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Research on Optimal Planning Method of USV for Complex Obstacles

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Abstract –**In this thesis, based on the selected intelligent optimization algorithm - ant colony algorithm, introduced its system and its typical applications are analyzed through operational focus and discussion method algorithm. The main structure of the paper can be divided into two parts: the typical obstacles modeling and the use of global path planning ant colony algorithm. In part modeling, the use of the grid method view and draw use MATLAB model for global planning. In the global planning, the use of MATLAB simulation of the optimal path planning** of **USV facing typical obstacles, to achieve the desired objectives.**

Index Terms - USV. Obstacles modelling. Ant colony optimization algorithm intelligence. Route optimization.

I. Introduction

As autonomous marine vessels, the true meaning of USV autonomy is the ability to interact with the external environment. One important aspect of it is reflected in the ability to interact with global path planning capability. To achieve USV in the water sailing, autonomous path planning is an important part [1].

Path planning refers to search an optimal or a sub-optimal path from the starting position to the target position in the environment [2]. Route planning has two key technologies are environmental modelling and planning algorithms. Environmental modelling is the first problem to be solved in USV route planning, because any kind of planning algorithms are corresponding with specific modelling techniques. A reasonable model of the environment can help to reduce the amount of search and time-space occupancy [3]. USV route planning environmental modelling methods is commonly used in the grid method, the geometry of space law, topological method and the electronic chart and so on. The main consideration in environmental modelling is the environmental data storage, query and update. Features of grid method are simple, easy to implement, can be applied to different algorithms, having the ability to express an irregular obstacle. USV route planning algorithms commonly includes two ways: conventional planning methods and intelligent planning. Traditional methods include: artificial potential field method, dynamic planning, A* method, D* method and so on. Intelligent planning methods include: genetic algorithm, colony algorithm, particle swarm algorithm, neural networks and fuzzy logic algorithms [4]. Furthermore, it is a mixed planning method to combine traditional planning and intelligent planning method. The accuracy of the global path planning method depends on getting the accuracy of environmental information. It can usually get the optimal solution, but that need to predict the precise global environmental information. In essence, the global planning is a constrained optimization problem. In general, when the USV completes a given task, it can choose many pieces of the path, but in practical applications tend to choose a given criterion for the optimal (or near optimal) path. General guidelines are: the shortest path, minimum energy consumption or using the shortest time and so on.

II. Usv Motion Model And Environmental Modeling

A. USV motion model

USV's three degrees of freedom planar motion model can be divided into two parts: the kinematic model and dynamic model.

Kinematic model are:

$$\dot{\eta} = J(\eta)\upsilon \tag{1}$$

Dynamics model are:

$$M_{\dot{v}} + C(v)v + D(v)v + g(\eta) = \tau + w \tag{2}$$

Where: $J(\eta)$ is coordinating transformation matrix; η is the position state when the ship in the fixed coordinate system; v is the velocity vector of the hull coordinate system; τ is control amount; w is environmental forces; M is the ship inertia matrix which including the additional mass; $C(v)$ is the ship Coriolis centripetal force matrix which including additional mass; $D(v)$ is water damping matrix.

B. USV environmental modeling

Grid method is to use the same size grid to divide the robot working space, and use the grid array to represent the environment, each grid point to one of two states, or in free space, or in the obstacle space. Shown in the figure 1, black cells represent obstacles, marked as 1, white grids represent the free space, marked as 0. The shortest path is obtained by this raster. Specific steps are as follows：

1) Adjacency matrix in mapping

Enter the matrix of 0 and 1 indicates the robot needs to find the optimal route map. Where 0 represents can adopt, 1 represents an obstacle.

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2) A grid method represents the basic operation actions in two-dimensional

Searching algorithm takes the form of a grid, suppose USV stay currently in the node n, so the USV have eight feasible basic movements, there are eight corresponding scalable node, The eight nodes were lettered as: North (N), northeast (EN), east (E), southeast (ES), south (S), southwest (WS), west (W) and northwest (WN).As shown in Fig.1.

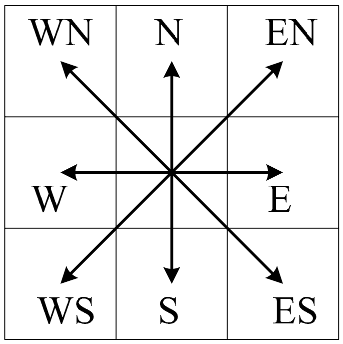

Fig.1 Collection of USV's basic dimensional actions

3) Judging distance criterion

Starting from a certain point, the location which can be reached in one step has obstacle denoted by 0. The location can be reached within a step, calculated its path length with side length as 1.

