

Research on position prediction of manned sightseeing submarine based on Kalman filter algorithm

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Abstract. Aiming at the safety problem of manned sightseeing submarine, a position prediction method based on Kalman filter algorithm is proposed in this paper. First, the submarine topographic map and current distribution map of the submarine area were generated by ArcGIS software, and a continuous dynamic system model was established, and the influence of current on submarine movement was considered. Secondly, a preliminary algorithm model of the submarine is established, considering the motion state of the submarine in three-dimensional space, and the position of the submarine at different time points is calculated by kinematic formula. Finally, Kalman filter algorithm is used to optimize and predict the preliminary algorithm model, and the probability density map of submarine predicted position is generated by MATLAB programming, so as to realize the accurate prediction of submarine real-time position. The research results of this paper provide a strong support for improving the accuracy of submarine position prediction, and also provide a guarantee for the safe operation of submarines.

Keywords: Manned sightseeing submarine; Position prediction; Kalman filtering; ArcGIS; MATLAB.

1. Introduction

With the development of modern tourism, people's desire to explore the mysterious deep sea is increasing, and the number of tourists seeking excitement and challenge is also increasing. This makes the submarine manned sightseeing project gradually rise in the world, becoming a highlight of tourism. Since the 1950s, countries around the world began to pay attention to the development of underwater tourism industry, and invested in the research of manned sightseeing submersibles to meet people's yearning and curiosity for the underwater world[1].

So far, the manned underwater sightseeing submarine industry has formed a complete industrial chain, including design, manufacturing, operation and other links. However, with the popular development of the project, the safety problem of submersibles has become increasingly prominent. For example, on June 18, 2023, the United States tourist submarine Titan lost contact during the sightseeing submarine wreck, which eventually led to the loss of precious lives of five rich people. The incident was a wake-up call about the challenges that must be overcome to ensure the safety of the tourist submarine program. Therefore, in order to ensure the safety of the tourist submarine project, we must build a model to predict the position of the submersible at all times, and overcome the problems of communication defects and propulsion loss.

Wang zheexing, Li Jun et al. described the positioning and detection methods of underwater robots such as ultrasonic sensor underwater ranging, Lidar underwater ranging, and underwater binocular vision ranging, and elaborated the principles, but lacked practical models to verify the effectiveness of these methods[2]. Considering that the existence of underwater noise causes the final value to change dramatically, Shangchengchao uses Kalman filter to estimate the real value of the distance and Angle between the underwater robot and the marker, and effectively eliminates the uncertainty factors[3]. On the basis of force analysis, Yuan Guang established the nonlinear mathematical model used to verify the algorithm and the time-varying state-space equation required by the paper control algorithm[4]. Through a large number of experiments, the influence of controller parameters on the control effect was analyzed and the controller parameters were determined, which reflected the accuracy of the model predictive control method.

However, the above authors have a common problem, they do not analyze the influence of external parameters of ocean conditions on submersibles, which will cause a misjudgment of the practicality of submersibles. To solve this problem, we found the underground elevation data from the official website of NOAA, which specializes in providing Marine data, applied Arcgis mapping software to simulate terrain, and drew 3D dynamic simulation diagram of ocean current and wind field.

In terms of development prospects, the development of sonar technology is highly complex, and the development of sonar technology in the future will be more refined. At present, the degree of marketization is not high. With the deepening of research and the increasing number of experiments, the technical barriers and talent barriers will be broken in the future to open the marketization. In the future, the submersible manufacturing industry will take safety as the first element, and promote the national government to issue relevant normative documents on the manufacturing of deep-sea submersibles, and regulatory authorities should focus on developing operational norms such as the way and time conditions of deep-sea submersibles.

This paper intends to solve the following problems: The position of submersibles changes over time. In order to reduce uncertainty and improve safety, various information should be sent regularly to the main ship.

The research scheme of this paper is as follows:

(1) The uncertainties caused by the external Marine geographic environment include seabed topography and ocean currents. The submarine topographic map and ocean current distribution map of the Ionian Sea area were generated by Arcgis software.

(2) Develop a position prediction model: based on the generated topographic map, establish a preliminary model and a random walk model with MATLAB software, determine the position of the submarine, and regularly send the horizontal and vertical positions to the main ship; The dynamic prediction method based on physical model and data fusion technology is adopted, and the Kalman filter is combined to make real-time position prediction.

(1) The positioning problem is related to the mechanical defect of the submersible, which makes it located in a neutral buoyancy point in the ocean, increasing the difficulty of search and rescue.

