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Robot path planning based on particle swarm algorithm with forgetting factor and immune operator

YUQIN WANG[2]

Abstract. In order to improve the searching ability and precision of the robot in the unknown environment, an improved particle swarm optimization algorithm was proposed. The robot path planning environment model was established, the optimal parameters and fitness of the particles were optimized by introducing the forgetting factor, and the immune operator was used to find the global optimal solution. Compared with the artificial potential field method and the traditional particle swarm optimization algorithm, the improved particle swarm optimization algorithm had fast convergence speed and high search accuracy, the control performance of robot path planning had been improved significantly. The freescale smart car experiment platform was established, using an algorithm to evaluate the efficiency of the optimization algorithm, the experimental results showed that the space and time efficiency of the robot based on the improved particle swarm optimization algorithm had been significantly increased, achieved good control effect, validated the accuracy and feasibility of the control method.

Key words. Particle swarm optimization, robot, path planning, forgetting factor, immune operator.

1. Introduction

Robot Path Planning Research Originally originated in the late 1960s, Nils Nilssen and Charles Rosen et al of Stanford Institute developed a mobile robot called Shakey to use robotic intelligence to achieve autonomous decision-making and active obstacle avoidance in complex environments. China's robot mobile technology research began in 1970s, the main research results [1]: Tsinghua University

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[2]Workshop 1 - College of Mechanical and Electronic Engineering of Chaohu University, Chaohu, Anhui, China; e-mail: wyql11@126.com

independently developed THMR-III and THMR-V intelligent robot; Institute of Automation Institute of Chinese medicine developed intelligent explosion-proof robot; Harbin Industry University developed the first generation of DY-I tour guide service robot; Shanghai University developed the shopping guide robot etc. With the development of computer, control, automation and sensor technology, robots have been widely used in various fields. How to realize the intelligence of the robot and meet the various needs of the people is the main direction of the current and future development of the robot, the first problem to be solved is the robot path planning. In this paper, based on the study of particle swarm algorithm, an improved algorithm was proposed to optimize the searching ability of robot path and improve the convergence speed.

2. Robot path planning environment modeling

Robot path planning was that in the space area with obstacles, the robot could automatically identify and avoid obstacles according to certain evaluation criteria, and found an optimal collision free path from the starting point to the end point. To simplify the complexity of modeling the robot environment, made the following assumptions.

(1)The obstacles in the planning environment were described by polygons;

(2)The location of the obstacles were known and fixed;

(3)Under the condition of not considering the space height, the moving environment of the mobile robot was set up as a two-dimensional finite space [2];

(4)The size of the robot was ignored as a particle.

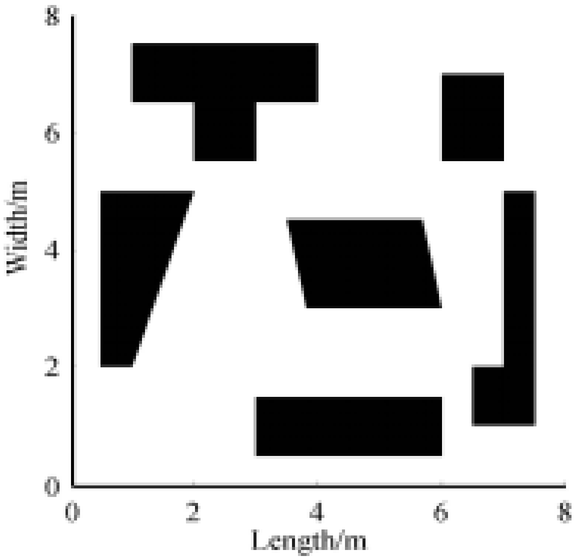

Fig. 1. Robot path planning environment model

Robot path planning environment model as shown in Fig. 1, the movement environment is distributed with six obstacles of different shapes, the initial position coordinates is (0, 0), the target point coordinates is (8, 8).

