Design and Simulation of Automatic Parking System Based on Fuzzy Controller

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***Abstract*—With the development of automatic driving and fuzzy theory, people pay more and more attention to the application of fuzzy logic in engineering technology. The automatic parking module in the automatic driving system has always been the focus of research. Automatic parking modules can greatly assist drivers in parking operations, greatly reduce parking difficulties and make people more convenient and fast parking. In this paper, an automatic parking system based on the fuzzy controller is proposed. The fuzzy controller of automatic parking system is constructed by using fuzzy theory, and the robustness of the whole system is examined by fuzzy logic. Firstly, the vehicle motion rules and trajectory changes are analyzed in detail, and the real parking lot model is simulated. Then, the input and output variables of the whole system are analyzed by fuzzy theory and the membership function is constructed. Based on the experience of human experts, the parking rules are tested and summarized, and a reasonable and practical rule base is established. Finally, MATLAB is used to code, build the visual interface of parking lot and vehicles, and draw the cyclic iterative function to detect the vehicle position and direction angle, so as to act as a sensor. The results show that using a fuzzy controller to construct an automatic parking system can effectively improve the parking level.**

***Index Terms*—Automatic Parking, Controller Theory, Fuzzy Logic, MATLAB, System Optimization**

I. PURPOSE

THE real significance of research is to solve practical problems. In recent years, with the development of fuzzy theory, the engineering application of fuzzy theory has been favored by more and more engineers. Combined with the rise of the current automatic driving system, engineers will pay more attention to autopilot related technologies, especially complex systems. This system cannot be analyzed by a certain scale mathematical model, which has always been a difficult problem for engineers. However, fuzzy system theory can perfectly solve this complex and imprecise system. It can use fuzziness to solve the fuzziness of the system and make the whole system reach a new steady state.

A. Research Question

In view of the current development of automatic driving, the automatic parking module has attracted extensive attention from engineers. This problem is a very typical complex system. It cannot establish the mathematical model of the system and summarize the overview of the system by using simple mathematical formulas. Therefore, in the face of such a complex system - automatic parking system, this paper will study it, analyze its practical scheme, and build a reasonable system to solve the problem of automatic parking in the parking lot.

B. Potential Value of Research Question

Today, with the booming development of Intelligent Vehicles, people are getting more and more comfortable and convenient in travel. At the same time, parking problems seem to be the most insidious problem on the road to "autonomous driving". Especially in densely populated cities, the limited space is designed into more parking spaces, and parking spaces tend to become narrower and narrower. For drivers, parking and parking under some unknown obstacles has become a big challenge. [1] To reduce the difficulty of the driver's reversing operation, the automatic parking system has been extensively studied. [2~3]

Therefore, the study of automatic parking system will bring the following three potential values to people:

1) Accelerate the improvement of automatic driving system.
2) Assist human parking technology to reduce parking collision.
3) As a means to solve complex systems, increase its universality.

II. INTRODUCTION

In this paper, the method of fuzzy controller is used to solve the problem of automatic parking. As we all know, the two most important parameters to control the vehicle are wheel steering angle and speed. In this scheme, the vehicle speed is a certain value, and the change of wheel steering angle is mainly analyzed. By analyzing the vehicle trajectory, two important input variables can be obtained, namely, vehicle position and vehicle direction angle, and the final control of the vehicle trajectory requires the wheel steering angle as the output variable. The input and output are combined by fuzzy controller to construct the analysis rule base of fuzzy inference system (FIS).

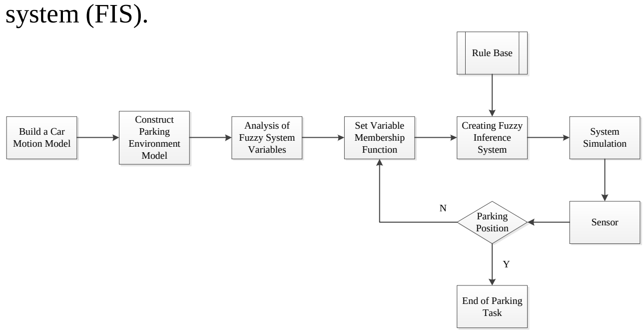

Fig. 1. Flow Chart of Automatic Parking System.

