

## Group Path Planning Based on Variable Dimension ABC Algorithm

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### Abstract

*Group mobile robot path planning is a multi-objective optimization problem, as the requirement of obstacle avoidance, traditional robot path planning optimization method has the problem of algorithm complexity, large search space and low efficiency, it is difficult to obtain the optimal solution. In order to improve the efficiency and the positioning accuracy of group robot path planning, we put forward a group mobile robot path planning method based on variable dimension artificial bee colony algorithm. Firstly, we take robot working environment to model, then taking group robot path network as nectar source, the ultimate goal of path planning is to find minimal path network, to find an optimal swarm robot moving path network which avoids obstacles through the mutual cooperation between bees. Simulation experiment results show that the path planning method based on variable dimension artificial bee colony algorithm improves the efficiency of swarm robot path planning, it can find optimal solution of swarm robot path planning during the shortest time, and it can avoid obstacles safely, it provides basis to group robot task coordination.*

**Keywords:** path planning; multiple mobile robots; artificial bee colony algorithm

### 1. Introduction

In recent years, with the development of computer technology and communication technology, intelligent robots are playing a more and more important role in human society. Intelligent robots can replace humans to perform tasks under dangerous environment and hard environment, to reduce the mission risk and to increase the probability of success, the mission planning and task coordination problems of intelligent robot group have been received more and more attention by researchers[1-2]. The aim of path planning is to generate a feasible path which meets the kinematic constraints and specific task constraints of intelligent individual through self environmental awareness and search algorithm under known, partially known and unknown environments[3]. The first step is to establish environment model of task interval of path planning. Establishment methods of existing environmental model are grid method, geometric model, topological model and so on[4-5].

In recent years, with the rapid development of heuristic optimization algorithm, some bionic intelligent optimization algorithms have been widely used in the problem of path optimization, such as genetic algorithm, particle swarm optimization algorithm and ant colony algorithm, and achieving a good effect according to the different problems of the model[6-7].

We take the path planning problem of the group system as the research object in this paper, combining with the ability to solve the global optimization of multi variable function of ABC algorithm[8], and improving in allusion to the characteristics of the path planning problem of the group system, and we put forward Artificial Bee Colony

Algorithm with Modified Dimensionality(MDABC), realizing the fast optimization of path planning for the group system.

## 2. Group Path Planning Mathematical Model

### 2.1. Group path Planning Problem Model

Supposing that the working space  $D$  of the group system is composed of two parts, including free space  $S_f$  and obstacle space  $S_o$ . Obstacle space  $S_o$  includes  $k$  obstacles, then mapping to the environment model to obtain the set of obstacles  $(O_1, O_2, \dots, O_k)$  through environment modeling. The group system is composed of  $n$  independent individuals, task set is composed of the  $m$  tasks which are distributed in the working group. Individual collections can be expressed as  $(R_1, R_2, \dots, R_n)$ , a collection of tasks can be expressed as  $(T_1, T_2, \dots, T_n)$ . The difference is the task executor is a smart individual robot set  $R$  comparing to the single robot path planning, and task points are also extended to a task set  $T$ , we could obtain the initial position  $P_{oi}$  set  $P_o = (P_{o1}, P_{o2}, \dots, P_{on})$  and target location  $P_{gi}$  set  $P_g = (P_{g1}, P_{g2}, \dots, P_{gm})$  according to specific task requirements and initial conditions. The goal of group system path planning is to generate optimal path network which meets shortest time, safe obstacle avoidance, mutual collision avoidance and shortest path constraints between the initial position of the individual set and target set. The path  $P^{ij} = (P_1^{ij}, P_2^{ij}, \dots, P_L^{ij})$  can be composed by sequence point in working space  $D$  from individual  $I$  to target  $j$ .

