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Secondary parallel automatic parking of endpoint regionalization based on genetic algorithm

Bo Su[1] · **Junhan Yang**[2] · **Lijuan Li**[1] · **Yu Wang**[3]

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Abstract

Automatic parking technology can overcome the difficulties of drivers in tight spaces during parking. In this paper, in order to improve the accuracy of parallel parking in tight spaces, a secondary parallel automatic parking method of endpoint regionalization based on genetic algorithm is proposed. Firstly, a secondary parallel parking method of endpoint regionalization is proposed and a collision constraint function is established by planning the secondary parallel automatic parking path and analyzing the possible collisions during parking. Secondly, the secondary parallel parking path is planed by estimating the minimum parking length and designing a reasonable terminal area for parking. The simulation made on MATLAB verifies the feasibility of the method. In order to improve the efficiency of secondary parallel automatic parking of endpoint regionalization and achieve the shortest automatic parking path, a parking path function with constraint conditions is established in this paper and optimizing is done by taking the parking path function as target function with genetic algorithm. The simulation results show that the secondary parallel automatic parking of endpoint regionalization based on genetic algorithm can enable cars to park in the designed terminal area correctly without collision and the parking path is shortened by 4.1% compared with that of the original one.

Keywords Automotive engineering · Automatic parking · Endpoint regionalization · Genetic algorithm · Parking path function · Optimizing

1 Introduction

With the continuous increase of car ownership in China, the contradiction of demand and supply of parking spaces is increasingly prominent. And land resources in China's major cities are in shortage, and the land price continues to rise, resulting in small parking spaces. Small parking spaces cause inconvenience to parking, resulting in frequent parking accidents. With a sensor system detecting the surrounding environment of parking, the automatic parking system can effectively solve the parking difficulty in a small parking space. In order to improve the performance of automatic parking, domestic and foreign automobile enterprises and scientific research personnel have done a lot of research work: Reeds and Shepp [1] proposed a path connected by circulars and straight lines. The curvature of parking path in this method is not continuous, and the vehicle is required to decelerate or stop and steer off at curvature intermittent points, which easily lead to the steering wheel losing the best steering opportunity. Paromtchik and Laugier [2,3] proposed a regression algorithm, among which the starting point and endpoint of parking are connected with different sinusoidal curves, and the change of a starting point requires one operation each time, so the process is cumbersome; Müller et al. [4,5] et al have studied the collision problem in parking and obtained a control law of steering wheel angle, which requires no park in parking; Li et al. [6,7] used B-spline curve to plan a parking path, and Demirli and Khoshnejad [8] used polynomial function of 5th degree to design the parking path, while a relatively large parking space is required in the two methods; Zhao et al. [9], Rigatos et al. [10], and Guo et al. [11,12] et al used the fuzzy-logic control strategy to realize automatic parking, and Zheng et al. [13], Maravall and de Lope [14] and Hanafy et

✉ Bo Su
bsu@xidian.edu.cn

1 School of Aerospace Science and Technology, Xidian University, Xi'an 710071, China

2 School of Computer, Xi'an University of Science and Technology, Xi'an 710054, China

3 LinkedIn Corporation, 1000 W Maude Ave, Sunnyvale, CA 94085, USA

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al. [15] used ant colony algorithm, genetic algorithm and bee colony algorithm to design a parking controller for parking respectively; Due to hardware equipment constraints, artificial intelligent controlled and designed parking controllers are poor in real-time at present. The current parking strategy is divided into two categories: (1) path planning [16]: plan an optimal parking path according to kinematic characteristics of vehicles and parking collision constraints, and enable vehicles of parking automatically according to the planed path through control algorithm; (2) artificial intelligent control [17]: transfer a driver's parking experience into the design of the controller through fuzzy-logic control, neural network, genetic algorithm, and others to achieve automatic parking.

In order to improve the accuracy of automatic parallel parking in a small parking space, a secondary parallel automatic parking method with endpoint regionalization based on genetic algorithm is proposed in this paper. Firstly, a secondary parallel parking method with endpoint regionalization is proposed and a collision constraint function is established by planning the secondary parallel automatic parking path and analyzing possible collisions during parking. Secondly, the secondary parallel parking path with endpoint regionalization is planed by estimating the minimum parking length and designing a reasonable terminal area for parking. In order to further improve the efficiency of secondary parallel automatic parking with endpoint regionalization, and to achieve the shortest automatic parking path, a parking path function with constraint conditions is established in this paper, and the function is taken as the target function to achieve the shortest secondary parallel automatic parking path with endpoint regionalization through optimization with genetic algorithm [18].

The paper is organized as follows. Section 1 present the current status of parallel parking strategy. Section 2 presents the planning of secondary parallel parking path with endpoint regionalization. In Sect. 3, in order to further improve the efficiency of the secondary parallel automatic parking with endpoint regionalization and achieve the shortest automatic parking path, a parking path function with constraint conditions is established to search the shortest path based on secondary parallel automatic parking with endpoint regionalization by taking the parking path function as the target function and conducting optimization with genetic algorithm. Finally, we summarize our work and outline directions for future research in Sect. 4.

