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Research on submarine lost contact search technology based on ArcGIS and genetic algorithm

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Abstract: *In this paper, a technical solution based on ArcGIS and genetic algorithm is proposed for searching submarine after losing contact. First, a three-dimensional submarine terrain model is established by ArcGIS to simulate the Marine environment where the submarine may lose contact. Then, the Cartesian coordinate system is established, and the random walk model is used to describe the motion state of the submarine after the loss of contact. The probabilistic model is optimized by Bayesian inference to improve the accuracy of submarine position prediction. After determining the search area, genetic algorithm is used to optimize the search path so that the search equipment can locate the submarine and return to the initial point as soon as possible. The results show that this method can effectively predict the position of the submarine after the loss of contact, and provide an efficient search path for the search equipment, and provide technical support for the search and rescue of the submarine after the loss of contact.*

Keywords: *ArcGIS, Genetic algorithm, Submarine lost contact, Search path optimization*

1. Introduction

With the continuous development of deep-sea exploration and marine scientific research, submersibles are increasingly used in the ocean. However, the loss of power may expose submersibles to situations where they cannot move on their own and to dangerous situations, which poses a threat to the submersibles and the personnel onboard. Unpowered submersibles can be placed in dangerous situations, and position prediction and search and rescue strategies need to be established to deal with them.

MCMS is a Greece-based company that builds submarines capable of carrying humans to explore the deepest parts of the ocean. Now MCMS is hoping to win regulatory approval to open up safety procedures to deal with the submarine's loss of communication with its mother ship and possible mechanical failures, including loss of propulsion.

Since submarines are at risk of losing power in a deep-sea environment and are unable to move autonomously, this can lead to dangerous situations. In order to meet this challenge, it is necessary to build a position prediction model to estimate the likely position of a submarine after losing power. At the same time, search and rescue strategies need to be developed so that the submarine can be located and rescued in time. Therefore, this paper aims to build a position prediction model and optimize search and rescue strategies to ensure the safety of submarines.

2. Research Methods

This study mainly includes the following steps:

(1) Establish ArcGIS three-dimensional spatial model: Establish a three-dimensional submarine terrain model based on digital elevation model (DEM) to simulate the Marine environment where the submarine may lose contact.

(2) Establish a Cartesian coordinate system: Establish a three-dimensional Cartesian coordinate system to describe the position change of the submarine after the loss of contact.

(3) Establish a random walk model: The random walk model is used to describe the motion state of the submarine after losing contact.

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(4) Application of Bayesian inference: The probabilistic model is optimized by Bayesian inference to improve the accuracy of submarine position prediction.

(5) Determine the search scope: Determine the search scope according to the probability density map.

(6) Use genetic algorithms to optimize the search path: Use genetic algorithms to optimize the search path so that the search equipment can locate the submarine and return to the initial point as soon as possible.

In summary, this paper mainly adopts various methods, such as ArcGIS 3D modeling, random walk model, Bayesian inference and genetic algorithm, to predict the position of the submarine after losing contact and optimize the search path.

3. Model building and solving

3.1 3D submarine terrain modeling and submarine lost contact search technology scheme based on ArcGIS

3.1.1 Establishment of Arcgis three-dimensional spatial model based on DEM

The seabed environment is complex and changeable, and the environment of different sea areas may be different from each other. In order to facilitate search and rescue and show the macro image of the sea area, we choose to establish Arcgis 3D spatial model based on DEM to simulate the sea area environment.

DEM (Digital Elevation Model), represents the elevation corresponding to a finite sequence of three-dimensional vectors of the seabed topography on the sea area D. The DEM is a three-dimensional spatial model of the seabed.

After the seafloor situation is processed, the Arcgis 3D spatial model is established, and the collected sea area data are used to obtain the stratification information of each bottom layer, and then the whole bottom layer is inscribed in the form of TINs, and the solid filling is carried out by using the stretching expansion of one face between the adjacent bottom layer TINs.

3.1.2 Establishment of Cartesian coordinate system

The ocean is a three-dimensional space, and the description of the motion state of the submersible in the ocean needs to be established in a three-dimensional coordinate system, from which the Cartesian coordinate system () is selected to describe the position change state of the submersible in the ocean. The following two factors need to be considered when establishing the Cartesian coordinate system.