As shown in Figure 1, this figure is the flow chart of the overall solution of the automatic parking system. Firstly, the vehicle motion is analyzed and modeled, the input and output variables are determined, the vehicle motion equations are analyzed, and the relationship between them is found. Then, the parking lot model is constructed for later simulation to optimize the system adjustment. Finally, the most important step is to create a fuzzy inference engine and propose a reasonable rule base based on human expert experience. When the above steps are completed, the simulation test is carried out by MATLAB, the value obtained by the fuzzy inference system is sent to the vehicle motion model to run according to a certain trajectory, and the vehicle position and parking space position are continuously judged until the end of the program.

III. Methodology

Through the explanation of the above overall scheme, each step of the method will be described in detail below, from the establishment of the model, to the derivation of the motion trajectory formula, to the construction of the fuzzy controller, and finally to the realization of the automatic parking control system.

A. Real Vehicle Dimension Parameters

In this paper, we pick a Jetta car, [4] which is simplified as a rectangle, as the model size of the vehicle. The main vehicle dimension parameters are shown in Figure 2. The values for the parameters are listed in Table 1.

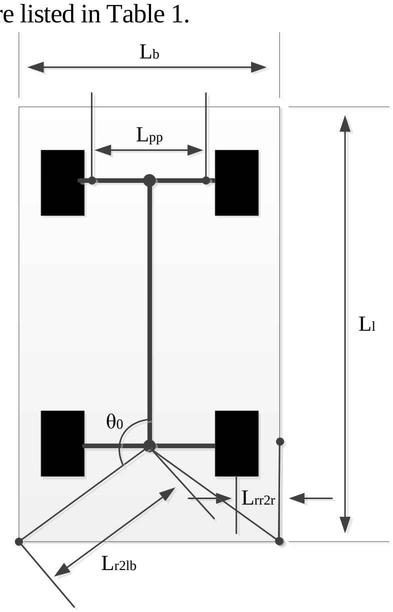

Fig. 2. Vehicle Parameter Model.

TABLE I
Vehicle Parameter Table

Dimension parameter of vehicle	Value (m)
Length	4 .428
Width	1.66
Wheelbase (La)	2.471
Front overhang (Lfa2h)	0.825
Rear overhang (Lra2t)	1.07
Front tread (Lfw)	1.429
Rear tread (Lrw)	1.422
Distance between two kingpins (Lpp)	1.329
Distance between the rear wheel to the right side (Lrr2r)	0.119

B. Parking Lot Parameters

Most of the parking lots' lengths are above 5.0 m, and the widths are more than 2.3 m. [4] Due to the above fact, we choose the reference parking lot as 5.0 × 3.0 m, as shown in Figure 3. The values for the parameters are listed in Table 2.

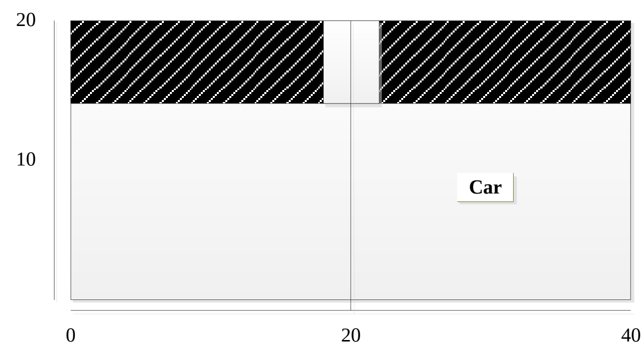

Fig. 3. Schematic Diagram of Parking Lot.

