of accidents caused by inexperienced drivers will decrease. In this paper, we propose a new method to search for a path that allows parking in a narrow parking environment from the start position to the parking target location by generating a path based on map information, arcs and straight lines. We propose a path generation method that is closer to human decision-making by effectively using arcs and straight lines.

Key words: Vehicle, Parking, Automatic parking, Path planning, Circular arcs and straight lines

INTRODUCTION

In recent years, especially in urban areas, the increase in automobiles has led to a shortage of parking spaces, and resulting in increased parking spaces are being built on smaller lots. Consequently, a lot of accidents in the parking lots are caused by inexperienced drivers. The development of autonomous driving technology is essential for comfort improvement and crucial for preventing such traffic accidents. As a result, it has been actively pursued in recent years. And driving assistance features and autonomous driving technology have now reached the practical stage. One can see that various automobile companies now equip their commercially available vehicles with driving assistance features such as automatic braking (collision mitigation brake) and adaptive cruise control (ACC), which continuously monitor the distance between the vehicle and the lead car using cameras and radar. These safety features have become standard equipment in many vehicles.

In addition to the systems that provide support while driving on public roads, such as automatic braking and ACC, automated parking systems that help parking tasks on behalf of the driver have been widely adopted. Commercial facilities such as shopping malls and coin parking lots downtown have often narrow parking spaces with columns between them or limited space to accommodate more vehicles. In such parking lots, the use of automated parking systems is expected to reduce accidents caused by inexperienced drivers, and research into automated parking and robot control has been conducted extensively. Specifically, the various strategies have presented a method based on Rapidly exploring Random Trees (RRT) (Zheng, K., & Liu, S. 2018). Moreover, based on minimum turning radius, some path planning methods have been suggested (Gao, H. et al., 2022; Wang, J. et al., 2013; Liang, Z. et al., 2012). The method using RRT (Zheng, K., & Liu, S. 2018) involves setting a target point and randomly generating points from both the parking starting position and the parking target position. This process is repeated until the paths connecting the parking starting position and the parking target one is connected.

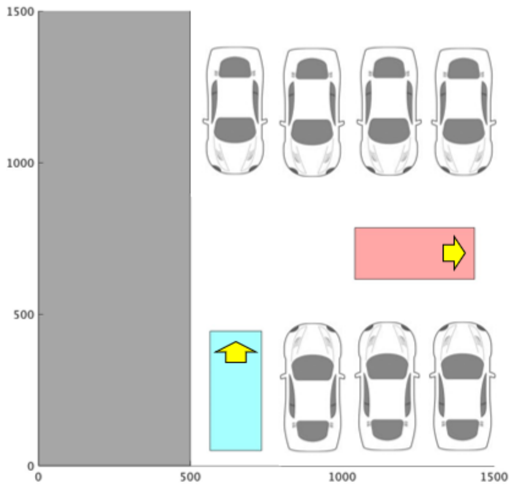


Figure 1. Parking Map

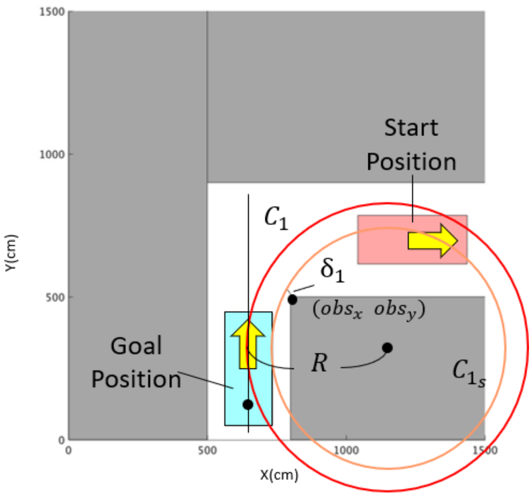


Figure 2. *STEP 1*

However, since points are randomly connected, the trial count and computational complexity increase as the paths connecting from the parking starting position to the parking target one. Additionally, the generated paths tend to be complex. In the minimum turning radius (Wang, J. et al., 2013), simpler paths to RRT-based method are generated. However, it does not take methods into account some situations, such as K-turn or paths from the parking starting position.

From the above, we propose a new method for exploring a path that allows parking in the direction specified from the parking starting position to the parking target one in a narrow parking lot. Specifically, desirable parking paths considering the presence/absence of obstacles are generated by using arcs and straight lines based on map information. For environments where K-turn is necessary, a path generation method that is closer to human decision-making is proposed by using arcs and straight lines.

