Optimization study of underwater long baseline positioning trajectory

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Abstract

With the economic and military development of today’s era, more and more fields have higher and higher requirements for the positioning accuracy of underwater vehicles. In order to solve the optimization of long baseline trajectory smoothing, the intersection algorithm of simplified model and the optimization algorithm based on redundant measurement-Gaussian Newton method are studied, the comparison between Kalman prediction and alpha prediction and smoothing optimization algorithm in the Ca and CV states, and the Kalman filtering, alpha filtering and interactive multi-model (IMM) filtering algorithm in the maneuvering state, simulation experiments show that the IMM algorithm smoothing effect is better, and the Kalman filter algorithm of the CV model has a small error.
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Abstract- With the economic and military development of today's era, more and more fields have higher and higher requirements for the positioning accuracy of underwater vehicles. In order to solve the optimization of long baseline trajectory smoothing, the intersection algorithm of simplified model and the optimization algorithm based on redundant measurement-Gaussian Newton method are studied, the comparison between Kalman prediction and alpha prediction and smoothing optimization algorithm in the Ca and CV states, and the Kalman filtering, alpha filtering and interactive multi-model (IMM) filtering algorithm in the maneuvering state, simulation experiments shows that the IMM algorithm smoothing effect is better, and the Kalman filter algorithm of the CV model has a small error.

Keywords: acoustic base line smoothing algorithm, acoustic positioning system, long baseline smoothing algorithm

I.Introduction

Underwater acoustic positioning technology is the core technology of underwater platform navigation. High precision and robust underwater acoustic positioning system can provide accurate location information for underwater equipment[1], which has important research significance. This paper studies the positioning principle of underwater platform, establishes the mathematical model of long baseline positioning[2], studies the basic positioning algorithm and trajectory filtering algorithm, and simulates and analyzes the performance of the algorithm. The positioning accuracy is improved[3]. Long baseline positioning system (LBL) is to deploy three or more base stations under the water, and the distance between each base station is generally between hundreds of meters and thousands of meters. The latest hipap700 long-range acoustic positioning system is theoretically estimated to have a maximum operating distance of 8000 meters[4], a maximum working water depth of 6000 meters and a positioning accuracy of 12m[5]. Its working mode is generally divided into two types: interrogation response mode and synchronous beacon mode[6]. Compared with short baseline and super baseline positioning systems[7], long baseline positioning system can achieve higher positioning accuracy in a large range, and the advantage of baseline navigation and positioning technology is that its navigation accuracy is independent of water depth, which greatly reduces the impact of water depth on positioning accuracy[8]. However, the disadvantage is that the system composition is relatively complex, the deployment of baseline array needs to consume a lot of cost, and needs to do a lot of correction work, which consumes a lot of time and energy[9]. The latest hipap700 long-range acoustic positioning system is theoretically estimated to have a maximum operating distance of 8000 meters, a maximum working water depth of 6000 meters and a positioning accuracy of 12m[10]. Its working mode is generally divided into two types: interrogation response mode and synchronous beacon mode[11].

II.Long baseline positioning model

For the general positioning system, the error caused by the platform motion is often ignored in the positioning solution[12-14]. After the measured time delay is obtained, it is solved by ball intersection and other methods. And then calculates the position of the platform by geometric method to the working mode of long baseline positioning can be divided into two types: one is query response mode and the other is synchronous beacon mode. In Figure 1, is platform location, indicates the location of the transponder[15-16].

![Fig. 1. Long baseline positioning model](image1)

### III.Simulation analysis

The long baseline positioning system is used to simulate the positioning of surface ships, and three cases are considered respectively. The first is that there is only one transponder to detect the ship three times and locate the ship based on the data obtained; The second is two transponders to locate the ship. The first two methods can only detect the distance of the ship without involving three-dimensional information.

#### A. Positioning simulation and error analysis

Most of them use three transponders to detect and locate the ship and get the specific location information of the ship.