In a word, the mathematical model of multi robot path planning problem can be described as a path set which composed of the starting positions of the individual and the different target positions and path points and their connections in working space  $D$ .

$$\begin{aligned}
 P &= \sum_{i \in R, j \in T} P^{ij} \\
 \text{s.t.} &= \begin{cases} T(P) = 1 \\ C(P^{ij}, P^{kl}) = 1 \quad i, k \in R; j, l \in T \\ P_0^{ij} = P_0^i \\ P_g^{ij} = P^j \end{cases} \quad (1)
 \end{aligned}$$

### 2.2. Cost Function Analysis of Group System Path Network

The evaluation function of the group path planning problem can be expressed as:

$$J = \omega_1 J_l + \omega_2 J_\phi + \omega_3 J_d + \omega_4 J_a + \omega_5 J_T \quad (2)$$

In the formula,  $\omega_1, \omega_2, \omega_3, \omega_4, \omega_5$  are positive constants, they show weight coefficient of each evaluation parameter,  $J$  is global cost function value of path network,  $J_l$  is the overall length of the path network,  $J_\phi$  is the smoothness cost of path network, the calculation method is shown in the formula (3),  $a_k$  is the path network of  $k$ ,  $\phi$  is the maximum steering angle permitted by the individual,  $J_d$  is the shortest distance of the path segments required by the individual, the goal is to make the path network to meet the individual movement of the minimum linear movement constraints, its values could be obtained through formula (4),  $d_i$  is the

line length of the  $i$  path,  $J_a$  is the penalty term, the current searched path network will be punished to enhance the value of the path network when  $P \cap T \neq \Phi$ , and its security weaknesses will directly affect the value of the evaluation function,  $J_T$  is the cooperative function, its accession is an important symbol of the problem of group path planning, its specific mathematical definition can be shown as formula (5).

$$\begin{cases} J_\phi = 0, \frac{a_k^T \cdot a_{k+1}}{|a_k| |a_{k+1}|} > \cos \phi \\ J_\phi = \sum_{i=1}^n \left(1 - \frac{\frac{a_k^T \cdot a_{k+1}}{|a_k| |a_{k+1}|}}{\cos \phi}\right), \frac{a_k^T \cdot a_{k+1}}{|a_k| |a_{k+1}|} \leq \cos \phi \end{cases} \quad (3)$$

$$\begin{cases} J_d = 0, d_i > l_{\min} \\ J_d = \frac{\sum_{i=1}^n l_{\min} - d_i}{l_{\min}}, d_i < l_{\min} \end{cases} \quad (4)$$

$$\begin{cases} J_T = 0, S^{1j} \cap S^{2j} \cdots \cap S^{nj} \neq \Phi \\ J_T = \frac{t_{\max} - t_{\min}}{t_{\min}}, S^{1j} \cap S^{2j} \cdots \cap S^{nj} = \Phi \end{cases} \quad (5)$$

### 3. ABC Algorithm Mathematical Model

In the initial setting of the algorithm, initializing  $M$  initial solution  $M = M_e + M_o$  randomly, more excellent half solution  $M_e$  as the initial source,  $M$  is the population quantity. The number of solutions contained in the set  $M_e$  is equal to the number of the employed bees, the number of solutions contained in the solution set  $M_o$  is equal to the number of observations, each solution vector  $x_i (i = 1, 2, \dots, M)$  is  $D$  dimension vector which is consistent with the optimization parameters. Each observation bee choose the nectar which they need to go to collect honey with a certain probability  $p_i$  according to Russian roulette mechanism,  $p_i$  is defined as:

$$p_i = \frac{\text{Fit}_i}{\sum_{j=1}^{M_e} \text{Fit}_j} \quad (6)$$

$\text{Fit}_i$  is fitness value,  $M_e$  is the number of nectar, it is equal to the number of employed bees. Formula (6) is suitable to solve maximum problem, in order to apply the ABC algorithm to solve the minimum value problem, we take the fitness calculation formula of nectar as the following improvement:

$$\text{Fit}(pos) = 2 - sp + \frac{2(sp - 1)(pos - 1)}{m_e - 1} \quad (7)$$

$Pos$  is the position number in the whole solution group,  $sp$  is the selection parameter,  $\text{Fit}(pos)$  is the nectar of fitness value after the change of new fitness value. According to the new fitness formula, the probability formula of observation bee is as follows:

$$p_i = \frac{\text{Fit}(pos)_i}{\sum_{j=1}^{M_e} \text{Fit}(pos)_j} \quad (8)$$

The update and evolution of solution is shown as follows:

$$v_{ij} = x_{ij} + \omega(x_{ij} - x_{kj}) \quad k \in \{1, 2, \dots, M\}, j \in \{1, 2, \dots, D\} \quad (9)$$

In order to make the updated solution different from the old solution,  $k \neq j$ ,  $\omega$  is the random number between [-1,1].

