Autonomous Vehicle Parking Using Artificial Intelligent Approach

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Abstract—This paper devotes to the design and implementation of a hybrid artificial intelligent control scheme for a car-like vehicle through the performance optimization of the task of car parking. The genetic algorithm is used to determine the feasible parking locations. The Petri-net is used to replace the traditional system flow chart and most importantly, to plan alternative parking routes especially in a global space. A fuzzy controller is utilized to drive the car along the optimal parking route.

Keywords—Optimization, Genetic Algorithm, Petri net, Fuzzy Control, Parallel Parking

I. INTRODUCTION

The study of motion autonomy for various vehicles has always been a significant point of interest for researchers globally. A classical approach for solving the motion problem is to apply Dubin’s curves [1] or Reed & Sheep curves [2]. Lafferriere and Sussmann [3] presented the motion plan for vehicles based on a constructive proof of controllability. Marry and Sastry [4] approached the problem by steering a nonholonomic system by means of sinusoids between arbitrary points. However, neither of them addressed the issue of obstacle avoidance. Paromtchik and Laugier [5] presented an approach where a vehicle was driven along a sinusoidal path in reverse direction. The parking space is scanned in advance before the vehicle reverses into it.

Recently, intelligent control methods are used more extensively, such as fuzzy logic controller, neural network controller, and genetic algorithms. Yasunobu and Murai [6] proposed a human experience based fuzzy logic controller. Jenkin and Yuhas [7] introduced a simplified neural network controller trained on the basis of kinematics data. These methods have also been extended to applications in autonomous mobile robot control and yielded much success [8-16].

With regard to the problem of autonomous parallel parking, several factors must be considered so that some of the platform technology developed for mobile robot systems industry can be easily extended to parking applications. Hwang et al.[17] have proposed that Petri nets are well-suited to the modeling of concurrent systems and [18-20] propose many analytic techniques allowing Petri nets to verify the occurrence of potentially undesirable states.

This paper presents an automatic parallel parking planning system for a car-like vehicle, with the intention of applying the research results of robot motion planning into real-world applications. Unlike traditional design methods, the proposed method focuses primarily on the path planning in a global parking region and it combines with Petri nets and genetic algorithms to present an optimal car parking scheme. The overall scheme solves the parallel parking problem and extends the problem to larger parking space. The presented strategy can be used in parking aid devices, and it has the potential to be integrated into automobiles.

II. ARCHITECTURE OF PARKING SYSTEM

A. Problem Description

Automatic parking is defined as an autonomous car from a traffic lane maneuvering into a parking lot to perform parallel, perpendicular or angle parking. The automatic parking aims to enhance the safety and comfort of drivers and passengers while driving in a restrained area where much attention and experience is required. The parking maneuver is achieved by means of coordinated control of the steering angle and speed, which takes the actual circumstances into account to ensure collision-free motion within available space.
### Table I. Definitions of Variables

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>$f_x$, $f_y$</td>
<td>Position of the center of front wheels</td>
</tr>
<tr>
<td>$r_x$, $r_y$</td>
<td>Position of the center of rear wheels</td>
</tr>
<tr>
<td>$\phi$</td>
<td>Orientation of the steering wheels with respect to the frame of the vehicle</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Angle between vehicle frame orientation and X-axis</td>
</tr>
<tr>
<td>$l$</td>
<td>Wheelbase of vehicle</td>
</tr>
<tr>
<td>$O$</td>
<td>Center of curvature</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Distance from point $O$ to the midpoint of front wheels axle</td>
</tr>
<tr>
<td>$r$</td>
<td>Curvature radius;</td>
</tr>
<tr>
<td>$v$</td>
<td>Speed of front wheels</td>
</tr>
<tr>
<td>$k$</td>
<td>Curvature of trajectory</td>
</tr>
</tbody>
</table>

#### B. Modeling of the Car-Like Vehicle

Consider the kinematical model of the car-like vehicle shown in Fig. 1, where the rear wheels are fixed parallel to the car body and are allowed to roll or spin but disallowed to slip. This ensures that the rear wheels are always tangent to the automobile orientation. The corresponding parameters of the vehicle listed in Table I are defined as follows.

The rear wheel is always tangent to the automobile orientation. Under normal conditions, the reserved velocity is about 5km per hour slow; thus, we can suppose that it appears a no-sliping condition and the velocity of the rear wheel in vertical director must be zero. This so-called nonholonomic constraint is described as

$$
\begin{align*}
\dot{x}_r &= v \cos \theta \cos \phi \\
\dot{y}_r &= v \sin \theta \cos \phi \\
\dot{\theta} &= \frac{v \sin \phi}{l}
\end{align*}
$$

This is used to generate the next backward state position of the vehicle when the present states and control input are given.