(2) In addition to positioning information, the following information should be regularly sent to the main ship: the horizontal and vertical speed, acceleration, angular speed, and angular acceleration of the submersible.

2. Research Method

It is easy to predict the future position of submersible and reduce the uncertainty of position prediction.

External parameters of the Marine environment around the submersible, such as water pressure, temperature, salinity, current velocity, etc.

Analysis: It is beneficial to predict the position of submersible and reduce the uncertainty caused by environmental changes.

System status: check the integrity and operating status of submersible components, and check the problem of insufficient propeller power.

Analysis: Predict the probability of failure and prevent mechanical failure.

Communication status: communication unimpeded and information intensity between submersible and main vessel.

Analysis: Predict communication delay, missing lost information, and possibility of communication interruption.

According to the transmission of the above information, it can help establish an accurate and reliable positioning model and effectively avoid the risk of accidents. To ensure the transmission of information, the submersible is fitted with some additional equipment.

Positioning system: sonar positioning system, GPS receiver.

Water temperature sensor, speed sensor, water pressure sensor, salinity sensor, flow sensor, underwater camera.

Communication equipment: sonar communication equipment, emergency signal transmitter.

Power plant monitoring equipment, backup propulsion equipment, backup engine.

Remote sensor, remote control equipment.

3. Model Building and Result Analysis

3.1. Description of related concepts

Assuming that the defective submarine would be at a neutral buoyancy point, meaning that the submersible cannot float or sink by its own control, but is always in a state of equal buoyancy and gravity, the submersible could be anywhere in the ocean due to the influence of Marine environment such as ocean currents.

3.2. Analysis of uncertainty factors

The factors affecting the position of submersible mainly include environmental factors, equipment factors and unknown obstacles.

Environmental factors: seabed topography, ocean currents, ocean water density, etc.

Equipment factors on the submersible: mechanical failure of the equipment, measurement errors of the instruments on the submersible (negligible), partial data missing during transmission.

Unknown obstacle: Marine life.

In order to build an accurate model to accurately predict the position changes of the submersible on the timeline, our team conducted in-depth research. We collected and analyzed data on the topography of the Ionian seafloor and ocean currents in the area. These data are crucial to understanding the trajectory of submersibles in the water.

Our team used ArcGIS software to map the topography of the seafloor. As shown in Figure 1 below, this map clearly shows the topographic features of the Ionian Sea. This result provides the basic data for our model, which helps us to better predict the trajectory of the submersible underwater.

We also incorporated these topographic data and ocean current data into the preliminary model we built below. This allows our model to more accurately predict the position of the submersible at different points in time(Figure 2).

