Chapter 15

Front-in parking method for intelligent electric vehicles using proportional–integral–derivative control

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Chapter Outline

Artificial Intelligence-Empowered Modern Electric Vehicles in Smart Grid Systems
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15.1 Introduction

The development of artificial intelligence has cleared the path for groundbreaking transportation solutions, most notably autonomous driving, which is a powerful tool for reducing accidents and traffic congestion (Junkai et al., 2021; Khayyam et al., 2013; Sungwoo et al., 2011). Automated parking systems have proven to be adept at achieving smooth parking for vehicles in the larger context of autonomous driving (Khalid et al., n.d; Li et al., 2022; Lei et al., 2022; Rahbari et al., 2017). These systems do, however, primarily use parallel and perpendicular parking techniques.(Talati et al., 2021) Since many electric cars (EVs) have charging outlets located at their front ends, this poses a serious problem. The use of conventional perpendicular parking techniques can result in charging cable lengths that are unsafe or ineffective (Ahmed et al., 2021; Fehér et al., 2020; Tao Peng et al., 2020; Vamsi Krishna Reddy & Venkata Lakshmi Narayana, 2022; Ykun Xie et al., 2020). Addressing this issue becomes essential given the predicted increase in EV use.

On the other hand, existing advanced control algorithms place extremely high demands on the computing speed and storage space of microcontroller systems, which can lead to computation and storage explosions. This greatly limits their application in the automotive industry. The parking process is a low-speed driving process, and the real-time requirements for the system are not high. This chapter adopts the PID method to control the parking process of the vehicle, overcoming the issue of "computation explosion" and effectively achieving front parking (Talati et al., 2021).

This chapter proposes a new automated parking method based on front parking to address the aforementioned issues. This method mainly includes the kinematic modeling of the vehicle, path planning based on geometric deductions according to the relative position between the vehicle and the garage, and the utilization of PID control algorithm to reduce the computational load of the system for better engineering application.

This study found a research gap in the requirement for an automatic parking system specifically developed for electric vehicles (EVs). Existing automatic parking systems mostly focus on parallel and perpendicular parking approaches, which may not be suited for EVs due to their charging outlets being located in the front. This can lead to problems such as short charging wires or safety dangers from very long cables. With the anticipated development of EVs in the future decades, developing a parking system that tackles these difficulties is critical (Ahmed et al., 2021; Fehér et al., 2020; Tao Peng et al., 2020; Vamsi Krishna Reddy & Venkata Lakshmi Narayana, 2022; Ykun Xie et al., 2020). Furthermore, existing advanced control algorithms employed in automated parking systems exert tremendous demands on microcontroller systems' computing speed and storage space, resulting in computation and storage explosions. This restricts their use in the automotive industry. The parking procedure, on the other hand, is a low-speed driving operation with less strict real-time requirements. As a result, this work proposes using a PID control technique to govern the parking process, so avoiding computation explosion and ensuring efficient front parking.

The research aims to innovate a new method for automatic parking systems to accommodate front-in parking, which is crucial for EVs with front-mounted charging connections. The work contributes by creating a geometrically derived path planning algorithm that makes use of the vehicle's and the parking spot's relative positions. First, the vehicle's kinematics are modeled, and then the parking process is monitored and controlled using a PID (proportional−integral−derivative) controller. Using PID control simplifies the algorithm, solves the problem of computation explosion, and displays robustness, all of which are necessary for front-in parking in the near future of EVs. Matlab® and CarSim are used to simulate the car's kinematic model alongside the actual vehicle parameter model, allowing for a more thorough study of the motion simulation during the standard parking procedure. The findings of the simulation verify that the proposed tracking control strategy will successfully lead to the expected parking outcome.

15.1.1 Motivation

The rise of EVs and the concomitant changes in the transportation landscape, as well as the computational difficulties posed by sophisticated control algorithms in automated systems, serve as the driving forces behind this work.

First and foremost, the automobile sector is changing due to the approaching domination of EVs. EVs are becoming increasingly popular as the globe moves toward more environmentally friendly forms of transportation because of their lessened impact on the environment and reliance on fossil fuels (Ahmed et al., 2021; Fehér et al., 2020; Tao Peng et al., 2020; Vamsi Krishna Reddy & Venkata Lakshmi Narayana, 2022; Ykun Xie et al., 2020). However, this change presents certain difficulties, one of which is the positioning of many EVs' charging terminals at the front. Traditional parking techniques, particularly perpendicular parking, might result in unfeasible charging cable lengths that are either too short or unsafely long. This problem raises questions regarding EV use and safety overall as well as charging ease. It is essential to address this issue with an automated parking system designed especially for EVs to enable smooth charging and improve the user experience in general.

Second, there are major computing hurdles associated with integrating complex control algorithms into automated systems. Despite the impressive capacities of these algorithms, the processing power of microcontroller systems is frequently insufficient to meet their demanding computational needs. Their practical implementation in real-world situations is constrained by this difference, notably in the automotive sector where dependability, efficiency, and safety are crucial. The parking procedure, however, offers a chance to investigate control systems that prioritize ease of use, effectiveness, and little computational load because it is a low-speed operation. This is the driving force behind the decision to use a PID control algorithm for parking operations, a method renowned for its reliability and capacity to reduce computational load while still delivering the required results.

Given these reasons, this study aims to close these gaps by creating an automatic parking technique that is specifically created for EVs, taking into account the charging-related difficulties and computing limitations. The research intends to propose a workable solution that not only simplifies parking for EVs but also increases the viability of deploying advanced control strategies in practical automotive applications by adopting a PID control strategy and utilizing cutting-edge simulation tools. The ultimate goal of this research is to develop a sustainable and effective transportation ecosystem that harmoniously balances the needs of users and the environment through the integration of EVs and intelligent control systems.

