A method of Space Characterization for underwater vehicle path planning

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Abstract. multi unmanned underwater vehicle (AUV) cooperative mission is the trend of underwater combat application. It is an important task to search for the target in unknown environment. This paper describes the design and development of planning spatial representation by vector description and mesh model combination. The method adopt the grid planning regional elements and grid attribute mark to construct the route search algorithm which can reduce the search time and space overhead and improve the planning efficiency in path planning process.

1. Introduction

Since 1990s, the role of submarine underwater battlefield has changed significantly, which has been more and more applied in coastal waters to support joint operations. However, expensive conventional submarines and nuclear submarine can easily be found and attacked by other anti-submarine forces. Navy unmanned stealth system are needs in the area of traditional sea power cannot reach to collect information and target. In addition, to carry out non-combat naval activities, such as collecting meteorological and oceanographic data also need to consider the use of unmanned systems to improve quality and reduce costs. In this case, the unmanned underwater vehicle emerged as one of the most important equipment in underwater warfare.

The unmanned underwater vehicle float in the specified location to complete the communication, navigation and other tasks, select the best navigation nodes, avoid all kinds of threats, and complete the task with the minimum cost according to the planned route process. Route planning is the combination of geographic information system, location and navigation system, control system of high precision, high speed computer processing system, which has been widely used in various systems including navigation aircraft, surface ships, ground vehicles and robots, etc. Route planning for unmanned underwater vehicle is in the vehicle's physical condition (motor performance, maximum distance, depth, navigation, communication, etc.) combined with the navigation task (starting point, search scope, target, attack way, the aircraft arrived time, etc.) and surface, underwater environment (seafloor topography, acoustic environment, current, threat, no fly zone etc.) to complete the task of finding the optimal sailing route.

The research of route planning is very rich. One of the problem is how to represent the planning space. A planning space model should be convenient to search, reduce the amount of data storage. In view of the above problems, this paper designed and developed the planning space combined vector description and mesh model to solve time-consuming problem when elements are polygon or other set elements of geometry mode in high complexity regional.
2. II. COMMON PLANNING SPACE MODEL

Finite element models of hot-rolled RHS/SHS stub columns were developed by using the non-linear finite element program ABAQUS [5], in which two steps including linear perturbation and non-linear analyses were performed in order to obtain the ultimate carrying capacity and failure modes of RHS/SHS stub columns. Material properties and cross-section dimensions measured from Joanna’s test [6] were included in the finite element model. The typical nomenclature is defined in Figure 1.

Taking the two-dimensional route planning as an example, the common planning spatial models are as follows:

1) Grid model

As Figure 1 shown on the left, the planning area is divided into grid array (or pixels), and each grid is marked as prohibited or free property. The data structure can be expressed as a two-dimensional array. The complexity of the planning problem can be represented by the array size M * N. The array size M * N depends on the grid resolution. The simulation of the planning area is more sophisticated when the resolution is high which will greatly increase the complexity of the problem. And the complexity of the problem is greatly reduced when the resolution is low which lost many regional planning details, such as the no sail zone between the narrow channels and so on. It may lose the optimal solution.

2) The four tree model

As Figure 1 shown on the right, the grid size changes with the change of regional planning which shows the characteristics of hierarchical. The complex area is described by the fine grid and the flat changed area is described by coarse grid, which greatly reducing the size of the problem. However, this method needs to use the complex encoding and decoding algorithm, and the complexity of the whole region is not necessarily to effectively reduce the complexity of the planning problem.

3) Polygon model

The polygon is used to approximate the boundaries of the forbidden area. The polygons are closed and each polygon can be represented by a set of vectors that are connected to each other (Figure 2). The K polygon can be used to describe the k prohibited area. Each polygon is described the two-direct connection vector sequence (each vector can be defined by a pair of integer or real coordinates). The total number of vectors of all the polygons is N. it can be called "the area complexity" because of the related to the total storage of the planning region. To be exact, the regional complexity should be related to the total number of K, but K is generally less than n.
3. PLANAR GRID OF PLANNING AREA

In the process of establishing the planning space, the accurate and planning time will be a pair of irreconcilable contradictions if under water space are divided into discrete grid map. The sparse grid will make the low route accuracy while the close grid makes the too large planning space and occupies a large number of computing resources. The planning based on vectors can obtain high precision route. But the frequent cross detection between the path and route planning factors (such as threat area, restricted area, etc.) is a very time-consuming work in planning process.

