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Global path planning approach based on ant colony optimization algorithm

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Abstract: Ant colony optimization (ACO) algorithm was modified to optimize the global path. In order to simulate the real ant colonies, according to the foraging behavior of ant colonies and the characteristic of food, conceptions of neighboring area and smell area were presented. The former can ensure the diversity of paths and the latter ensures that each ant can reach the goal. Then the whole path was divided into three parts and ACO was used to search the second part path. When the three parts pathes were adjusted, the final path was found. The valid path and invalid path were defined to ensure the path valid. Finally, the strategies of the pheromone search were applied to search the optimum path. However, when only the pheromone was used to search the optimum path, ACO converges easily. In order to avoid this premature convergence, combining pheromone search and random search, a hybrid ant colony algorithm(HACO) was used to find the optimum path. The comparison between ACO and HACO shows that HACO can be used to find the shortest path.

Key words: mobile robot; ant colony optimization; global path planning; pheromone
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1 INTRODUCTION

Path planning algorithm is important for control and navigation of robot. Path planning on mobile robot means that an optimum path from the starting position to terminal point is found for robot to pass through the barrier area safely without collision in barrier environment. Currently, path-planning algorithm can be roughly categorized by local path planning approach and global path planning approach. For the former such as artificial potential field, less known information is needed in local environment and the environment is varied but it is easy to fall into local minimum. However, for the latter such as geometrical method, more known information is needed and the environment is definite. Moreover, the global map of environment is required. Recently, many intelligent path-planning approaches such as path planning evolution algorithm and genetic algorithm have been presented to optimize the path, but the computing cost of these approaches is too high and it is difficult to form the feasible solution and to design the evolution operators or genetic operators in complicated environment. Many researchers[1−7] overcome these defects by introducing ant colony optimization (ACO) algorithm. But there are some troubles for ant colony algorithm to solve some path-planning problem in complex environment. In this paper, ant colony optimization algorithm is modified to optimize the global path. In order to simulate the real ant colonies, according to the foraging behavior of ant colonies and the characteristic of food, conceptions of neighboring area and smell area are presented and the valid path and invalid path were defined, then the strategies of the pheromone search were applied to search the optimum path. However, when only the pheromone is used to search the optimum path, ACO is easy to early converge to a path and will not always find the shortest path. In order to avoid this premature convergence, combining pheromone search and random search, a hybrid ant colony algorithm was used to find the optimum path. The simulation experiment shows that this approach is valid.

2 RESEARCH BACKGROUND

2.1 Brief introduction of ACO

Biologists find that the ants in natural world possess some self-organizing characteristics in the process of looking for food, for example: 1) the ants will release a substance called pheromone, 2) these pheromone will decrease gradually, 3) the ants can find out if the same kind of pheromone exists in a certain scope and can move along the path which has more pheromone. Owing

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to these characteristics, the ants can find the shortest route from nest to food. Refs.[8−9] use the symmetry double bridge experiment and non-symmetry double bridge experiment to show it, respectively. Furthermore, the ant colony possesses better ability to adapt them to the environment around them. Fig.1 shows that the ants can find the optimum route again quickly when a barrier suddenly appears in the path they pass[10].

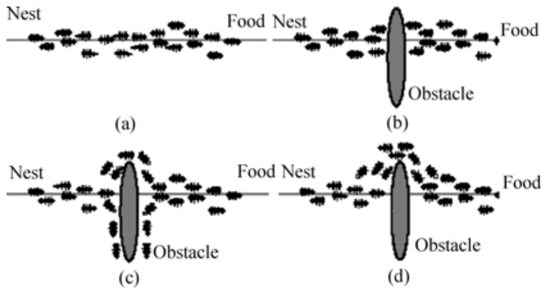

Fig.1 Self-adaptive behavior of ant colony
(a) Real ants follow a path between nest and food source;
(b) An obstacle appears on the path: ants choose whether to turn left or right with equal probability;
(c) Pheromone is deposited more quickly on shorter path;
(d) All ants have chosen shorter path

This behavior inspires many scientists and in 1990s, Dorigo et al[11] presented ACO that simulates the behavior characteristics of real ant colonies. Although this algorithm has been brought forward for only ten years, more and more scholars pay attentions to it, which is also used to solve many problems such as traveling salesman problem (TSP)[12]. There is currently much ongoing activity in the scientific community to extend and apply ant-based algorithm to many different discrete optimization problems.

