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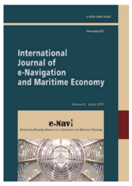

Original article

Design of Marine Search and Rescue Route Based on an Ant Colony System Algorithm

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Abstract

With the development of the global marine transportation industry, marine accidents frequently occur due to the complex and changeable climate environment, and maritime search and rescue work has thus received much attention. To improve marine search and rescue operations, an algorithm for environmental modeling and search path optimization based on an ant colony system is proposed. First, MAKLINK is selected to build an ecological model. Secondly, the relevant parameters of the ant colony system algorithm are established, and the search and rescue route is designed. Finally, simulations of the environmental model and route design are constructed in search and rescue waters in Zhoushan, Zhejiang Province, using MATLAB. Experimental results prove the validity of this algorithm.

Keywords: Ant colony system algorithm, Search and rescue route, MAKLINK

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1. Introduction

With the rapid development of marine transportation, marine activities have become more frequent, and the number of water traffic hazards and accidents is increasing, which brings new challenges to maritime rescue work. The search and rescue of casualties is a significant part of the marine security work that plays an essential role in the emergency management systems and ensures the safety of maritime activities When accidents happen, the capacity of the maritime searching routes is helpful to improve the success rate of marine rescue. Moreover, the emergency response speed, search and rescue ship speed, wind, waves, types of search and rescue ships, and rescue route path are affecting the time of the search and rescue operation. Thus, the planning of a rescue route has a significant impact on the efficiency of guiding rescue ships. An optimal search and rescue route scheme can significantly shorten the voyage, reduce the time.

2. Literature Review

At the present stage, the research on rescue path planning is mainly focused on the route planning of land robots, which is representative of the path planning through the intelligent algorithm. Scholars have chosen many different algorithms for path planning.

In the research of Tan (2007), a novel method for the real-time globally optimal path planning of mobile robots was proposed based on the ant colony system algorithm. Dramski (2012) discussed the differences between two path routing algorithms. Dijkstra algorithm and simplified ant colony optimization were used to search optimal routes for ships in restricted waters in simple static navigation situations.

Then, Chang Hui Song (2014) improved an ant colony algorithm based on the grid environment model for the global path planning method. The main idea of this improved ant colony algorithm was distributing each ant route dynamically. This method costs less time, and the path is smooth. Agnieszka (2014) proposed a new path planning method to design the dynamic environment through the ant colony algorithm. A concise description of the developed approach and the results of real navigation situations were included. The best path was found in the barrier-free environment. The static obstacles were added and the optimal path was recalculate to realize the planning inspired by providing new ideas for modeling methods.

To solve the problems of multi-objective ship routing optimization considering the weather, Zhang (2021) proposed a novel intelligent and compelling ant colony optimization algorithm considering the factors of safety, energy and time. While Dong (2021) addressed a novel double ant colony algorithm for planning ship routing in complex marine environments, which is accurate and efficient. The lowest energy consumption route was introduced as application with good performance.

Based on the experience from previous studies, experts and scholars have conducted a lot of researches to optimize route planning. However, the existing path planning studies are based on general navigation application scenarios, while the adaptability of rescue scenarios is not considered. This paper studies the maritime search and rescue routes to solve the practical problems encountered in the marine search and rescue. The search and rescue route is designed based on the ant colony algorithm and MAKLINK. The water environment model is established, and the ant colony algorithm is used for the purpose of reducing the time of search and rescue and improving the traditional route design method.

3. Design of Marine Search and Rescue Route Based on Ant Colony Algorithm

3.1 Environmental Modeling of Search and Route Design Based on Ant Colony Algorithm

3.1.1 Main steps for search and rescue environmental modeling

(1) The space scale of the sea area is set up, and the environmental boundary is given as：

$$O_i = \{(x_1, y_1), (x_2, y_2), ..., (x_n, y_n)\}, i = 1, ..., m, n \geq 3 \quad (1)$$

(2) The expansion of processing is used to deal with obstacles such as islands, shallow water zones, no navigation zones, which are transformed into convex polygonal obstacles and represented by coordinates. While collision avoidance space is reserved.

(3) Link the vertices of a convex polygon, or connect the vertices to the space boundary, and each obstacle should be greater than or equal to two.

(4) Check linked line segments and eliminate unqualified line segments, such as lines that intersect convex polygons boundaries, and clips exceeding 180 degrees from convex polygon boundaries. The water environment MAKLINK can be formed.