![Fig. 2. Ship trajectory simulation diagram](image2)

#### B. Simulation Kalman algorithm

The simulation set up the platform  for uniform linear motion, the initial position is \((x_0, y_0) = (1000, 1000)\) m. The angle between the motion direction of the platform and the horizontal direction is 45 degrees. The error is caused by Gaussian white noise with standard deviation of 5m. Due to the existence of noise and other errors, there is no solution in individual periods, so it needs real-time prediction. The trajectory is predicted and filtered in real time. The results of Kalman prediction and alpha beta prediction are as follows:

![Fig. 3. Prior filtering and filtering error](image3)

It can be seen from the above figure 2 and figure 3 that the true trajectory and observation trajectory of ship navigation generally show linear characteristics. At the same time, the filtered predicted trajectory and the real trajectory are almost on the same line. At the same time, the error of a priori filtering is always above the filtering error, which shows that the accuracy of real data after filtering is improved and the error is reduced.
Fig. 4. Effect diagram of predicted trajectory

Fig. 5. Prediction trajectory error diagram

Fig. 6. Effect drawing of smooth filtering

Fig. 7. Error diagram of smooth filtering trajectory

Fig. 9. IMM filter trajectory

Fig. 10. IMM filtering trajectory error diagram

C. Smoothing performance of the algorithm

Considering the motion state of platform maneuver, it is divided into three stages. The first stage: 0-200s, set the motion direction. The second stage: 200-280s, set different directions and parameters. The third stage: 280-440s, set to uniformly accelerate linear motion. Carry out different speed allocation processing, and the simulation results are as follows:

D. The filtering effect of IMM filtering algorithm is shown in the figure below:

IV. Conclusion

Based on the long baseline positioning mode, this paper analyzes the results and filtering errors of long baseline positioning under different modes. The comparison of Kalman prediction and alpha beta prediction and smoothing optimization algorithm in Ca and CV state is adopted. It can be seen that the underwater positioning system has better positioning accuracy and long baseline analysis. At the same time, when the vehicle changes speed underwater, the smooth filtering algorithm can effectively reduce the positioning error of the system and improve the accuracy of underwater positioning. Taking a long baseline underwater platform positioning and navigation system as the background, this paper studies the optimization algorithm of long baseline navigation and track smoothing filtering. This paper constructs the original model and simplified model of long baseline navigation. For two working modes, four navigation algorithms are studied, which are nonlinear optimization method, differential evolution method, spherical intersection method and Gauss Newton method. Aiming at the smooth filtering problem of long baseline navigation maneuver state, the adaptive filtering algorithm is studied and applied to the software platform of engineering project. The effectiveness of the algorithm and the stability and reliability of the software are verified by experiments.

V. DISCUSSION

Firstly, aiming at the motion of the platform, the original model of long baseline navigation is established, and the optimization algorithm of solving the original model is studied. Next, the oblique distance correction algorithm is used to simplify the original navigation model in the query response mode, and the approximation method is used to simplify the original navigation model in the synchronous beacon mode. The intersection algorithm of the simplified model and the optimization algorithm based on redundant measurement - Gauss Newton method are studied. Simulation results show that the optimization algorithm based on Gauss Newton can use the information of all array elements when the effective array elements are greater than three. Due to the limitation of test conditions, the track calculated by the navigation algorithm may be uneven and discontinuous in the presence of error. Therefore, the track smoothing filtering algorithm is studied. The prediction
performance of Kalman filtering algorithm and alpha beta filtering algorithm is simulated and analyzed. In the maneuvering state, the Kalman filtering, alpha beta filtering and interactive multi model (IMM) filtering algorithms are studied. The simulation shows that the prediction performance of Kalman filtering method is better, and the smoothing performance of IMM algorithm is better when the target acceleration changes greatly. If you want a smoother trajectory, choose the IMM algorithm. If you want a smaller error, choose the Kalman filtering algorithm of CV model.

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