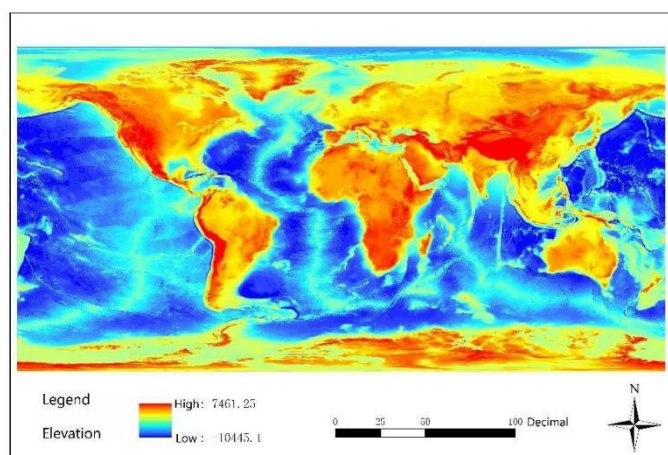


Figure 1. Global topographic map

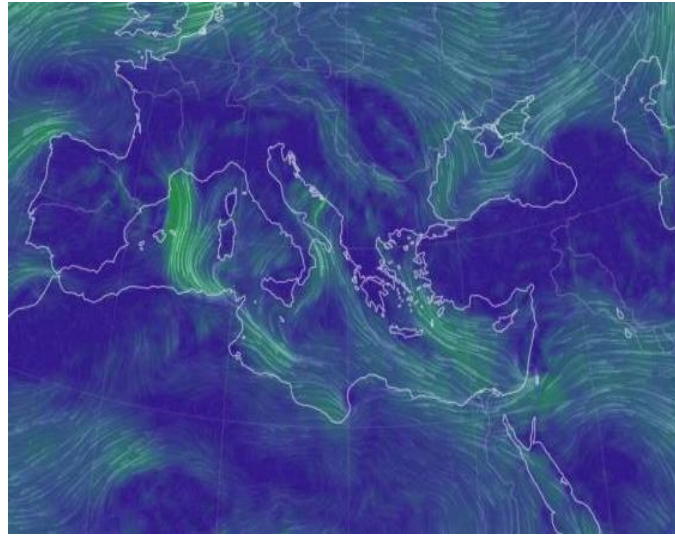


Figure 2. Ocean currents in the Ionian Sea

3.3. Continuous dynamic system model of ocean currents

According to the formula

$$\frac{dv}{dt} = -\alpha v + \beta F \quad (1)$$

Our team built a systematic model that describes the continuous dynamics of ocean currents. In this model, representing the velocity of the current at time t represents the rate of change of the velocity of the current. In addition, α it represents the coefficient of friction, which is used to describe the slowing effect of friction on the speed of the ocean current, and β is the coefficient of the influence of external driving forces on the speed of the ocean current. F represents the external driving force, which can be determined by wind, temperature difference and other factors. To simplify the model, let's assume that F is constant. Through this model, we can better understand the dynamics of ocean currents, and pave the way for better positioning of submersibles below.

The following is the change of ocean current velocity over time in the three-dimensional space generated in MATLAB(Figure 3).

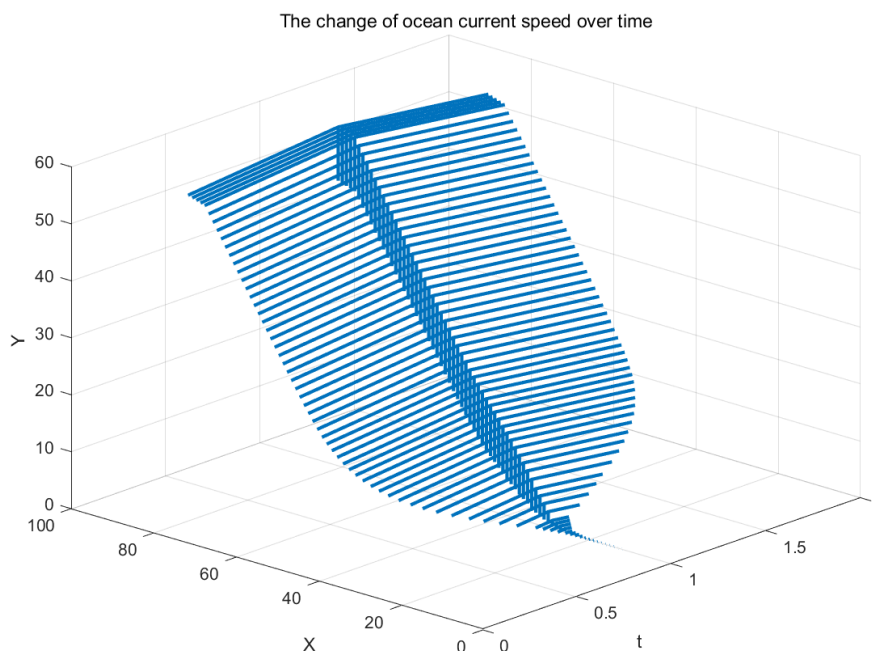


Figure 3. Changes in ocean current velocity over time

3.4. The establishment of preliminary algorithm model

If the submersible is only affected by the Marine environment in the ocean, the equipment factors and unknown obstacles on the submersible are ignored. Since the submersible can be regarded as a particle relative to the ocean, it is necessary to consider the motion state of the point in three-dimensional space:

Position: Establish a Cartesian coordinate system (x,y,z) and treat the submersible as a particle.

Velocity: Velocity is the rate of change of position over time and is also a vector that represents direction and magnitude. In three dimensions, the velocity can be expressed as vx, vy, vz.

Acceleration: Acceleration is the rate of change of velocity over time, again a vector.

Angular velocity: Angular velocity is a measure of the rate at which an object rotates, expressed as a vector.

Angular acceleration: Angular acceleration is the rate of change of angular velocity with time, expressed as a vector.

In the Marine environment, the movement of submersibles is affected by many factors, such as ocean currents, seabed topography, and other Marine meteorological influences. In order to more accurately simulate the motion trajectory of the submersible in the ocean, we first need to set the initial position, initial speed, acceleration, angular velocity and angular acceleration of the submersible.

