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Automatic Obstacle Avoidance Path Planning Method for Unmanned Ground Vehicle Based on Improved Bee Colony Algorithm

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Abstract

In order to solve the problems of low accuracy and long time-consuming of traditional obstacle avoidance path planning methods for unmanned ground vehicle (UGV), an automatic obstacle avoidance path planning method based on improved bee colony algorithm is proposed. Based on the analysis of the working principle of the bee colony algorithm, the differential evolution algorithm is used to improve the local search ability of the bee colony algorithm; the kinematics model of the UGV is constructed, and the improved bee colony algorithm is used to optimize the obstacle avoidance path planning of the UGV. On this basis, the obstacles in the path planning are extracted by the multi-objective optimization algorithm. Finally, the obstacle avoidance path automatic planning of UGV based on improved bee colony algorithm is completed. The simulation results show that the maximum error of the proposed method is about 2%, and the planning time is short, so it has certain research value.

Keywords: Improved bee colony algorithm; Sub evolutionary algorithm; Local search; Kinematics model; Improved bee colony algorithm; Multi-objective optimization;

1. Introduction

With the continuous development of science and technology, vehicle engineering technology has been developing rapidly. UGV has emerged to meet the needs of social development. UGV is applied in various working conditions, which saves manpower and material resources and creates certain economic benefits [1]. Obstacle avoidance path planning is a key point in the research of UGV. Obstacle avoidance path refers to that after receiving effective environmental information, the UGV evades obstacles, selects the shortest route and saves time, and plans a shortest and optimal path at the starting point. Therefore, it is of great significance to study the automatic planning of obstacle avoidance path for UGV. The bee colony algorithm is applied to the obstacle avoidance path planning of UGV to improve the working efficiency of UGV. Bee colony algorithm is artificial bee colony algorithm, referred to as ABC algorithm, which has certain swarm intelligence [2]. By simulating the behavior of bee colony evolution, the algorithm optimizes the problems existing in the process of its movement. However, with the increasing complexity of the solution space dimension and multi-objective search, the disadvantages of the algorithm are also exposed. The convergence speed of the algorithm is slower and slower, and the precision of local optimal search is lower. The algorithm is good at finding problems, but it is poor in dealing with the problems found. Therefore, the artificial bee colony algorithm is improved and applied to the obstacle avoidance path planning of UGV, so as to improve the working efficiency of UGV. Therefore, researchers in this field have done a lot of research.

Reference [3] proposed a convex approximation obstacle avoidance path planning model prediction method for unmanned vehicles. This method analyzes the convex approximation principle of obstacle avoidance, optimizes the selection point of obstacle reference point, and expands the range of obstacle avoidance path. Through the improvement of the method, with the help of model predictive control and curvilinear coordinate system, the external conditions of UGV, the geometric constraints of the Road, the structural constraints of vehicles, the shortest obstacle avoidance path and the lateral speed of vehicles are taken into account proportion, complete the path planning of vehicles under the influence of complex obstacles. This method can obtain a reasonable and smooth path and avoid obstacles in the vehicle path. However, this method is easy to be affected by external factors when comprehensively analyzing vehicle factors and road factors, resulting in low accuracy of obstacle path planning, which is not conducive to universal application. In Reference [4], a dynamic obstacle avoidance oriented rolling time domain path planning method for intelligent vehicles is proposed. Aiming at the problem of vehicle avoiding obstacle path planning in low speed environment, the vehicle lane is divided according to certain rules, and the boundary of vehicle road is fitted by cubic Lagrange interpolation method. The dynamic traffic scene is simulated with the help of regional virtual force according to the divided lane area, the vehicle kinematics model is constructed, the obstacle model is predicted, the vehicle and obstacle are

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avoided, the control input of vehicle model, state variables and other dynamic constraints are integrated, and the multi-objective rolling time domain controller is established to obtain the control value of vehicle front wheel angle and avoid obstacles. This method can effectively avoid obstacles, control the vehicle moving forward target, and ensure the effective planning of vehicle obstacle avoidance path. However, this method takes a long time to plan the path in the process of model building and vehicle virtual force field, and has certain limitations. Reference [5] proposed a path planning method for unmanned vehicles based on improved RRT algorithm. In this method, two RRT trees are generated at the beginning and the end at the same time, and the parallel multiple paths are calculated. The evaluation function is used to select the optimal path, and the path is optimized and smoothed. The algorithm efficiency of this method is high, but the method is simple, and the factors considered are less, and the planning accuracy is not good.

