Navigation Planning of Submarine in 3D Space Based on Space Contraction Ant Colony Algorithm

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***Abstract*—The purpose of the submarine navigation planning is to plan the optimal automatically route from the current point to the specified target location according to the optimization goal of safety, concealment and fast navigation. To improve the stability and efficiency of navigation planning algorithm, this paper proposes a submarine navigation planning algorithm based on space contraction ant colony algorithm and simulates it in MATLAB environment. The results show that the algorithm not only becomes convenient and effective, but also improves the operating speed.**

Keywords-submarine; ant colony algorithm; space contraction; 3D space; navigation planning

I. INTRODUCTION

Submarine navigation planning is one of the key technologies for its automation and intelligent navigation. It is of great significance for the safety, concealment and high efficiency of submarine navigation. There are many intelligent algorithms for studying path planning at home and abroad, but most of them are used in 2D space. At present, the main methods used to solve navigation planning problems in 3D space include genetic algorithm [1], A^* search method [2], artificial virtual potential field method [3], and ant colony algorithm [4]. Although these methods can solve some practical problems, they can't beyond their limitations. The genetic algorithm mainly solves some simple path planning problems in the external environment. But when the external environment conditions become complex, the feasibility of the algorithm will be greatly reduced. The artificial virtual potential field method is easily trapped in the situation of

local minimum, and this method can't be generalized when using complex optimization criteria. Traditional ant colony algorithm is a kind of optimization algorithm, which has the advantages of robustness, good universality, and strong computing power. However, it also has the disadvantages of stagnation and long search time.

Reference [5] using one of the improved ant colony algorithms, that is, the parallel optimization algorithm based on multi-ant colony synergy, greatly improves its stability and search ability. When solving practical engineering problems, the running speed of the algorithm is particularly important. The space contraction ant colony algorithm used in this paper is to reduce part of the optimization ability without affecting the stability, while reducing the size of the solution composition space through certain operations during the operation of the algorithm, thereby reducing the composition contained in each solution. In this way, it can make it possible for the ant to construct a solution that reduces the number of structural steps needed to speed up the algorithm.

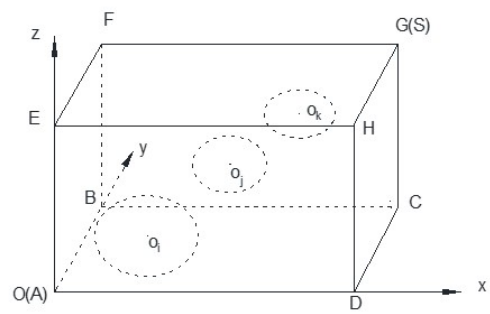

Figure 1. 3D environmental model

II. SUBMARINE 3D SPACE MODELING

The problem of submarine 3D space navigation planning is mainly to consider how to make the submarine navigation safe and the driving path shortest. As shown in Fig. 1, in Cartesian coordinate system O-XYZ, O(A) is taken as the starting point and G(S) is the end point. And a regular geometry is constructed as the submarine simulation work space. Among them, o_i, o_j and o_k are obstacles. In order to facilitate the study of the abstract path planning of the model, coordinate transformation is needed. The coordinate system o-xyz is converted to another one. In the new one, O(A) is taken as the origin point, and AG direction is the positive direction of Z' axis, and h (h is the length of A to G) is taken as the step to make a plane perpendicular to the Z' axis. X' axis and Y' axis can be selected appropriately. The transformation relationship between the coordinate system O-X'Y'Z' and O-XYZ is:

$$\begin{pmatrix} x+h \\ y+h \\ z \end{pmatrix} = \begin{pmatrix} \cos\alpha_x & \cos\alpha_y & \cos\alpha_z \\ \cos\beta_x & \cos\beta_y & \cos\beta_z \\ \cos\gamma_x & \cos\gamma_y & \cos\gamma_z \end{pmatrix} \begin{pmatrix} x' \\ y' \\ z' \end{pmatrix} \quad (1)$$

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In equation (1), α_x, α_y and α_z are the angles between the X axis and the x' axis, the y' axis, and the z' axis, respectively. β_x, β_y and β_z are the angles between the Y axis and the x' axis, the y' axis, and the z' axis, respectively. γ_x, γ_y, and γ_z are the angles between the Z axis and the x' axis, the y' axis, and the z' axis, respectively.