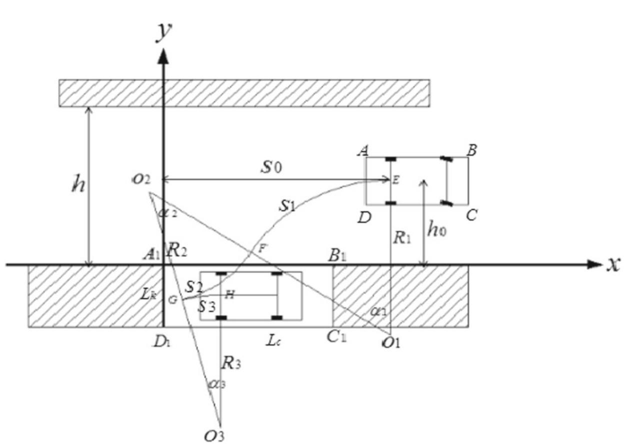

Fig. 1 Secondary parallel parking path planning

2 Planning of secondary parallel parking path with endpoint regionalization

2.1 Planning of secondary parallel parking path

The second parallel parking path planning refers to that at the beginning of parking, the vehicle is parallel with a parking line, and the vehicle drives backward when the steering wheel is turned right to a certain position, and stops when the vehicle rear axle reaches point F, and then the vehicle body has been partially entered into the parking space; The steering wheel is turned left to a certain position and drives backward continuously, stops when the vehicle rear axle reaches point G, and then the vehicle has a certain angle with the parking line; The steering wheel is turned right to a certain position and the vehicle drives forward until the vehicle is strictly parallel with the parking line, and it must be ensured that the vehicle will not collide with other obstacles during parking. In this paper, the arc tangent parking path planning method is used, and the second parallel parking path planning is shown in Fig. 1, among which the vehicle drives along the planned path $EFGH$.

$ABCD$ are four points in a vehicle body; $A_1B_1C_1D_1$ are four points in a parking space; $\alpha_1, \alpha_2, \alpha_3$ are central angles of three sections of circular arc; R_1, R_2, R_3 are radiuses of three sections of circular arc; h is the road width; h_0 is the longitudinal distance between the midpoint of the vehicle rear axle and the parking line; s_0 is the lateral distance between the vehicle and the left side of the parking line; L_c, L_k are the length and width of a parking space respectively. The vehicle drives to point G along arc EF and arc FG with O_1 and O_2 as centers respectively, and at this point, there will be a certain angle between the vehicle and the parking line, and then the vehicle drives to point H along arc GH with O_3 as its center, and at this point, the vehicle is parallel with the parking line. According to their geometric relationship as follows, $\alpha_1 = \alpha_2 + \alpha_3$

(1) The coordinate of starting point E: $E(s_0, h_0)$
(2) The coordinate of center o_1: $o_1(x_1, y_1) = (s_0, h_0 - R_1)$
(3) The coordinate of center o_2: $o_2(x_2, y_2) = (x_1 - (R_1 + R_2)\sin\alpha_1, y_1 + (R_1 + R_2)\cos\alpha_1)$

(4) The coordinate of center o_3: $o_3(x_3, y_3) = (x_2, +(R_2 + R_3)\sin\alpha_3, y_2 - (R_2 + R_3)\cos\alpha_3)$
(5) The coordinate of parking spot B_1: $B_1(L_c, 0)$
(6) The coordinate of parking spot C_1: $C_1(L_c, -L_k)$

In the second parallel parking process, possible collisions are shown in Fig. 2: (1) collision of the left front end of a vehicle and the left side of a road; (2) collision of the right rear of a vehicle and the right parking space; (3) collision of left rear of a vehicle and the left parking space; (4) collision of the right front of a vehicle and the right sparking space when the vehicle parks with the second arc; (5) collision of the right rear of a vehicle and the bottom parking space; (6) collision of the left rear of a vehicle and the left parking space; (7) a vehicle is beyond the parking line when the vehicle parks with the third arc; (8) a vehicle is not completely parked in the parking space.

When a vehicle drives at the turning radius R_1, it can be seen from the graph (1) in Fig. 2 that the following condition should be met to avoid collision of point R_2 and the left obstacle:

$$O_1B \le h - y_1 \tag{1}$$

where, $O_1B = \sqrt{(R_1 + \frac{W}{2})^2 + (L + L_f)^2}$

It can be seen from graph (2) in Fig. 2 that the following condition should be met to avoid collision of the right rear of the vehicle and the obstacle when the vehicle drives in the parking space:

$$O_1D \ge O_1B_1 \tag{2}$$

where, $O_1D = \sqrt{(R_1 - \frac{W}{2})^2 + L_r^2}$, $O_1B_1 = \sqrt{(x_1 - L_c)^2 + y_1^2}$