III. USV GLOBAL OPTIMAL PLANNING BASED ON ANT COLONY ALGORITHM

A. Summary of ant colony algorithm

Ant colony algorithm in the practice of the application, also can be called Intelligent Multi-Agent System [5], which doesn't need to learn all the details of the question, but only needs to consider demanding index effects on the overall environment, it is greatly improving the efficiency of the arithmetic to solve the problem of global path planning. According to the definition and discussion of ants, we can analysis system model to sum up the logical structure of the ant running system, which is shown in Fig.2:

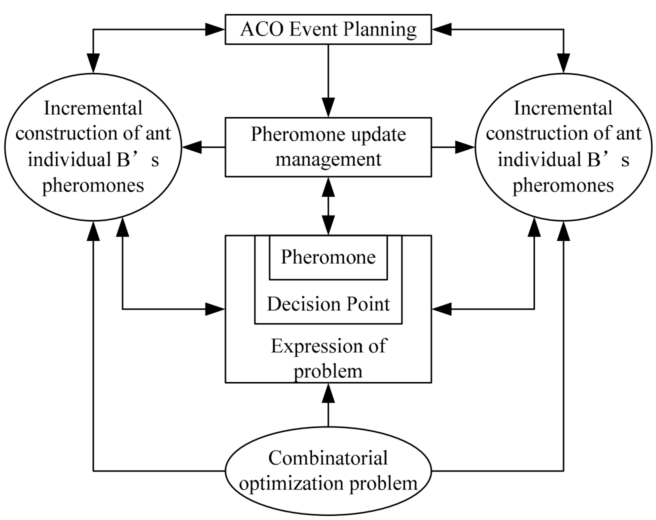

Fig.2 The logical structure of the basic ant colony algorithm

Fig.2 discusses the rules of ACO's activities, pheromone's update management controls the individuals' pheromone releasing concentration of ant colony, and different background set to the issue and set the optimum planning conditions required restrict pheromone's update management degree of the ant colony. Combinatorial optimization problem achieves the desired goal by constantly updating and repeating the complex ant colony pheromone control system.

One typical application of the ant colony algorithm is traveling salesman problem (also known as TSP) [6], that is, going to other locations from one location once and only once, then returning to the original point of departure, and obtain the shortest path through by the algorithm. Ant Colony Algorithm can solve the problem well because it can solve Optimization Selection Problem under complex background.

The basic steps of the ant colony algorithm can be summarized as follows by the example of TSP:

1) Parameter initialization process. Make time and cycle times are 0, and specify the maximum number of cycles. Make directed graph the same amount of initial hormones on each side.

2) Set the number of cycles.

3) Set the ant individuals' taboo table index k.

4) Given the number of ants, k=k+1.

5) Strike next destination randomly selected by the individual ants according to transition probability formula.

6) Change the tabu table pointer, update the digital information of the ant's new location to the tabu table.

7) If all locations have not been arrived, execute step (4), otherwise continue to step (8).

8) Update each route's concentration of pheromone.

9) If the requirements of the problem are satisfied, that the maximum number of cycles is satisfied, and then outputs the calculated results of the proceedings, otherwise the tabu table is reset to blank and skips to step (2).

The index of known problems can be calculated according to those steps after analysing concrete steps of ant colony algorithm, so as to achieve the objectives' requirements and achieve specific optimization metrics. So this analysis step can be used in practical algorithm.

B. USV global path planning based on ACO

Design process of USV's global path planning based on ACO.

1) Symbol Definition

Symbols used in this article are defined as follows:

NC ——the total cycle times;

M ——the number of ants;

τ_{ij} ——pheromone between any two nodes, τ is the pheromone matrix, τ_0 is the initial value of the pheromone;

α ——weight of pheromone;

β ——weight of inspiring information;

ρ ——volatile coefficient;

Q ——increased strength factor of pheromone;

$Allow$ ——each ant's optional target collection of every generation;

$Tabu$ ——each ant's taboo point collection of every generation, that is the collection of arrived nodes.

