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Integrated submarine search and rescue program based on different water level risk response studies

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Abstract: *The paper begins with a preliminary analysis of the three states of a submarine when it has not lost power, when it has lost power, and when it is under the influence of external factors such as ocean currents. Secondly, the macroscopic huge ocean is decomposed into multi-level superposition surfaces to analyze the possibility that the submarine may appear at a certain point. Finally, the Bayesian probability is used to calculate the probability density of the possible locations of the submarine, then the line connected to the point with the highest probability on each surface layer of the seawater is the locating submarine movement trajectory. In this paper, we consider multiple submersibles moving in the same area, and firstly, we consider the performance of each submersible as well as the influence of ocean current, water temperature, water depth, density and topography that may be affected underwater, so as to select the optimal equipment adapted to the current underwater environment. Secondly, the interactions between the submersible equipment are considered. The radar recognizes and senses each other's information to understand the position between itself and other submersibles, to ensure safety and improve underwater work efficiency at the same time. Through the integration of various innovative technologies and means, this paper proposes an all-round efficient solution to the problem of submarine rescue in the complex marine environment. The program not only shows originality in academics, but also shows significant practical value in actual implementation.*

Keywords: *submersible, localization model, multilayer superposition, circular search*

1. Introduction

Mini Cruising Maritime Submarines (MCMS), headquartered in Greece, is an innovative company specializing in the design and manufacture of submersibles capable of reaching the deepest depths of the oceans. These submersibles are characterized by their ability to move independently to a given location and perform a mission without being dependent on the host vessel, greatly enhancing their flexibility and range of operations. Currently, MCMS is planning to use its submersibles for a new tourist service - expeditions on the Ionian seabed, especially in search of shipwreck sites. This program will not only provide tourists with a unique historical experience, but also help to promote local economic development and marine cultural research. However, the deep-sea environment is challenging, especially in terms of safety[1].Submersibles may experience a loss of communication with the host vessel during a mission, or mechanical failures such as loss of propulsion. These situations require MCMS to have a comprehensive set of safety procedures and contingency plans in place to safeguard passengers and equipment. In particular, the loss of power may leave the submersible in a state of neutral buoyancy, not floating or sinking, which renders traditional search and rescue methods inapplicable.

Against this background, MCMS faces an urgent technical need to develop a model to predict the position of a submersible under different scenarios. Such a model would need to take into account a combination of factors, including the direction and speed of ocean currents, changes in the density of seawater, and the complex topography of the seafloor. All of these environmental factors may affect the position and drift trajectory of a lost submersible. To ensure real-time positioning of the submersible and rapid response in an emergency, MCMS needs to work with ocean engineering experts, data scientists, and safety consultants to develop a highly accurate position prediction model. This model will enable the rescue team to quickly and accurately locate the lost submersible and effectively carry out the rescue mission even in the harsh marine environment.

2. Exploration of the Time Varying Position of Submarines in Water

In this paper, in order to ensure that Greek companies are able to safely provide Ionian undersea shipwreck exploration services, it is necessary to develop a model to predict changes in the position of a submarine in the water over time. This model needs to take into account the fact that the submarine may be located on the seabed or in the mesopelagic layer, influenced by currents, seawater density and seabed topography[2].