It can be seen from graph (3) and (6) in Fig. 2 that the following condition should be met to avoid collision of the left rear of the vehicle and the left obstacle when the vehicle drives in the parking space:

$$x_A \ge 0 \tag{3}$$

When a vehicle drives at the turning radius R_2, it can be seen from the graph (4) in Fig. 2 that the following condition should be met to avoid collision of the right front of the vehicle and the right obstacle when the vehicle drives into the parking space:

$$O_2C \le O_2B_1 \tag{4}$$

where, $O_2C = \sqrt{(R_2 + \frac{W}{2})^2 + (L + L_f)^2}$, $O_2B_1 = \sqrt{(x_2 - L_c)^2 + y_2^2}$

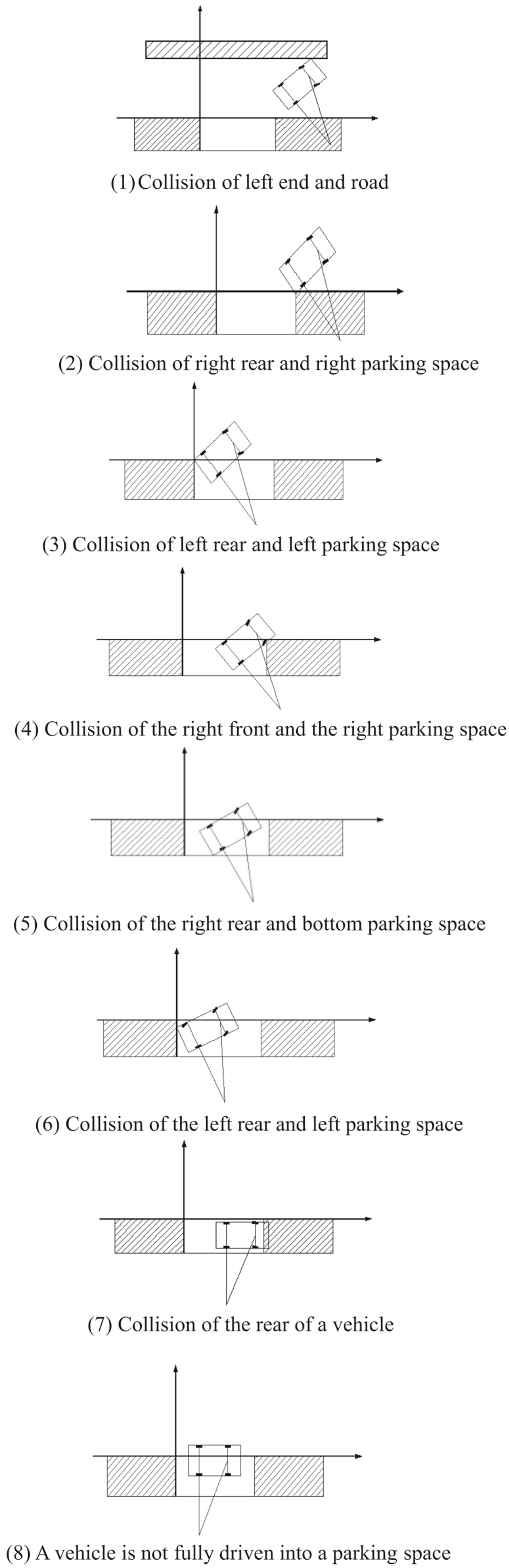

Fig. 2 Possible collisions in secondary parallel parking

It can be seen from graph (5) in Fig. 2 that the following condition should be met to avoid collision of the bottom right of the vehicle and the obstacle below the parking space when the vehicle drives in the parking space:

$$y_D \geq -L_k \tag{5}$$

When a vehicle drives at the turning radius R_3, it can be seen from the graph (7) in Fig. 2 that the following condition should be met to avoid that the vehicle front is not beyond the right parking line:

$$\begin{cases} x_B \leq L_c \\ x_C \leq L_c \end{cases} \tag{6}$$

It can be seen from graph (8) in Fig. 2 that the following condition should be met to make the vehicle drive into the parking space fully:

$$y_3 + R_3 + \frac{W}{2} \leq 0 \tag{7}$$

According to the above collision analysis, the following multiple constraint equations can be constructed:

$$\begin{cases} O_1 B \leq h - y_1 \\ O_1 D \geq O_1 B_1 \\ x_A \geq 0 \\ O_2 C \leq O_2 B_1 \\ y_D \geq -L_k \\ x_B \leq L_c \\ x_C \leq L_c \\ y_3 + R_3 + \frac{W}{2} \leq 0 \\ R_i = \sqrt{R^2 - L^2} - \frac{W}{2} (i = 1, 2, 3) \\ R \geq R_{\min} \end{cases} \tag{8}$$

A mathematical model is provided for the second parallel parking with endpoint regionalization by analyzing possible collisions in the process of second parallel parking and establishing collision constraint equations.