15.1.1.1 Contribution of work

The research described in this chapter significantly advances the fields of automatic parking and intelligent transportation systems, particularly in the context of electric cars (EVs):

The main contribution of this study is the creation of a brand-new automatic parking technique that is especially suited for EVs or front-in parking. This approach considers a special factor that regular parking systems sometimes ignore: the positioning of charging connections at the front of EVs. By solving this issue, the suggested solution makes sure that EVs can park in the best possible way without running into problems with charging cable length or safety threats from extra cables. This addition improves the usefulness and convenience of EVs by directly addressing a significant flaw in the existing automated parking systems.

1. A PID control method has been incorporated for the parking process, which is a significant advance. The PID control approach offers an effective substitute for complex control algorithms, which frequently need considerable processing resources. This method puts an emphasis on simplicity and durability while taking advantage of how low-speed parking maneuvers are. The research helps to overcome the computational difficulties that have prevented the practical application of advanced control techniques in the automotive sector by implementing PID control.
2. **Path planning based on geometric deductions:** Another significant contribution is the creation of a path planning algorithm based on geometric deductions. The suggested method provides an accurate and efficient technique to design the parking trajectory by using the relative positions of the car and the parking space. This geometric method simplifies the process of path design and helps to provide a more exact and efficient parking solution.

3. **Integrated simulation approach:** This work is distinctive in that it uses both Matlab and CarSim for simulation. With the vehicle's kinematic model and its real-world parameters combined, this method enables a more thorough analysis of the parking process. The simulation results strengthen the validity and applicability of the research findings by validating the viability and efficacy of the suggested control approach.
4. **Enhanced engineering application:** This research contributes to a more useful and engineering-friendly automated parking solution by tackling the difficulties unique to EVs and using a PID control strategy. The emphasis on front-in parking is in line with the changing patterns in EV usage and design, making the suggested approach useful and practical in real-world situations.

In summary, the specific issues offered by EVs in the context of automated parking are addressed in this work through a novel approach. This research offers insights and solutions that can have a significant impact on the integration of EVs and intelligent transportation systems, from the development of a front-in parking method that takes charging port placement into account to the use of PID control for effective and practical parking maneuvers.

15.2 Organization

By embracing the revolutionary effects of artificial intelligence on transportation, especially autonomous driving and parking systems, the "Introduction" chapter establishes a foundational framework. The necessity for specialized parking solutions is highlighted by the unique issue presented by electric cars (EVs) with front charging ports in Section 15.2. The chapter also covers the computational requirements of sophisticated control algorithms in practical settings in Section 15.3. This study suggests a novel automated parking strategy for EVs that uses a PID control algorithm to reduce computing complexity and charging-related problems. The work makes a contribution by providing an EV-centric parking approach, integrating PID control, articulating geometric path planning, and verifying via cosimulation in Section 15.4. This is driven by the rise of EVs and the need for simplified control strategies in low-speed parking in Section 15.5. The chapter's conclusion summarizes the study's scope and organization by detailing the chapter's structure, which includes relevant works, the suggested model, simulation results, and conclusions.

15.3 Related work

In the literature (Marin-Plaza et al., 2019; Wang et al., 2015; Yin et al., 2016), the vehicle kinematic model is primarily established using the Matlab (Bryan et al., 2021; Lodhi et al., 2023; Wang, 2014) platform and path planning and tracking controllers are designed for simulation analysis. However, this method cannot comprehensively simulate the process of automated parking. Therefore, in this chapter, a joint simulation using Matlab and CarSim is conducted. An experimental vehicle model is built in CarSim based (Adhikary et al., 2023; Chen et al., 2013; Costa et al., 2023; Kalinowski et al., 2014; Wang & Han, n.d) on the vehicle's kinematic model and actual parameters, and a combined simulation experiment is performed with a parking path tracking controller designed in Matlab. The experimental results validate the effectiveness of the proposed control method in this paper.

Badue et al. (2021) conducted an exhaustive survey on autonomous vehicles. The authors investigated various aspects of autonomous vehicles, including their technologies, challenges, and applications, and provided valuable insight into the current state of the field. Zhang et al. (2019) presented a system for unmanned rolling compaction of rockfill materials. Their research centered on the automation of compaction processes in construction, demonstrating the effectiveness of the unmanned system in boosting productivity and efficiency. García-Ortiz et al. (1995) gave a general introduction of the ITS technologies, including sensors, communication systems, and control algorithms, and focused on how they improve transportation efficiency and security. A robotic traffic simulator was developed by Kalúz et al. (2016) to instruct sophisticated control methods. Their focus was on creating a simulator that simulates traffic situations and serves as a platform for testing and evaluating control methods. Deja et al. (n.d.) highlighted the potential benefits of drones in various fields, and their study also identified the difficulties that must be overcome for the effective integration of drones into industrial operations, such as logistics, inventory management, and quality control. The role of mechatronic systems in cutting-edge goods with embedded control was covered by Isermann (2005). The author stressed how mechatronic systems' combination of mechanical, electrical, and software components enables the development of novel products with improved functionality and performance. The performance and environmental impact of an electric bicycle were evaluated by Abagnale et al. (2015), who also discussed the benefits and drawbacks of e-bike technology. Choudhury et al. (2014) highlighted the requirement for reliable and strong sensor technologies by emphasizing the necessity of sensor performance and dependability in a number of applications. Zhang et al. (2021) conducted a review of collision-avoidance navigation systems for Maritime Autonomous Surface Ships (MASSs). The authors examined various collision-avoidance techniques and systems used in MASS and provided an overview of the current state of research in this field. Using Salp Swarm Optimization, Ahmed et al. (n.d.) presented a grid integration study of a photovoltaic (PV) system supporting an EV charging station. The authors investigated the integration of renewable energy sources with EV charging infrastructure, optimizing the grid integration of a PV system to support EV charging operations.