2) Planning objectives

For obstacle environment that only has obstacles, USV global planning's target is taken as the shortest route:

$$J = L_{\min} \tag{3}$$

3) Adjacency matrix

For any two nodes on the global map, $Point_i$ and $Point_j$, adjacency matrix is the cost of sailing between any two nodes, it can be represented by D_{ij}, linear distance between any two nodes represents the cost of sailing:

$$D_{ie} = \sqrt{\|Point_i - Point_j\|} \tag{4}$$

Note that: the distance between obstacles node and other nodes is 0, which means impassable.

4) Heuristic information

For any point in the global map defined as $Point_i$, $Point_j$ is the goal of USV global path planning, So $Point_i$'s heuristic information is represented as distance of the linear straight line from $Point_i$ to the target point $Point_e$. It can be calculated as follows:

$$\eta_i = 1/\sqrt{\|Point_e - Point_i\|} \tag{5}$$

Heuristic information of each point is the countdown of a straight line from each point to the target point.

5) State transition rule

For the state transition rule of ants, this paper uses the roulette method. Set an ant of a certain generation at point i currently, and point j is an arbitrary point that the ant can go next step, so according to the pheromone of each node, the probability of reaching each node can be calculated as follows:

$$p_{ij}^k(t) = \begin{cases} \dfrac{[\tau_{ij}(t)]^\alpha \cdot [\eta_j]^\beta}{\sum\limits_{k \in \{N - tabu_k\}} [\tau_{ij}(t)]^\alpha \cdot [\eta_j]^\beta}, \text{if } j \in \{N - tabu_k\} \\ 0 \qquad\qquad , \quad \text{otherwise} \end{cases} \tag{6}$$

Among them, point i is the point where USV currently is; point j is the next point USV may reach; τ_{ij} is the pheromone concentration of point i, j. η_j is heuristic information of point j. α is weight parameters of pheromone importance, β is the weight parameter of importance for heuristic information.

After the node's probability is obtained, in accordance with the roulette method, the node next step to go is determined.

6) Pheromone update rule

After an ant in a generation completes a round of searching, update pheromone matrix, and ants that did not reach the target point are not counted. Pheromone updating method is as follows:

$$\tau_{ij}(t+1) = (1-\rho)\cdot\tau_{ij}(t) + \Delta\tau_{ij}$$

$$\Delta\tau_{ij}(t) = \begin{cases} \dfrac{Q}{L_k(t)}, & \text{if ant k reachs point i, j} \\ 0, \text{if ant k doesn't reachs point i, j} \end{cases} \tag{7}$$

Among them, ρ is the pheromone evaporation rate. Q is the information increasing strength. $L_k(t)$ is the path length this ant of this generation has passed when it reached the target point traversed.

7) Steps of the algorithm

a) Enter the initial pheromone matrix, in this paper, the initial pheromone of all locations is uniform, initial pheromone of all positions is equal. Assigns it as a small integer, select the initial point and end point then set various parameters.

b) Calculate collection $Allow$ of points for ants' optional target, according to pheromones of each point, the probability of each node targeted from $Allow$, and use roulette algorithm select the next point the ant will go, and put the point in the collection of taboo-point which is called $Tabu$.

c) Update path, and the path's length.

d) Repeating step (b) and (c), until ant reaches the end or nowhere to go.

e) Repeating step (b), (c) and (d), until M ants of a generation iterated over.

f) Update the pheromone matrix, the ants which did not reach the goal are not counted.

g) Repeat step (b)-(f), until the ants of the generation NC iterated over.

IV. Simulation

Below this paper using MATLAB software simulates global planning based on ant colony optimization.

Parameters of the simulation are as follows:

NC, the total number of cycles valued 100;

M, the number of ants valued 50;

τ_0, the initial value of the pheromone valued 8;

α, weight of the pheromone valued 1;

β, weight of the inspiring information valued 7;

ρ, evaporation coefficient of the pheromone valued 0.3;

Q, increasing intensity of the pheromones valued 1;

Fig.3 gives the first case of USV global planning simulation's results, where the starting point, target point and the obstacle environment are shown in the figure. As it can be seen in Fig.3, USV planned a route bypassing the entire obstacles region, and finally arrived the target point.

Fig.4 is the simulation's result of each generation's USV global planning path length. The route length of USV's final path is about 2700 meters, and it can be seen that the algorithm converges quickly, after 40 generations, the planning algorithm has converted to a minimum.

