Optimal Path Planning for Robot Based on Ant Colony Algorithm

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***Abstract*—With the development of computer technology and intelligent computing, robot technology also gets more and more attention, in view of this, the robot path planning problem is also particularly important. In this paper, the optimal path planning for robot based on ant colony algorithm is proposed by studying the related literature and important techniques about robot path planning in China and abroad. This paper mainly considers that under the condition of sensing the current environment, the robot dynamically avoids the obstacles and meets the requirements of the least time and the minimum walking path. On the basis of introducing the robot path planning problem, the mathematical model is established for the ant colony algorithm, and the experiment is conducted through the analogue simulation. The experimental results show that the model can intelligently choose a path for the robot with dynamic obstacle avoidance, having the shortest time and shorter distance, and has a certain contribution to the intelligent development for the robot.**

Keywords—path planning; ant colony algorithm; immune operator; nonlinear programming

I. INTRODUCTION

In current society, with the development of computer technology and intelligent computing, human beings are moving towards diversification. Besides, robot technology is widely used in the fields of planetary exploration, deep ocean exploration, military, home, and so on [1]. Mobile robot is the leader in the field of robot, who uses the sensor to perceive the machine parameters and the current environment, to avoid obstacles to reach the destination and finally successfully complete the job. Such as a home entertainment robot developed by a foreign company, is a mobile robot, and also the world's first biped robot to complete the walking, running, jumping, casting and a series of difficult actions [2]. The realization of these actions requires the robot develop to the direction of intelligent, with self-organization, self-learning, adaptive and other intelligent capabilities. As the basis of intelligent and difficult action, the robot path planning refers to the robot starts from a specific location and reaches another specific location without collision and obstacle avoidance according to certain requirements. A large number of scholars in China and abroad have done in-depth study on robot path planning, and they summed up a variety of path planning methods. The commonly used in current include: neural network algorithm, artificial potential field, grid method, and so on [3]. Although all these methods can plan a path, but they did not consider whether the path could be the optimal.

This paper mainly considers that under the condition of sensing the current environment, the robot dynamically avoids the obstacles and meets the requirements of the least time and the minimum walking path. On the basis of introducing the robot path planning problem, the mathematical model is established for the ant colony algorithm, and the experiment is conducted through the analogue simulation.

II. OVERVIEW OF ROBOT PATH PLANNING

One of the most important components of mobile robots is the path planning. Its main target is to overcome obstacles and avoid collision to find an optimal path to another location. The optimal path should be the shortest and cost the least time, and so on [4].

The path planning problem studied in this paper refers to that finding a no collision path for a robot from a specific position to another specific position with a certain degree of static and known obstacles and satisfying a certain degree of optimization parameters. The problem can also be described as finding a connection line in the AS (representing a free space without collision) [5], connecting from a specific location gbegin to another specific location gend. This curve should match certain performance parameters, or make sure that there is not such a connection curve.

III. ANT COLONY ALGORITHM AND ITS IMPROVEMENT

A. The Basic Idea of Ant Colony Algorithm

Each ant in the nature passing a road will leave pheromone, pheromone intensity reflects the direction of the ants tending to walk, the greater the intensity, the bigger the possibility of ants will walk. Within the same time, the shorter path and the greater the intensity of the pheromone, the more ants will be, that is, ants will automatically find the shortest path [6]. Then the later passing ants will determine whether to choose this path according to the number of ants walking through here, the more the number, the greater the possibility for the ant to choose this path. The way the ants communicate with each other will help them find a shorter path between the nest and the food.

It is the optimization behaviour showed by the ant group to inspire Marco Dorigo, and he proposed ant algorithm in his doctoral thesis for the first time [7].

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B. Mathematical Model of Classical Ant Colony Algorithm

In order to better understand the mathematical model of the ant system, TSP, that is traveling salesman problem will be firstly introduced. The TSP problem is intended to find a shortest route through the various cities and only once, provided the distance between the given N cities and the two cities. Describing as a given graph G= (V, A), where V is the vertex set, A is the edge set of each vertex interconnection. Already known the distance between each vertex [8], requiring determine a shortest Hamilton loop, that is, the shortest loop traversing all vertex and only once.