Within the context of intelligent vehicles, Villagra et al. (n.d.) addressed automated driving. The paper supplied an overview of the technologies and systems employed in automated driving, including perception, planning, control, and safety concerns. Liu (2021b) presented a paper on the optimization and control of energy-saving train automated driving systems. Optimizing energy consumption and control strategies in train unmanned driving systems was the focus of this paper, which provided insights for increasing energy efficiency in smart train operations.

Whereas, Liu (2021a) introduced the train unmanned drive system. The paper provided an overview of the train unmanned drive system, discussing its features, benefits, and challenges, laying the groundwork for further investigation. DeepDrive, a deceleration decision-making approach for advanced driver assistance systems, was proposed by Veluchamy et al. (2023). Contributing to the development of intelligent driver assistance systems, their research employed optimized Generative Adversarial Networks (GAN) and Deep Convolutional Neural Networks (CNN) to make deceleration decisions. Tang et al. (2023) conducted a review of hybrid PV and thermoelectric energy conversion systems. The authors investigated the combination of PV and thermoelectric technologies for energy conversion and provided insight into the potential of hybrid systems for efficient energy use. Bosque et al.'s (2014) study presented an exhaustive view of the hardware implementation of these intelligent systems, highlighting their practical advancements and challenges.

The literature that has already been published (Marin-Plaza et al., 2019; Wang et al., 2015; Yin et al., 2016) has mostly concentrated on employing Matlab-based car kinematic models for simulation analysis in automated parking systems; however, these techniques don't adequately capture the entire parking process. This study creatively uses Matlab and CarSim in a collaborative simulation to fill this gap, producing an experimental car model based on real-world characteristics (Adhikary et al., 2023; Chen et al., 2013; Costa et al., 2023; Kalinowski et al., 2014; Wang & Han, n.d.). For electric cars (EVs) with front-mounted charging connectors, this method is especially important since it gives a more precise and realistic portrayal of the parking process. Diverse research (Abagnale et al., 2015; Ahmed et al., n.d; Badue et al., 2021; Bosque et al., 2014; Choudhury et al., 2014; Deja et al., n.d; García-Ortiz et al., 1995; Isermann, 2005; Kalúz et al., 2016; Liu, 2021a, 2021b; Tang et al., 2023; Veluchamy et al., 2023; Villagra et al., n.d; Zhang et al., 2019, 2021) in intelligent transportation systems and autonomous vehicles emphasizes various areas of transportation technology while mainly ignoring the issue of specialized automated parking solutions for EVs. This gap is further highlighted by these studies. By offering an EV-specific automatic parking methodology, this research aims to close this gap, advancing intelligent transportation systems and improving the integration of EVs in a sustainable and user-centered way.

1. **Proposed Model**
2. **System Model**

The automatic parking of electric cars (EVs) is the focal point of the system model used in this study. The Ackermann steering principle is used to create the EV's kinematic model, which takes into account the low-speed nature of parking maneuvers. For the purpose of calculation, the model reduces a four-wheel vehicle to a two-wheel vehicle. The wheelbase, vehicle width, and steering angles (l, s), where s is the corresponding steering angle, are the main factors. Additional characteristics of the parking environment include garage size, vehicle length, and minimum turning radius.

15.3.1 Problem formulation

The creation of an automatic parking system specifically designed for EVs, especially those with front-mounted charging connections, is the main issue this research attempts to solve. EV charging requirements must be accommodated, efficient parking must be ensured, and computing complexity must be kept to a minimum. The investigation's goals are to:

1. **Create a kinematic model:** To appropriately depict the low-speed parking process, create a kinematic model of the EV based on the Ackermann steering concept. Create a path planning system that takes into account extreme positions and trajectory stages for perpendicular parking. Make sure to enter the parking space quickly while keeping in mind the EV's size and the layout of the garage.
2. **Implement path tracking control:** Utilizing the PID method's applicability for low-speed settings, propose a path tracking control algorithm. Reduce computational effort while making sure the EV precisely follows the required trajectory.
3. **Cosimulation validation:** Use cosimulation with Matlab and CarSim to verify the suggested strategy. Show that the control model is effective in precisely directing the EV along the intended trajectory and achieving parking objectives.

This chapter proposes an innovative automated parking system that optimizes path planning and tracking control through the use of a PID algorithm to overcome the shortcomings of current parking methods for EVs, particularly those with front-mounted charging connectors. The project seeks to validate the effectiveness of the suggested strategy in obtaining successful and precise parking outcomes for EVs using cosimulation trials.

15.4 Establishment of vehicle kinematic model

Setting the parking process as an extremely low-speed motion (typically below 5 km/h), the wheels of the vehicle roll at low speeds, and the vehicle generally does not experience lateral sliding, so lateral forces can be neglected, resulting in no wheel slip angle. In practical engineering, the vehicle motion model is usually simplified to establish the vehicle kinematic model. This chapter establishes the vehicle kinematic model based on the Ackermann steering principle (Badue et al., 2021; Chen et al., 2013; García-Ortiz et al., 1995; Zhang et al., 2019), as shown in Fig. 15.1.