GENERATING STRATEGY OF PARKING PATH

Vehicle Models

In the case of four-wheeled vehicles, there is often a minimal change in the slip angle during low-speed motion. In such a case, the Ackermann steering geometry is a well-known method for describing the motion of the vehicle (Tsujisawa, T. 2007). In this paper, we refer to the use of the Ackermann steering geometry to define the path based on the rear axle of a four-wheeled vehicle. By using Ackermann steering geometry, the line connecting the turning center and the rear wheel axle center always remains orthogonal to the central axis of the four-wheeled vehicle. This makes it easier to generate paths using arcs and straight lines.

Path Planning Method

In this paper, we consider environments with close obstacles and a need for K-turn. We aim to generate a path from the red square to the blue square. The red and blue squares are the starting position and the parking target one. The yellow arrow also indicates the forward direction of the vehicle. The path planning method proposed in this paper generates a path from the parking target position to the parking starting one by planning the path in reverse. The proposed path planning consists of the following steps:

STEP 1

The red circle (C_1) in Figure 2 represents the minimum turning radius circle and the orange circle (C_{1_s}) is a circle with its radius adjusted to ensure that the distance between the right side of the vehicle and the obstacle is at least δ_1. Note that δ_1 is a safety margin on the inner wheel offset. The centers of the two circles have the same coordinates. A straight line is drawn from the rear axle center of the parking target position to the front axle center, ensuring that this line is tangent to circle C_1 and that the center of circle C_1 is positioned such that the obstacle's corner is within circle C_{1_s}. Therefore, we consider the following conditions:

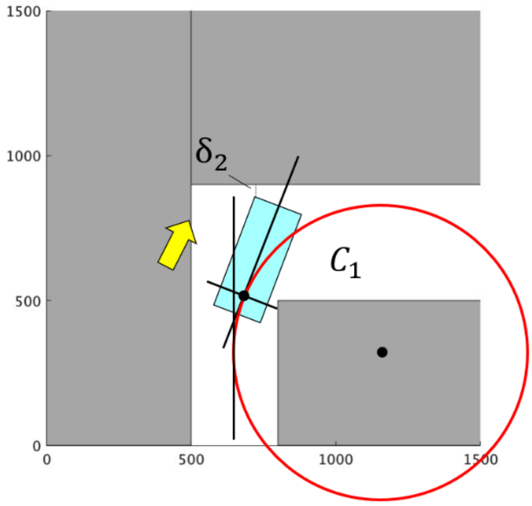


Figure 3. *STEP 2*

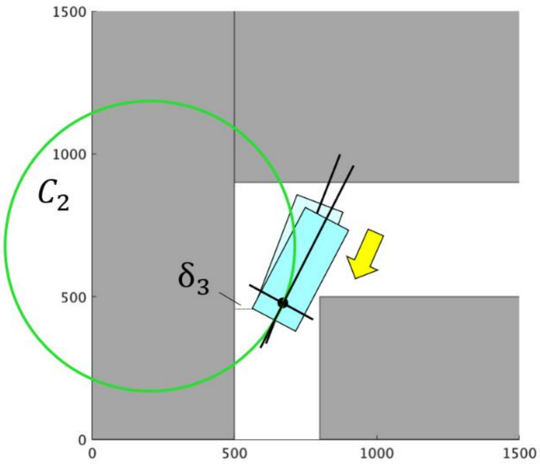
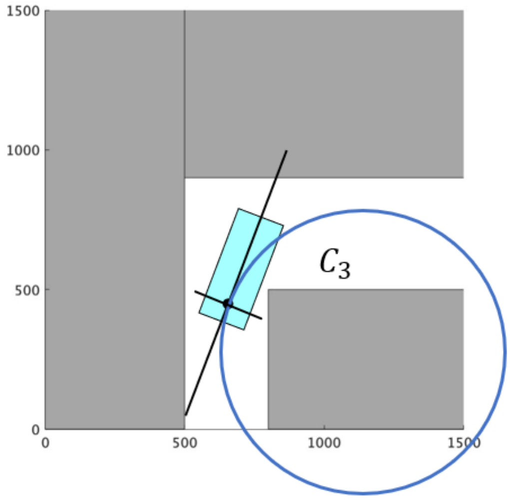