2.2 Analysis of minimum parking length

The analysis of minimum parking length is shown in Fig. 3. When a vehicle drives back to a parking space at fixed turning radius R_2, it is required to ensure that vehicle body point C will not collide with point B_1 in the parking space and the whole body conducts circular motion at the circular circle o_2, and he turning point of the body point C is R_C. The geometric relationship can be obtained from the figure available:

$$R_c = \sqrt{\left(R_2 + \frac{W}{2}\right)^2 + (L + L_f)^2} \tag{9}$$

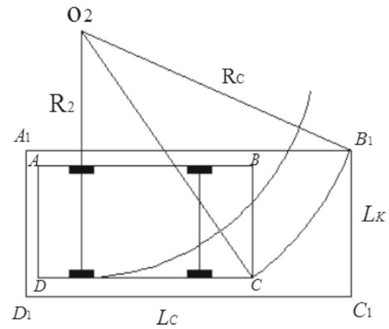

Fig. 3 Analysis of minimum parking space length

It can be known from Fig. 3 that there is the following geometric relationship for the parking space length:

$$\left(R_2 + \frac{W}{2} - L_K\right)^2 = R_c^2 - (L_c - L_r)^2 \tag{10}$$

It can be obtained from (9) and (10) that :

$$L_c = \sqrt{(L + L_f)^2 - L_k^2 + 2L_k \left(R_2 + \frac{W}{2}\right)} + L_r \tag{11}$$

The analysis of (11) shows that with the increase of R_2, L_c increases, so when R_2 is the minimum value, L_c is the minimum value. A parking space meeting requirements is the prerequisites for designing parking with endpoint regionalization. During parking, when the actual parking space length is greater than the theoretical minimum parking space length L_c, the parking path can be planed. Otherwise, the systems will not be able to automatically park.

2.3 Design and simulation of endpoint regionalization of secondary parallel parking

In order to verify the validity of the parking algorithm, Tianjin FAW XIALI N5 is taken as an example in this paper, and the parameters of the vehicle are as follows: axle base $L = 2.405$ m, front overhang $L_f = 0.80$ m, rear overhang $L_r = 0.95$ m, vehicle width $W = 1.645$ m, minimum turning radius of the vehicle $R_{\min} = 5.568$ m, setting parking space width $L_k = 2.1$ m, the calculated minimum parking space length $L_c = 6.142$ m, and the initial setting parking location $s_0 = 7.5$ m, $h_0 = 1.7$ m and $\alpha_1 = 45°$; Allowing for collision constraint conditions and the parking space size, the value range of R_i can be calculated by taking the final coordinate area of the midpoint of the vehicle rear axle as an optimization target according to the initial position and endpoint area of the midpoint of the vehicle rear axle. The design of endpoint of secondary parallel parking with endpoint regionalization and parking conditions is shown in Table 1.

Table 1 Design of terminal area in secondary parallel parking with endpoints regionalized and parking conditions

Horizontal setting: $(1.944\,\mathrm{m} \pm \varepsilon)$	Vertical setting $(-1.05\,\mathrm{m} \pm \varepsilon_1)$
It is required to meet the following in horizontal direction: $(R_1 + R_2)\sin\alpha_1 - R_2\sin\alpha_3 + x_1 = S_0$; $x_{2\,\min} \le R_3\sin\alpha_3 \le x_{2\,\max}$	It is required to meet the following in vertical direction: $h_0 + y_{1\,\min} \le R_1(1-\cos\alpha_1) + R_2(\cos\alpha_3 - \cos\alpha_1) \le h_0 + y_{1\,\max}$; $y_{2\,\min} \le R_3(1-\cos\alpha_3) \le y_{2\,\max}$
Parameter range: $0\,\mathrm{m} \le \varepsilon \le 0.994\,\mathrm{m}$	$0\,\mathrm{m} \le \varepsilon_1 \le 0.227\,\mathrm{m}$
First parking setting: $\varepsilon = 0.9\,\mathrm{m}$	When $\varepsilon_1 = 0.18\,\mathrm{m}$, then $y_{1\,\min} = 0.87\,\mathrm{m}$, $y_{1\,\max} = 1.23\,\mathrm{m}$
Secondary parking setting:	When $\varepsilon_1 = 0.12\,\mathrm{m}$
When $\varepsilon = 0.2\,\mathrm{m}$	Then, $y_{2\,\min} = 0.06\,\mathrm{m}$, $y_{2\,\max} = 0.3\,\mathrm{m}$
Then: $x_{2\,\min} = 0.5\,\mathrm{m}$, $x_{2\,\max} = 1.1\,\mathrm{m}$	