In Fig. 15.1, 2e represents the wheelbase, K is the vehicle's wheelbase, φ represents the vehicle's equivalent steering angle, φ_l is the left wheel steering angle, and φ_s is the right wheel steering angle. For ease of calculation, a four-wheel vehicle is simplified to a two-wheel vehicle, and based on the Ackermann steering principle, it can be obtained that (Junkai et al., 2021):

$$\varphi = \frac{(\varphi_l + \varphi_s)}{2}$$

Based on the actual conditions, under the satisfaction of the Ackermann steering principle, there exists an approximate linear conversion relationship between the steering wheel angle and the equivalent Ackermann front wheel angle (Li et al., n.d.):

$$\theta_{tw} \approx m \cdot \varphi$$

where θ_{tw} is the steering wheel angle, m is the conversion coefficient, and based on actual measurement results, $m \approx 16.2$. The kinematic equations of

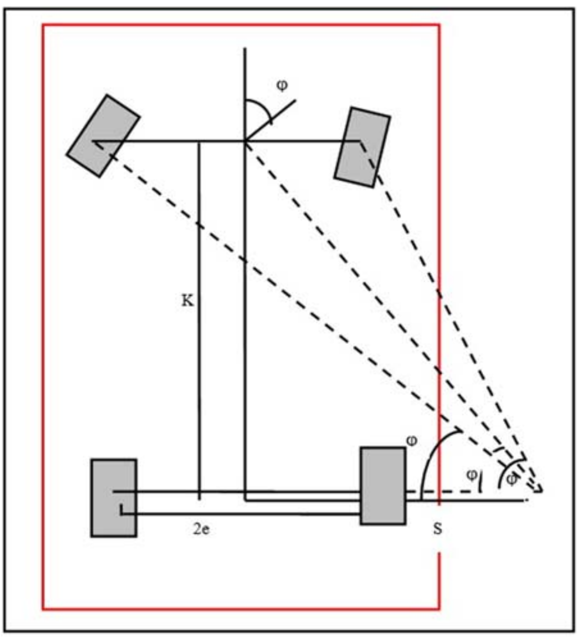

FIGURE 15.1 Vehicle kinematic model (CHEN et al., 2013).

the vehicle with the rear axle center as the reference point are as follows (Khayyam et al., 2013):

$$\begin{cases} Ys = w_{\mathrm{g}}\cos\theta\cos\varphi = w\cos\theta \\ x_{\mathrm{s}} = w_{\mathrm{g}}\sin\theta\sin\varphi = w\sin\theta \\ \theta = \dfrac{w\cdot\tan\varphi}{k} \end{cases}$$

where y_s and x_s are the y and x coordinates of the rear axle center, w is the vehicle's center velocity, and θ is the vehicle's yaw angle.

15.5 Path planning algorithm based on geometric deduction

The parking system senses parking environment information through sensors to plan the parking path. If the path meets the requirements, the parking operation is performed; otherwise, the system is closed. The parking methods for front parking include perpendicular parking and diagonal parking. This chapter focuses on the planning research of perpendicular parking.

15.6 Determination of extreme positions

The garage model is set as a rectangle with a length of 5200 mm and a width of 2500 mm, while the model of the vehicle body is set as a rectangle with a length of 4542 mm and a width of 1786 mm.

The parking process is designed with three stages as follows:

Forward stage trajectory: The vehicle moves from the midway parking point to the front of the garage. The vehicle enters the garage with the minimum turning radius, and the steering wheel is in the full lock position during this stage. The midway parking point and the entrance of the garage have the shortest vertical distance, which represents the extreme position.

Entry stage trajectory: The path can be planned based on the rear axle center position from the previous stage, the heading angle θ, and the final position of the rear axle center when the vehicle is fully parked.

Reverse stage trajectory: The midway parking point should maintain the same orientation during the reverse stage. The circle corresponding to this stage should be tangent to the circle corresponding to the first forward stage. Based on the vehicle's initial position, heading angle, and the circle obtained from the forward stage, the circle corresponding to the reverse stage, the midway parking point (i.e., the tangent point of the two circles), and the corresponding steering wheel angle are determined.

15.7 Forward stage

The forward stage of the vehicle consists of two trajectory segments: the first segment is the vehicle's movement from the midway parking point to the garage, and the second segment is the entry trajectory.

15.8 Movement to the garage stage

Taking the bottom-left corner of the parking space as the coordinate origin, with length as the x-axis and width as the y-axis, the angle between the car and the x-axis is the heading angle θ, with counterclockwise direction as positive. To ensure that the car can fully enter the garage, the posture of the car when entering the garage can be set as shown in Fig. 15.2 (Sungwoo et al., 2011)

$$\theta = \frac{\pi}{2} - \arctan\frac{D_x}{D_K} \cdot \arccos\frac{Q_x - e}{\sqrt{D_x^2 + D_M^2}}$$

Based on geometric relationships, the heading angle θ of the car at this time is given by (Rahbari et al., 2017):

$$\begin{cases} y_s = 0 - (D_{\mathrm{lf}} + K) \cdot \cos\theta + \dfrac{D_x}{2} \cdot \sin\theta \\ y_r = Q_x - d - (D_{\mathrm{lf}} + K) \cdot \sin\theta - \dfrac{D_x}{2} \cdot \cos\theta \end{cases}$$

where D_{lf} is the vehicle width, K is the vehicle length, Q_x is the garage width, and d is 300 millimeters.

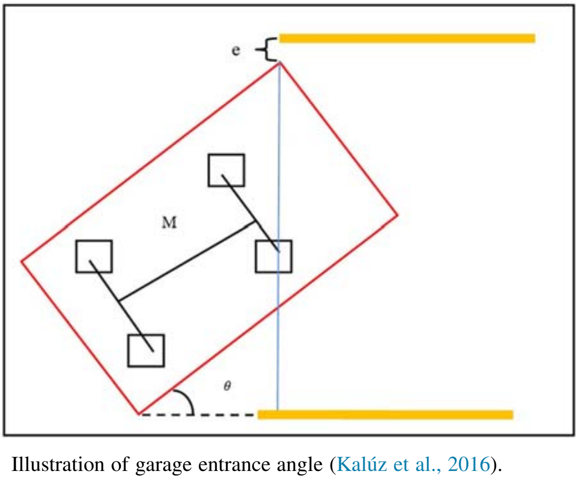

FIGURE 15.2 Illustration of garage entrance angle (Kalúz et al., 2016).