2.2 Our ideas

The founder of ACO, Dorigo et al[13] summarized the application of ACO which involved the traveling salesman, quadratic assignment, job-shop scheduling, vehicle routing, scheduling problems, sequential ordering, and graph coloring, etc. In fact the problem about the robot path planning is very similar to the foraging behavior of ants, so the robot path planning can be regarded as follows: the ants look for their food across the barrier area. As long as the amount of ants is large enough, these ants stand to avoid the barrier and find optimum route to the food. Fig.1 is a typical example. Many foreign researches focused on simulating the way of communications and cooperation between ant colonies in multi-robot system[14−15]. Several scholars studied the path-planning problem based on ACO[1−7]. Köse[3] used ACO to solve the problem of how robots walked along the wall. Fan et al[4−5] also carried out researches on ACO for robot path planning, but there are some defects, for example, the starting position is only one and ACO will quickly converge to a path because of the heuristic pheromone. Because there is only one goal in Ref.[4], it is difficult for ants to find the goal. The ants in Ref.[5] crawl from a node on a line to a node on another line and lastly ants can reach the goal, but ants can not move along the line. In Refs.[6−7], the ants are categorized by two groups, which are put on starting position and goal position and choose the next grid according to pheromone, respectively. Only when two ants meet each other, a path will be created. Obviously when the amount of free grids is larger, the probability that two ants encounter each other is smaller. So this approach only adapts to less free grids and the simulation experiments in Refs.[6−7] were also done in such environment. In fact, ACO is initially used to solve TSP, for TSP is a traversing problem in which the ants in a node can traverse any of other nodes according to tabu list. However, for robot path planning, ants traverse only some nodes. But in order to ensure ants move from nest to food, each ant should be put on the different starting position, otherwise the algorithm converges quickly to a path, so the neighboring area is built near nest where there is no barrier in this paper. If an ant is in the neighboring area, it will move towards the food. Then a smell area is built to help ants find the food. If an ant enters into this area, it will find the food along the direction of food. In barrier area the ants do not smell the food for the shelter of barrier and only choose the path according to pheromone. In this way, ants search the path away heuristically from neighboring area to food. If it enters into the smell area, it will find the food along the direction of smell. So the whole path is made up of three parts: 1) path between the nest and initial position of each ant; 2) path between initial position of each ant and the position that ants enter into smell area; 3) path between the position that ants enter into smell area and food.

3 PATH PLANNING THEORY BASED ON ANT COLONY ALGORITHMS

3.1 Environmental modeling

It is supposed that the robot walks in a finite region (map) where there are some static barriers. For the convenience, the robot is regarded as a particle ignoring its size. Meanwhile, the barrier is stretched according to security and the size of robot, so that the borderline of barrier is safe for robots and these barriers do not intersect each other.

In order to depict environmental information, there are three important factors: 1) How to store the information in computer; 2) Convenience for user; 3) Good efficiency in problem solving. In this paper, the two-dimension Cartesian rectangle grid was used to depict the environment. Each grid has a weight, which means the probability of existing barrier. When the weight is 1, it means there is a barrier in this grid; while the weight is 0, there is no barrier and robots can walk freely. The size of grid has serious influence on performance of robot. If the size is small, resolution of environment is high, but the anti-jamming ability is low and a great number of memory units are required, which results in low speed. If the size is large, the case is contrary to the above.

3.2 Neighboring area

Commonly, the ants move around near their nest where there is no barrier and ants can walk freely. Ants in neighboring area can walk autonomously through barrier area towards food. A sector or triangular region is built near nest to depict the neighboring area, which is shown in Figs.2(a) and (b). The method to build neighboring area is as follows: find the shortest distance denoted by d as shown in Fig.2(c) towards food from nest to barriers, and then build the sector or triangular region towards food with the shortest distance as the radius or triangle's height.

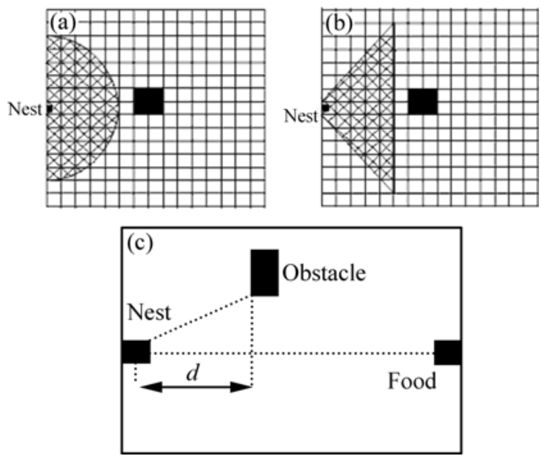

Fig.2 Diagram of neighboring area
(a) Sector region; (b) Triangular region; (c) Method to build neighboring area

3.3 Smell area

Any food has a smell, which attracts ants to move towards it, so the smell area shown in Fig.3 is built. If ants enter into smell area, they will move following the smell, and finally reach the goal. In non-smell area, ants do not smell food for the barrier and only choose path.