TABLE II
Parking Lot Parameter Table

Dimension parameter of environment	Value (m)
Parking Lot Length	5.0
Parking Lot Width	3.0

C. Vehicle Dynamic Model

The vehicle dynamic model used in this article is shown in Figure 4. F is the front middle point of the vehicle model. R is the rear middle point of the vehicle model. α is the angle between the vehicle model and the x-axis. β is the wheel steering angle. In the reference frame, (x_f, y_f) are the coordinates of the midpoint F which is the front axle of the vehicle model.

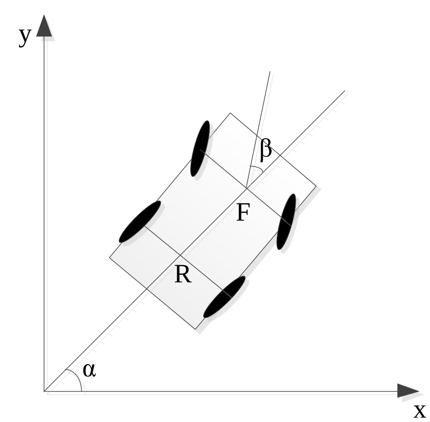

Fig. 4. Vehicle Dynamic Model.

According to the kinematic analysis, when the vehicle is running, its trajectory will change with the change of wheel steering angle and speed. Therefore, for the analysis method of controlling the motion trajectory of the vehicle, we should grasp the wheel steering angle and speed.

In this scheme design, the vehicle speed is set as a constant value s and the wheel steering angle is set β while it will be controlled as the output of the fuzzy controller. When the vehicle is controlled to the specified parking position, different wheel steering angles will be generated due to different positions and directions of the vehicle， this is an iterative process. The following is the iterative formula:

$$\dot{\alpha} = \frac{s*\sin\beta}{|RF|} \tag{1}$$

$$\dot{x_f} = s * \cos(\alpha + \beta) \tag{2}$$

$$\dot{y_f} = s * \sin(\alpha + \beta) \tag{3}$$

Where, α is the directional angle of the vehicle relative to the coordinate axis, and RF is the center distance of the front and rear wheels of the vehicle.

As shown in the iterative formula of the above, the vehicle direction angle α and the steering angle β will be determined by the vehicle continuous iterative updating; the location of the vehicle will also vary according to α and β. Therefore, the new position variables and direction angle variables will be given by the following formula:

$$x_f(n+1) = x_f(n) + s * \cos(\alpha(n) + \beta(n+1)) \tag{4}$$

$$y_f(n+1) = y_f(n) + s * \sin(\alpha(n) + \beta(n+1)) \tag{5}$$

$$\alpha(n+1) = \frac{s*\sin\beta(n+1)}{|RF|} \tag{6}$$

D. Automatic Parking System Path Planning

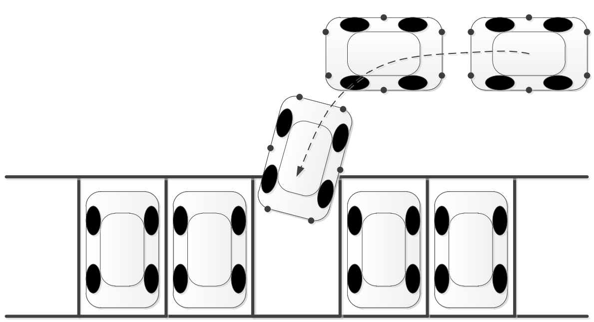

Fig. 5. Parking Path Planning.

As shown in Figure 5, this is the final planned route for the automatic parking system. It is the optimal solution in the system. According to the decision-making and optimization processing, the system selects the optimal path. Each iterative process of path selection needs to pass through the fuzzy reasoning system.

E. Fuzzy system structure design

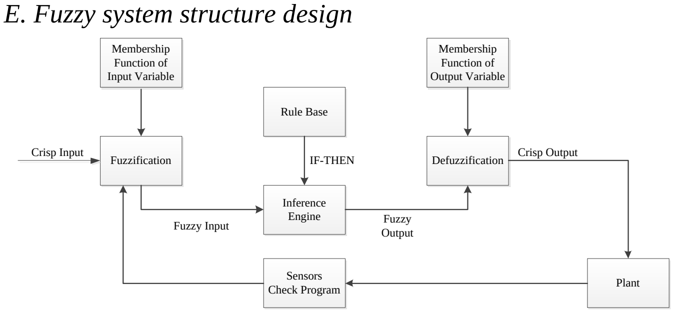

Fig. 6. Flow Chart of Fuzzy System Design.