Next, the coordinates of the rear axle center at this time are determined by (Khalid et al., n.d.):

$$\begin{cases} y_2 = x_s + S_{\min} \cdot \sin\theta \\ y_2 = x_s - S_{\min} \cdot \cos\theta \end{cases}$$

where $S_{\min}$ is the minimum turning radius.

15.9 Storage stage

This stage starts when the car designed in Section 3.2.1 begins to enter the garage. At this time, the steering wheel is in the full lock position. To ensure that the car can fully enter the garage, it is only necessary to ensure that the radius of the trajectory circle corresponding to the car's entry is larger than the minimum turning radius. When designing the car's complete entry into the garage, the position of the rear axle center should be at the center point of the garage entrance. The trajectory of the car's entry into the garage is shown in Fig. 15.3.

From Fig. 15.3, it can be seen that there is a relationship between the center and the radius of the circle (Li et al., 2022):

$$\begin{cases} S_3 \sin\dfrac{\theta}{2} = \dfrac{BC}{2} \\ y_3 = y_c \\ x_3 = x_c - S_3 \end{cases}$$

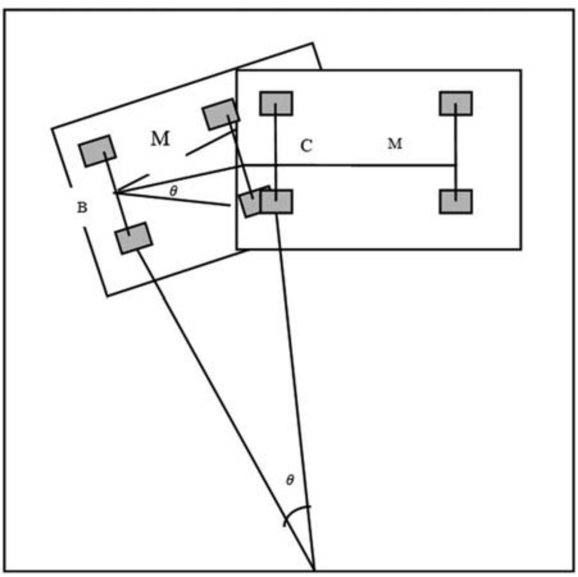

FIGURE 15.3 Storage illustration.

15.10 Reverse stage

Assuming the initial position of the car is (y_f, x_f), with a heading angle of θ, the center of the front axle is (y_2, x_2), and the center of the rear axle is (y_1, x_1), with a radius of S_1, as shown in Fig. 15.4.

Based on geometric relationships, it can be determined that (Lei et al., 2022).

$$\begin{cases} S_1 = \dfrac{y_f - y_1}{\sin\theta} \\ \sqrt{(y_1 - y_2)^2 + \left(x_2 - \frac{y_f - y_1}{\tan\theta} - x_f\right)^2} = S_1 + S_{\min} \\ x_1 = \dfrac{y_f - y_1}{\tan\theta} + x_f \end{cases}$$

The coordinates (y_1, x_1) and S_1 can be obtained from the above equation. At this time, the slopes of the two centers are (Ahmed et al., 2021):

$$m = \frac{x_2 - x_1}{y_2 - y_1}$$

The coordinates of the intersection points of the two circles are (Vamsi Krishna Reddy, A. K., & Venkata Lakshmi Narayana, 2022):

$$\begin{cases} y = -\sqrt{\dfrac{S_{\min}^2}{m^2 + 1}} + y_2 \\ x = m(y - y_2) + x_2 \end{cases}$$

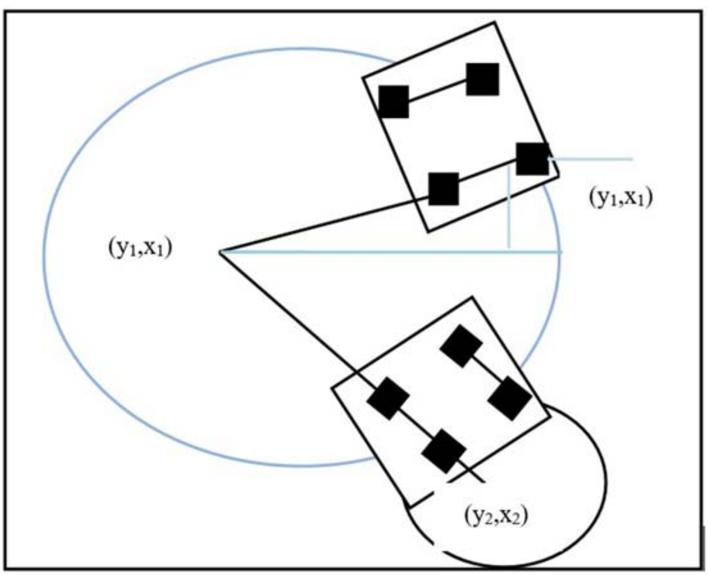

FIGURE 15.4 Reverse trajectory illustration.

In summary, the steering wheel angles required for the first two trajectories of the parking process are given by (Fehér et al., 2020):

$$\begin{cases} \theta_{rx1} = \dfrac{m \cdot S_1}{K} \\ \theta_{sw2} = \dfrac{m \cdot S_{min}}{K} \end{cases}$$

The planned path of the rear axle center throughout the parking process is shown in Fig. 15.5.

Path Tracking Control Algorithm Based on PID well-designed path planning is a prerequisite for successful parking, and carefully planned parking path through vehicle tracking control ensures the success of parking.

The commonly used tracking control methods for cars mainly include three algorithms: PID, model predictive control (MPC), and linear quadratic regulator (LQR) (Abagnale et al., 2015; Ahmed et al., n.d.; Choudhury et al., 2014; Zhang et al., 2021). The MPC and LQR algorithms obtain optimal solutions within a certain time domain based on the state equations, as shown in Fig. 15.6.