The method to build smell area is: scanning the area from food toward nest, and the area before meeting barrier is smell area.

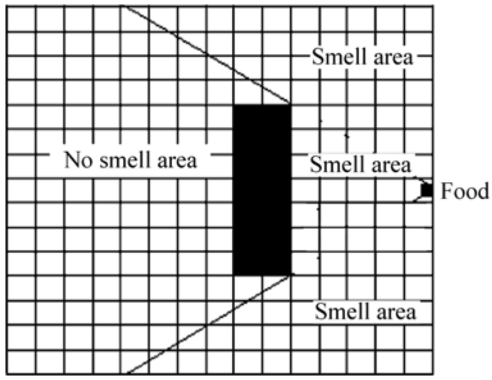

Fig.3 Diagram of smell area and no smell area

3.4 Path structure

The whole path is made up of three parts: 1) path between the nest and initial position of each ant is denoted by the sign "path0"; 2) path between initial position of each ant and the position that ants enter into smell area is denoted by the sign "path1"; 3) path between the position that ants enter into smell area and food is denoted by the sign "path2", as shown in Fig.4. So the whole length of path $L_{\text{path}}=L_{\text{path0}}+L_{\text{path1}}+L_{\text{path2}}$.

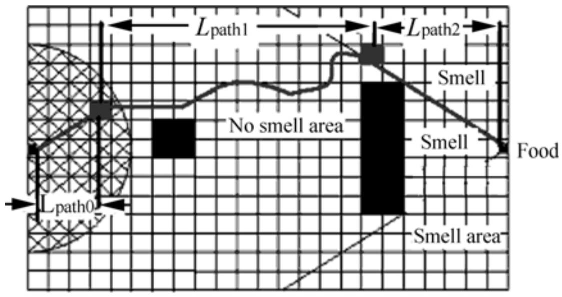

Fig.4 Diagram of path structure

3.5 Adjusting path

The path, which ants pass, is snaky and needs to be adjusted. The method shown in Fig.5 is as follows First find point Q from point S so that the line between S and the point next Q crosses the barrier while the line between Q and S does not cross the barrier, then connects

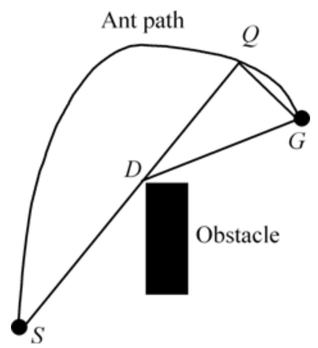

Fig.5 Diagram of adjusting path

Q and S, and finds the point D which is nearest to barrier on QS. The line SD is the part of final path. Lastly let S=D, find the next D until S=G. Lines produced in this way form the real path. Line $\overline{SDG}$ is the final path from S to G in Fig.5. Apparently $\overline{SD}$ is the shortest distance between S and D, and $\overline{DG} < \overline{DQ} + \overline{QG}$, so line $\overline{SDG}$ is the shortest path passing barriers along curve $\overline{SG}$. Assuming the total of grids is N, and the number of grids between initial position and final position is M, the worst case time complexity of this approach is $O(N^2)$ and the best case time complexity is $O(M^2)$.

3.6 Searching path direction

Ants may choose one of three grids denoted by the number 0, 1, and 2 respectively towards the food as shown in Fig.6. Each ant chooses a direction according to the probability to the next grid.