First, the submarine should send its position information to the primary vessel on a regular basis in order to minimize prediction uncertainty. This requires that the submarine be equipped with positioning equipment, such as a GPS system or a sonar system, in order to accurately determine its position in real time. In addition, the submarine should be equipped with communications equipment, such as a radio or underwater communications system, to communicate with the primary vessel[3].Secondly, the company should carry additional search equipment on board the main vessel in case of emergency. This equipment can include sonar systems, underwater cameras, and drones. These devices can help the company search and locate the submarine in case it is lost. When selecting equipment, factors such as cost, maintenance, readiness, and use of the equipment need to be considered. Then, a model using information from the location model is built to recommend initial deployment points and search patterns to minimize the time to locate the lost submarine. This model can utilize probabilistic and statistical methods to calculate the probability of finding a submarine based on known location information and the coverage of the search equipment. This probability changes as time and search results accumulate. In order to extend the model to other tourist destinations, such as the Caribbean, some modifications to the model are required. First, it is necessary to collect relevant data for the Caribbean, such as information on currents, seawater density, and seafloor topography. Then, the parameters and algorithms of the model are adjusted according to these data to adapt to the new environmental conditions. In addition, if there are multiple submarines moving at the same time in the same area, the model also needs to be modified. Consideration can be given to considering each submarine as a separate entity and modeling them based on their position and velocity information. The interactions and influences between the submarines also need to be considered to ensure the accuracy and reliability of the model. In summary, building a model that can predict changes in submarine position over time is key to ensuring the safe operation of submarines. By sending location information on a regular basis, carrying additional search equipment, and modeling initial deployment points and search patterns, it is possible to reduce prediction uncertainty and minimize the time to locate a lost submarine. It is also necessary to extend the model to other destinations and to accommodate the movement of multiple submarines[4].

The modeling of data processing is shown in Fig. 1.

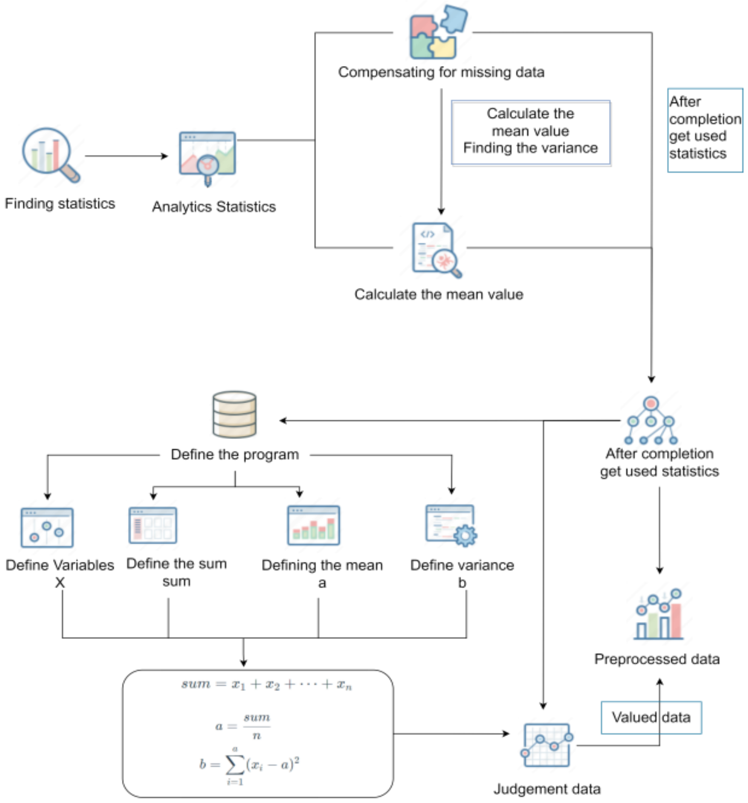

Figure 1: Flow chart of data processing

The Bayesian formula is as follows

$$P(A_i \mid B) = \frac{P(B \mid A_i)P(A_i)}{\sum_j P(B \mid A_j)P(A_j)} \tag{1}$$

According to the Bayesian formula, a probabilistic model is established to solve the problem, and in this paper, a probability density model is simulated by assuming a random initial velocity, current direction, and random acceleration. Assume that the state of the submersible is$\vec{x}_t = [x_t, y_t, z_t, \dot{x}_t, \dot{y}_t, \dot{z}_t]^T$, where x_t, y_t, z_t denotes the position of the submersible in three-dimensional space, and$\dot{x}_t, \dot{y}_t, \dot{z}_t$ denotes the corresponding velocity.