When the vehicle position and direction angle are detected by the sensor, its value is crisp input. The fuzzy system needs to fuzzification the crisp input, and then obtain the fuzzy input according to the input membership function; when the fuzzy input reaches the inference engine, the system will map the input according to the inherent rules to obtain the fuzzy output, and then obtain the crisp output according to the output membership function and defuzzification method. Finally, transfer the crisp output value - wheel steering angle to the equipment for operation. After the operation, the vehicle sensor will detect the vehicle position and direction angle again, and compare it with the target. If it is consistent with the goal, the procedure will be ended; If not, continue to blur and cycle until the end.

F. Membership function

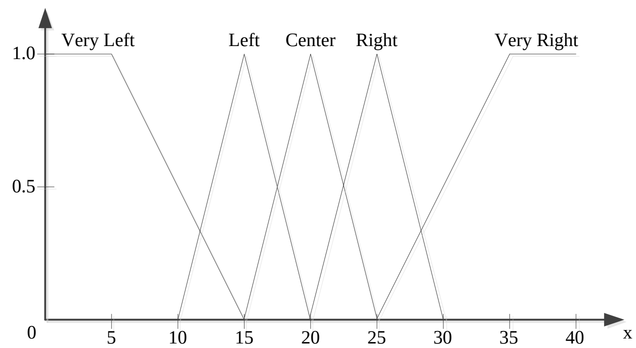

Fig. 7. Input Variable – Vehicle Position x. (meter).

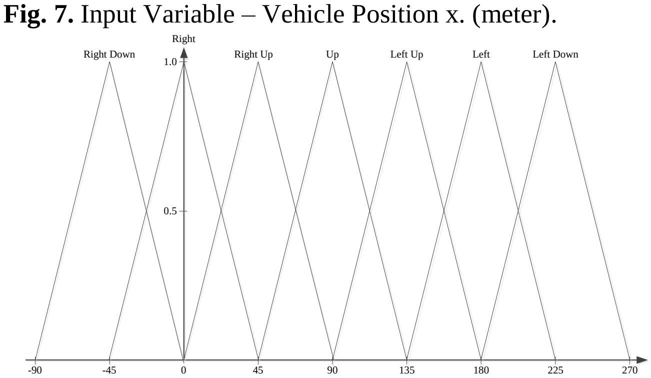

Fig. 8. Input Variable – Vehicle Angle α. (°).

Automatic vehicle parking is a typical nonlinear control problem, which is generally solved by fuzzy control methods.[5] The more the number of input and output variables of the fuzzy controller, the finer the division of the fuzzy set of the input and output variables, the higher the control accuracy of the controller.[6] However, while increasing the number of input and output variables and increasing the number of fuzzy sets, the number of fuzzy controller control rules will also increase exponentially, forming a so-called "dimension disaster",[7] which seriously affects the response speed of the controller. While the increase in the number of fuzzy rules also increases the possibility of rule errors.[8] Therefore, it is necessary to reasonably select the number of controller input and output variables, divide the fuzzy set number of each input and output variable, and take into account the response speed of the controller while ensuring the control accuracy of the controller.

Therefore, it is necessary to reasonably select the number of controller input and output variables, divide the fuzzy set number of each input and output variable, and take into account the response speed of the controller while ensuring the control accuracy of the controller. So, our system chose the membership function of inputs and output based on the judgment factors for human drivers [9]: x (the horizon position of the vehicle) and α (the angle of the vehicle contract with the parking area) as the input of the fuzzy controller, β (the angle of the steering wheel) as the output of the fuzzy controller.