① In order to describe the position change of the submersible in the deep ocean as accurately as possible, two basic physical quantities, velocity and acceleration, are introduced, both of which are vectors and can represent direction and magnitude. In three-dimensional space, velocity and acceleration have a value in each of the three dimensions, so velocity can be ex- pressed as and acceleration can be expressed as.

② Considering that the submersible may have rotational motion itself when it malfunctions or loses connection with the host, two physical quantities of angular velocity and angular acceleration are introduced for this purpose.

3.1.3 Random-walk modeling to determine operational state

The Cartesian coordinate system can only describe the model of the position of the submersible, in the open distributed environment, the subject often has to interact with unknown or even completely unfamiliar subjects, the movement of the submersible in the deep sea is approximated to a random walk, based on the performance of the submersible's past movement, the Cartesian coordinate system alone cannot predict the specific steps and directions of its development in the future. There are different types of irregular walks in the system where the submersible is located in the topic, and they all have similar structures. Individual random events are unpredictable, but the behavior of a randomly large number of groups is precisely knowable, and the charm of the probabilistic world lies in the fact that there is inevitability implied in chance.

The initial position of the submersible is already selected and is noted as the target node, which in turn allows us to obtain the probability transfer matrix B of the target node.

Combining the probability transfer matrix with the Markov chain leads to the expression for the prob-

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ability of the random wandering model

3.1.4 Bayesian inference to further improve the probability model

The movement of the submersible in the ocean after the failure is also affected by the temperature, density, current and other external factors, so Bayesian inference is introduced to calculate the influence of external factors on the state of the submersible movement.

In which, it indicates the probability of the change of the external disturbing factors affecting the movement of the submersible such as the sea current before obtaining the information of the submersible, and this probability is not affected by the state of the submersible; it indicates the total probability of the change of the operating state of the submersible, and it is a standardized constant to ensure that the probability of the sum of one.

3.1.5 What information to send to minimize uncertainty

During normal operation of a submersible, a variety of information such as current speed, main direction of current, water temperature, salinity, dive depth, surface wind speed, wave height, etc. can be sent to the host ship periodically to ensure that the host ship has a complete grasp of the operational status of the submersible. The premise for the submersible to be able to acquire and send such information is that the submersible is equipped with a variety of equipment such as electromagnetic current meters, acoustic Doppler current profilers (ADCP), depth thermometers, temperature sensors, remote sensing satellite sensors, and so on.

Based on the 3D spatial model, the code was entered into MATLAB to produce the terrain environment as shown in Figure 1.

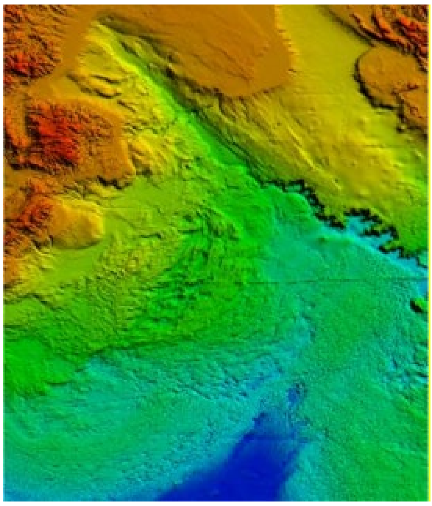

Figure 1: Topographic elevation map of the sea area

Diver trajectories are derived from a Cartesian coordinate system with a stochastic wandering model (Figure 2).

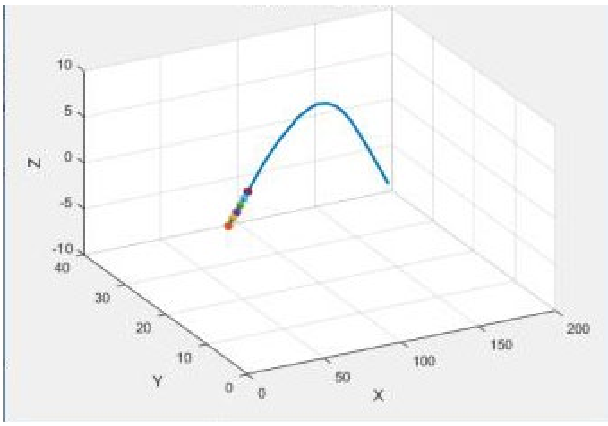

Figure 2: Three-dimensional trajectory of the submersible

ISSN 2706-655X Vol.6, Issue 3: 67-73, DOI: 10.25236/IJFET.2024.060309

The optimized position of the submersible after introducing Bayesian inference is shown in Figure 3.