A probabilistic 3D plot of a possible location of a simulated submarine in a given space is shown in Fig. 2.

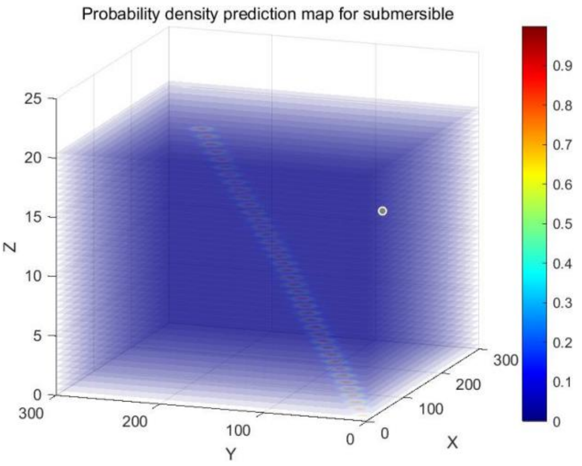

Figure 2: Submarine probability density prediction map

Assuming that the ocean as a whole consists of multiple lamellar structures, each surface consists of countless points, the submarine appears at each point has a certain probability, through the calculated probability of this paper to locate the submarine's movement trajectory.

Through the above, this paper gets the possible position of the submarine, so that the model achieves the function of localization, and the search area is more extensive, in which each point represents the result of one simulation or predicts the possible position of the submarine to stay, and if the point is red then the greater the chance of appearing near the point, and vice versa if the point is blue, the smaller the chance of the submarine appearing near this point.

In this paper, four standard quantities are set to evaluate the facilities through investigation and analysis, which are search and rescue range, accuracy, reliability, and durability of facility use. Through hierarchical analysis, their respective weights are analyzed, and then each cost as well as the repair cost is calculated to derive the benefit ratio.

Device Utility Function $U(e)$ can be defined as a function of device search efficiency and cost as follows

$$U(e) = \alpha \cdot E(e) - \beta \cdot C(e) \tag{2}$$

Where e denotes the different search devices, the$E(e)$ denotes the search efficiency (e.g. detection range, depth, etc.) of the equipment, the $C(e)$ denotes the total cost of the equipment (including purchase, maintenance, and usage costs), theα and β are weight parameters to adjust the relative importance of search efficiency and cost in the utility function.

Total Cost $C(e)$ This can be further broken down into

$$C(e) = C_{purchase}(e) + C_{ma\mathrm{int}enance}(e) + C_{readiness}(e) + C_{usage}(e) \tag{3}$$

After analyzing the costs of purchase, maintenance, readiness, and use, the search equipment that is suitable for the seabed is selected.

3. Consideration of shorter searches

This paper considers two methods of reducing time. The first is to reduce the distance between them to minimize time consumption; the second is to achieve time savings by using ocean currents to increase speed if the distance is very long[5].

The search area and initial deployment points are shown in Fig. 3.

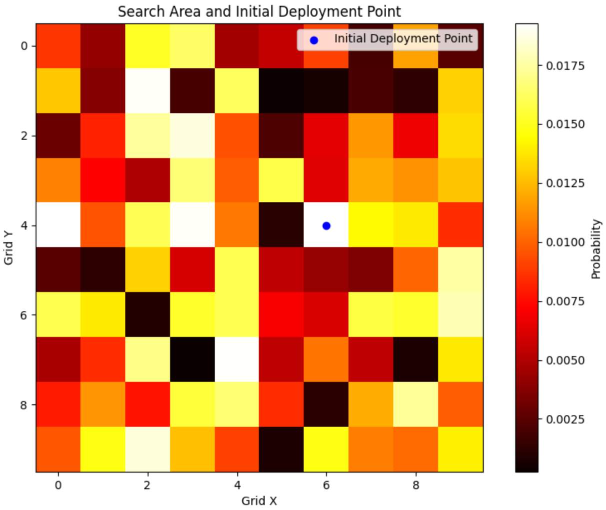

Figure 3: Search area and initial deployment point

First, this paper calculates the probability density of a submarine appearing at a certain place after losing power. In this paper, the ocean is assumed to be composed of countless planar surface layers, and the circular search is utilized to present a circular search starting from the location with the highest probability of a submarine appearing in each piece of the layer, by continuously expanding the radius.