Based on the above problems, this paper proposes an automatic obstacle avoidance path planning method based on improved bee colony algorithm. Based on the analysis of the working principle of the bee colony algorithm, the differential evolution algorithm is used to improve the local search ability of the bee colony algorithm; the kinematics model of the UGV is constructed, and the improved bee colony algorithm is used to optimize the obstacle avoidance path planning of the UGV, and the automatic obstacle avoidance path planning of the UGV based on the improved bee colony algorithm is completed. The technical route of this paper is as follows.

1. The basic working principle of bee colony algorithm is analyzed, and the differential evolution algorithm is used to improve the bee colony algorithm;
2. The kinematics model of UGV is constructed, and the operation mode of UGV is analyzed;
3. The improved bee colony algorithm is used to optimize the obstacle avoidance path planning of the UGV. The obstacles in the path planning are extracted and optimized by the multi-objective optimization algorithm. The obstacle avoidance path planning of the UGV based on the improved bee colony algorithm is completed.
4. Experimental analysis.
5. Conclusion and future prospects.

2. Bee Colony Algorithm and Its Improvement

Artificial bee colony algorithm is an optimization method proposed by imitating the behavior of bees. It is a specific application of the idea of cluster intelligence. Its main feature is that it does not need to know the special information of the problem, and realizes the optimal bee colony based on the calculated probability solution. The solution only needs to compare the pros and cons of the problem. Through the local optimization behavior of each artificial bee individual, the global optimal value is finally brought out in the group, with a faster convergence rate.

2.1. Working principle of artificial bee colony algorithm

Artificial bee colony algorithm is a kind of intelligent optimization algorithm based on honeybee's honey collecting behavior. In the process of optimization, the algorithm takes into account the exploitation and search of food sources, to a certain extent, surpasses the local optimum and finds the global optimum with the maximum probability [6]. In each search process, the bee colony follows the forerunner to find the target and the optimal path solution. If the food source is found to fall into the local optimum, he will choose to explore other food sources. The artificial bee colony algorithm uses the fitness value guidance method for global optimization. The fitness function is used to explore the minimum value optimization:

$$sy_i = \begin{cases} \dfrac{1}{1+y_i} & y_i \geq 0 \\ 1+abs(y_i) & y_i < 0 \end{cases} \tag{1}$$

In the formula, y_i represents the global objective function to be processed.

In the process of global optimization, artificial bee colony algorithm needs to determine the population, the number of iterations and the control factors. In the search space, multiple initial solutions are generated randomly.

Suppose ψ represents the number of food sources, the number of each food source is N, and each optimal solution $x_i(i=1,2,3...N)$ is a multidimensional vector η, which is the number of parameters to be optimized.

On the basis of the above analysis, the subsequent wasps search the optimal solution effectively. Each member of the bee colony searches to produce a new candidate food source [7], namely:

$$\chi_{ic} = x_{ic} + \vartheta_{ic}(x_{ic} - x_{dc}) \tag{2}$$

In the formula, $d \in 1,2,3...N$, $c \in (1,2,3...\eta)$, ϑ_{ic} any number in the range of [0,1], and $d \neq c$, a new fitness function is obtained and evaluated:

$$sx_{ic} = \begin{cases} \dfrac{d}{1+x_{ic}} \\ 1+abs(x_{ic})\ d \end{cases} \tag{3}$$

After the bee colony completes the search of the optimal food source, it will share the final high-quality information with its peers [8, 9]. The probability of the bee colony to select the food source is as follows:

$$G_i = \frac{sy_i}{\sum_{d=1}^{N} sx_{ic}} \quad or \quad G_i = \frac{sy_i}{\max(sx_{ic})} \tag{4}$$

According to the probability solution obtained by the above calculation, if the solution is greater than any number between [0,1], then it means that the bee colony has not obtained the optimal solution and continues to calculate. If the solution exceeds the range, it indicates that the optimal solution is obtained. Therefore, the solution can be retained and the optimal solution can be obtained by continuous search.