(5) The mathematical description of the water environment link map generates a mathematical expression map of the water environment.

3.1.2 Establishment of the search and rescue water area environment

Mathematics is described as follows:

After processing, the state space is obtained. All nodes of the global path are noted using the set A, $g \in A$ which is any node represented by coordinates (x, y). $OS = \{M_1, M_2, M_3, ..., M_n\}$ is not navigable and consists of islands and prohibited navigation zones. Viable area is represented by $FS = \{W_1, W_2, W_3, ..., W_n\}$ which is freely navigable. S is the starting point of the search and rescue ship and T is the place of the accident. Search and rescue routes can be represented as a sequence of path points in the set, after the sequence is connected as $P_0, P_1, P_2, P_3, ..., P_n$ .Thus, the environment model is obtained and shown in figure 1.

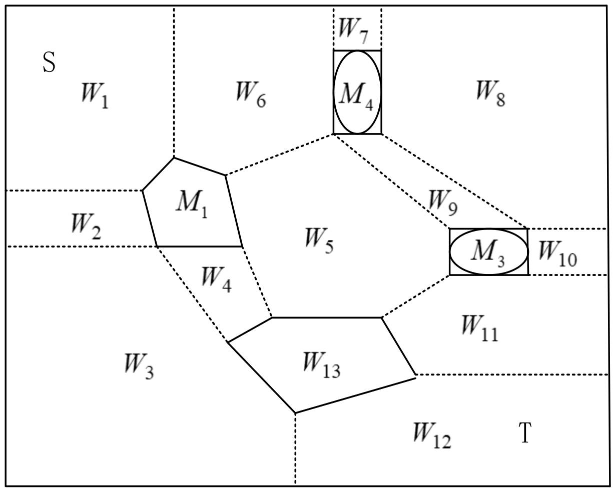

Figure 1: The expression of water environment

3.2 Design of Search and Rescue Route Based on Ant Colony Algorithm

3.2.1 Description of the relevant definitions and symbols

Definition and expression of the main parameters are shown as:

(1) $A = \{1, 2, 3, ..., k, ..., m\}$ is a set of all ants in the ant

colony algorithm, k ∈ A is an ant, m represents the size of the ant size; T_{ij} represents pheromones between node g_i and node g_j.

(2) There are r pathes from a node k to $i_1, i_2, i_3, ..., i_r$, $a_1, a_2, a_3, ..., a_r$ ants are through the r path in the last iteration. The node clustering is given as

$$sta(i) = \sqrt{\sum_{i=1}^{r}(\frac{m}{r} - a_1)^2} \tag{2}$$

(3) To improve the speed of finding ants and avoid local optimization, the number of alternative paths w is determined according to the node i.

$$w = \left[\frac{sta(i)}{\max sta(i)}(r-1) + 0.5\right] + 1 \tag{3}$$

(4) Status Transfer Rule

At moment, t ant k is in a certain condition g_i ∈ A ants at this time k set of subsequent nodes for the $A_k(t)$, select any point g_i ∈ $A_k(t)$ the probabilistic formula is :

$$p_{ij}^{k}(t) = \frac{\zeta_{ij}[\tau_{ij}(t)]^{\alpha} * [\eta_{ij}(t)]^{\beta}}{\sum_{r \in A_k} \zeta_{ij}[\tau_{ir}(t)]^{\alpha} * [\eta_{ir}(t)]^{\beta}} \tag{4}$$

α is pheromone importance, β is importance of heuristic function, ζ is information weight, otherwise, the probability formula value is 0.

(5) Local pheromone update

Local pheromone update rule formula is as follows :

$$\tau_{ij}(t+1) = \begin{cases} \tau_{ij}(t) - 5/d_{iend} & \text{m / 3 select the same path or m/2 select the path} \\ \tau_{ij}(t) + 1/d_{iend} & \text{otherwise} \end{cases} \tag{5}$$

τ_{ij} is a pheromone of the i to the j node , d_{iend} is the distance from the i to the end point.

(6) Global pheromone update

The global pheromone update rule formula is as follows :

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \sum_{i=1}^{m}\psi_i \tau_{ij}^{\ t}(t) \tag{6}$$

$$\Delta\tau_{ij}(t) = \sum_{k=1}^{m}\Delta\tau^{k}_{\ ij} \tag{7}$$

If an edge (i, j) exists on the path $x^k(t)$, make th e

$$\Delta\tau_{ij}(t) = \frac{Q}{f(x^k(t))} \tag{8}$$

3.2.2 Determine the route cost function

We evaluate the advantages and disadvantages of search and rescue routes through the voyage, smoothness and the turning angle of search and rescue ships.