#### C. Reference Trajectories for Parallel Parking

It is important to provide a reasonable reference path so that the car can successfully accomplish the parallel-parking mission. In order to implement a feasible and smooth trajectory for the rear reference path, a method based on the derivation of a fifth-order polynomial [9] has been well adopted.

$$
\begin{align*}
\dot{x}_r &= (x_{ref} - L_2 \cos \theta) + \frac{W}{2} \sin \theta \\
\dot{y}_r &= (y_{ref} - L_2 \sin \theta) - \frac{W}{2} \cos \theta \\
\dot{x}_f &= [x_{ref} + (L_1 + l) \cos \theta] + \frac{W}{2} \sin \theta \\
\dot{y}_f &= [y_{ref} + (L_1 + l) \sin \theta] - \frac{W}{2} \cos \theta
\end{align*}
$$

If $x_r(t) \geq x_{ob}$ and $y_r(t) \leq y_{ob}$, the rear-right corner of the vehicle would hit the obstacle. Similarly, if $x_f(t) \geq x_{ob}$ and $y_f(t) \leq y_{ob}$, the front-right corner of the vehicle would hit the obstacle. Through this test, the suitable region could be characterized as illustrated in Fig. 4.

#### D. Ready-For-Parking Space

While an actual parking environment is considered, not all the trajectories are feasible. To avoid collision, the vehicle must be positioned inside a suitable region before it can perform the parking procedure. Therefore, the preliminary task is to determine a suitable region from two other constraints. One is the limitation of the maximum curvature given by

$$
k(x) = \frac{y''}{\left[1 + (y')^2\right]^{\frac{3}{2}}} \leq k_{max}
$$

The other is the distance from the car to the obstacle point $(x_{ob}, y_{ob})$, as illustrated in Fig 2. According to the vehicle’s dimensions as defined in Fig. 3, we can solve the values of $(x_{ref}, y_{ref})$ and $(x_f, y_f)$ from the reference point $(x_{ref}, y_{ref})$ produced by the reference trajectory.

The suitable region could be characterized as illustrated in Fig. 4.
III. PETRI NETS AND GAS

For human drivers, especially the beginners, it is usually difficult to determine a suitable parking space. Most often, the decisions are made instinctively. The parking process is a discontinuous action involving moving forward and reverse; therefore, different actions must be taken to find a suitable path for an optimal solution.

Petri nets based on discrete event formalisms have been proved as a potential means of achieving collision avoidance, task-preserving human-intervention, and route controlling. We has utilized an effective method with the concept of Petri nets while solving this particular problem. Petri net flow chart with initial and target markings is developed as shown in Fig. 5. \( P_1 - P_9 \) are defined as nine subareas in this parking field.

A. Optimal Path Planning with GA

In this section, we use the well known genetic algorithm (GA) to determine an optimal parking path.

While designing an optimal path for vehicle parking, there are various performance indices that are generally considered. In the proposed method, an additional factor is placed into consideration, that is, the number of gear changes. In general, a parking procedure that requires more than two gear shifts would be considered inefficient.

**Distance**: In the process of parking a vehicle, the relative position of the parking spot with respect to the car is a very important factor. Therefore, it is essential to consider the forward and backward movement when weighing the distance.

**Curvature**: The curvature of a vehicle directly affects the rotary angle of the wheels. The maximum value usually doesn’t exceed 45 degrees. An overlarge curvature for a vehicle in motion could cause the passengers a physical discomfort or even dizziness.

**Number of gear changes**: Generally, when considering the parking process, the procedure requires more than simply reversing a vehicle into the desired parking spot. The number of gear shifts needs to be considered as another important factor. More gear shifts will result in more extended distances; therefore, the corresponding cost should also be minimized.

According to the performance indices previously specified, the fitness function for the optimization problem can be designed.

\[
fitness = \frac{1}{\left( W_D D + W_{\theta} \frac{N_{\theta}}{N_{\theta, max}} + W_{\delta} \frac{\sum \phi}{\sum \phi, max} \right)} 
\]

where

\( W_i \): weighing scalar
\[ D : \left( \sum_{i} \text{trajectory}_i \right) \text{ total distance moved} \]

\[ N_g : \text{number of gear changes} \]

\[ \phi_i : \text{orientation of the steering wheels with respect to the frame of the vehicle of the } i\text{-th moving segment} \]

The design of the optimal parking path for a vehicle illustrated in Fig. 6 is summarized as the following steps. The initial position \((x_0, y_0)\) is randomly selected first.

**Step1:** Search for the point \((x_p, y_p)\) randomly within each \(P5\)-position, \(p = 1, 2, \cdots, n\).

(Randomly generate \(n\) chromosomes on the initial population.)