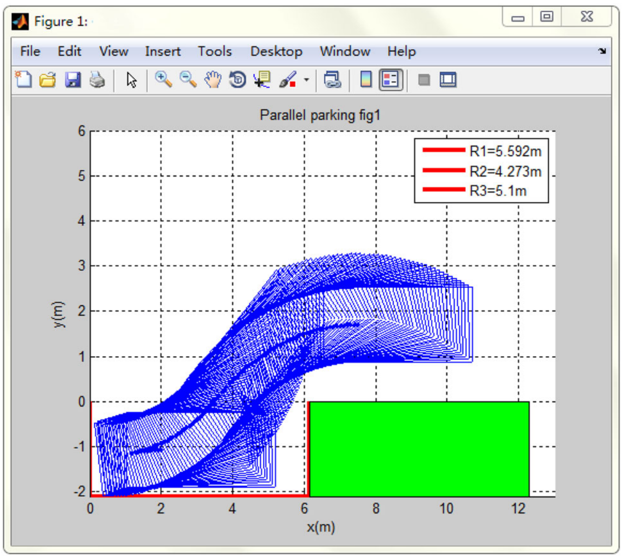

Fig. 4 Simulation of secondary parallel parking of endpoint regionalization

According to those parameters and design, it can be calculated as follows: $4.2\,\mathrm{m} \le R_1 \le 5.978\,\mathrm{m}$; $4.2\,\mathrm{m} \le R_2 \le 4.873\,\mathrm{m}$; $4.2\,\mathrm{m} \le R_3 \le 7.03\,\mathrm{m}$; $9^\circ \le \alpha_3 \le 16^\circ$; with a view of collision constraint function, $4.39\,\mathrm{m} \le R_1 \le 5.658\,\mathrm{m}$, $4.2\,\mathrm{m} \le R_2 \le 4.873\,\mathrm{m}$, $4.2\,\mathrm{m} \le R_3 \le 5.1\,\mathrm{m}$, $35^\circ \le \alpha_2 \le 36^\circ$ and $9^\circ \le \alpha_3 \le 10^\circ$; In the secondary parallel parking, $R_1 = 5.592\,\mathrm{m}$, $R_2 = 4.273\,\mathrm{m}$, $R_3 = 5.1\,\mathrm{m}$, $\alpha_1 = 45^\circ$, $\alpha_2 = 35^\circ$, $\alpha_3 = 10^\circ$; A simulation model of secondary parallel parking with endpoint regionalization is established in MATLAB, and the simulation of it is shown in Fig. 4.

The simulation shows that (1) if R_1, and R_2 changes within the scope of constraint conditions, when R_2 reduces, R_1 will increases, and the parking effect is good; when R_2 increases, R_1 reduces, and the parking effect is good. (2) The path planning method of secondary parallel parking with endpoint regionalization enable vehicles of parking in designed endpoints without collision better and achieving ideal parking.

In order to further improve the efficiency of the secondary parallel automatic parking with endpoint regionalization and achieve the shortest automatic parking path, in this paper, a parking path function with constraint conditions is established to search the shortest path based on secondary parallel automatic parking with endpoint regionalization by taking the parking path function as the target function and conducting optimization with genetic algorithm.

3 Secondary parallel automatic parking with endpoint regionalization based on genetic algorithm

3.1 Genetic algorithm

Genetic algorithm, GA for short, is an efficient global optimization search algorithm combining the survival of trap fittest in biologic evolution process and random information exchange mechanism of chromosomes within a group based on natural selection and theory of heredity. Its main characteristic is to operate directly on the structure of the object, there is no derivation and limited function continuity; with global internal implicit parallelism and better optimization ability. These properties of genetic algorithms have been widely used in the fields of combination optimization, machine learning, signal processing, adaptive control and artificial life as the key technology in modern intelligent computing. GA conducts random optimization search to target spaces with artificial evolution method by simulating the evolution process of natural organisms. In the algorithm, possible solutions in a problem domain are taken as individuals or a chromosomes of the group, and each individual is encoded into a symbol string form to simulate the biologic evolution process of genetic selection and natural elimination, and to evaluate each individual according to intended functions applicable to targets by conducting genetics-based operation, replication, crossover and mutation repeatedly to the group, to obtain netter groups according to the evolutionary programming of survival of the fittest, and to search optimal individuals in those optimal groups globally meantime to obtain the optimal solution satisfying the requirement. The optimization function is the most classical application of genetic algorithm.

Genetic algorithm provides a general framework for solving complex and systematic optimization problems, which can achieve relatively good results for solving nonlinear, multi-model and multi-objective function optimization problems.

3.2 Establishment of parking path function and analysis of constraint conditions

The secondary parallel automatic parking with endpoint regionalization is divided into three sections: S_1, S_2 and S_3. Assuming that the total distance of a vehicle is S, according to the geometric relationship in Fig. 1, it can be obtained that:

$$S = S_1 + S_2 + S_3 \tag{12}$$

$$S = \pi(\alpha_1 R_1 + \alpha_2 R_2 + \alpha_3 R_3)/180^\circ$$

In the simulation of secondary parallel parking with endpoint regionalization, R_1 is related to R_2. Within constraint conditions, there is some kind of inverse relationship between R_1 and R_2. In view of collision constraint and end area constraint, a group of data meeting requirements of secondary parallel parking with endpoint regionalization with R_1 and R_2 obtained in the simulation of secondary parallel parking with endpoint regionalization established in MATLAB are shown in Table 2.