The search and rescue shortest path simulation is shown in Fig. 4.

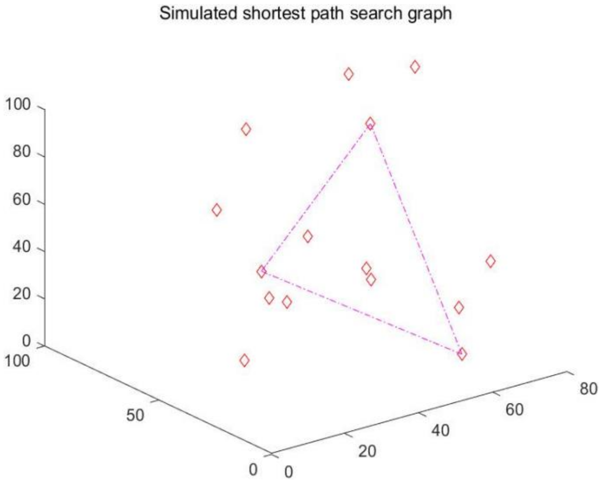

Figure 4: Simulation of the shortest path for search and rescue

Second, in order to achieve the purpose of the shortest search time, this paper assumes that multiple search and rescue vessels will arrive at the submarine's location from different search and rescue points, and builds a computational shortest path model to simulate and demonstrate the shortest time for that path.

4. Consider multiple submersibles in the same area

In other areas, the work of submersibles is affected by different currents, water temperatures, depths, densities and terrains, and is interfered by unknown factors. At the same time, in the process of multiple submersibles working together, the radar between the submersibles recognizes each other's sensing information and understands the position between itself and other submersibles to avoid collision.

The case of multiple submersibles in the same area is shown in Fig. 5.

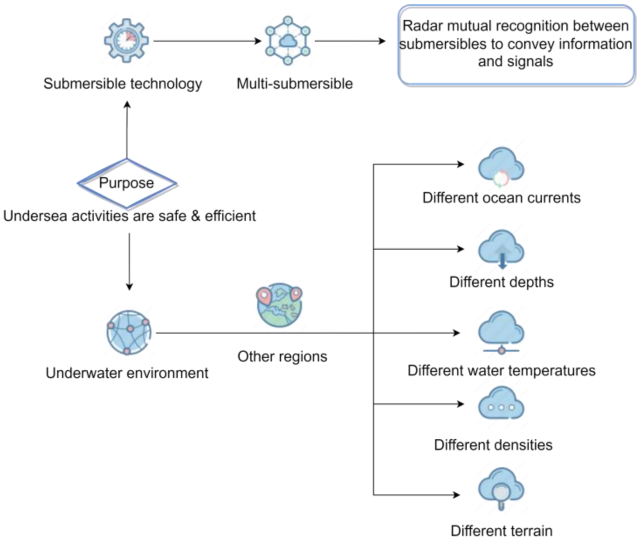

Figure 5: Analysis of the situation of multiple submersibles in the same region

In this paper, the underwater topography is simulated by three-dimensional technology. From shallow to deep, it can be seen that the underwater terrain is not flat, and the submersible needs to pass through layers of obstacles in the process of traveling. Therefore, the performance requirements of the submersible are extremely high, and the restrictions on the search equipment carried by the submersible are also strong, through the comparative analysis of the previous article, combined with the real situation of the waters, carry the most appropriate equipment.

The 3D simulated topography of a particular sea area is shown in Fig. 6 and the contour lines are shown in Fig. 7.