2.2. Improvement of artificial bee colony algorithm based on differential evolution algorithm

In the artificial bee colony algorithm, when searching the optimal solution, the bee colony search will only randomly select a food source nearby, and can not obtain more food sources with the help of other information, which will lead to the food quality guarantee, resulting in the weak search function of the bee colony algorithm. Therefore, this paper uses differential evolution algorithm multi artificial bee colony algorithm to improve the global search ability of bee colony algorithm [10].

Set the individual optimal value to p, the improved artificial bee colony algorithm is improved by considering other interference factors:

$$q_{ic} = x_{ic} + \varpi_{l1}(p_c - x_{ic}) + \varpi_{l2}(x_{icd} - x_{icd2}) \tag{5}$$

In the formula, l_1, l_2 represents a different source of food, ϖ represents a factor that interferes with a colony's search for food. When the difference between the food source found by the bee colony and its corresponding fitness is large, interference individuals will be generated in its search process. These individuals have strong interference ability, which will affect the direction of the bee colony algorithm, affect the global optimization, and otherwise affect the convergence of the algorithm [11]. Therefore, considering that the bee colony can get the best food as soon as possible, the selection probability is optimized, that is:

$$G_i = (\frac{sy_i}{\max sy_i}) \times 10\% + 0.9 \tag{6}$$

In the formula, $\max sy_i$ represents the maximum fitness value of the food source.

3. Obstacle Avoidance Path Planning of Unmanned Ground Vehicle Based on Improved Bee Colony Algorithm

3.1. Kinematics model construction of unmanned ground vehicle

In order to realize the automatic path planning of the UGV, it is necessary to analyze the operation mode of the UGV. In this paper, the kinematics model of UGV is constructed, and the operation mode of UGV is analyzed.

Suppose the coordinate system of the outer body of the UGV is aob, its inertial coordinate system is AOB, the a axis of the outer body of the UGV overlaps with the main shaft of the vehicle, they're all UGV, its A axis is on the right side of the unmanned vehicle, and its inertial coordinate system a-axis keeps the same direction with the vehicle's moving direction, and its b axis is on the right side of the vehicle's driving direction [12]. The motion model of the UGV is shown in Figure 1.

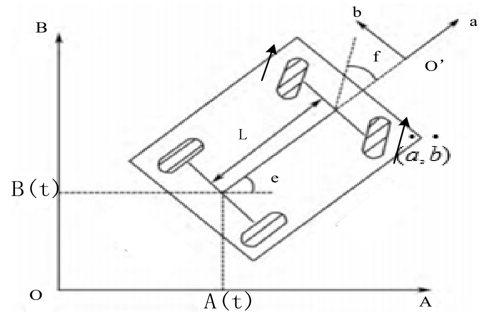


Figure 1. Motion model of unmanned ground vehicle

In Figure 1, $(A(t), B(t))$ represents coordinates in the axis coordinate system of the rear wheel of an UGV, t represents the operating time of the UGV, e represents the yaw angle of the UGV, f represents the angle of rotation of the front tire of the unmanned floor, L represents the distance between the front and rear axle of an UGV, $(\dot{a}, \dot{b})$ represents the longitudinal and transverse running speed of the vehicle in the coordinates of the UGV. According to the operation model of the UGV, the kinematic model of the UGV is constructed as follows:

$$\begin{cases} A(t) = a(t)\cos e(t) + b\sin e(t) \\ B(t) = a\sin e(t) + b\cos e(t) \\ f(t) = \dfrac{a\tan f(t)}{L} \end{cases} \tag{7}$$

3.2. Obstacle avoidance path planning of UGV based on improved bee colony algorithm

In the improved bee colony algorithm, its fitness function is the key factor of obstacle avoidance path planning [13]. The UGV must successfully avoid obstacles and arrive at the destination with the shortest time and shortest path, so as to improve the working efficiency of the UGV. In the obstacle avoidance path planning, the safety and length of UGV are regarded as the key points of path planning. Obstacles cannot overlap with the driving path of UGV [14-16].