The basic idea of ABC algorithm is to search every potential solution and evaluate through swarm, if the new solution is better than the old one, then using the searched new solution replace the poor old solution, until selecting the optimal solution. If a solution is still not improved after a certain number of cycles, the solution will be abandoned, the corresponding hired bee will be transformed into the investigation bee, and solving the new solution through formula (10).

$$x_i = x_{\min} + \text{rand}(0, 1)(x_{\max} - x_{\min}) \quad (10)$$

#### 4. Group Path Optimization Method based on MDABC Algorithm

Bee colony algorithm has good flexibility, multi functionality and robustness in solving optimization problem, but the dimension of the solution is certain, this is difficult to meet the requirements in solving multi path or group system path network optimization problem. The number of navigation points is the dimension of the solution in the method of generating path generation for endpoint, the distance between the path points is the length of a single route segment  $r$ . If the number of navigation points (the dimension of the solution) and the  $r$  are fixed, it's hard to get a smooth path if we just change the navigation point to optimize the route, it is shown in figure 1(a), initialization path is  $s-P_1-P_2-P_3-g$ , optimized path is  $s-P_1-P_2-P_3-g$ , if you keep the number of the navigation points unchanged and change  $r$ , it is shown as figure 1(b), this will lead to the optimized route segment less than the minimum line movement distance of the robot's requirements, such as  $\|P'_3g\| < l_{\min}$ , it will increase the robot's control error, if the number of navigation points and  $r$  are changed, it ensures the smooth sailing route and meet the kinematic constraint of the robot, it is shown as figure 1(c).

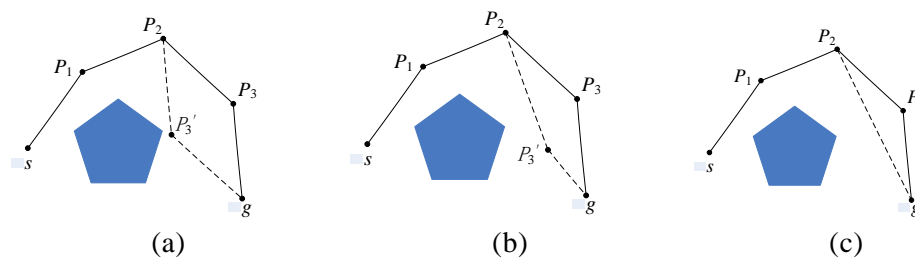


Figure 1. Progress of Optimizing Path

The method of figure 1(c) can reduce the path points, this requires the dimension of the solution is variable, traditional ABC algorithm cannot meet such requirements. We put forward Artificial Bee Colony Algorithm with Modified Dimensionality, and taking overall structure design to the solution, it doesn't affect the operation of the algorithm when the dimension changes, the structure of each solution is expressed as:  $\text{Food}_i = \{\text{Waypoint}[], \text{Bas}, \text{Fitness}\}$ ,  $i \in (1, 2, \dots, SN)$ ,  $SN$  is the number of food sources.

$Food_i.Waypoint[]$  is the path point set which constitutes path,  $Food_i.Bas$  is the mining times of food sources, it prevents premature convergence and fall into local optimum, and improves the quality of solution,  $Food_i.Fitness$  is the fitness value of food source, or excellent degree of solution, the calculation formula is as follows:

$$Food_i.Fitness = 10^4 / J_i \quad (11)$$

$J_i$  is the cost of a path, the cost of the path is smaller, the adaptation degree of the food source is larger.

The position update mode of following bee is as follows:

Selecting 1 food sources  $Food_i$  randomly,  $Food_i.Waypoint[]$  updates as shown in the formula (12).

$$Food_i.Waypoint[k] = Food_i.Waypoint[k] + rand * (Food_j.Waypoint[k] - Food_i.Waypoint[k]) \quad (12)$$

$i \in (1, 2, \dots, SN)$   $SN$  is the number of food sources,  $k \in (1, 2, \dots, D)$   $D$  is the dimension of solution.

## 5. Simulation Experiment

Algorithm initialization parameter setting are shown in table 1.