3. Optimal path solving based on improved particle swarm optimization

3.1. The basic principle of improved PSOalgorithm

The forgetting factor is a weighting factor in the error measure function and is widely used in the least squares algorithm, which has the characteristics of fast convergence speed, strong tracking ability and small fluctuation error [3]. Because PSO algorithm is slow and easy to produce "premature" phenomenon, the forgetting factor is introduced in PSO algorithm to improve the convergence speed and the precision of global search ability in the optimization process.

Immune operator is a new operator [4], which is widely used in traveling salesman problem (TSP). Compared with the crossover and mutation operator in the genetic algorithm, the immune operator has the characteristics of high flexibility and strong adaptability when solving the path problem, by finding the global optimal solution in the whole particle group, to avoid falling into local extremum, eliminate data saturation, overcome the "premature" problem.

3.2. The optimal index and fitness of particle

It supposed that the optimal path was $P_1P_2\dots P_{n-1}P_n$, where P_1 was the starting point and P_n was the end point. By adjusting the position of P_i $(i = 1, 2, \dots, n)$, the shortest path was obtained. The path planning process is shown in Fig. 2.

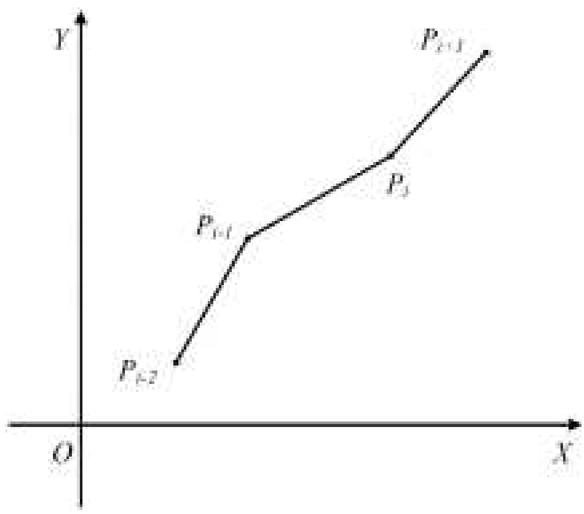

Fig. 2. Path planning process

It can be seen from Fig. 2 that the shortest distance of line segment $P_{i-1}P_i$ can be obtained by adjusting the coordinates of P_{i-1} and P_i, set the coordinates of P_{i-1} point: $X_{i-1} \in [Min\ X_{i-1}, Max\ X_{i-1}]$, $Y_{i-1} \in [Min\ Y_{i-1}, Max\ Y_{i-1}]$; set the coordinates of P_i point: $X_i \in [Min\ X_i, Max\ X_i]$, $Y_i \in [Min\ Y_i, Max\ Y_i]$. The distance of $P_{i-1}P_i$ is:

$$|P_{i-1}P_i| = \sqrt{(X_i - X_{i-1})^2 + (Y_i - Y_{i-1})^2} \tag{1}$$

where the coordinate range of each point is set to:

$$\begin{cases} E(:, X_i) &= Min\ X_i + (Max\ X_i - Min\ X_i) * rand(Size, 1) \\ E(:, Y_i) &= Min\ Y_i + (Max\ Y_i - Min\ Y_i) * rand(Size, 1) \end{cases}$$

The optimal solution $X = (X_1, X_2, \ldots, X_n)$ and $Y = (Y_1, Y_2, \ldots, Y_n)$ are obtained by combining the n-group two-dimensional variable X_1,Y_1;...;X_n,Y_n. In order to improve the optimization speed and convergence precision of the particle, a weighting matrix with forgetting factor is added to the overall path objective function, as shown in Eq. 2.

$$J_1(X_i, Y_i) = \frac{|P_1P_n|}{W_n} = \sum_{i=1}^{n} \frac{\sqrt{(X_i - X_{i-1})^2 + (Y_i - Y_{i-1})^2}}{\rho^{i-1}} \tag{2}$$

whereweighted matrix$W_n = diag\left(\rho^{n-1}, \rho^{n-2}, \ldots, \rho, 1\right)$, the value of the forgetting factor ρ is 0 to 1 [5]. When the ρ is larger, the recognition ability is stronger.