III. Design of Space Contraction Ant Colony Optimization Algorithm

The space contraction ant colony optimization algorithm uses the standard ACS (Ant Colony System) algorithm as its basic framework. Based on this, the main design adds a space contraction transformation operation. Now it gives several definitions as follows.

A. Basic building block

When the scale is n, the composition of the solution to this problem is C = {c_1, c_2, c_3, ……, c_n}, where c_i (i = 1, 2, 3, n) is the basic component. The solution to each problem is composed of connections between n basic components c_ic_j ($i \neq j$), that is, c_ic_j constitutes the smallest part of the solution. We call it the basic building block of the solution, or simply, the building block. $V = \{c_ic_j \mid c_i \in C, c_j \in C \text{ and } c_i \neq c_j\}$ is called a building block set. There are $n \times (n-1)$ building blocks in building block set V.

B. Extended building block

The combination of several basic building blocks constitutes an extended building block. For example, the basic building blocks c_ic_j, c_jc_k, c_kc_l ($i \neq j \neq k \neq l$) may constitute an extended building block c_ic_l. After the basic building block is used to construct the extended building block, the component set C of the original solution needs to be adjusted to obtain a new set of components of the solution $\bar{C}$, and a new building block set $\bar{V}$ is obtained at the same time. For instance, for the example given earlier, the number of elements in the updated collection $\bar{C}$ is (n-2), and will not contain the basic components c_j and c_k as compared with the original set C. The scale of the new building block set $\bar{V}$ is $(n-2) \times (n-3)$.

C. Distance of the building block

$d(c_i, c_j) = |c_ic_j|$ is called the distance of the building block c_ic_j.

D. The building block weight

In the building block set V, each building block c_ic_j ($i \neq j$) corresponds to a weight, called building block weight, denoted as $w_{c_ic_j}$. The calculation method of the building block weight $w_{c_ic_j}$ differs depending on the state transition strategy of the ant colony algorithm. For AS (ant system) algorithm using a random scaling rule as a state transition strategy, the building block weight $w_{c_ic_j}$ is taken as $\tau_{ij}^{\alpha}\eta_{ij}^{\beta}$.

The process of using ant colony algorithm to solve discrete domain optimization problem can be regarded as the process of selecting and combining blocks according to their respective weight value and a certain transfer strategy. The idea of the space contraction transformation method designed in this paper is to set a weight threshold w^*, and the algorithm updates the building block weight after each run (implicit pheromone update). After the algorithm runs a certain number of times, all the building block weights will be compared with the weight threshold w^*, and all the building blocks corresponding to these whose weights are greater than the weight threshold w^* will be reassembled so that the basic building blocks are combined to extended building block. To rebuild a new solution component set $\bar{C}$, the number of elements in the set decreases, and the dimension of its corresponding building block set $\bar{V}$ decreases, and the algorithm continues constructing the solution in a contracted space. Repeat until the stop condition is satisfied. The algorithm flow is shown in Fig. 2.