Variable x has 5 fuzzy sets, variable α has 7 fuzzy sets, variable β has 7 fuzzy sets. Meanwhile, in order to improve the robustness of the fuzzy controller and reduce the adjustable parameters, this paper adopts a triangular/trapezoidal, fully overlapping membership function. The membership functions of inputs and output are shown in Figures 7, 8, and 9.

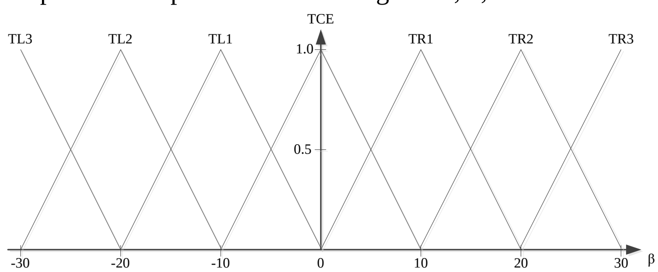

Fig. 9. Output Variable – Wheel Steering Angle β. (°).

G. Fuzzy Rules

The fuzzy rules for the bay parking are chosen as

1) IF x is VL AND α is LD, THEN β is TL2;
2) IF x is L AND α is LD, THEN β is TL2;
3) IF x is CE AND α is LD, THEN β is TL3;
4) IF x is R AND α is LD, THEN β is TL3;
5) IF x is VR AND α is LD, THEN β is TL3;

Table 3 shows the fuzzy rules established based on the driver's vertical parking experience.

TABLE III
RULE BASE TABLE

AND	**Very Left(VL)**	**Left (L)**	**Center (CE)**	**Right (R)**	**Very Right(VR)**
Left Down(LD)	TL2	TL2	TL3	TL3	TL3
Right(R)	TL1	TL2	TL2	TL3	TL3
Right Up(RU)	TR1	TL1	TL2	TL2	TL2
Up(UP)	TR2	TR1	TCE	TL1	TL2
Left Up(LU)	TR2	TR2	TR2	TR1	TL1
Left(L)	TR3	TR3	TR2	TR2	TR1
Left Down(LD)	TR3	TR3	TR3	TR2	TR2

By using fuzzy inference system and reasonable rule base to establish a practical inference engine, the relationship between input and output can be obtained, as shown in Figure 10.

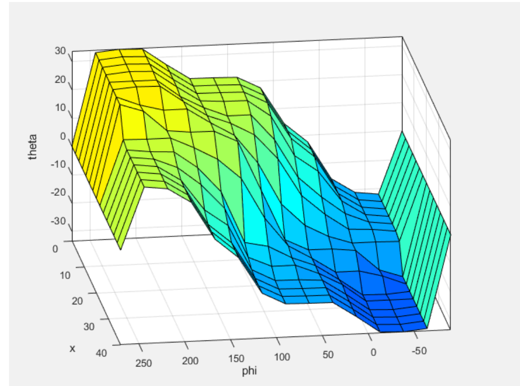

Fig. 10. Relationship Between The Inputs and The Output.

IV. RESULTS AND DISCUSSIONS

A. Simulation Result

In this section, we assume that the vehicle has different initial conditions including the positions and the poses. We set up the dynamic model that is built in Section III in MATLAB. Meanwhile, the fuzzy logic controllers are implemented in MATLAB model too. [10] The trajectories of the vehicle for various initial conditions appear in Figures 11, 12, and 13, which show that the vehicle is parked successfully.

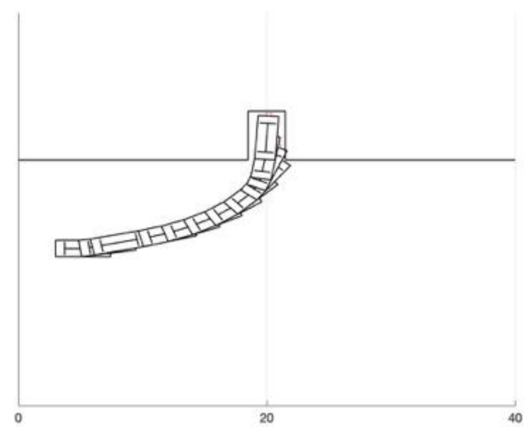

Fig. 11. Simulation Result 1.

