Research on Adaptive Segmentation Design Method of Route

Jin Zhang\textsuperscript{1,2,3,*}, ShuJun Li\textsuperscript{2,3}, and Mo Wang\textsuperscript{2,3}

\textsuperscript{1}32023 Troop, Dalian, Liaoning, 116021, China
\textsuperscript{2}Department of Military Oceanography and Hydrography & Cartography, Dalian Naval Academy, Dalian, Liaoning 116018, China
\textsuperscript{3}Key Laboratory of Hydrographic Surveying and Mapping of PLA, Dalian Naval Academy, Dalian, Liaoning, 116018, China
\textsuperscript{*}Corresponding author’s e-mail: zjin_vic@163.com

Abstract. With the continuous improvement of China’s international influence and the gradual implementation and deepening of the “One Belt, One Road” strategy, the scope of the ship’s activities has expanded from offshore waters to global seas. In view of the limitations of the protection needs of offshore navigation for many years, the traditional maritime protection has the characteristics of fixed coverage, fewer factors involved, and lower informationization. This paper introduces the current vector route design method for avoiding obstacles, and proposes a new double-sided convex hull expansion algorithm for its deficiencies in algorithm complexity. The shortest path to avoid obstacles is planned, and the feasibility and superiority of the algorithm are verified by experiments.

1. Introduction

In recent years, the implementation of naval joint military exercises and escort operations has improved the joint guarantee level of ships and ocean voyages to a certain extent. However, the maritime security model and automation level of offshore navigation have not been completely changed and significantly improved, especially in the design, assessment and nautical charting of ship routes. The traditional maritime security model of small-scale, single-factor, and human interaction is difficult to meet the comprehensive protection needs of ships sailing in the ocean [1]. Therefore, a new mode of protection for route design and information services for the world's oceans is established, providing users with navigation plans, chart data and other relevant information between any two ports [2][3]. It can significantly enhance the support capability and level of large-scale naval vessels sailing in the ocean, and has a positive exploration and reference for the innovative development of naval forces' maritime security model. It has high use value and broad application prospects.

2. Planning and design method for Ocean Route

The route after the adaptive segmentation is inevitably passed through the obstacle navigation zone. Affected by the complex marine environment, this temporary route change will undoubtedly greatly increase the probability of accidents and seriously affect navigation safety. Therefore, in the route design phase, the planned route of the navigational barrier zone needs to be re-optimized to ensure that the entire planned route is in a navigable state. The shortest route planning problem in the obstacle navigation area can be abstracted as an obstacle path planning problem [4]. The most commonly used
algorithm for current obstacle route planning is the route binary tree method and convex hull boundary algorithm [5].

2.1. Route binary tree algorithm
The route binary tree algorithm is a classic algorithm for planning the shortest path between obstacles. The shortest path planning in the obstacle environment between the starting point and the ending point is achieved by bypassing each obstacle passing through the route. The procedure for establishing a route binary tree from the starting point $S$ to the ending point $T$ is as follows [6]:

1) Determining whether the route $ST$ intersects with the obstacle, and if not, the route is the shortest distance route; if yes, finding the nearest obstacle $O_i$ that is closest to the point $S$;

2) The vertices of $O_i$ are connected to $S$, according to the dichotomy characteristics of the obstacles, the left and right lines with the largest difference from the $ST$ orientation are taken, and the intersections $P_1$, $P_2$ of the two lines with $O_i$ are obtained;

3) Determining whether $P_1$ and $P_2$ are located on the route closest to the obstacle, and if not, regard it as a node, and if so, regard it as an intermediate waypoint and perform a bypass obstacle until it finds a waypoint that meets this condition (as shown in Figure 1, the $SP_1P_2T$ route, $P_1$ is the intermediate route point);

4) Finding the left and right child nodes of the route binary tree (like point $P_1$, $P_2$ in Figure 1). As the current test point, repeating the above steps until the binary tree is established;

5) According to the combination of "depth first" and "exploration search", all the routes in the binary tree are obtained, and the redundant nodes are deleted to obtain the shortest distance route.

The process of the route binary tree algorithm can be divided into two stages: establishing a binary tree and traversing the binary tree. It can be regarded as a stage of constructing a transit route network from the start point $S$ to the end point $T$ and searching for the shortest path in the route network.

2.2. Convex hull boundary algorithm
Convex hull is the most common and basic structure in computational geometry. The convex hull is the natural limit boundary of the data point. It is the smallest convex polygon containing all the data points. The line segment connecting any two points must be completely located in the convex polygon, and the area of the constituting area also reaches the minimum [7]. The basic idea of the convex hull boundary algorithm is as follows [8]:

Let $M$ be the set of obstacles associated with path $R$, satisfying:
In the formula, \( o_i \) represents any obstacle in the obstacle set \( O \). Let the point \( p_j(x_j, y_j) \) be the apex of \( o_j \in O_k \).

\[
d_j = \frac{ax_j + by_j + c}{\sqrt{a^2 + b^2}}
\]

In the formula, \( a, b, c \) are the parameters of the equation of the line where the path \( r \) is located.

The result of the route planning is shown in Figure 2. The gray area is the obstacle, the solid line is the route in the route network, and the dotted line is the route that was deleted during the search. The convex hull boundary algorithm converts the path planning problem in the obstacle space into a convex hull calculation problem, and uses the convex hull boundary to bypass all obstacles associated with the path at one time. A large number of experimental results show that the algorithm can quickly construct a dynamic space network model based on obstacle information, and meet the real-time and efficient requirements of automatic path planning.