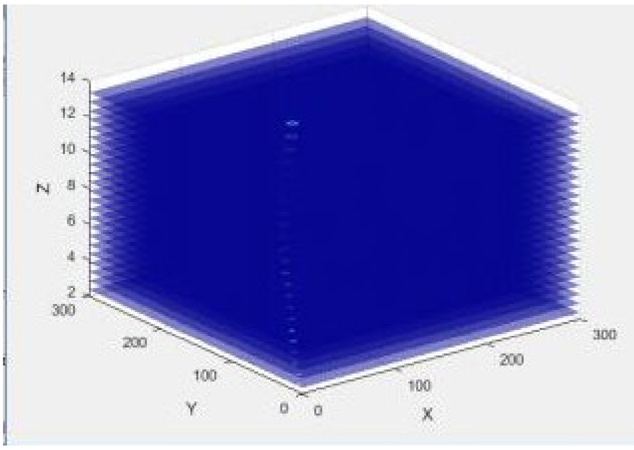

Figure 3: Probability density of the predicted position of the submersible

Uncertainty factors and equipment to reduce uncertainty are shown in the Table 1.

Table 1: Uncertainties and their detection equipment

equipment	index
Electromagnetic Current Meter	water velocity
CTD	temperature of the body of water
	salinity
	profundity
	surface velocity
drift buoy	sea surface temperature

3.2 Genetic algorithms are used to optimize the search path

This question uses a hierarchical analysis to determine what kind of search equipment the main ship is equipped with. In order to be able to search for the submersible in time when the submersible malfunctions, it is recommended that MCMS equip the main ship with sonar, sub- mersible, UAV and other equipment [1-4]. In order to facilitate the MCMS to choose the suitable SAR equipment for the main ship according to the specific situation, a hierarchical analysis model is established to provide a reference for it [5-7].

The target layer is the SAR equipments for the main ship; the criterion layer selects the three equipments of sonar, submersible, and UAV; and the equipment availability, maintenance difficulty, equipment condition, and utilization cost are selected as the indicator layer(Table 2, Table 3 and Table 4).

Table 2: Weighting of level 1 indicators

kind	A1	A2	A3
weights	0.3	0.2	0.5

Table 3: Indicator level judgment matrix

A	B1	B2	B3	B4
B1	1	1/5	1	1/4
B2	5	1	6	1
B3	1	1/6	1	1/3
B4	4	1	3	1

Table 4: Weighting of secondary indicators

	B1	B2	B3	B4
weight	0.0906	0.4538	0.0943	0.3614
	$\lambda_{max} = 4.0407$			

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The maximum eigenvalue of each layer and its eigenvectors can be calculated by using the square root method and the sum-product method, and in this paper, Matlab is used for direct extraction and consistency judgment, and the results are shown in Table 5.

The weight matrix obtained using the eigenvalue method can be obtained (Table 5).

Table 5: Weighting matrix

	Index weight	A1	A2	A3
B1	0.0906	0.3	0.2	0.5
B2	0.4538	0.2	0.2	0.6
B3	0.0943	0.3	0.3	0.4
B4	0.3614	0.3	0.4	0.3

Based on this matrix, the score for the criterion layer can be calculated (Table 6).

Table 6: Guideline layer score

A1	A2	A3
0.25465	0.28173	0.46372

Based on the scores, it is possible to select the SAR equipment that is appropriate for the main ship's situation.

Overall, the choice of what kind of SAR equipment to select is very subjective, and when making the choice, the weight indicators at the guideline level can be modified on their own according to the specific situation, and the results will be changed as a result, as will the final type of equipment selected[8].

In accordance with the probability density map of the predicted position of the submersible, set the search range and depth to the region of probability density 0.1 and above. The region is simplified into a straight column with the probability density of 0.1 and above as the base and its length in the z-axis direction as the height of the region cut from the figure above.