Introduce symbols to simulate the behaviour of the real ants is shown as Table 1:

TABLE I. SYMBOLIC MEANING OF ANT BEHAVIOR

Symbol	Meaning
M	The total number of ants in ant colony
p_{ij}^{k}	The probability of ant k transferred from city i to city j
$\tau_{ij}(t)$	The pheromone concentration on the edge of t time (i, j)
$\Delta\tau_{ij}(t)$	The pheromone increment on edge of t time (i, j)
a	The information heuristic factor, indicating the relative importance of pheromone concentration
$d_{ij}=\{i,j=1,2...n\}$	The Euclidean distance between city i and city j
$\eta_{ij}=1/d_{ij}$	The heuristic function on the edge (i, j), that is, the visibility, indicating the aspiration level transferred from city i to city j
β	Expectation heuristic factor, indicating the relative importance of visibility
ρ	The attenuation coefficient of pheromone within time interval (t, t + n), where $1\geq\rho\geq 0$

In the initial state, the pheromone intensity on each path is the same. Suppose $\tau_{ij}(0)=C$, and the pheromone concentration at edge (i, j) is $\tau_{ij}(t)$.

So the probability p_{ij}^{k} of ant k (k = 1, 2 ... m) in city i to select city j at time t is:

$$p_{ij}^{k}=\begin{cases}\dfrac{\tau_{ij}^{a}(t)\eta_{ij}^{\beta}(t)}{\sum_{k\in allowed}\tau_{ij}^{a}(t)\eta_{ij}^{\beta}(t)} & k\in allowed\\ 0 & else\end{cases} \quad (1)$$

In the formula, the ant will determine whether or not to take this path through the value of a [9]; β reflects the relative importance of visibility, that is, the ant will determine whether or not to transfer this path based on the value of heuristic information, and the criteria are similar to the greedy rule [10].

The ants complete a cycle after n moments, and then the amount of pheromone on each path is adjusted according to the following formula:

$$\begin{aligned}&\tau_{ij}(t+n)=\rho\tau_{ij}(t)+\Delta\tau_{ij}(t,t+n)\\&\Delta\tau_{ij}(t,t+n)=\sum_{k=1}^{m}\Delta\tau_{ij}^{k}(t,t+n)\\&\Delta\tau_{ij}^{k}(t,t+n)=\begin{cases}\frac{Q}{L_k}, If\ the\ ant\ K\ passes\ through\ the\ path(i,j)\\ 0\quad else\end{cases}\end{aligned} \quad (2)$$

Among them, the meaning of each symbol is as shown in Table 2:

TABLE II. SYMBOLIC MEANING OF PHEROMONE FORMULA

Symbol	Meaning
$\Delta\tau_{ij}(t,t+n)$	The increase of pheromone on the path (i, j) in this cycle
$\Delta\tau_{ij}^{k}(t,t+n)$	The amount of pheromone left by the ant of number k on the path (i, j) in this cycle
ρ	The persistence coefficient of pheromone on the path
$1-\rho$	The attenuation coefficient of pheromone on the path (also known as the volatilization coefficient, the evaporation coefficient)
L_k	The path length that the ant of number k walked in this cycle
Q	Pheromone intensity, which has a certain degree of relationship with the convergence rate of the algorithm

C. The Program Structure of Ant System

The program structure flow is shown as Figure 1.

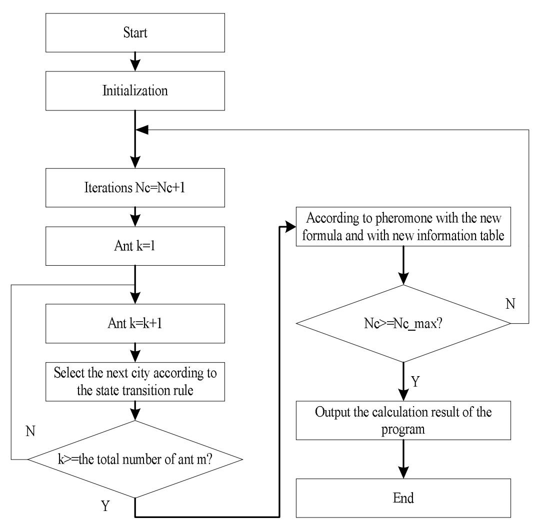

Figure 1. Program structure flow.

D. Improvement of Ant Colony Algorithm

Due to the disadvantages that the path searching time of ant colony algorithm is long and it is easy to fall into the local optimal solution, this paper uses the self-adaptive adjustment method to improve the bearing coefficient ρ of pheromone, and then updates the improved bearing coefficient into the pheromone update formula of ant colony algorithm.

The formula for improved ρ is as follows:

$\rho_{ij} = e^{\frac{\tau_{ij}(t)_{\min}}{\tau_{ij}(t)}} + e^{-1}$, where $\tau_{ij}(t)_{\min}$ represents the minimum value of pheromone concentration on the edge (i, j) of time t.