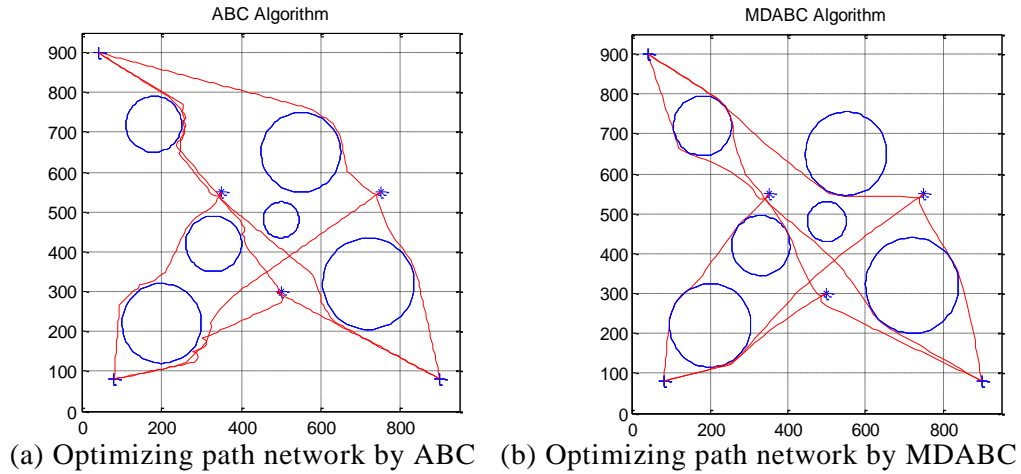
**Table 1. Parameters Setting of Algorithm**

Maximum iteration number( $T_{max}$ )	Colony size(SN)	Guide bee population(EN)	Upper limit of food source(Bas)	$\phi_{max}$	$l_{min}$
400	100	10	50	$\pi / 2$	10m

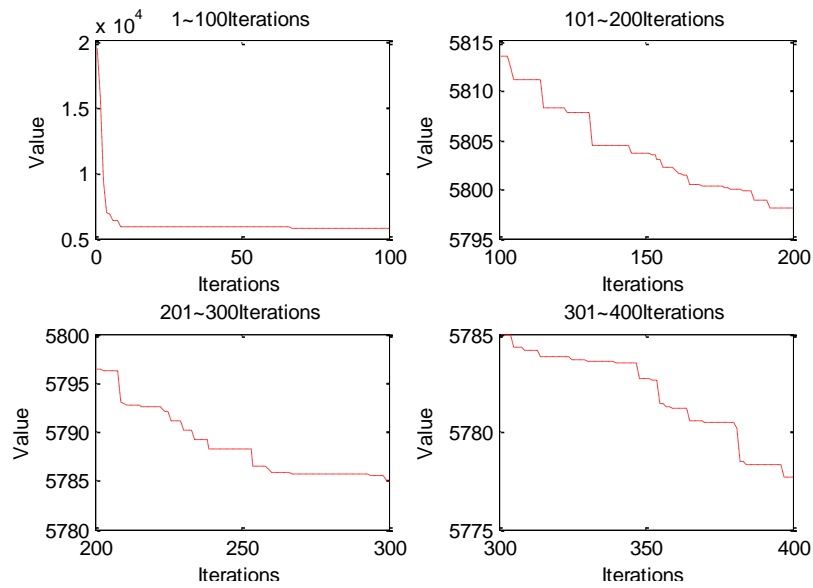
Applying the method of endpoint elicitation to generate path network to robot group, avoiding all kinds of threats successfully and reaching the target point, then using MDABC to optimize path network, to obtain the path network which meets the requirements of the value and smoothness.

The optimization results are shown in figure 2, it can be found from simulation results that the path network which obtained through traditional ABC algorithm could get the initial path from the starting point to the target point, but the cost value and smoothness of the obtained path can't meet the requirement of robot motion constraint, using the random and good searching ability of MDABC algorithm and the characteristics of flexible transformation of solution, to take iterative optimization for path network.