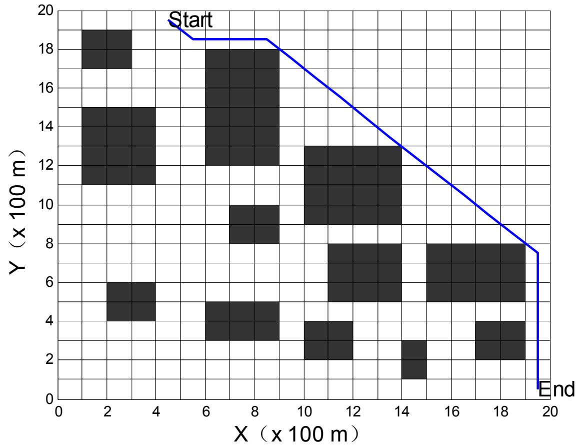

Fig.3 USV global planning with the obstacle environment results

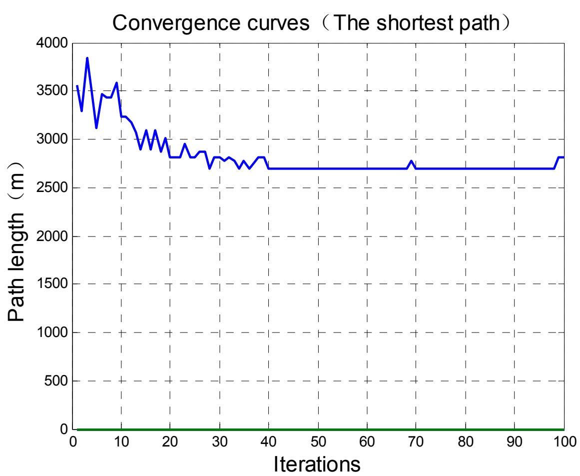

Fig.4 The result of USV every generation path length with obstacle environment

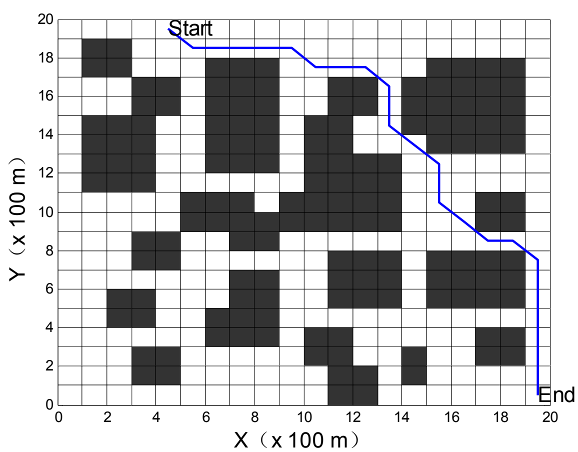

Fig.5 USV global planning with the obstacle environment results

Here is the second simulation case. Fig.5 is the USV global planning simulation results of second case, in which the starting point, target point and the obstacle environment are shown in Figure. From Fig.5, USV planned a route bypassing all the obstacles and finally arrived target point.

From Fig.6, the result of each generation's path length in the second simulation case's USV global planning is shown. The route length of USV's final path is about 3000 meters, and it can be seen that the algorithm also converges quickly. After 40 generations, planning algorithm begins converging, although there are some fluctuations in the converging process, but the overall trend is converging.

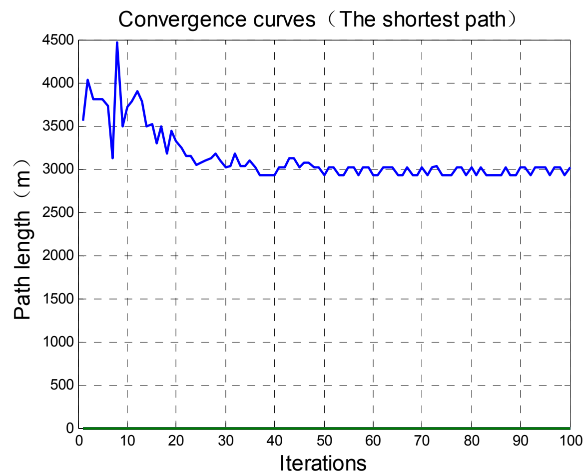

Fig.6 The result of USV every generation path length with obstacle environment

V. Conclusion

This paper started with the optimal control of USV, used grid method modelling typical obstacles, and simulated it with MATLAB. It analysed the significance of the formation of ant colony algorithm, discussed its principles and characteristics of complex objects' choosing. This paper also described the origin of the ant colony algorithm, method of establishing model, and common examples of the algorithm. Finally this paper optimized USV's route in obstacle environment using Ant Colony Algorithm.

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