The improved algorithm flow chart is shown in Figure 2:

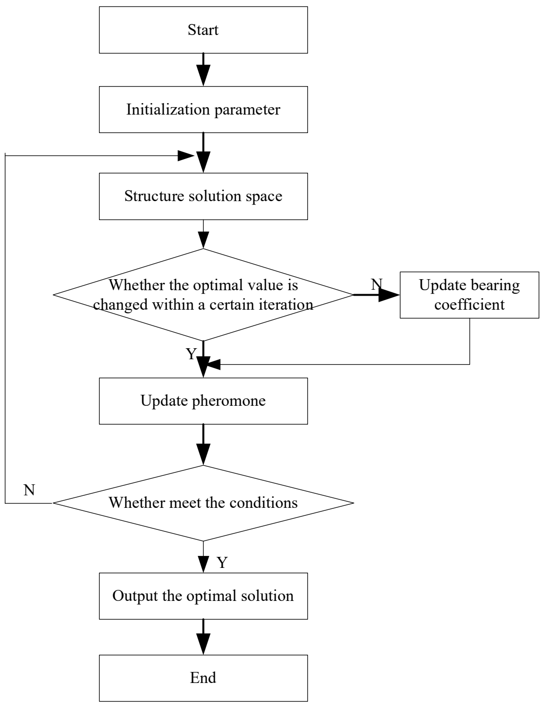

Figure 2. The improved algorithm flow chart.

IV. SIMULATION EXPERIMENT

In the dynamic path planning, firstly the Dijkstra algorithm is used to find the shortest path in the known static environment. As the robot moves forward, if there is an obstacle to be collided, it must find a suitable node in the shortest path to avoid the obstacle. The robot can sense the general range of motion of the obstacle through the sensor and advance in the direction of the grid with high pheromone intensity.

The algorithm implementation flow chart is shown in Figure 3:

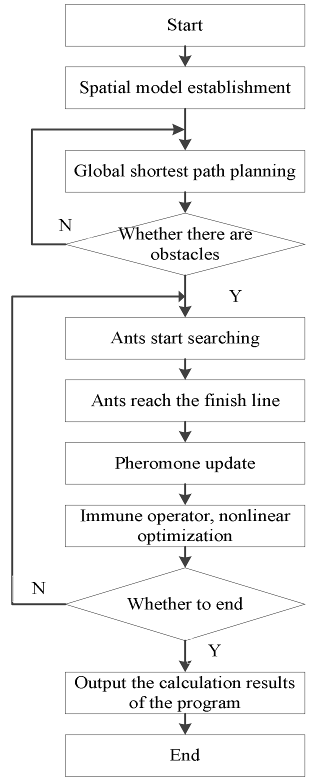

Figure 3. The algorithm implementation flow chart.

Through this flow chart, the path planning steps of the mobile robot can be obtained as follows:

Step 1 Parameter initialization

Initialize the maximum number of iterations of the ant colony algorithm, the number of groups, the starting point and the target point, and the number of rows and lines of the grid N.

Step 2 Using Dijkstra algorithms to find a global optimal path

The robot moves along the searched shortest path, and if there is an obstacle to be collided, it must find a suitable node to avoid obstacle in the shortest path. The robot can sense the general range of motion of the obstacle through the sensor and advance in the direction of the grid with high pheromone intensity.

Step 3 Detect the obstacle, the ants choose the next grid.

Determine whether there is obstacle for the next grid, if there is, use the ant colony algorithm to achieve dynamic avoidance obstacles, and turn to step 4. Otherwise, continue move along the initial global path.

Step 4 Using ant colony algorithms to avoid obstacles

Select the next grid node to be reached according to the probability, and then use the roulette method to get the next grid. Turn to step 5.

Step 5 Make sure that the ants reach the local target

Within the specified steps, if the ants reach the target, record the length of the shortest path of the ant walking. Turn to step 6

Step 6 Update pheromone

Locally update for pheromone of local individuals that reach the local target according to the formula. Turn to step7.

Step 7 Confirm whether to end

If the upper limit of the number of cycles is reached, the shortest path should be output in the current group; otherwise, turn to step 4.

Step 8 Continue moving along the global path until the destination

After determining the local target point, cycling the operation. Once encounter obstacle, turn to step 3.

According to the above steps, find a global optimal path by Dijkstra algorithm, and avoid the obstacles with ant colony algorithm. The global shortest path planning results is shown as Figure 4. The robot is about to encounter obstacles is shown as Figure 5. The obstacle avoidance map of robot is shown as Figure 6. The final path of Robot is shown as Figure 7.