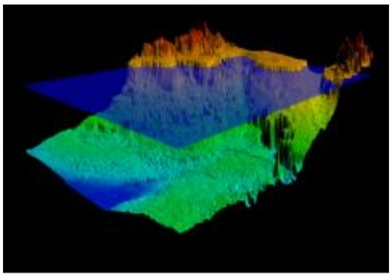

Figure 6: Three-dimensional simulated topographic map of a sea area

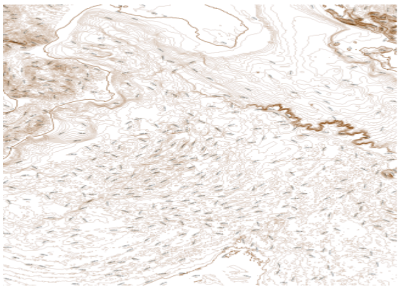

Figure 7: Contour map

As analyzed earlier in this paper, it is known that submersibles are affected by ocean currents, water temperature, water depth, density, and topography. Here in this paper, the positional changes of the submersible due to the effects of ocean currents will be analyzed in depth. When sailing at sea, ships need to take into account the speed and direction of ocean currents in order to find the best way forward, safely and in a time-efficient manner, while saving fuel and thus costs.

The change in position of the submarine under the influence of the current is shown in Fig. 8, and the change in current speed with time is shown in Fig. 9.

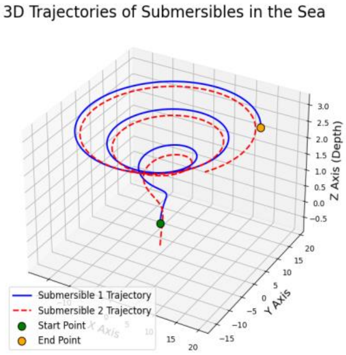

Figure 8: Change in position of a submarine under the influence of ocean currents

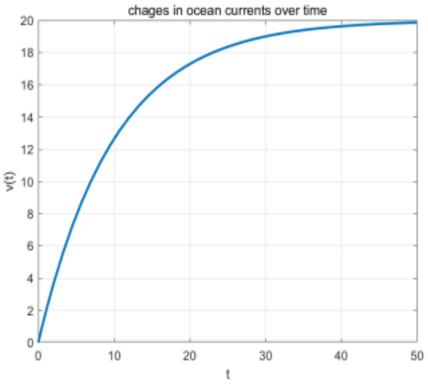

Figure 9: Change in velocity of ocean currents with time

5. Conclusions

By accurately constructing a 3D map of a certain sea area and utilizing Markov chain-based Monte Carlo simulation techniques, this paper achieves a statistical analysis of the possible locations of the lost vessel and proposes an innovative localization strategy.In this paper, a localization function model is developed to analyze three states of a submarine when it has not lost power, when it has lost power, and when it is under the influence of external factors such as ocean currents.

Incorporating a kinetic model of the search and rescue process, this study crafted a comprehensive model that considers the search patterns of the rescue vessel on the surface (e.g., spiral paths) as well as the kinetic interactions between the rescue submersible and the submersible in distress. The model covers a range of potential rescue scenarios and estimates the likelihood of successful rescue under different conditions, thereby providing theoretical guidelines and strategy options to optimize the actual rescue behavior. In this paper, we generalize the scope of the study to consider multiple submersibles moving in the same area. We also consider the interactions between the submersible devices to understand their positions between themselves and other submersibles through radar identification and sensing information to ensure safety and improve efficiency.

In summary, this study provides a comprehensive solution for submarine rescue, which not only enhances the emergency response capability of MCMS, but also contributes valuable theoretical and practical knowledge to the field of marine search and rescue. The implementation of this solution will effectively improve the efficiency and success rate of submarine rescue and provide scientific guidance and strategy selection for actual rescue operations. We expect the model to play an important role in future SAR work and continue to be optimized to adapt to the ever-changing marine environment and rescue needs.

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