Take the maximum R_1 and minimum R_1 to conduct curve fitting with R_2 respectively. The fitting figure is shown in Fig. 5. Through curve fitting, it can be obtained that with the change of R_2, R_1 changes between the two lines. The equation relationship of the two lines is as follows:

When R_1 is the maximum value:

$$R_1 = -0.9857R_2 + 9.8028 \tag{13}$$

When R_1 is the minimum value,

$$R_1 = -0.7554R_2 + 8.6107 \tag{14}$$

The objective function and constraint equation are established for the second parallel parking path according to above analysis:

Objective function:

$$S(R_1, R_2, R_3, \alpha_2, \alpha_3) = \pi(\alpha_1 R_1 + \alpha_2 R_2 + \alpha_3 R_3)/180^\circ \tag{15}$$

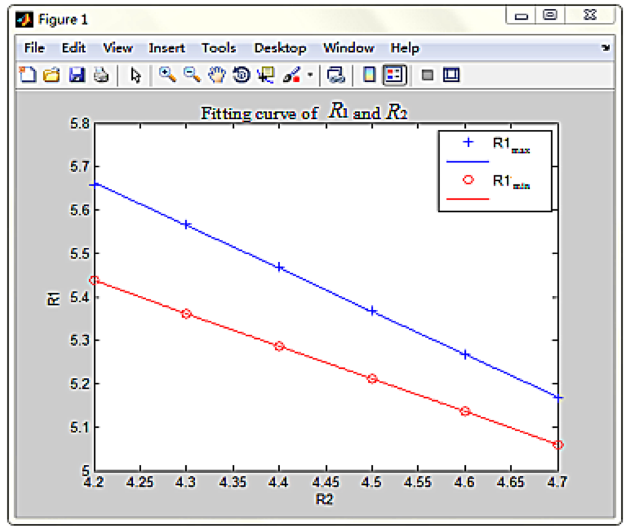

Fig. 5 Fitting curve of R_1 and R_2

Constraint conditions:

$$\begin{cases} R_1 + 0.9857R_2 \le 9.8028\,\mathrm{m} \\ -R_1 - 0.7445R_2 \le -0.86107\,\mathrm{m} \\ \alpha_1 = 45^\circ \\ \alpha_2 + \alpha_3 = 45^\circ \\ 35^\circ \le \alpha_2 \le 36^\circ \\ 9^\circ \le \alpha_3 \le 10^\circ \\ 4.93\,\mathrm{m} \le R_1 \le 5.658\,\mathrm{m} \\ 4.2\,\mathrm{m} \le R_2 \le 4.873\,\mathrm{m} \\ 4.2\,\mathrm{m} \le R_3 \le 5.1\,\mathrm{m} \end{cases} \tag{16}$$

3.3 Simulation of secondary parallel automatic parking with endpoint regionalization based on genetic algorithm

The parking path function is taken as a target function and is optimized with genetic algorithm. Parameters of the genetic algorithm are set as follows: For convenience, the decision variable is set to : when $R_1 = x_1$, $R_2 = x_2$, $R_3 = x_3$ and $\alpha_3 = x_4$, $\alpha_2 = 45^\circ - x_4$. In the genetic algorithm, double precision coding is used and the scaling transform function of fitness is set to be Rank. In selection operation, roulette selection operator is used; in crossover operation, arithmetic crossover operator is used; in mutation operation, boundary variation operator is used. The scale of population N is 50; the crossover probability P_c is 0.8; the mutation probability P_m is 0.01 and the maximum generation T is