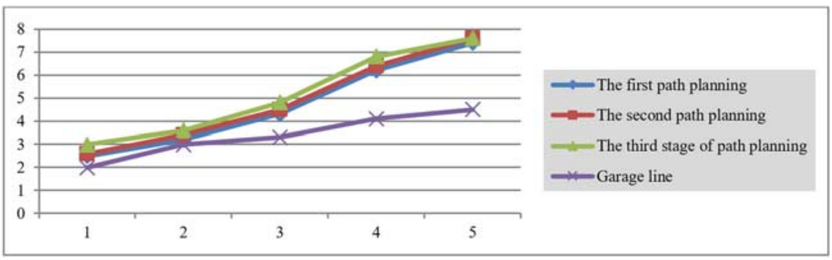

FIGURE 15.5 Parking trajectory planning.

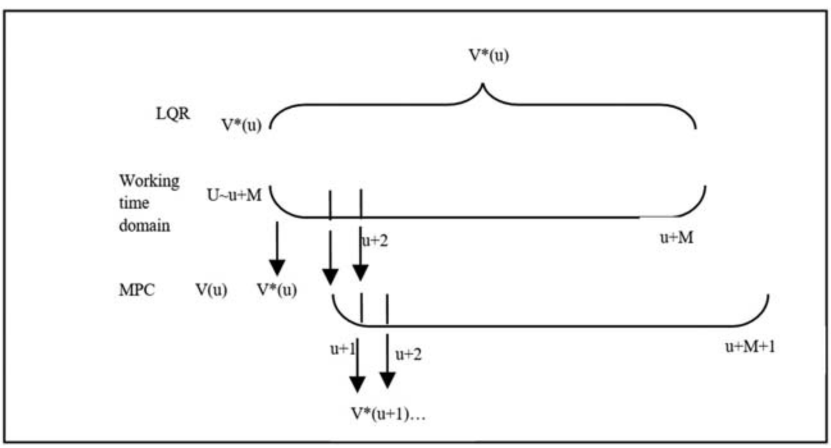

FIGURE 15.6 Working time domain of MPC and LQR.

The PID algorithm adjusts the control variable based on the difference between the actual value and the desired value at the previous moment. Therefore, although the overall control performance of LQR and MPC is better than PID, the corresponding computational workload of LQR and MPC(Deja et al., n.d; Kalúz et al., 2016; Isermann, 2005) is much higher than PID (Bosque et al., 2014; Liu 2021b, 2021a; Tang et al., 2023; Veluchamy et al., 2023; Villagra et al., n.d). For the parking system, the entire process is a low-speed state, and the requirement for effectiveness is not as high as in high-speed driving states. Therefore, using PID control can ensure tracking performance, reduce computational workload, lower the requirements on the microcontroller, and make the system more suitable for engineering applications.

The selected car model in this chapter is an automatic transmission car, and the parking process is a low-speed driving process. To ensure the comfort of the parking process and reduce parking errors, the maximum vehicle speed during the parking process is set to 2 km/h, while the idle speed of the automatic transmission car can reach 7 km/h. The main parameters controlled during the parking process are: (Junkai et al., 2021) brake wheel cylinder pressure and (Li et al., n.d) steering wheel angle.

The lateral error between the actual car position and the reference position is given by (Ykun Xie et al., 2020):

$$E_{\mathrm{err}} = \mathrm{ex} \times \cos\theta_{\mathrm{des}} - \mathrm{e}x \times \sin\theta_{\mathrm{des}}$$

The error between the actual steering wheel angle and the desired steering angle is given by (Tao Peng et al., 2020):

$$\theta_{\mathrm{err}} = \theta_{\mathrm{rx}} - \theta_{\mathrm{rxdes}}$$

The error can be defined as (Yin et al., 2016):

$$err = \theta_{\mathrm{err}} + m \times E_{\mathrm{err}}$$

where k is a coefficient.

Therefore, the PID controller is given by:(Wang et al., 2015)

$$v(m) = M_{\mathrm{Q}} \times e\mathrm{err}(m) + M_{\mathrm{I}} \sum_{i=1}^{m} f(i) + M_{\mathrm{E}}[f(m) - f(m-1)]$$

15.11 Simulation detail and result analysis

Simulation validation has become an essential part of product development. Traditional parking experiments require sample vehicles, hardware platforms, experimental sites, etc. In actual experiments, equipment damage and unnecessary personnel injuries may occur due to imperfect algorithms and operational errors. With the integration of vehicle simulation software, powerful simulation software can replace some physical tests.

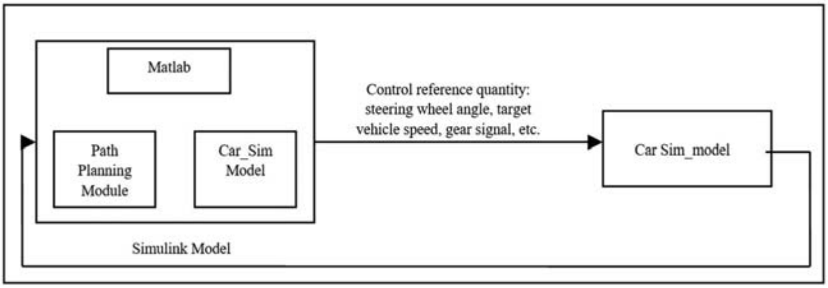

FIGURE 15.7 Cosimulation schematic.

Based on the CarSim vehicle dynamics simulation software, this chapter establishes the target vehicle model and simulates the parking environment. Combining the path planning method and PID path tracking controller, a Simulink® model is built for cosimulation to verify the rationality of the path planning method and the effectiveness of the controller.

15.12 Cosimulation with Simulink and CarSim

The path planning module and tracking control module are built in Matlab software and linked with the configured CarSim. CarSim transfers the model to the mdl file in the target directory through a data interface and adds it to the Simulink module library in the form of an S-function. Simulink interacts with the CarSim software through the S-function, completing the cosimulation, as shown in Fig. 15.7.