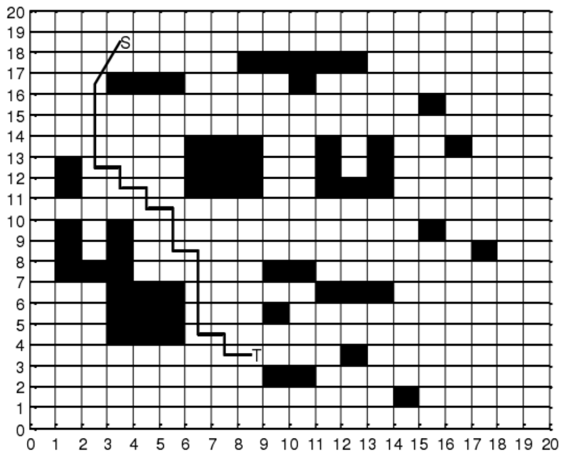

Figure 4. Global shortest path planning results.

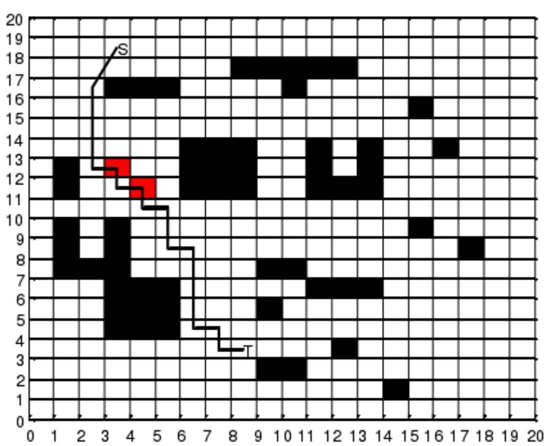

Figure 5. The robot is about to encounter obstacles.

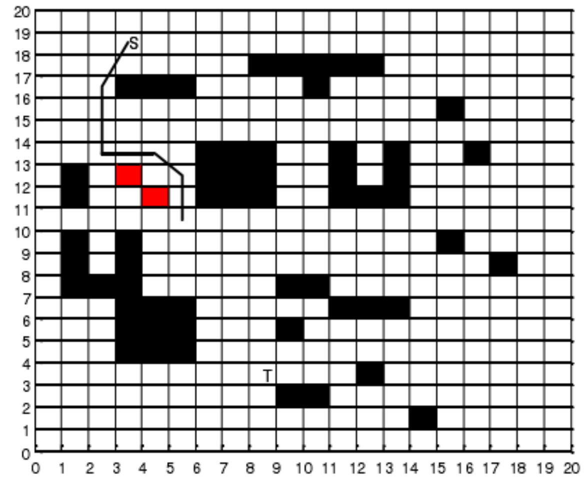

Figure 6. Obstacle avoidance map of robot.

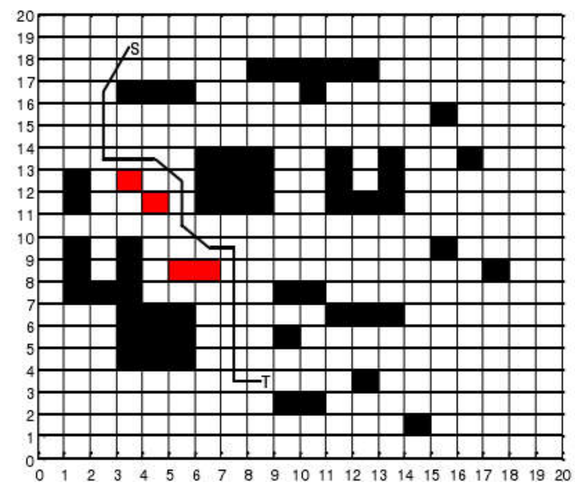

Figure 7. Final path of Robot.

In the above figures, the red part represents the moving obstacles. As shown in Figure 4 to 7, the model firstly determined a global shortest path, and the robot moved along the path. When the robot encountered obstacles, it used ant colony algorithm to avoid obstacles, and then moved forward until finish the whole path.

V. CONCLUSION

Mobile robot is an important branch of robotics. Because of its adaptability, large working space and other advantages, it has been rapidly developed in recent years. And for the study of mobile robot, what should be firstly solved is the obstacle avoidance and path planning problem. In this paper, the optimal path planning for robots based on ant colony algorithm is proposed by studying the related literature and important techniques of robot path planning in China and abroad. This paper mainly considers that under the condition of sensing the current environment, the robot dynamically avoids the obstacles and meets the requirements of the least time and the minimum walking path. On the basis of introducing the robot path planning problem, the mathematical model is established for the ant colony algorithm, and the experiment is conducted through the analogue simulation. The experimental results show that the model can intelligently choose a path for the robot with dynamic obstacle avoidance, having the shortest time and shorter distance, and has a certain contribution to the intelligent development for the robot.

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