(1) Voyage

Set a search and rescue route has n nodes, then there is a path n - 1 section, the sum of the length is the search and rescue voyage, namely:

$$dist(x) = \sum_{i=1}^{n-1} d_i \tag{9}$$

(2) Evenness

Evenness refers to the deviation Angle of the search and rescue route at each path point. The harmony of the deviation Angle of all path points is the smoothness of the search and rescue route. The smaller the total deviation angle, the smoother the search and rescue route, and the formula is

$$smooth(x) = \sum_{i=2}^{n-1} \theta_i \tag{10}$$

(3) Ship turning angle

Due to dynamic factors, the turning angle of a point should not be too large. If the path has multiple turning points of more than 90 degrees, then it is not the optimal search and rescue path. M represents the number of turning corners. Combined with three factors, the cost function of the route is：

$$f(x) = \omega_1 dist(x) + \omega_2 smooth(x) + \omega_3 M_\theta * 10 \tag{11}$$

where $\omega_1, \omega_2, \omega_3$ have $\omega_1 + \omega_2 + \omega_3 = 1$.

3.2.3 Search and rescue air route design process

The design flow chart of search and rescue route based on ant colony algorithm is as follows:

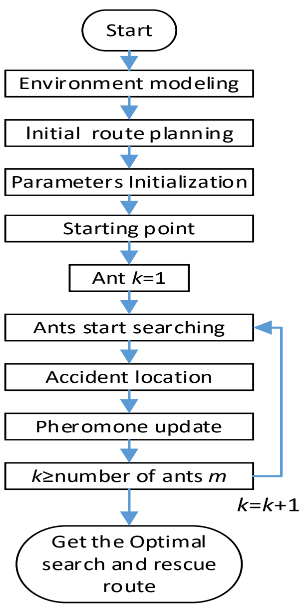

Figure 2: Flow chart of search and rescue route design

The specific steps are as follows:

(1) Establishment of the environmental model of the search and rescue water area

The search and rescue water environment model is constructed through the modeling method.

(2) Algorithm parameter initialization

The total number of ants is m, the initial pheromone is tij(0)=t0 , t0 is a constant. LOPT[*] is an empty array. The optimal path will be stored in LOPT[*]. m random initial solution is generated, and the route through (i,j) has s initial solutions. Their total cost is respectively $f^1,f^2,f^3, \cdots f^s$, then the initial information of path (i,j) is:

$$\tau_{ij}(0) = \sum_{k=1}^{s} \frac{Q}{f^k} \tag{12}$$

4. Simulation experiment and the results

4.1 Simulation environment

The search and rescue water environment model required for simulation is constructed. The specific methods and contents are as follows.

Water area environmental parameters and the coordinate map of 200× 200km are set. The starting point S (search and rescue center) and destination (accident) T are (20,180) and (160,90). Based on the projection of the search and rescue sea environment around Zhoushan, Zhejiang Province, the composition is expressed as four islands.

Search and rescue water environment model, as shown below:

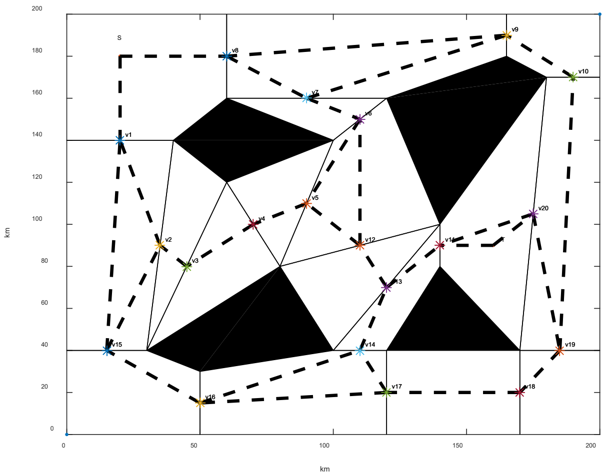

Figure 3: Undirected network diagram

4.2 Simulation results and its analysis

In the simulation experiment, we first used Dijkstra to plan an initial search and rescue route from the starting point to the accident site, and then optimize the search and rescue route through the ant colony algorithm, and finally get the optimal maritime search and rescue route. After the program operation, the resulting search and rescue routes are shown in the following figure:

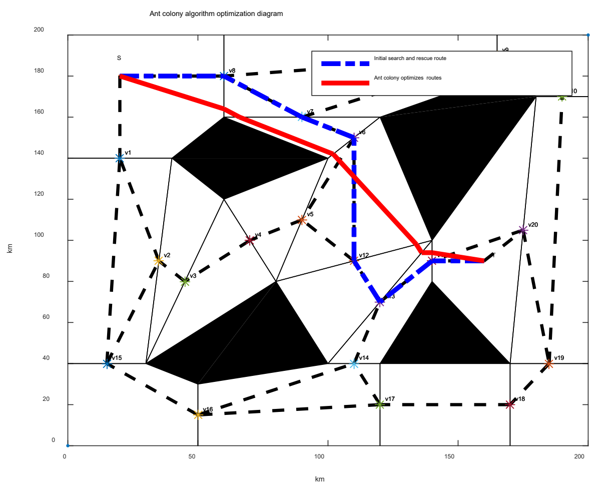

Figure 4: Ant colony algorithm optimization

The number of iterations is shown in the figure below:

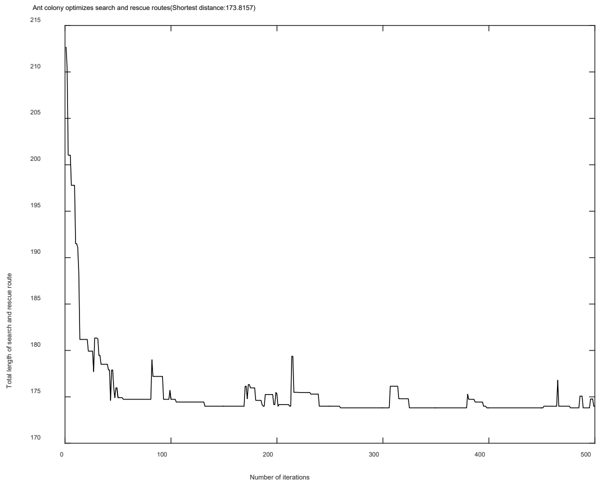

Figure 5: Graph of iteration times

The specific results are as follows:

(1) Planning Time is 7s

(2) Initial search and rescue route

Blue dotted lines are expressed as the initial search and rescue route, with six inflection points, and the specific path is

$$S\rightarrow v8\rightarrow v7\rightarrow v6\rightarrow v12\rightarrow v13\rightarrow v11\rightarrow T \quad (13)$$

Turning corner of the search and rescue route is:

$$27.6°\rightarrow 2.1°\rightarrow 64.3°\rightarrow 30.7°\rightarrow 91.9°\rightarrow 39.2° \quad (14)$$

Search and rescue route distance is 229.06km.

(3) Optimization of the search and rescue route

Red solid line is represented as the route optimized by the ant colony algorithm, and the specific optimized path coordinate is

$$S\rightarrow(60,164)\rightarrow(66,160)\rightarrow(102,142)\rightarrow(134,98)\rightarrow(136,94)\rightarrow(140,94)\rightarrow T \quad (15)$$

Turning corner of the search and rescue route is:

$$5.7°\rightarrow 2.2°\rightarrow 25.7°\rightarrow 4.4°\rightarrow 32.5°\rightarrow 2.7° \quad (16)$$

Search and rescue route distance is 173.8157 km.

(4) The analysis

According to the simulation results, the sea search and rescue route design has fast search route planning, smooth search route, no over-turn angle and short distance which meet the requirements of search route design. It proves the feasibility of search and rescue route based on ant colony algorithm.

5. Conclusions

This paper proposed an algorithm of rescue waters environmental modeling route design for waters in Zhoushan. The search and rescue ships can reach the site of the accident within shorten navigation time. The main achievements of this article are concluded as follows:

(1) The use of search and rescue environment modeling with MAKLINK to replace grid modeling, reduces the modeling difficulty and reduces the number of model reconstruction.

(2) Combining the ant colony algorithm with the Dijkstra algorithm effectively accelerates the search and rescue route search efficiency and shortens the search time.

However, there are still some deficiencies and future studies in the search and rescue route design. The design of the water environment only considers the island and shallow water areas. The factors such as wind, waves, sea currents, and weather of dynamic environment will be taken into consideration in future.

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