On this basis, combined with the continuous dynamic system model of ocean currents established above, we introduce a random walk model to simulate the influence of the randomness of ocean currents on the motion of submersible. Random walk model is a kind of mathematical model widely used to describe the motion of particles in fluid. Through this model, we can get the degree of influence of ocean current on the movement of submersible, so as to predict the real-time position of submersible more accurately.

After determining the initial state of submersible and the influence of ocean current, we can use the kinematic formula to calculate the trajectory of submersible in a period of time. The kinematics formula consists of the following two parts:

$$\text{Velocity formula: } v = v_0 + at \quad (2)$$

Including, v represents the speed of the submersible at a given time, v_0 represents the initial speed of the submersible, a represents the acceleration of the submersible, t represents time. Through this formula, we can get the velocity information of the submersible at different time points.

$$\text{Position formula: } x = v_0t + \frac{1}{2}at^2 \quad (3)$$

Including, x indicates the position of the submersible at a given time, v_0 represents the initial speed of the submersible, t represents time, a represents the acceleration of the submersible. Through this formula, we can calculate the position information of the submersible at different time points.

Through the above steps, we can simulate the motion trajectory of the submersible in the Marine environment more accurately. It should be noted that in practical applications, we also need to consider other factors, such as the maneuverability of the submersible, sensor error, etc., to improve the accuracy of the simulation. In conclusion, using the random walk model and kinematics formula, we can provide a more reliable prediction of the motion of the submersible in the Marine environment.

Finally, MATLAB was used to write the code to make the trajectory of the submersible in the three-dimensional space, as shown in Figure 4.