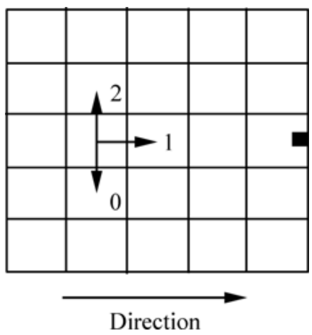

Fig.6 Diagram of choosing path direction

At time t, the probability $p_{ij}^{k}(t)$ that ants move from grid i along j ($j \in \{0,1,2\}$) to the next grid is as follows:

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}(t)]^{\beta}}{\sum\limits_{S \in J_k(i)} [\tau_{ij}(t)]^{\alpha} \cdot [\eta_{ij}(t)]^{\beta}}, & j \in J_k(i) \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

where $J_k(i)$={0,1,2}−tabu_k is the set of all grids that ants may choose, tabu_k is the set of grids that ants walk through just now; α and β denote the importance of pheromone and heuristic factor respectively; η_{ij} is a heuristic factor denoting the anticipant degree that ants move from grid i to j to the next grid. In ant system (AS), η_{ij} is generally the reciprocal of distance between city i and city j. So without loss of generality, supposing η_{ij}=1, there is

$$p_{ij}^{k}(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^{\alpha}}{\sum\limits_{S \in J_k(i)} [\tau_{ij}(t)]^{\alpha}}, & j \in J_k(i) \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

The following is the way for an ant to choose direction: if the probability of each optional direction is equivalent, the ant chooses its direction randomly; otherwise the ant chooses its direction with maximal probability according to Eqn.(2).

3.7 Invalid paths and valid paths

Definition 1 The path along which ants do not reach their goal in limited time is called invalid path.

There are several instances:

1) Ants move out of borderline supposed.

2) Ants move into a dead angle around which there are barriers.

3) Ants may choose a grid in some directions but ants have passed it or there is a barrier in it.

4) The length of path exceeds the maximum length.

Definition 2 The path along which ants can reach their goal in limited time is called valid path.

It can be concluded that the path, which an ant passes if it enters into smell area, is valid path as shown in Fig.4.

3.8 Adjusting pheromone

According to the above, an ant moves along one of the three directions to the next grid, so there are three pheromones in each grid. Each pheromone is adjusted according to Eqn.(3).

$$\tau_{ij}(t+n) = \rho \tau_{ij}(t) + \Delta \tau_{ij} \tag{3}$$

$$\Delta \tau_{ij} = \sum_{k=1}^{m} \Delta \tau_{ij}^{k} \tag{4}$$

where $\Delta\tau_{ij}$ denotes the increment of pheromones from grid i along j($j \in \{0,1,2\}$) to the next grid in current iteration; $\Delta\tau_{ij}^{k}$ denotes the quantity of pheromones of kth ant from grid i along j; ρ is the remnant of pheromone in a path after volatilization. Here ρ=0.9. If kth ant does not pass grid i along j to the next grid, $\Delta\tau_{ij}^{k}$=0. $\Delta\tau_{ij}^{k}$ is expressed as follows:

$$\Delta \tau_{ij}^{k} = \begin{cases} \dfrac{P}{L_k}, & \text{if } k\text{th ant pass grid } i \text{ to direction } j \\ 0, & \text{otherwise} \end{cases} \tag{5}$$

where P is positive constant; L_k is the length of path after adjusting in current iteration.

3.9 Algorithm

The path planning based on ACO(PPACO) is as follows:

Step 1 Environmental modeling.

Step 2 Neighboring area and smell area are set up.

Step 3 Some ants are placed in neighboring area.

Step 4 Each ant chooses next grid.

Step 5 If an ant brings about an invalid path, it will be deleted, otherwise repeats Step 4 until each ant reaches the terminal.

Step 6 The valid paths are adjusted and the optimum path is saved.

Step 7 The pheromones on valid path are modify.

Repeat Steps 3, 4, 5, 6, and 7 until this algorithm reaches supposed iterative times or exceeds maximum execution time.

4 SIMULATION EXPERIMENT

Fig.7 shows the experimental environment, which is 450×300, and the size of grid is 2×2. The grid is not displayed in Fig.7. The ants are placed simply on a side of triangle area but not in a sector or triangle area. Smell area is the gray area shown in Fig.7. Here α=140°, β=140°. N_{ant} is the number of ant. It is supposed N_{ant}=10 and the iterative times is 20. The experimental results are shown in Fig.8. Grey snaky lines are the paths(invalid paths and valid paths) that ants pass when they pass barrier area (The paths in smell area are not shown in Fig.8). Curve from A to B is the final path.