Figure 2. Convex hull boundary algorithm

However, its limitations are also very obvious. The algorithm uses the characteristics of the convex hull boundary to contain the point set to construct the dynamic space network model. According to certain optimization rules, the optimal path planning can be carried out. In the special obstacle space, because the convex hull boundary idea fails to plan the relevant path between the obstacle entities inside the convex hull, the comprehensiveness of the constructed spatial network model is insufficient. Especially in the shortest path planning problem has a greater limitation. In Figure 2, the shortest path \( (SP_4P_3T) \) in the network model constructed based on the convex hull boundary algorithm is not the actual shortest path \( (SP_2P_5P_7T) \).

3. Bilateral convex hull expansion algorithm

Although the convex hull boundary algorithm improves the construction efficiency of the network model, the comprehensiveness of the constructed network model is insufficient [9]. When the convex hull boundary is used for the collision avoidance path planning, only the outermost path of the obstacle associated with the path is planned, and the path inside the associated obstacle is not planned, thereby losing part of the path inside the obstacle. In this paper, a two-sided convex hull expansion algorithm is proposed. Based on the improvement of path and obstacle convex hull operation, the dynamic spatial network model is constructed by extracting the convex hull boundary of the left and right side of the associated obstacle.
3.1. Algorithm principle and boundary algorithm

3.1.1. Algorithm principle.
Based on the improvement of path and obstacle convex hull operation, the two-sided convex hull expansion algorithm is used to construct the dynamic space network model by extracting the convex hull boundary of the left and right side of the associated obstacle. The method of associating the left and right side convex hulls of the obstacles keeps the boundary of the outermost convex hull unchanged, and adds two families of detection paths inside the associated obstacles to prevent the loss of the shortest path.

3.1.2. Boundary algorithm.
The convex hull boundary algorithm performs convex hull operations on the same path on the upper and lower point sets, and the result is equivalent to the result of performing a convex hull operation on all obstacles associated with the path. The latter is superior to the former in terms of the number of operations and the efficiency of the operation.

3.2. Position judgment and route network simplification

3.2.1. Position judgment.
The spatial network model constructed by the convex hull boundary algorithm has the defects of lack of comprehensiveness [10]. To overcome this problem, this paper proposes a double-sided convex hull expansion calculation, in which an important step is to divide the left and right positions of the associated obstacles. Starting from the direction of the path (pointed to T from S in Figure 3), the definition is to rotate 180° clockwise to the right of the path and 180° counterclockwise to the left of the path; Let the obstacle be $O_i$, and the center point be $A_i$, and divide the obstacle $O_i$ according to the relative position of the obstacle center point $A_i$ and the path $ST$. In Figure 2, obstacles S and T are located on the left side of the route, and W is on the right side of the route.

![Figure 3. Obstacle position judgment](image)

3.2.2. Route network simplification.
In order to reduce the complexity of the network model structure constructed by the double-sided convex hull expansion algorithm, it is necessary to simplify it in the network model construction process [11]. Simplified processing method for a single obstacle: if there is only one associated obstacle, the convex hull boundary is divided into two left and right paths by the starting point, if the shorter length path $r_{min}$ satisfies:

$$r_{min} \cap O = \emptyset$$

(3)

Only $r_{min}$ is retained. As shown in Figure 3.6:
The path from the starting point $S$ to the ending point $T$ intersects the obstacle zone $O_1$, bypassing $O_1$ with a convex hull boundary and generating a left path $r_{S-B-T}$ and a right path $r_{S-A-T}$. If multiple obstacles passing through the route are located on one side of the route, the simplification method is the same as above.

4. Experiment and analysis

Simulation experiment for the shortest route planning for the navigation obstacle area as shown in Figure 5. (1) (2). The result is shown in Figure 6. Among them, (a), (b), and (c) are experimental (1) results, and (d), (e), and (f) are experimental (2) results.

Comparing Figure 6, it can be found that in the experiment (1), the convex hull boundary algorithm and the double convex hull expansion algorithm can both plan the shortest route, and the route binary tree algorithm needs to delete the redundant nodes. In experiment (2), both the convex hull expansion algorithm and the route binary tree algorithm can plan the shortest route, and the convex hull boundary algorithm plans the wrong shortest route. The convex bundle boundary algorithm has insufficient
authenticity for the shortest route automatic planning, and the other two algorithms have strong stability when planning the actual shortest path.

Figure 6. Three algorithms experimental results

5. Conclusion
This paper introduces the route binary tree method and convex hull boundary algorithm, and proposes a double convex hull expansion algorithm for its respective deficiencies. According to the relationship between the navigation zone and the route, it is divided into the left and right obstacle navigation zones, and the convex hull operation is performed on the route and the left and right side obstacle navigation zones respectively, regarding the convex hull boundary as a new route and searching for the shortest path in the constructed route network. The experiment proves that the full convex hull expansion algorithm not only overcomes the problem of high complexity of the route binary tree algorithm, but also overcomes the defect that the convex hull boundary algorithm loses the shortest route between the obstacles. The search function of the shortest route in the complex obstacle navigation area is realized, which lays a foundation for the subsequent route evaluation and navigation map support method research.

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