Figure 4. *STEP 3*



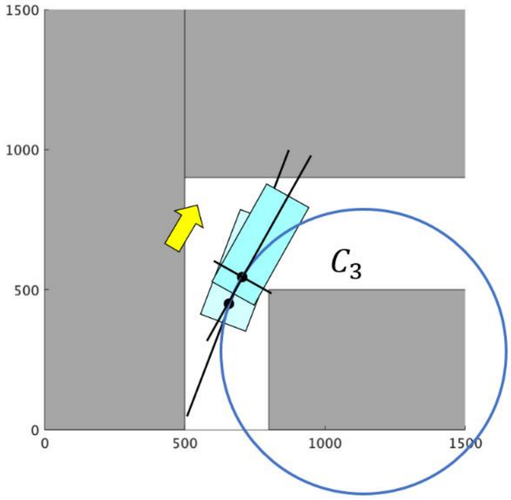


Figure 5. *STEP 4-1* **Figure 6.** *STEP 4-2*

$$\left(abs_x - C_{1_x}\right)^2 + \left(abs_y - C_{1_y}\right)^2 < \left\{R - \left(\frac{C_W}{2}\right) - \delta_1\right\}^2, \tag{1}$$

where abs_x and abs_y represent the x and y coordinates of the corner of the obstacle, C_{1_x} and C_{1_y} are the x and y coordinates of the center of circle C_1, R is the minimum turning radius, and C_W is the vehicle width. By setting C_{1_x} and C_{1_y} satisfying the condition of (1). The obstacle's corner is enclosed within circle C_{1_S}. Thus, when vehicles are traveling along the circle C_1, a safe distance is maintained.

STEP 2

The vehicle is moved forward so that the line connecting the rear axle center and the front center of the vehicle touches circle C_1 and the rear axle center passes through circle C_1. Note that the vehicle is moved forward until the distance from the left front of the vehicle to the obstacle becomes δ_2 (see Figure 3).

STEP 3

Determine the center of the green circle (C_2) with the minimum turning radius to be tangent to the rear axle, as shown in Figure 4. Reverse the vehicle so that the rear axle center passes over circle C_2. Note that, continue reversing until the distance between the vehicle's right side and the obstacle becomes δ_1, or the distance between the vehicle's left rear and the obstacle becomes δ_3.

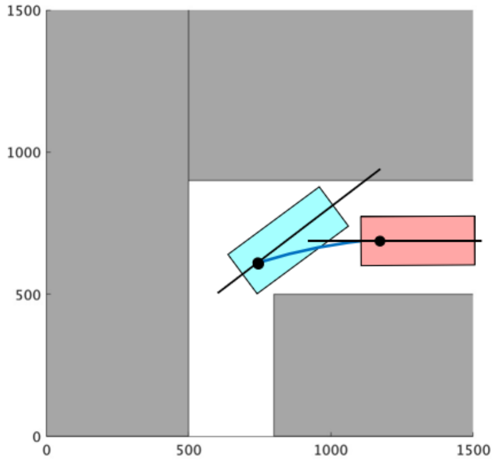


Figure 7. *STEP 5*

Figure 8. Vehicle Model

Table 1. Vehicle Parameters

Parameter	Value[cm]
Length	394
Width	169.5
Wheelbase	255
Minimum Turning Radius	322

Table 2. Comparison of The Number of K-turn

Road Width[cm]	Number of K-turn[times]	
	Conventional (Ogata, R. et al., 2023)	Proposed
400	2	1
380	5	3

STEP 4

Determine the center of the blue circle (C_3) so that it is tangent to the vehicle's rear axle (see Figure 5 (*STEP 4-1*)). Next, as *STEP 4-2*, advance the vehicle so that the rear axle passes over the circle C_3, as shown in Figure 6.

STEP 5

In *STEP 4,* if the distance between the left front of the vehicle and the obstacle becomes δ_2, then it returns to *STEP 3*. When the distance between the vehicle's left front and the obstacle is longer than δ_2, the vehicle can make a turn, and is advanced. As illustrated in Figure 7, Generate an arc such that it connects the coordinates of the rear axle center when the vehicle's left front is closest to the obstacle and the axis of the parking starting position (the line passing through the rear axle center to the front axle center).

STEP 6

The parking path is generated by retracing each of the created paths in reverse order through each of the above STEPs.

SIMULATION

The simulation results of the path planning from the red square parking starting position in Figure 1 to the blue square parking target position are shown.

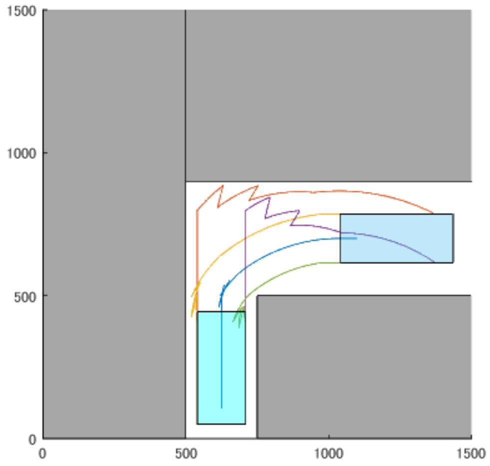


Figure 9. Conventional Method (400[cm])