In the cosimulation, CarSim provides a comprehensive and accurate car motion model and designs the corresponding parking environment, while Simulink/Matlab facilitates computation and analysis. The combination of the two allows for rapid and accurate simulation, generation of corresponding parameter graphs and simulation process animations, effectively avoiding issues caused by using single software resulting in poor effects, and other problems.

15.13 CarSim parameter settings

Referring to the parameters of commercial car models, the main parameters of the experimental model car are set as shown in Table 15.1.

The parking process is a low-speed process. For automatic transmission cars, only the brake wheel cylinder pressure needs to be controlled to adjust the speed. The inputs and outputs for CarSim are shown in Table 15.2.

TABLE 15.1 Main parameters of the car model.

Parameter name	Parameter symbol	Parameter value
Wheelbase/mm	K	2600
Vehicle width/mm	D_X	1786
Vehicle length/mm	D_k	4542
Front suspension/mm	m_f	1142
Rear suspension/mm	m_s	800
Minimum turning radius/mm	$S_{\min}$	5000

TABLE 15.2 CarSim inputs and outputs.

Type	Enter	Output
1	Steering wheel angle/(°)	Vehicle *x*-coordinate/m
2	Brake wheel cylinder pressure/MPa	Vehicle *y* coordinate/m
3	Gear	Vehicle heading angle/(°)
4	–	time/s
5	–	Vehicle center speed/(m/s)

15.14 Path planning and tracking controller

The Simulink model consists of three main modules: the tracking control module, the path planning module, and the CarSim S-function module, as shown in Fig. 15.8. The path planning module includes coordinate axis transformation, obtaining initial position parameters, and planning data for two trajectory segments.

The tracking controller used the desired information obtained from path planning and the real-time information of the car to calculate the output values for brake wheel cylinder pressure, steering wheel angle, and gear position using control algorithms. These values are then fed back to the CarSim S-function to ensure that the car completes the parking task. The flowchart of the path planning and tracking control is shown in Fig. 15.9.

Based on the above content, the entire parking process can be divided into the following steps:

1. Turn the steering wheel to θ_{sw1} and reverse to the midpoint parking point.
2. Turn the steering wheel to θ_{sw2} and move forward to the garage entrance.

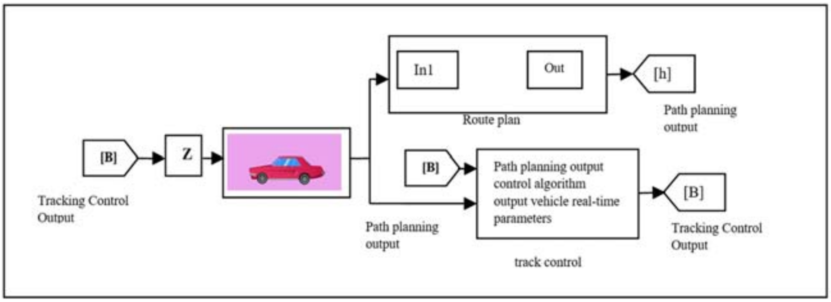

FIGURE 15.8 Cosimulation model.

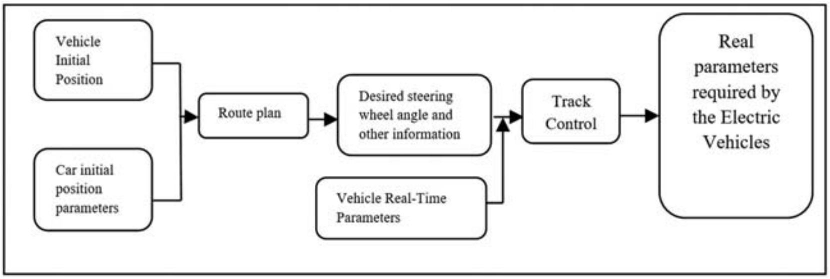

FIGURE 15.9 Path planning and tracking control schematic.

15.15 Drive the car into the garage and gradually align the vehicle parallel to the garage

15.15.1 Cosimulation experimental results

The effectiveness of the path tracking control model is validated through cosimulation experiments using CarSim and Simulink. The experimental results are shown in Fig. 15.10.

From Fig. 15.10, it can be observed that under the action of the designed tracking control model in this chapter, the model car can successfully complete the entire parking process along the planned path.

The main parameter variations of the car during the parking process are shown in Fig. 15.11.

It can be seen that the steering wheel angle and vehicle speed variations of the model car in the cosimulation process can be effectively controlled using PID. The steering wheel angle changes uniformly and maintains a good angle, while the speed remains low (below 2 km/h) with the brake wheel cylinder pressure less than 1.6 MPa (the general requirement for brake wheel cylinder pressure in cars is not greater than 8 MPa).

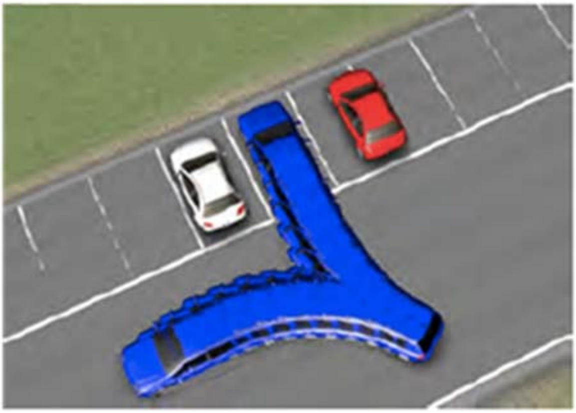

FIGURE 15.10 Simulation animation simulation animation.