When the robot collides with the obstacle during the path search process, the penalty function is used to plan the path, reduce the number of collision with the obstacle, and improve the safety of the robot. The penalty function is [6]:

$$J_2 = \sum_{k=1}^{m} \xi_k \tag{3}$$

where$m$ indicates the number of obstacles encountered by the mobile robot from the starting point to the end point, and ξ_k represents the penalty factor.

In the process of path planning, the robot needs to change the direction of motion to avoid obstacles and search for new paths. To shorten the time taken by the robot to change the direction of motion, select the following formula to optimize the path smoothness [7].

$$J_3 = \left[\sum_{i=1}^{n} \left(\frac{X_i - X_{i-1}}{Y_i - Y_{i-1}} - \frac{X_{i+1} - X_i}{Y_{i+1} - Y_i}\right)\right]^{-1} \tag{4}$$

The path planning function of the robot is linearly summed, and the total path evaluation function is obtained:

$$J = J_1 + J_2 + J_3$$

As the PSO algorithm, the particle of the greater the better, select the fitness function:

$$f = \frac{1}{J_1 + J_2 + J_3} \tag{5}$$

where,when $f$is maximum, can be obtained $Min\ J(X_i, Y_i)$, get the optimal path.

3.3. Particle optimization process

(1)Particle swarm initialization, set initial parameters;

(2)The fitness of the current particle swarm was calculated by Eq. 5;

(3)Updated the local optimal solution $Pbest$ and the global optimal solution $Gbest$ and updated the particle's position and velocity, the velocity $v_i(k)$ and the position $x_i(k)$ of each particle were:

$$v_i(k+1) = \omega v_i(k) + c_1\gamma_{1i}(k)\left[Pbest - x_i(k)\right] + c_2\gamma_{2i}(k)\left[Gbest - x_i(k)\right] \tag{6}$$

$$x_i(k+1) = x_i(k) + v_i(k+1) \tag{7}$$

whereγ_{1i} and $\gamma_{2i}$are the random numbers uniformly distributed within the interval [0,1]; ω is the inertial variable; $c_1$and $c_2$are the acceleration constants.

(4)The forgetting factor was introduced to improve the efficiency and accuracy of the solution;

(5)Using immune operator to detect whether the particle group into a local minimal, and produced a new generation of particles;

(6)When optimization to a fixed number of iterations, the fitness value to meet the requirements, the optimization was stopped, otherwise returned to step 2, until such time as the maximum number of iterations.

4. Path planning simulation

4.1. Parameter determination

Selected the number of particle initialization$N = 60$, $c_1 = c_2 = 1.8$, $\omega = 0.8$, immune probability $p_i = 0.76$,maximum number of iterations $Max\ DT = 200$,search space dimension $D = 10$.

4.2. Parameter optimization

In order to ensure the effectiveness of the optimal path, the value of the forgetting factor $\rho$was generally the best between $[0.99, 0.997]$ [8].The optimal index J optimization process is shown in Fig. 3.

As can be seen from Fig. 3, when $\rho = 0.997$, iterations to 200 steps, the path is shortest:$Min\ J = 11.8001\ m$.