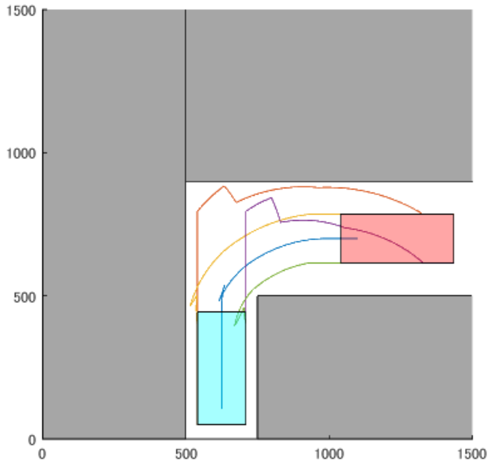


Figure 10. Proposed Method (400[cm])

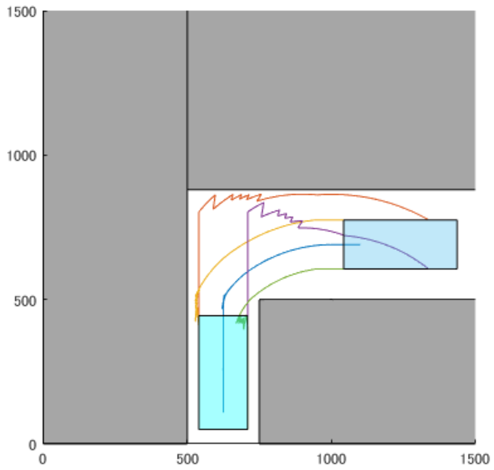


Figure 11. Conventional Method (380[cm])

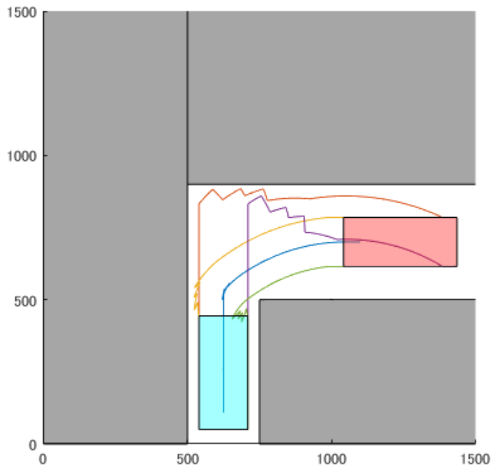


Figure 12. Proposed Method (380[cm])

Vehicle Parameters

The details of the vehicle used in the simulation are presented in Table 1. The vehicle model used in the simulation is shown in Figure 8 (Toyota motor corporation, n.d.).

Simulation Results

The simulation results of the parking path for the vehicle with parameters shown in Table 1 are presented. In this simulation, the parking lot size is set at 250[cm]×500[cm], and the road width is 400[cm] and 380[cm], and these are typical for parking lots commonly used in places like coin parking. Figures 9-12 represent the simulation results, and in these figures the blue line shows the path of the vehicle's rear axle center, and the other lines represent the paths of the four corners of the vehicle. Table 2 shows the results of the comparison of the number of K-turns between the proposed method and the conventional method (Ogata, R. et al., 2023) for the case that the road widths are set as 400[cm] and 380[cm].

From Figure 10, it is evident that for a road width of 400[cm], the proposed method can generate a parking path which includes only 1 K-turn. On the other hand, the conventional method needs 2 K-turns (see Figure 9). Moreover, we see from Figure 11 and 12 that although the proposed method can generate a path with only 3 K-turns. The conventional method requires 5 K-turns. In the case that the road width is further reduced to 375[cm], the conventional method could not generate any paths. On the other hand, the proposed method could generate parking paths. This result means that the proposed method enables path planning in parking lots and roadways designed with narrow parking spaces and road widths. From the above, the proposed method is useful and effective.

CONCLUSION

In this paper, a new planning method for desirable parking paths in spite of the presence of obstacles has been proposed by using arcs and straight lines. Specifically, we have focused on environments where obstacles are close to vehicles and K-turns are required. By using multiple straight lines and arcs with a minimum turning radius, obstacle avoidance can be achieved, and smooth paths to the desired destination can be planned. Furthermore, the resulting paths generated by the proposed planning method are close to decision making by human. In simulation results, the number of K-turn has been compared to the conventional method (Ogata, R. et al., 2023), and the effectiveness of the proposed path planning method has been presented.

As future challenges, by adopting not only arcs and straight lines but also clothoid curves, the proposed path planning method will be extended. Furthermore, the evaluation of the proposed method for parking lots which shaped complexly is one of important future works.

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