Assuming that the penalty function H_{punish} of an obstacle free path is not greater than the barrier free distance W_{safe} of the UGV, the punishment intensity of the path increases according to the shortest distance between the obstacle and the UGV H_{punish} is:

$$H_{punish} = \begin{cases} \tau_{safe}, 0 \le \tau_{safe} \le W_{safe} \\ 0, \tau_{safe} > W_{safe} \end{cases} \tag{8}$$

$$W_{safe} = \min_{c \forall \sigma} \min_{\mu \in [1,1]} \sqrt{(a(\mu) - o_a)^2 + (b(\mu) - o_b)^2} \tag{9}$$

In the formula, $a(\mu)$, $b(\mu)$ represents the coordinates of each point when the UGV is running, o_a, o_b representing the center of an obstacle in an UGV 's path, σ represents the total set of obstacles in the route.

When the minimum distance between the driving route and the obstacles is greater than the safe distance, the distance of the driving route of the UGV needs to be analyzed. Among them, the minimum length of the shortest distance traveled through the obstacle [17, 18], and the penalty function of the minimum length of the driving path of the UGV is:

$$K_i = \int_0^1 \sqrt{(a'(\mu))^2 + (b'(\mu))^2 d\vartheta} \tag{10}$$

According to the judgment of the distance between the UGV (UGV) and the obstacles, the objective function of its travel path is designed, and the automatic planning of the obstacle avoidance path of the UGV is completed:

$$R = \upsilon_1 H_{punish} + \upsilon_2 w_{safe} \tag{11}$$

In the formula, υ_1, υ_2 for the specific gravity coefficient, the path length of UGV and the proportion of obstacles in path planning are adjusted by specific gravity coefficient.

On the basis of the above obstacle avoidance path planning, it is necessary to further optimize the extraction of multiple obstacles in the planning path. Therefore, the multi-objective optimization algorithm is used to optimize the planned obstacle avoidance path [19, 20]. In the actual operation process of UGV the diversity index of obstacles can obtain the uniformity degree of planned route distribution, which is expressed by the following formula:

$$\Delta = \frac{m_f + m_k + \sum_{i=1}^{n} \left| m_i - \overline{m} \right|}{m_f + m_k (n-1) m} \tag{12}$$

In the formula, m_f represents the extreme value of the route planning, m_k represents the Euclidean distance of the boundary solution of the route, n represents the number of planned routes for obstacle avoidance paths, $\overline{m}$ represents the average value of Euclidean distance m_i. Of which:

$$\overline{m} = \frac{\sum_{i=1}^{n} m_i}{n-1} \tag{13}$$

When calculating the maximum distance between the two farthest obstacles, it is necessary to consider the maximum coverage of obstacles in the path:

$$F = \sqrt{\frac{1}{z} \left\{ \sum_{j=1}^{h} \frac{\min(V_i^{\max}, \lambda_i^{\max}) - \max(V_i^{\min}, \lambda_i^{\min})}{V_i^{\max} - \lambda_i^{\min}} \right\}} \tag{14}$$

In the formula, $V_i^{\max}$ and $V_i^{\min}$ represents the maximum and minimum of the actual obstacle coverage. In this case, the larger the value, the larger the coverage.

The width of obstacles is an important factor affecting the normal passage of UGV [21]. The distribution range of obstacle target space can be calculated by the following formula, namely:

$$\Re = \sqrt{\sum_{j=1}^{h} \max(V_i) - \min(V_i)} \tag{15}$$

In the formula, h represents the number of obstruction targets, $\max(V_i)$ represents the maximum objective function of an obstacle in route planning, $\min(V_i)$ represents the minimum value of the objective function of an obstacle in route planning [22].

The automatic path planning flow of UGV based on improved bee colony algorithm is shown in Figure 2.