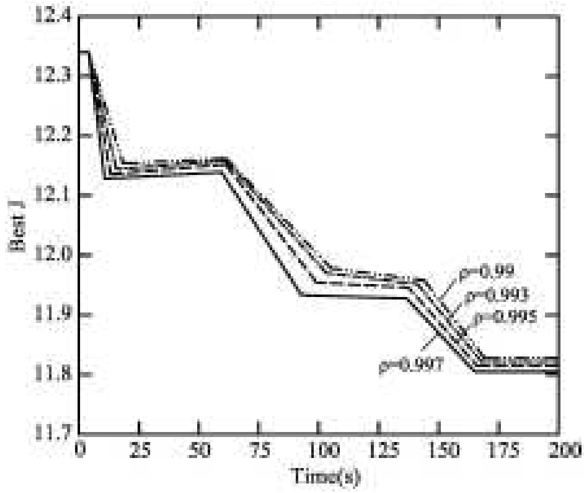

Fig. 3. Optimization process of path planning

4.3. Path simulation and analysis

In order to improve the superiority of PSO algorithm,the path obtained by the improved PSO algorithm was compared with the artificial potential field method in the literature [9]and the traditional PSO algorithm in the literature [10],the forgetting factor was 0.997.The simulation results are shown in Fig. 4.

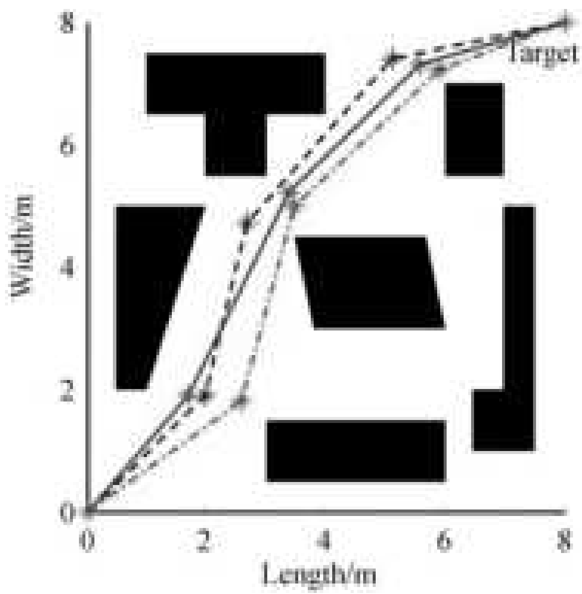

Fig. 4. Optimal path simulation

Extract the relevant data from Fig. 4, as shown in Table 1.

Table 1. Optimal path and execution time of different control strategies

Control method	Path length /m	Execution time /s
Artificial potential field method	12.2187	26.59
PSO	11.9894	22.47
Improve PSO	11.8001	19.86

It can be seen from Table 1 that the optimal path and execution time obtained by the artificial potential field method are the longest, and the optimal path and execution time based on the PSO algorithm with forgetting factor are obviously smaller than the other two control methods', and the control characteristic is obvious.

5. Experimental verification

In order to verify the accuracy and rationality of the improved PSO algorithm, Freescale smart car was selected as the robot obstacle avoidance experiment platform, as shown in Fig. 5.Intelligent vehicle selection 32-bit Kinetis controller, traffic information acquisition module selection of CMOS-type camera, laser radar rangefinder module using SICK LMS291-S05 laser measurement system to collect data, used RN-260 model motor drive robot front wheel, photoelectric encoder using BE420SM58-NO11K2R model sensor.Through the Kinetis controller designed robot robot obstacle avoidance movement control card,the Codewarrior software development system was used to compile the PSO control algorithm based on forgotten factor and immune operator, and the compiled program was introduced into the controller.

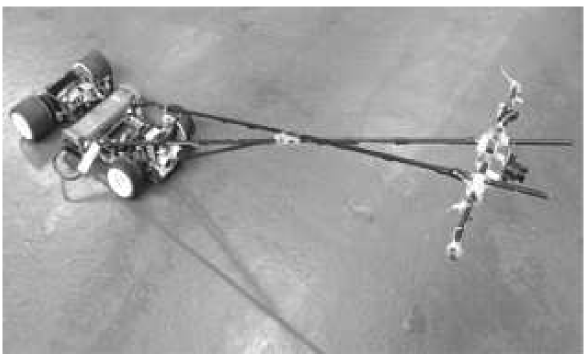

Fig. 5. Freescale smart car

Using the algorithm efficiency [11] to evaluate the robot's spatial and temporal search efficiency, the experimental results are shown in Fig. 6 and Fig. 7, respectively. Fig.6 shows the spatial search ratio of the smart car in the same area. Fig.7

shows the search efficiency of the smart car at the shortest path length.