Table 2 Relationship between R_1 and R_2 meeting constraint conditions

R_2	4.2	4.3	4.4	4.5	4.6	4.7
R_1	5.438–5.658	5.362–5.568	5.287–5.468	5.211–5.368	5.136–5.268	5.06–5.168

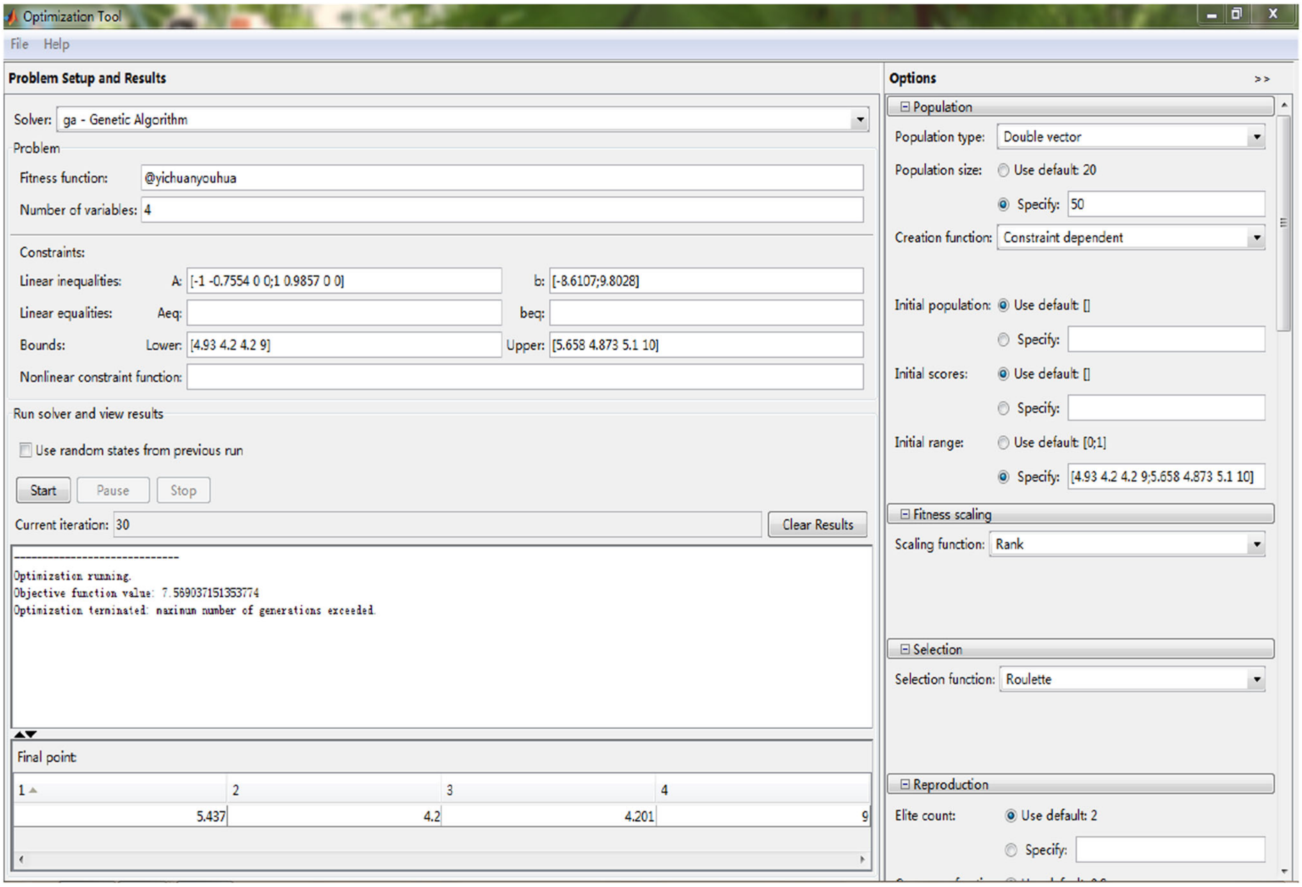

Fig. 6 Setting of genetic algorithm parameters

30. The parameters setting of genetic algorithm is shown in Fig. 6.

The operation result of genetic algorithm shows that when iteration comes to 30 generations of convergence, the best individuals of path objective function searched by genetic algorithm are: $x_1 = 5.437$ m, $x_2 = 4.2$ m, $x_3 = 4.201$ m and $x_4 = 9°$, namely $R_1 = 5.437$ m, $R_2 = 4.2$ m, $R_3 = 4.201$ m, $\alpha_3 = 9°$ and $\alpha_2 = 36°$. In the running process of genetic algorithm, with the increase of the number of iterations, the change trend of the best fitness and best individual distribution of the population are shown in Fig. 7.

It can be seem from Fig. 7 that the best fitness function changes greatly in the first 10 iterations and gradually becomes stable with the increase of the number of iterations, and reaches convergence after 30 iterations. A simulation model of secondary parallel parking with endpoint regionalization is established in MATLAB according to best individuals output with the genetic algorithm, and the simulation of the shortest path of secondary parallel parking with endpoint regionalization is shown in Fig. 8.

The simulation result shows that with optimized secondary parallel parking path with endpoint regionalization

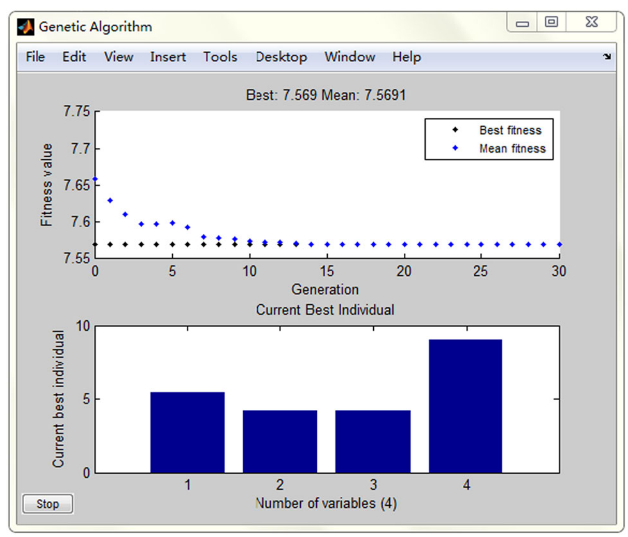

Fig. 7 Variation trend of optimal fitness and distribution of optimal individuals

with the genetic algorithm, a vehicle can not only be able to complete the secondary parallel parking with endpoint regionalization, but also to be able to achieve the shortest