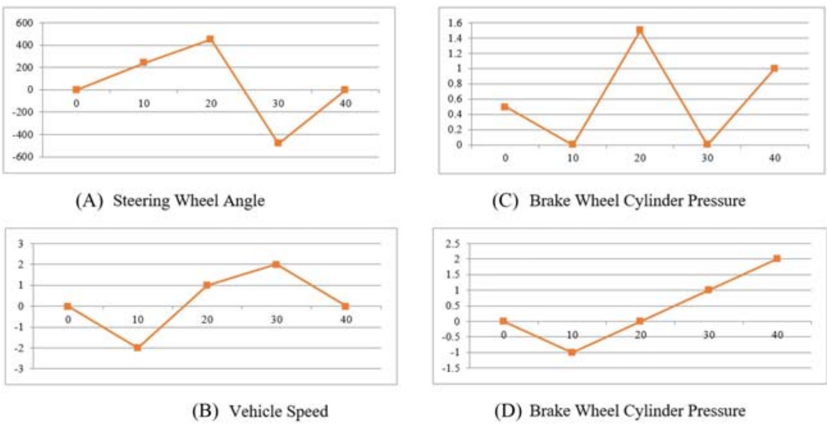

FIGURE 15.11 Main parameter variations of the car during the parking process.

The comparison between the actual vehicle trajectory and the planned trajectory is shown in Fig. 15.12.

1. Steering wheel angle
2. Vehicle speed
3. Brake wheel cylinder pressure
4. Brake wheel cylinder pressure

From Fig. 15.12, it can be seen that in the cosimulation, the designed PID controller can effectively track the reference path and drive the car to the target position. In the reverse stage, the initial position of the vehicle is consistent with the initial position of the path, and the vehicle can track the reference path well. Even if there is a deviation along the way, it can be

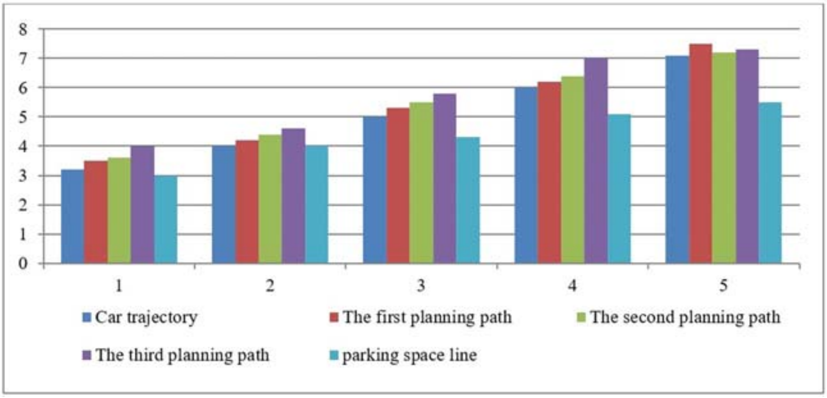

FIGURE 15.12 Comparison between the vehicle motion trajectory and the planned trajectory.

adjusted back, and the vehicle's driving trajectory is basically consistent with the reference path with small errors.

15.16 Conclusion

In this study, a parking method for EV parking systems was designed, which involves three segments: reverse, forward, and garage entry, with planned paths. By combining PID control with path tracking, the computational load of commonly used parking algorithms is reduced, making it highly applicable in engineering practice. An experimental model vehicle was built in CarSim based on the vehicle kinematics model and actual vehicle parameters. A simulation platform was established by integrating Simulink, and a path tracking control model was designed and tested through simulation experiments. The cosimulation results demonstrate that the designed control model, through the manipulation of input and output variables, enables the model vehicle to track the planned path effectively, confirming the effectiveness of the proposed path tracking control method.

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Article preview

Abstract

Artificial Intelligence-Empowered Modern Electric Vehicles in Smart Grid Systems
Fundamentals, Technologies, and Solutions
2024, Pages 417-439

Chapter 15 - Front-in parking method for intelligent electric vehicles using proportional–integral–derivative control

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Abstract

Automatic parking is a crucial component of intelligent autonomous vehicle technology, capturing the attention of researchers and the business sector. As the preponderance of modern electric vehicles (EVs) are equipped with front-facing charging ports, a new parking paradigm emerges: front-in parking. In contrast to the prevalent emphasis on reverse parking, this inventive method takes precedence. Utilizing the vehicle's inherent spatial relationship with the allocated parking spot, the proposed method employs a path planning framework based on geometric insights. This is achieved by meticulously modeling vehicle kinematics. Subsequently, the precision of PID (proportional–integral–derivative) control underpins the parking procedure. The strategic incorporation of the PID path tracking control method not only simplifies algorithmic complexity but also deftly circumvents the dilemma of "computation explosion." This method admirably meets the stringent requirements of front-in parking and is ideally in step with the direction EVs are taking. To demonstrate the effectiveness of this strategy, a car kinematic model is diligently crafted. In conjunction with the tangible vehicle parameter model, the synergistic interaction between Matlab® and CarSim enhances the simulation of the conventional parking process model. The results of these simulations demonstrate the effectiveness of the method. Adjustments to the steering wheel angle are consistently seamless and well-maintained, maintaining a favorable angle while maintaining a safe speed (below 2 km/h). Importantly, the brake wheel cylinder pressure treads cautiously at less than 1.6 MPa; this is especially noteworthy given that the conventional maximum limit for brake wheel cylinder pressure in automobiles is 8 MPa. A compelling contrast between the actual trajectory followed by the vehicle and the meticulously planned trajectory demonstrates the precision and dependability of the method. The extraordinary similarity of these two trajectories demonstrates the efficacy of the PID path tracking control strategy. These results bolster the proposed method's stature as a cornerstone of future intelligent vehicle technologies in the realms of EV automation and parking. As the automotive landscape evolves, the technique's proficiency in flawlessly maneuvering EVs into parking spaces, combined with its judicious management of critical parameters, positions it as a facilitator of enhanced safety, efficiency, and convenience.

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