In order to solve the above problems, we can use the combination of vector description and mesh model to mark the grid on vector map and accelerate the cross detection speed. This is a reasonable planning method of building space will not cause the loss of precision. The planning space establishment is divided into two steps.

Firstly, a grid scale is determined combined with the actual tactical need. And then the whole planning area is separated according to principle of the same size of all of the grid scale. Each longitude of the upper left corner is recorded to calculate the current grid point conveniently. The formula (1) can be calculated from the rows and columns of current the regional grid.

\[
\begin{align*}
    r &= \left\lfloor \frac{y_{\text{max}} - y}{d_r} \right\rfloor \\
    c &= \left\lfloor \frac{x - x_{\text{min}}}{d_c} \right\rfloor 
\end{align*}
\]  

(1)

In that, \( r \), \( c \) represent the rows and columns of current regional grid, \( x \), \( y \) represent latitude and longitude coordinates of the current points, \( x_{\text{min}} \), \( y_{\text{max}} \) is the latitude and longitude of the upper left corner in the planning space, \( d_r \), \( d_c \) represent the vertical and horizontal grid scale.

It is easy to mesh equal-area. Firstly, a minimum mesh size is determined by the actual tactical needs. Then to complete the whole area mesh according to the principle of same size grid scale. It should be noted that, when considering the size of the grid, each side of the planning area should be divided into 2n grid width. In order to realize the multi scale route network planning of different size, the strategy is to expand the grid scale in accordance with the upscaling methods gradually at the minimum grid basis.

As shown in Figure 3, the purple grid represents the smallest unit of grid at the lower left corner. The first layer of the route network scale is complete in this scale.

Then, the second layer scale increase the grid scale multiplication in the grid and the size of the green and purple (the smallest grid four times), and so on. The third route network is planned in sixteen times the minimum grid scale. In theory, this method can last up to a grid containing the whole planning area.
The advantage of such a grid division is that at each level, the grid is the standard size, the number of route networks are consistent, which provides convenience for the management of the route network.

4. IV. GRID ATTRIBUTE TAG FOR PLANNING ELEMENTS
The planning elements (such as the flow area, the threat area, the restricted area, etc.) will be marked by the grid management, and the corresponding relationship between the planning elements and the grid is established after the partition of the whole planning area. It is necessary to deal with the planning elements before marking the elements of the partition grid. The tangent concave polygon calculation is much more complex than the tangent convex polygons in route planning process, therefore, it will greatly accelerate the speed of route planning to restrict area of convex processing and limit the intersection zone to merge.

After the merge area is completed, the next step is to establish the corresponding relationship with the planning elements of the grid. The process to establish the corresponding relationship is followed on all grid traversal process and collision detection between the current mesh and all programming elements. If a programming element intersects with the grid, the planning elements ID will be add to the grid properties (each planning elements corresponds to a unique ID, the ID can find regional data corresponding to the join attribute grid).

When collision detection is carried out in the course of route search, it is only necessary to extract the planning elements contained in all the grids which have been passed through the AUV route. Therefore, it is not necessary to make collision detection with all the planning elements, which greatly reduces the amount of calculation. The method not only accelerates the collision detection speed, but also does not cause the loss of route accuracy.
As shown in Figure 4, there are A, B, C planning elements intersect the shadow region grid. So, the three planning elements ID will be joint the shadow region grid properties and the corresponding relationship between shadow grid and A, B, C elements is established. When path planning in the shadow of the grid, It’s only need to obtain A, B, C three elements vector to analysis and judge instead of analysis of all the elements of vector space. Which greatly reduce the search volume and time overhead in the planning and improve the efficiency of the route planning.

5. Conclusion
AUV is playing a more and more important role in military and civilian fields due to its low cost, high mobility and zero casualties and multi AUV joint tasks gradually become the trend of application. The range of the underwater vehicle can reach hundreds of kilometers and the planning area space is very large, so it is very important to build a reasonable route planning algorithm. This paper proposes an AUV path planning space characterization method. This method construct the route search algorithm by two steps, planning area grid and the planning elements of grid attribute mark. This method can reduce the search space and search times in path planning and improve the planning efficiency, also can reduce the space overhead. Which provides support to carry out effective AUV route planning and has application value in military reconnaissance, search and rescue, geological exploration etc.

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