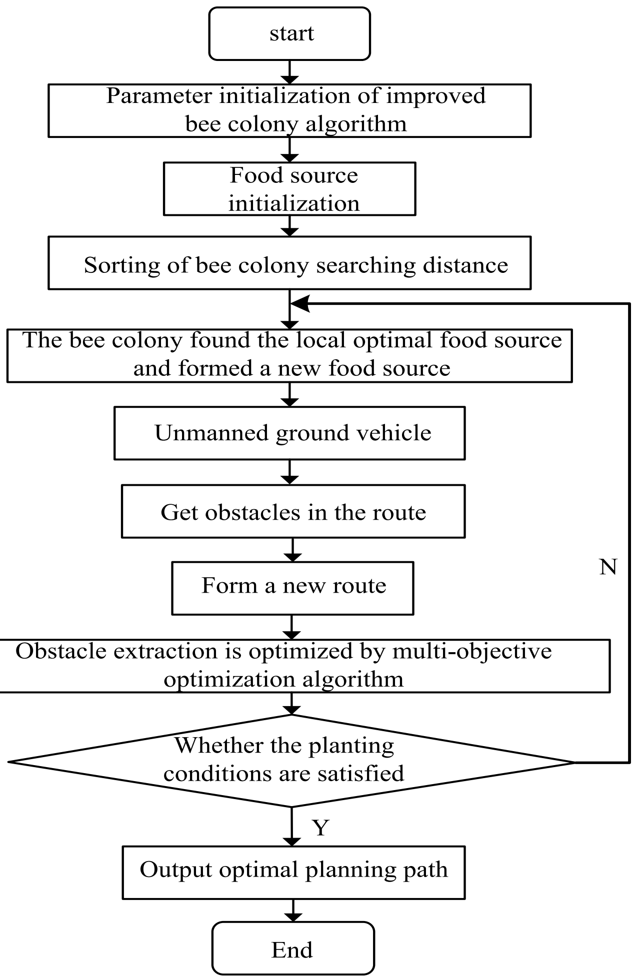
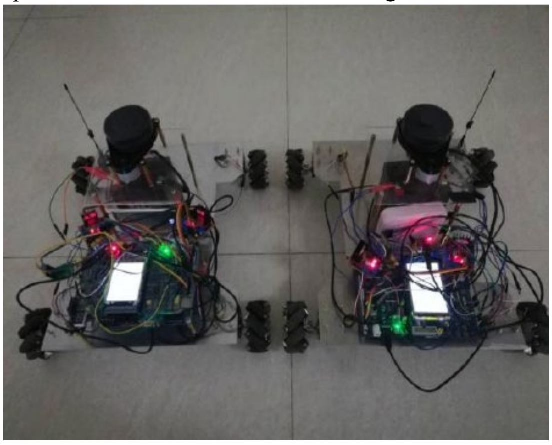


Figure 2. Automatic path planning process of UGV based on improved bee colony algorithm

4. Experimental Analysis

4.1. Experimental environment

In order to verify the scientific effectiveness of this method, simulation experiments are carried out. Methods [3] and [4] were used as experimental comparison methods. The experiment was carried out in the laboratory. The experiment is carried out in MATLAB 7 0 platform. The operating system of the experiment is windows 10 system, with 8GB memory and 3.6ghz CPU. Simulate UGV driving and obstacle avoidance path planning. The specific experimental environment is shown in Figure 3.



(a) Simulation of UGV

(b) Obstacle avoidance of unmanned ground vehicle

Figure 3 Real-time experiment

4.2. Experimental parameters

The experimental parameters are shown in Table 1.

Table 1 Experimental parameters

Parameter	Value
Number of obstacles/piece	10
Vehicle speed/M/S	5
Number of lanes	4
Iterations/times	10
Running time/min	60

4.3. Experimental indicators

Under the above experimental parameters design, the simulation experiment analysis is carried out. The error of obstacle avoidance path planning, the planning time and the effect of path planning are taken as the experimental indexes for experimental analysis.

1. Obstacle avoidance path planning error: obstacle avoidance path planning error is an important indicator to measure the proposed method. The lower the planning error is, the better the effectiveness of the method is.
2. Time consuming for obstacle avoidance path planning: the shorter the time required, the more efficient the vehicle can be.
3. Obstacle avoidance path planning effect: in the obstacle avoidance path planning of UGV, the search of obstacle free path is the key factor to improve its operation efficiency, which can improve the effect of path planning.

4.4. Experimental results

4.4.1. Error analysis of obstacle avoidance path planning with different methods

In order to verify the scientific effectiveness of the proposed method, the errors of the proposed method, the method in Reference [3] and the method in Reference [4] are analyzed experimentally. The lower the planning error is, the stronger the usability of the method is. The experimental results are shown in Figure 4.