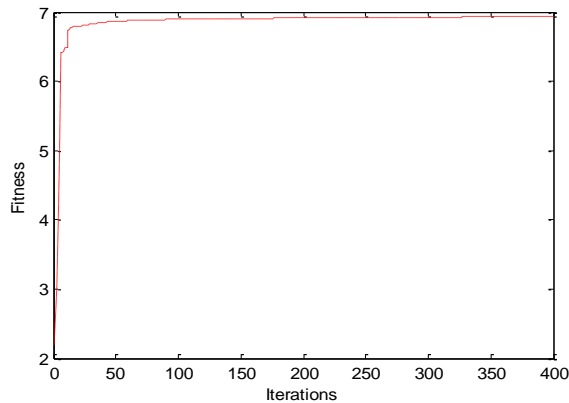
From figure 3 and figure 4, we can obtain the generation value and fitness value of the path network are optimized by the 100 generation of the algorithm, optimization is trivial during 100 to 400, because the path optimization problem is to find a feasible path which could meet the constraints of the intelligent body movement, the optimization results which obtained in the 0 to 100 generation are fully capable of meeting the needs of the problem.



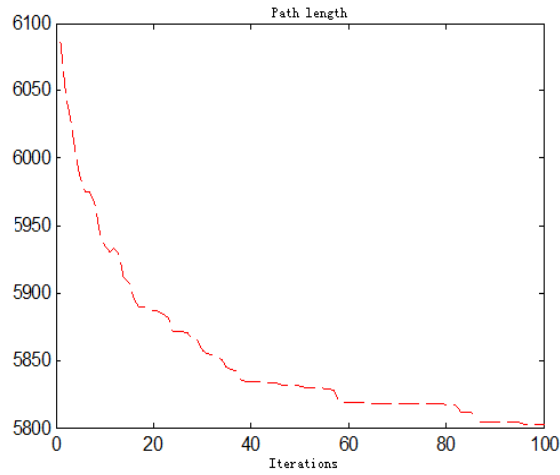
**Figure 2. Optimizing Path Network**



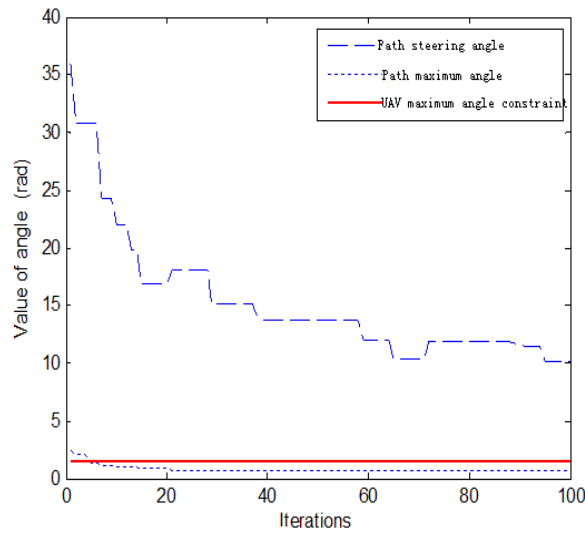
**Figure 3. Changes Value of Path Network with Iterations**



**Figure 4. Changes Fitness of Path Network with Iterations**



**Figure 5. Changes Length of Path with Iterations**



**Figure 6. Changes Smoothness of Path with Iterations**

Figure 5 and figure 6 represent the changing situation between path length and path smoothness of path network, the specific values of path length are shown in table 2. The sum of the path angle is the sum of each path angle, it represents the smoothness of path, the maximum rotation angle of the path network is less than the maximum angle constraint of the robot, it shows that the optimized path network can satisfy the robot's motion constraint.

**Table 2. Length of Path**

	A	B	C
I	565.60	835.90	482.04
II	746.30	510.61	488.97
III	527.61	830.90	800.51

## 6. Conclusion

This paper puts forward multiple cluster path planning method of the robot which combined endpoint heuristic initialization path network with MDABC. Using endpoint heuristic method in route network initial stage, and generating initial solution set in feasible path solution space, then optimizing path network through MDABC algorithm, and putting forward a new ABC model during optimization, to adjust the fitness according to dimension changing of the solution in solution space, the optimal solution is selected by greedy selection mechanism, and to obtain the path network point which meets the motion constraints of robot. This new method keeps the global search ability of ABC algorithm, and solves the problem of local optimum and robustness which faces multi constraint and multi task of path planning problem of multiple robot cluster. Simulation experiments show that the new method can plan a feasible optimal or sub optimal path for the multiple robot cluster under different task complexity and environment complexity, and analyzing the influence of the parameters on the performance through experiment.

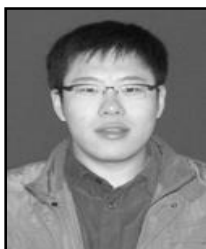
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