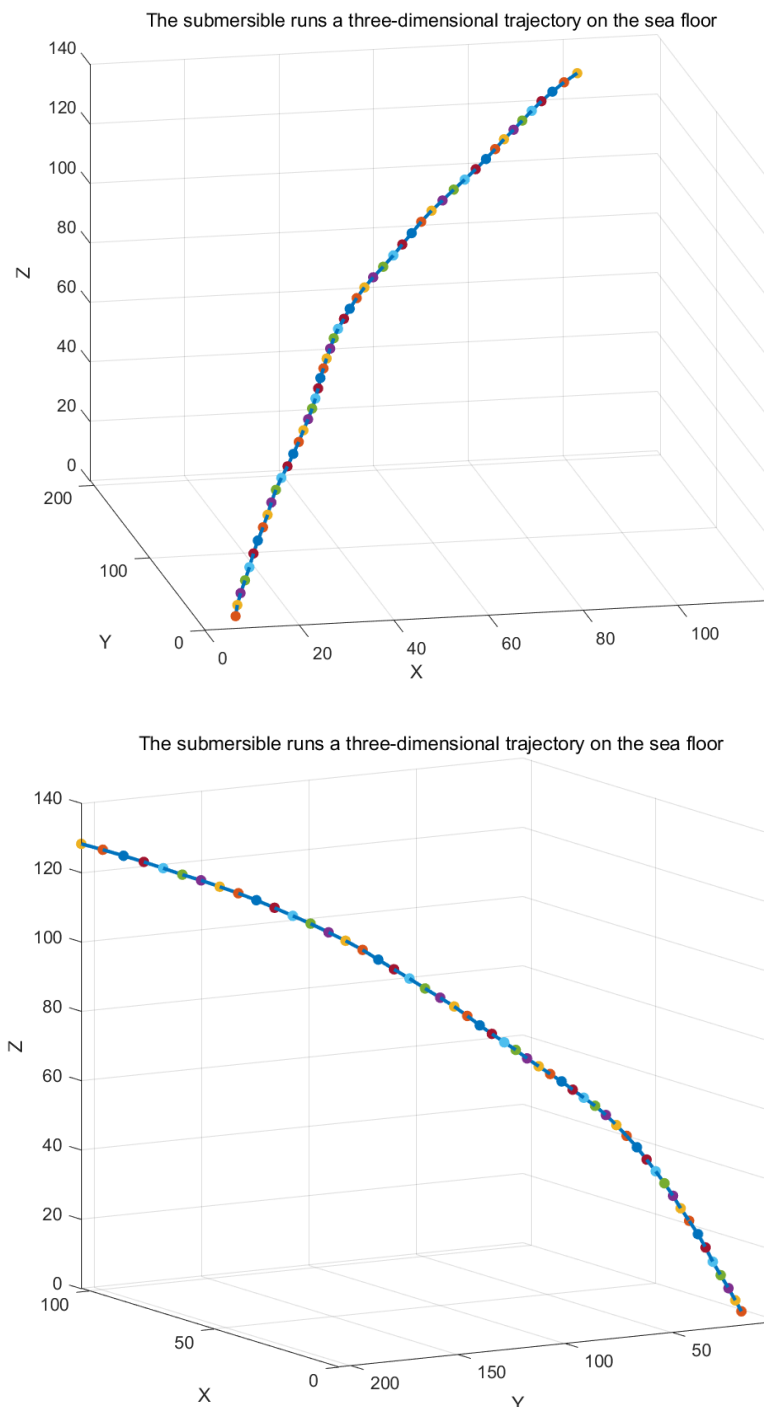


Figure 4. Establish a preliminary model to locate the location of the submersible

3.5. The establishment of Kalman filter algorithm model

In the process of modeling, our team first established a preliminary algorithm model for the motion characteristics of the submersible. The model is built in three dimensions and is designed to capture the movements of the submersible. In order to verify the accuracy and effectiveness of this preliminary algorithm model, our team further adopted Kalman filter algorithm to optimize and predict it.

Kalman filter algorithm is widely used in many fields[5-8]. Its main function is to improve the estimation accuracy of system state through real-time processing of measurement data. In this paper, we use Kalman filter algorithm to predict the state of submersible to evaluate its precise underwater position. Through the continuous optimization and adjustment of the algorithm model, we get a more accurate prediction position of the submersible[9,10].

In order to show the running track of the submersible more intuitively, we use MATLAB programming language to write the relevant code. By calculating the probability density of the predicted location, we generate a visualization. These images clearly show the trajectory of the submersible in the three-dimensional coordinate space, which is helpful for us to analyze and study the motion characteristics of the submersible better.

In MATLAB, by slicing along the Z-axis direction, as shown in Figures 5 and 6, we can more intuitively observe the movement trajectory of the submersible. These images not only validate our preliminary algorithm model, but also lay a foundation for us to further optimize the algorithm model and improve the positioning accuracy of submersible.

In short, in the course of our research, we established the preliminary algorithm model of submersible from the perspective of three-dimensional space, and tested its validity and accuracy through the prediction of Kalman filter algorithm. With the help of MATLAB programming algorithm, we generate the probability density map of the predicted position of the submersible and slice it along the z axis to make it more visual. These research results provide strong support for us to continue to optimize the algorithm model and improve the positioning accuracy of submersible in underwater environment.