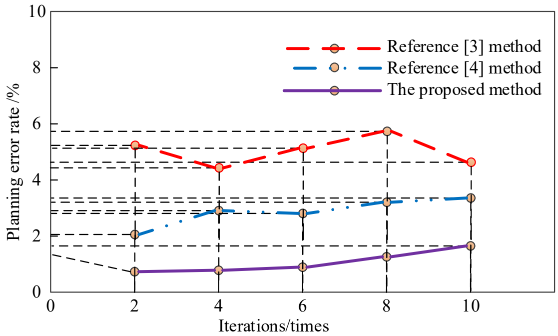


Figure 4. Comparison of path planning errors of different obstacle avoidance methods

It can be seen from the analysis in Figure 4 that there is a certain gap in the errors of the proposed method, the method in Reference [3] and the method in Reference [4] under the same experimental environment. The maximum error of the proposed obstacle avoidance path planning method is about 2%, and the planning errors of the methods in References [3] and [4] are higher than those of the proposed method. This is because the proposed method improves the artificial bee colony algorithm and constructs the motion model of UGV. According to the motion model, the obstacle avoidance path planning accuracy of the method is improved, the path planning error of the method is reduced, and the scientific effectiveness of the method is verified.

4.4.2. Time consuming analysis of different obstacle avoidance path planning methods

In order to verify the reliability of the proposed method, the time consumption of the proposed method, the method in Reference [3] and the method in Reference [4] are analyzed experimentally. Among them, the shortest time-consuming method of obstacle avoidance path planning is better. The experimental results are shown in Figure 5.

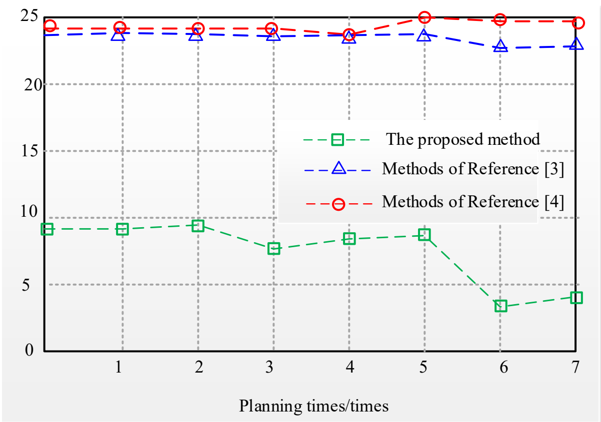


Figure 5. Time consumption comparison of different methods for obstacle avoidance path planning

From the analysis of Figure 5, it can be seen that there is a big difference in the time consumption of the proposed method, the method in Reference [3] and the method in Reference [4] for obstacle avoidance path planning of UGV. When the number of iterations is 3, the planning time of the proposed method is about 8 s, the planning time of Reference [3] method and Reference [4] method is about 22 s and 23 s respectively; when the iteration number is 7, the planning time of the proposed method reaches the minimum value, which is about 4 s, and the planning time of the method in Reference [3] and Reference [4] is about 23 s and 24 s, respectively; In contrast, the proposed method takes much less time than the other two methods. This is because the proposed method can evaluate the penalty function of obstacles through the motion model of UGV, which improves the planning speed and verifies the scientific effectiveness of the proposed method.

4.4.3. Effect analysis of different methods for obstacle avoidance path planning

In order to further verify the scientific effectiveness of the proposed method, the effect analysis of the proposed method, the method of Reference [3] and the method of Reference [4] in obstacle avoidance path planning are analyzed experimentally. The experimental results are shown in Figure 6.

It can be seen from the analysis in Figure 6 that there are some differences in the effects of the proposed method, the method in Reference [3] and the obstacle avoidance path planning method in Reference [4]. Among them, the obstacle avoidance path planning of this method is relatively stable, the shortest path can be found, and there are no obstacles to successfully reach the destination. The Reference [3] method has poor obstacle avoidance effect. When encountering obstacles, the selected path is long, and the planned path is not the optimal path. Because the robot will change the direction at a fixed angle, the path obtained in the real-time implementation process is not smooth. Referring to [4], the obstacle avoidance method can effectively judge the location of obstacles, but the planned path distance is long and the planning effect is poor. In contrast, this method can effectively avoid obstacles and reach the destination smoothly, which verifies the comprehensive effectiveness of this method.