**Step2:** Apply these points and initial position to the fifth order equation and make sure that the curvature \(k\) does not exceed \(k_{\text{max}}\). If \(k(x) \leq k_{\text{max}}\), the path allows the vehicle to navigate to \(P5\); trajectory1 is produced. If \(k(x) > k_{\text{max}}\), it is impossible for the vehicle to navigate directly to \(P5\); therefore, the vehicle should be navigated to a different point where it is able to perform the maximum curvature \(k(x) = k_{\text{max}}\).

**Step3:** Apply \((x_p, y_p)\) and \((x_G, y_G)\) to obtain trajectory0.

**Step4:** Find the number of gear changes. For example, the vehicle moved backward, forward, then backward, results in three gear changes.

**Step5:** Find the change of \(\phi\).

**Step6:** Calculate the fitness and select the better chromosomes with probabilities based on fitness.

**Step7:** If the process will be terminated if the stopping condition is reached or the optimal solution is achieved, otherwise, repeat steps 2-7 for another run.

IV. FUZZY CONTROL DESIGN

In this section a human-friendly controller is implemented. We put our focus on designing the tracking controller for the vehicle to complete the task of parallel parking.

A. Problem Description & Analysis

Suppose the goal position defined by \((x_G, y_G, \theta_f)\), the vehicle’s current position \((x, y)\), the orientation of the vehicle \(\theta_i\) and the horizontal angle \(\theta_G\) between the coordinates of \((x, y)\) and \((x_G, y_G)\) shown as in Fig. 7.

From which once can have

\[ \theta_G = \tan^{-1} \left( \frac{y_G - y}{x_G - x} \right) \]  \(\text{(6)}\)

\[ d_e = \sqrt{(x_G - x)^2 + (y_G - y)^2} \]  \(\text{(7)}\)

\[ u_1 = \theta_G - \theta_e \]  \(\text{(8)}\)

\[ u_2 = \theta_f - \theta_G \]  \(\text{(9)}\)

where \(d_e\) is the distance between vehicle and goal.

We propose a two-stage fuzzy logic controller shown as in Fig. 8 to command the steering angle of the front wheels for parking task. Stage1 control input variables are \(u_1\) and \(u_2\).

The output variable is \(\theta_e\). The proposed fuzzy control rules are listed in Tables II-III.

We introduce \(d_e\) and \(\theta_e\) as the input linguistic variables for the Stage2 controller. \(d_e\) is in the range of distance \([0,100]\) (m) and \(\theta_e\) is in the range of angle \([-180,180]\) (degrees). The output linguistic variable is the steering angle \(\phi\). Consider the actual condition of the vehicle, the range of \(\phi\) is \([-45,45]\) (degrees).

![Figure 6. Illustrations for parking trajectories.](image)

![Figure 7. Target tracking control system with terminal orientation angle \(\theta_f\).](image)
The objective of the controller is to make $e$, $u_1$, and $u_2$ converging to zero when $t \to \infty$. As a result, the vehicle would just need to go straight to reach a specified goal.

V. SIMULATION RESULTS

The simulation results presented here were based on a car-like platform (Toyota Camry) with the following dimensions: length 4.825 m, width 1.82 m, $l = 2.755$ m and $\phi_{\text{max}} = 45$ degrees. Each parking space is supposed to be of dimension $6.5 \times 2.5$ m.

In case 1, the vehicle is with the starting position characterized by $(20,30,-50^\circ)$ and the goal point, $(50,70,60^\circ)$. The experiments show the performance with and without parameter optimization. The resulting trajectories of the simulation results are illustrated in Fig. 9. The membership functions for the fuzzy controller, after optimization, are shown in Fig. 10.

After optimizing the controller, the focus is switched to tracking control of the reference path. In Fig. 11, the working efficiency for the trajectory tracking of the reference path is shown.

Next, we apply the proposed path optimization method and the fuzzy controller for finding the optimal parking path in a widespread parking lot. We set the generation=50 and the population=20; the corresponding results are shown in Fig. 12.
In this paper, a complete parking mechanism for autonomous car-like vehicles has been introduced and applied to solve the parallel parking problem. The architecture includes a Petri-net based, off-line global trajectory planner, a decisive trajectory tracking controller to verify effectiveness and applicability of our proposed approach will be appeared in the near future.

An integrated test for the autonomous parking planner with the trajectory tracking controller to verify effectiveness of the preliminarily developed algorithms. A real-world application of the proposed design is currently undergoing. An integrated test for the autonomous parking planner with the trajectory tracking controller to verify effectiveness and applicability of our proposed approach will be appeared in the near future.

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REFERENCES