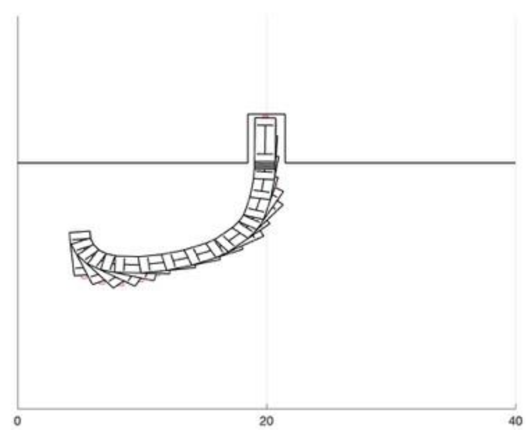

Fig. 12. Simulation Result 2.

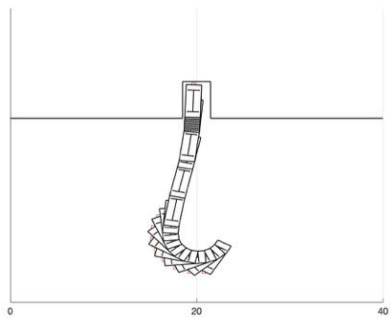

Fig. 13. Simulation Result 3.

B. Discussions

1) Parking with low-speed

In the first experiment, the vehicle set the speed at 1 m/s to make it easy to maintain and control. However, with the speed of 1 m/s, the vehicle will take a long time to park in the lot. Meanwhile, the low speed will cause the turning speed to be too slow and affect the finial effect. The simulation result of parking in low-speed shows in Figure 14.

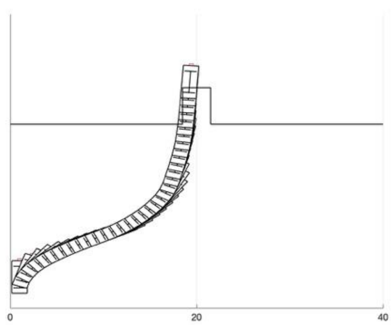

Fig. 14. Simulation of Parking in Low-Speed.

2) Parking with proper speed

From the experiment, the speed of 2 m/s is prefect to maintain and control. The simulation result of parking at the proper speed shows in Figure 15.

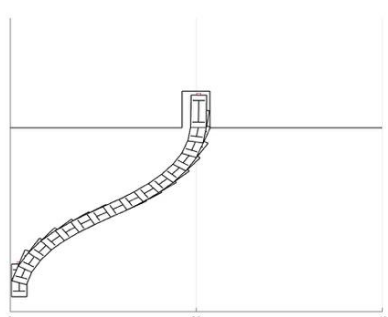

Fig. 15. Simulation of Parking in Proper Speed.

3) Parking with speed control logic

However, parking with the unchangeable speed of 2 m/s will still take a lot of time to park. Therefore, it is necessary to design a speed control logic that can automatically adjust the speed according to the situation. The main idea for the speed control is to ensure that the speed is small when the vehicle is close to the position of parking lot or the steering angle is large (If the speed is large while angle is large too, it will be easy to over-change the angle. So, the speed should be small when angle is large), and speed can be medium or large when the distance is large and the steering angle is small. The simulation result of the parking with the speed controlled by speed control logic is shown in Figure 16.

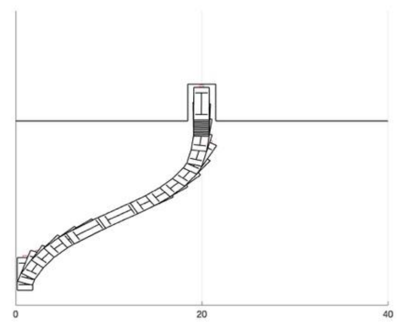

Fig. 16. Parking with Speed Logic Control.