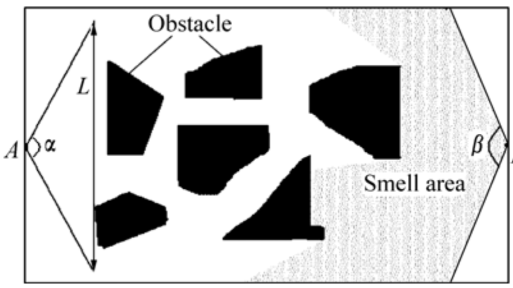

Fig.7 Experimental environment

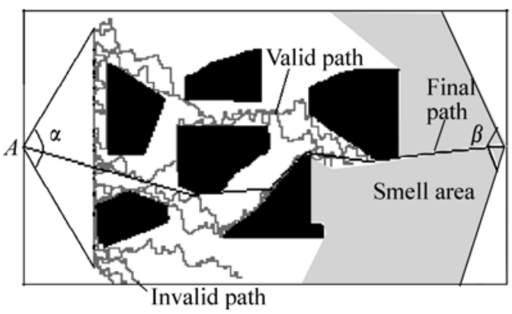

Fig.8 Result of experiment

But there are some problems. Fig.9 denotes the convergent process when N_{ant}=5, N_{ant}=10 and iterative times are 40. When N_{ant}=10, the algorithm converge to a path in iterative 10 times; it converges to a path in iterative 20 times as N_{ant}=10. Moreover, the path is not the shortest. The defect of ACO can be concluded, that is, it converges to a path easily.

In order to avoid precocity and stagnation, according to the strategies of pheromone search and random search, the hybrid ant colony optimization algorithm (HACO) is used. Namely some ants search optimum path according to PPACO, while the other ants search optimum path according to PPACO which is modified only in Step 4(MPPACO). The modified Step 4 is that each ant chooses the next grid randomly. The convergent process of the hybrid ant colony algorithm is shown in Fig.10. Curve 1 denotes HACO in which three ants use PPACO and two ants use MPPACO; curve 2 denotes HACO in which five ants use PPACO and five ants use MPPACO.

Fig.10 shows that curves 1 and 2 converge to a path after iterating 35 times and 26 times, respectively, and the final path is the shortest as shown in Table 1. So HACO can be used to avoid the premature convergence

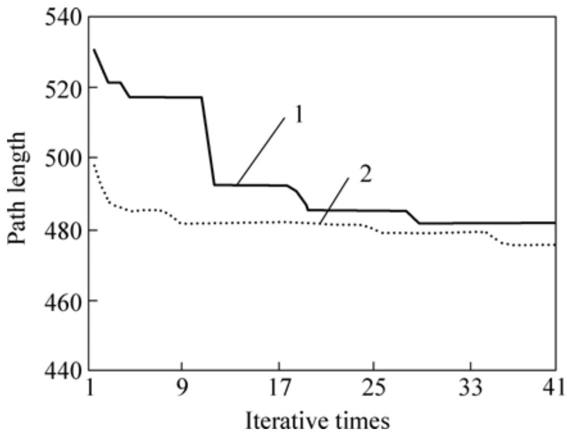

Fig.9 Convergence of PPACO

N_{ant}: 1—5; 2—10

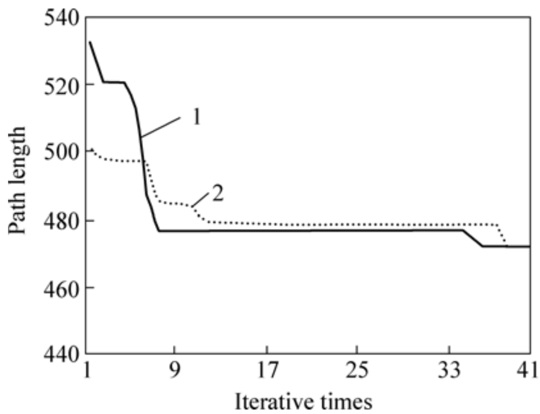

Fig.10 Convergence of HACO

Table 1 Comparison between PPACO and HACO

Algorithm	N_{ant}	
	5	10
PPACO	482	476
HACO	472	472

to some extent and its result is closer to the global optimum solution. The main reason is that ACO finds a local optimum path easily according to the heurist pheromone. However, HACO combines random choice and Heurist seek to search for the shortest path. When the Heurist seeks converge to a path, the random choice approach can find shorter paths, so the approach can avoid precocity and stagnation.

5 CONCLUSIONS

1) ACO was introduced to optimize the global path in complex environment. Neighboring area and smell area were presented to simulate the foraging behavior of real ant colonies, and the valid path and invalid path were presented to ensure path correct, then ACO was found to be easy to converge.

2) Combining pheromone search and random search, HACO was used in path planning to avoid precocity and stagnation.

3) The simulation experiment results show that this approach is valid.

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