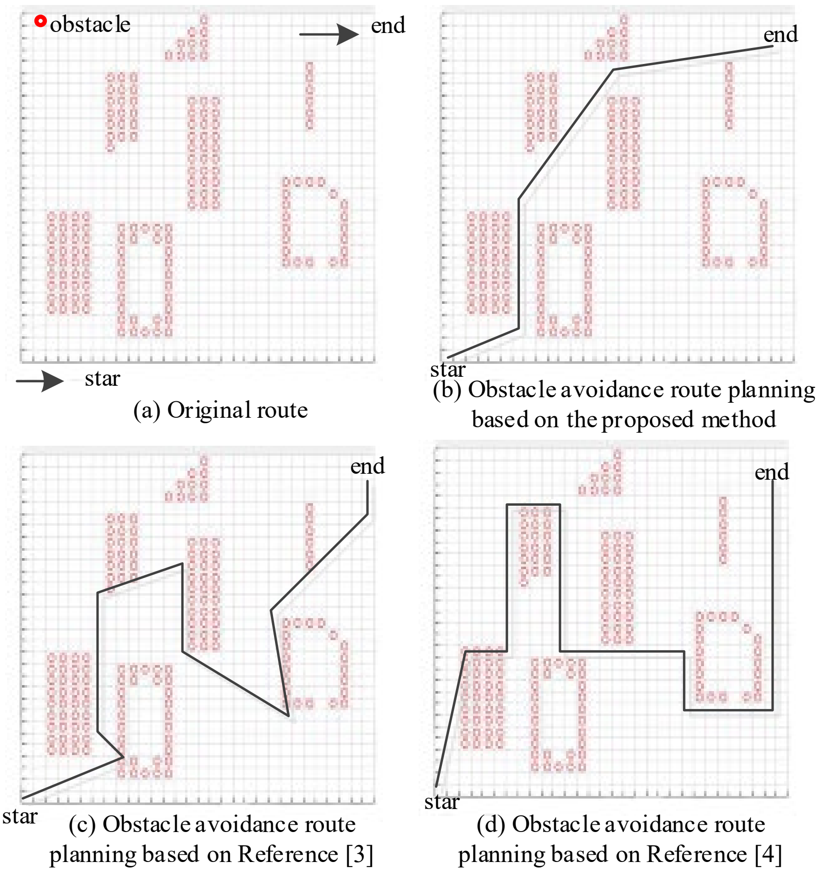


Figure 6. Comparison of different obstacle avoidance path planning methods

5. Conclusion

The obstacle avoidance path planning of UGV is a complex planning problem. In order to avoid the collision between UGV and obstacles, it is necessary to ensure the optimal route of obstacle avoidance path for UGV. Based on this, this paper proposes an automatic obstacle avoidance path planning method based on improved bee colony algorithm. This paper analyzes the working principle of the bee colony algorithm, as to improve the bee colony algorithm with differential evolution algorithm in order to enhance the local search ability of the bee colony algorithm. The study constructs the kinematics model of the UGV, and uses the improved bee colony algorithm to optimize the obstacle avoidance path planning of the UGV, and completes the automatic obstacle avoidance path planning of the UGV based on the improved bee colony algorithm. Compared with traditional methods, the proposed method has the following advantages:

1. The error of obstacle avoidance path planning using the proposed method is low, the lowest is about 2%, which verifies the accuracy of the proposed method;
2. When the proposed method is used for obstacle avoidance path planning, the shortest time is about 4 s, which verifies the efficiency of the proposed method;
3. In the experiment of obstacle avoidance path planning, the path planning of the proposed method is the best and the effect is good.

Although this paper has achieved some research results at this stage, there are still many deficiencies. In the future, it will be improved in the following aspects:

1. When improving the bee colony algorithm, we should pay more attention to the global optimization to avoid the defect of local optimization;
2. In the path planning of obstacle avoidance, the kinematic model of multiple parts of UGV should be considered when constructing the kinematics model of UGV, so as to improve the planning accuracy of obstacle avoidance path.

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