4) Membership Function Improvement

In the first experiment, all x membership function are set in triangle or trapezoidal shape, shown in Figure 17. But when the vehicle is closing to the center with a small angle, the x membership function CE take the action and made the steering angle hold still too early, so the vehicle will stop too close to the edge of the lot, the simulation is shown in Figure 18.

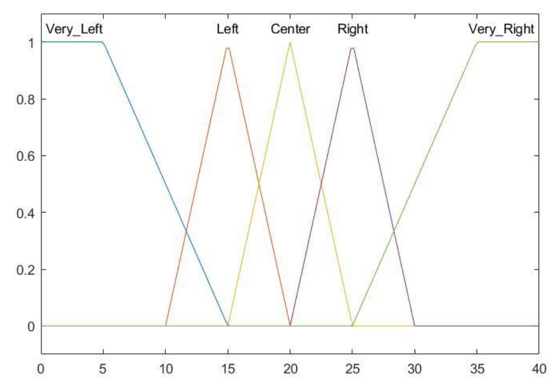

Fig. 17. Membership Function of CE in Triangle Shape.

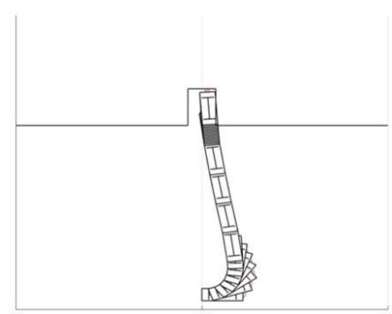

Fig. 18. Simulation Result with Triangle CE Membership Function.

The problem is caused by the premature action of the CE function. To improve the simulation, an effect method is to reduce the CE area function by changing the trigonometric function to a Gaussian function. The change of membership function is shown in Figure 19. Gaussian CE membership function effectively improved the accuracy of parking. The simulation result is shown in Figure 20.

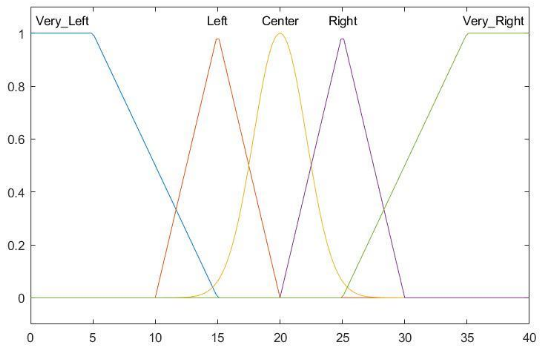

Fig. 19. Membership Function of CE in Gaussian Function.

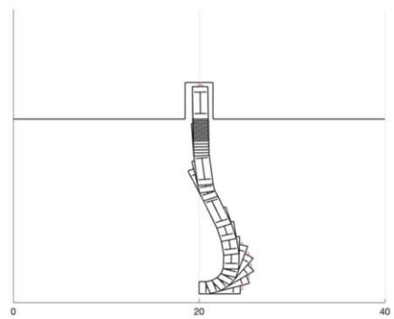

Fig. 20. Simulation Result of Gaussian CE Membership Function.

V. Conclusion

This paper uses MATLAB to model the traditional fuzzy system simulation to verify the feasibility of vertical parking. Through the analysis and optimization of simulation results, some basic triangular membership functions are optimized to Gaussian functions, and the speed control logic is optimized. Finally, a better vertical parking effect is achieved. The optimized parking path is closer to the human parking method, which improves the automatic and accuracy of parking. However, different parking conditions will lead to different decision results. The current system is only suitable for automatic parking under simple conditions. If you want to apply it in a complex environment, you still need to strengthen the robustness of the system and constantly optimize the fuzzy reasoning system. Feedback correction can be carried out through secondary detection, and the correctness of the automatic parking module can be checked by integrating information from the automatic driving sensor. Future work needs to further improve the accuracy of the parking space detection algorithm in variable parking conditions.

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