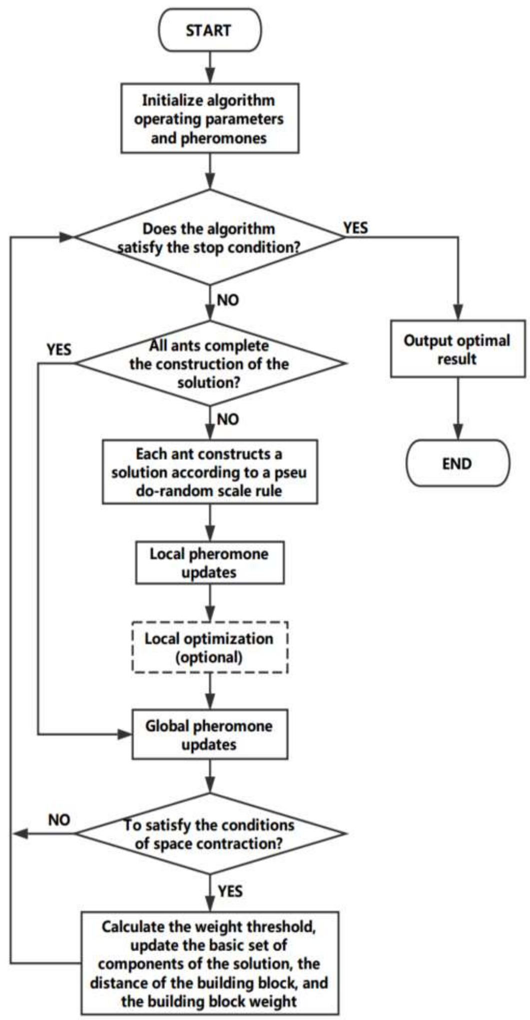

Figure 2. Flow chart of space contraction ant colony optimization algorithm

The submarine 3D space navigation planning studied in this paper uses the method of nodes represent the pheromone, which is to store the pheromone on discrete points in the 3D environment model. Any binary group <p, state> in the abstract environment model will correspond to a pheromone value, and the size of the pheromone value represents how much the discrete point attracts ants. On one hand, this method reduces the space complexity of the algorithm; on the other hand, it can also set the size of pheromone value on different feasible points to distinguish different regions.

1) Local pheromone updates

$$\tau_{ijk} = (1-\xi)\cdot\tau_{ijk} + \xi\cdot\tau_0 \tag{2}$$

In this equation, ξ (0< ξ <1) is a parameter and τ_0 is the initial value of pheromone.

2) Global pheromone updates

$$f_{eval}(m) = \sum_{i=1}^{n+1} L_m(i) \tag{3}$$

In this equation, A is the evaluation function value of the path taken by the m-th ant, and B is the length of the i-th path segment in the path taken by the m-th ant.

$$\tau_{ijk} = (1-\rho)\cdot\tau_{ijk} + \rho\Delta\tau_{ijk} \tag{4}$$

$$\Delta\tau_{ijk} = \frac{1}{f_{eval}^{*}} \tag{5}$$

Among them, ρ (0< ρ <1) is the pheromone evaporation factor and f_{eval}^{*} is the evaluation function value of the path taken by elite ants.

IV. Simulation Experiment

To verify the performance of the improved ant colony algorithm in this paper, MATLAB was used for simulation experiments. In this paper, a certain sea area in the South China Sea is selected as the area for submarine path planning research, and the study area is determined to be 119°-123° East longitude and 19.7°-22.1° North latitude. Simulation experiments are based on seafloor related data provided by electronic charts. In the experiment, the starting point of the submarine is 120.145° East longitude, 19.784° North latitude, -1950m depth; the end position is 120.563° East, 21.934° North, and -860m depth. The parameters of the ant colony algorithm are shown in Table 1.

The results of the 3D navigation path planning are shown in Fig. 3. From the figure, we can see that the route obtained by the simulation avoids obstacles effectively and it is as short as possible.

TABLE I. PARAMETER SETTINGS

Numble of ants	τ_0	q_0	ξ	ρ	Weight threshold w^*
30	3.17×10^{-6}	0.65	0.16	0.16	$0.96\cdot\tau_{max}^{*}$

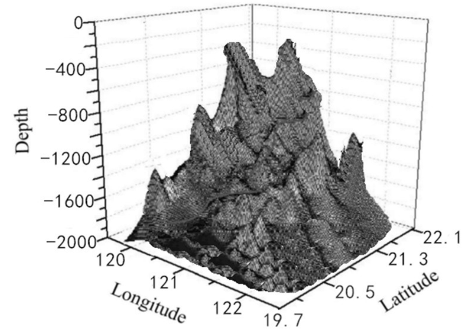

Figure 3. 3D navigation path planning

V. Conclusion

The improved ant colony algorithm is used to study the submarine 3D space path planning problem. Meanwhile, the 3D space environment modeling method as well as the path planning algorithm are designed in detail, and the specific flow of the algorithm is given in the paper. The simulation results show that the improved ant colony algorithm used in this paper can solve the submarine navigation path planning problem effectively, and the operation speed is improved at the same time.

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