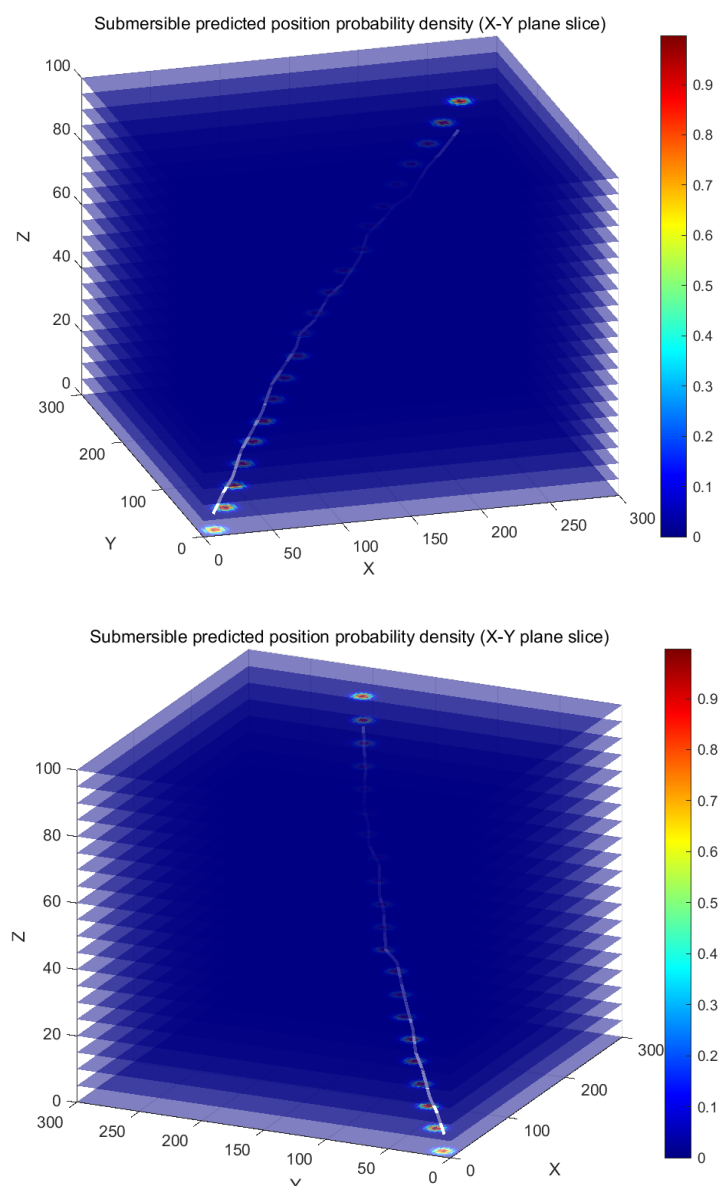


Figure 5. Probability density map of the predicted position of submersible

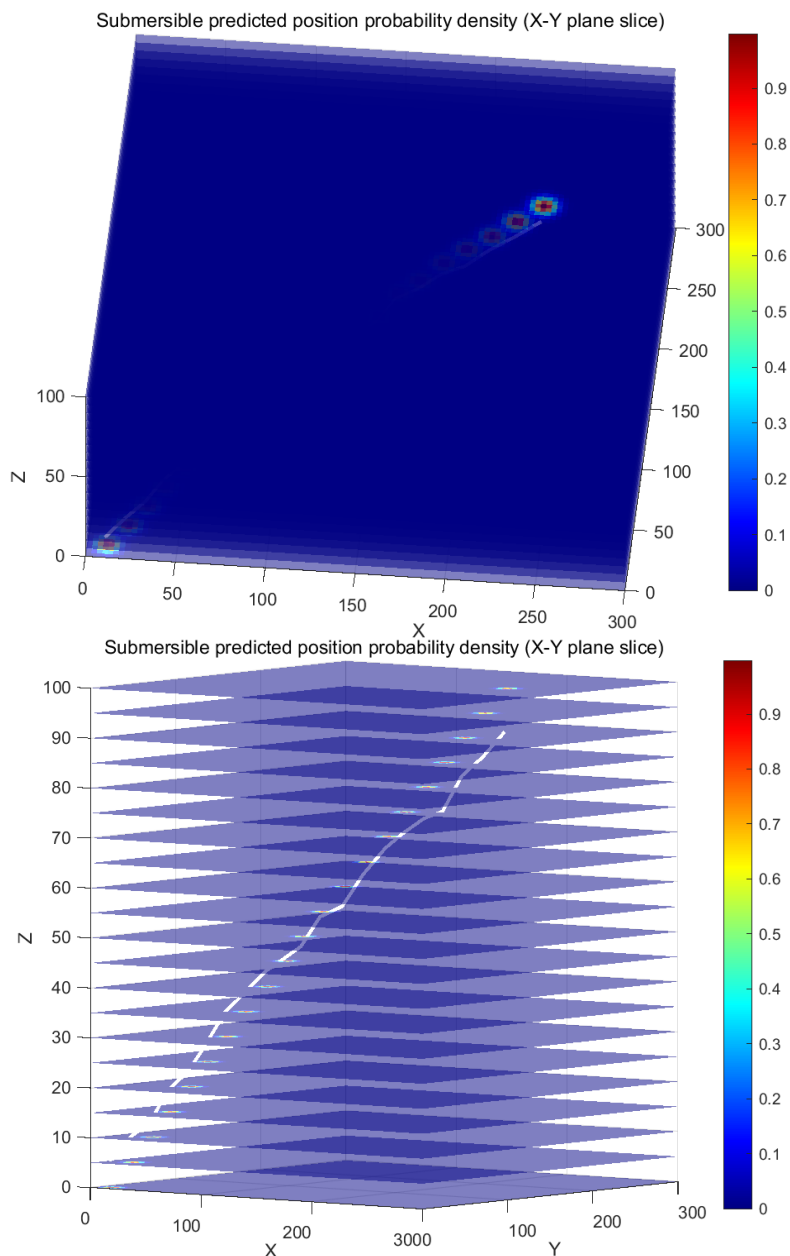


Figure 6. Probability density map of predicted position of submersible

4. Conclusions

Aiming at the safety problem of manned sightseeing submarine, a position prediction method based on Kalman filter algorithm is introduced. In this method, the preliminary algorithm model is established by using the submarine terrain and current distribution map, and the Kalman filter algorithm is used to optimize the model to accurately predict the real-time position of the submarine. The research results help to improve the accuracy of submarine position prediction and further ensure the safe operation of the submarine.

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