In this problem we use circular search method for 3D search. Circular search, that is, two search devices cooperate with each other, one of them as the center of the circle, the other to start from a certain radius of the circular search, after searching for a week, each time to expand the radius a little bit, continue to search. In the oceanic 3D space of this problem, it is assumed that the search devices move at a constant speed and the initial deployment point of the devices is set as the approximate center of the column, i.e., point (267.5, 272.5, 8). One search device is fixed at the initial deployment point and the other search device searches to locate the lost submarine within the region of the column[9].

In order to minimize the time taken by the search devices to locate the lost submarine, we investigate the approximate optimization model that minimizes the total time taken by the search devices after locating the lost submarine and returning to the initial deployment point. Since the speed of the search device is constant, i.e., the shortest path it has traveled is used as the objective function. Here we do the optimization along the lines of the traveler's problem and solve it using a genetic algorithm[10].

The Traveling Salesman (TSP) problem, i.e., a salesman is ready to travel to a number of cities to sell his products and then return to his place of departure. How to design a shortest travel route for him (starting from the premises, passing through each city exactly once and finally returning to the premises)?

The problem can be solved using a genetic algorithm to find the optimal route.

In this problem, in order to save the computation time of the genetic algorithm, we define a number of points in the region where the submarine appears with probability of 0.8 or more in the column, and take the search device used to locate the submarine as the traveler, with the initial deployment point as the station, and instead of a number of discrete points of a continuous path as the cities, we design a shortest path from the station through all the cities and then back to the station for the traveler, and get the search device in the A simplified model of efficient search within a high probability region.

Using genetic algorithm, the number of cities is defined as 16, divided into four layers of four points each layer, the shortest distance is 545.432, and the path planning diagram is as follows (Figure 4).

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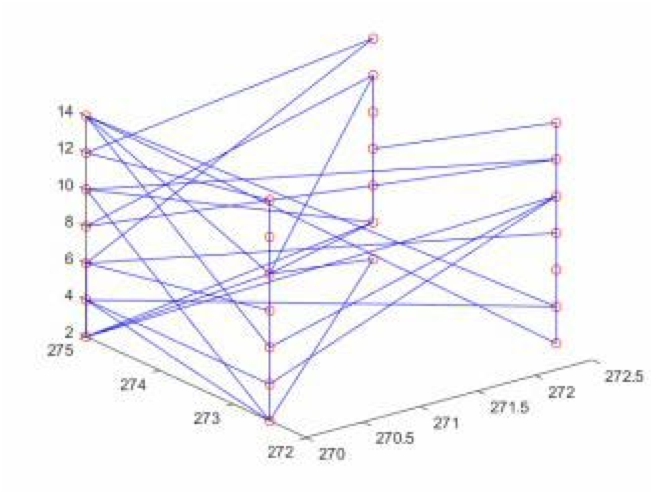

Figure 4: Route Planning Schematic

The probability distribution graph is obtained using Matlab as follows (Figure 5).

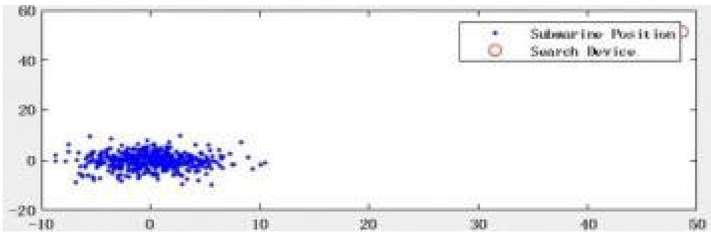

Figure 5: Probability distribution diagram for a submersible

4. Conclusions

The submarine lost contact search technology scheme based on ArcGIS and genetic algorithm proposed in this paper can effectively predict the position of the submarine lost contact and provide an efficient search path for the search equipment. This method comprehensively considers the motion state of the submarine after the loss of contact and the influence of external environmental factors. By constructing a three-dimensional space model and optimizing the search path, the search and rescue efficiency can be significantly improved. In the future, the method can be further combined with other new technologies, such as artificial intelligence, big data, etc., to further improve the search and rescue capability of submarines after losing contact. This study provides a feasible and efficient technical approach for submarine lost contact search.

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