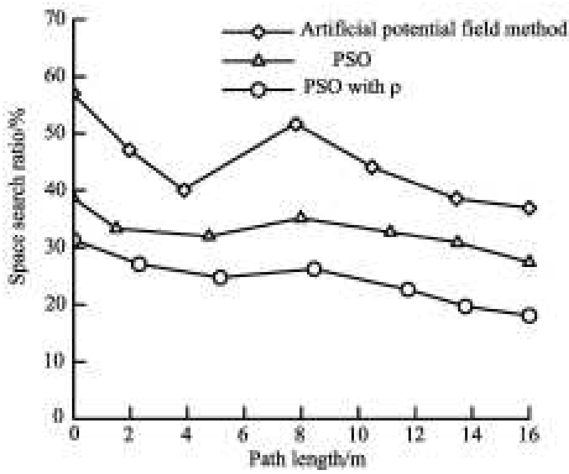

Fig. 6. Smart car space search patio

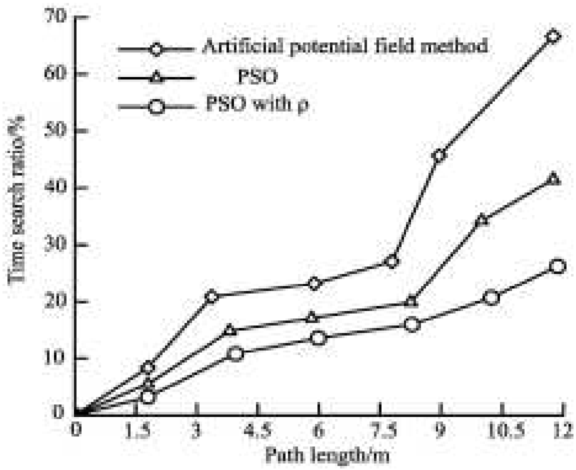

Fig. 7. Search efficiency of intelligent vehicle in the shortest path

In Fig. 6, the improved PSO algorithm can reach the end point when the search is less than 20% of the road, and the artificial potential field method and the PSO algorithm need to search 38% and 28% of the road respectively to reach the end point.In Fig.7, in the case of the shortest path, the artificial potential field method and the PSO algorithm search time are 2.49 times and 1.53 times as much as the improved PSO algorithm.It could be seen that the PSO algorithm with forgetting factor and immune operator was the best one in terms of space search efficiency and time efficiency, and the improved PSO control strategy was reasonable and feasible.

6. Conclusion

(1) The robot path planning environment model was constructed. In view of the problem that the particle swarm optimization algorithm had the advantages of slow convergence rate, poor precision and easy to fall into the local optimal solution in the path optimization process,an improved PSO algorithm with forgetting factor and immune operator was proposed, which could overcome the above problems effectively.

(2)The objective function was optimized by the improved PSO algorithm to determine the particle fitness. The simulation results showed that the optimal path based on the improved PSO algorithm was 3.43% and 1.58% shorter than the artificial potential field method and PSO algorithm respectively, the execution timewas shortened by 25.31% and 11.62%.Therefore, the improved PSO algorithm from the view of overall planning, improved the convergence speed and robustness of time-varying parameters,and optimized the optimization path.

(3)Based on the Freescale smart car and the 32-bit Kinetis controller, the robot obstacle avoidance experiment platform was established. The algorithm efficiency was used to evaluate the optimization algorithm, and the better control effect was obtained.The accuracy and feasibility of the improved PSO algorithm for robot path optimization was verified, which had a certain guiding significance for the future research of robot path planning.

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