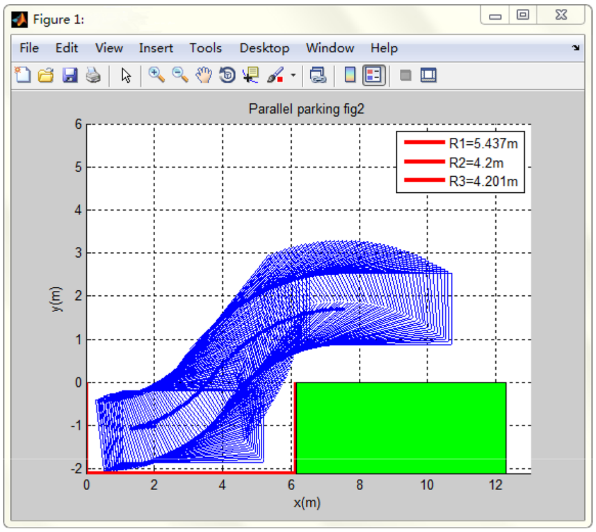

Fig. 8 Diagram of the shortest path in secondary parallel parking with endpoints regionalized

parking path. The shortest path S is 7.569 m. The Path S in the secondary parallel parking path with endpoint regionalization before optimization is 7.892 rmm, so optimized path is 4.1% shorter than that before the optimization, and the genetic algorithm can improve the parking efficiency effectively.

4 Conclusion

(1) A collision constraint function is established to improve the accuracy of automatic parallel parking in a small parking space, plan the path of second parallel parking path with end point regionalization, and analyze possible collision situations in the parking process; A reasonable parking endpoint area is designed by calculating the minimum parking length; A simulation model of automatic parallel parking path with endpoint regionalization is established in MATLAB, and the simulation result shows that the planning of secondary parallel parking path with endpoint regionalization can achieve accurate automatic parallel parking.

(2) In order to improve the efficiency of secondary parallel automatic parking with endpoint regionalization and realize the shortest automatic parking path, a parking path function with constraint conditions is established, and optimization is done through genetic algorithm by taking the parking path function as the target function. The simulation result shows that a vehicle can not only be able to complete the secondary parallel parking with endpoint regionalization, but also to be able to achieve the shortest parking path. The optimized path is 4.1% shorter than that before the optimization, so genetic algorithm can improve the parking efficiency effectively. In the future, we focus on improving the stability of the algorithm and the reliability of the experiment.

(3) In the automatic parallel parking process studied in this paper, the set vehicle speed is constant and the vehicle at the initial parking state is parallel with the parking line; in the follow-up study, in the view of inconstant vehicle speed in parking, there is an angle between the vehicle at the initial parking state and the parking line. Subject to cost and technology, most of the autopilot systems are still in the laboratory stage. With the development of integrated circuit industrialization and AI technology, the cost of autopilot system will be greatly reduced, and more and more automatic driving systems will go out of the laboratory.

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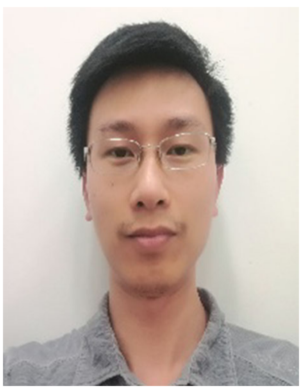
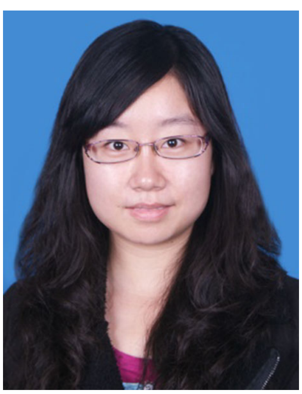
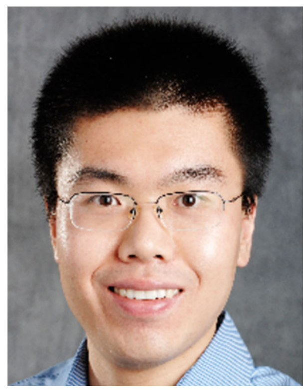


Bo Su (1982–) received his Ph.D. degree in communication and information engineering from Xidian University in 2012. He is currently an associate professor in the College of Aerospace Science and Technology of Xidian University. His research interests include wireless Ad Hoc, network measuring, communication network, IOT, and Internet of vehicles.



Junhan Yang (1985–) received her Ph.D. degree in computer science from China University of Mining and Technology in 2013. She is currently a lecture in the College of Computer Science and Technology of Xi'an University of Science and Technology. Her research interests include provable security, information security, and cryptography.

Lijuan Li (1997–) learns in space science and technology from Xidian University. She is currently a sophomore in the College of Aerospace Science and Technology of Xidian University. Her research interests include intelligence algorithm, Internet of vehicles, and communication network.



Yu Wang (1988–) received his Ph.D. degree in computer science from Michigan State University in 2015. He is currently a software engineer at LinkedIn Corporation. His research interests include the Internet of Things, cyber-physical systems, mobile computing, and distributed systems. He received the Best Paper Award Runner-Up at IPSN 2014.