Research on dynamic ocean surface simulation based on 3D sonar image

Menglei Li¹, Hejun Jiang², Yingjiao Rong², Shirui Wang¹ and Ping Sun*¹

¹CSSC Ocean Exploration Technology Institute Co., Ltd., Wuxi, Jiangsu, 214135, China
²Science and Technology on Near-Surface Detection Laboratory, Wuxi, Jiangsu, 214035, China
*Corresponding author’s e-mail: csscoeti@csscoeti.com

Abstract. The motion state of the ocean surface is changeable and has special irregularity. It is impossible to describe these characteristics in detail, which leads to the low accuracy of simulation for the sea surface. A simulation method of realistic dynamic ocean surface based on 3D sonar image algorithm is proposed. The number of adjacent points iteration of two adjacent images is calculated, and all the dynamic shallow surface sonar images are matched and combined. According to the edge coordinate information between the nearest adjacent images, the overlapping part between the two sonar image frames is analyzed. The two frames of sonar images beyond the threshold range of overlap are registered by ICP algorithm. The simulation of the dynamic ocean surface with the statistical model and FFT based wave generation method is carried out. The simulation results show that the research method of 3D sonar image algorithm is more accurate and can achieve more real simulation results.

1. Introduction
Ocean simulation system is widely used in the construction and decision-making of shipping, ocean engineering, development of marine resources, marine transportation and other systems [1-3]. In the process of using ocean visual simulation system, it is difficult to accurately describe the real dynamic ocean surface due to the diversity of ocean surface changes. Some scholars apply convolution back projection algorithm to the process of dynamic ocean surface simulation, and describe the ocean surface according to the principle of three-dimensional inversion formula. This method is not real enough in practice [4]. Others propose dynamic ocean surface simulation method based on irregular algorithm [5]. This method realizes the ocean surface simulation through two-dimensional reconstruction of the dynamic ocean surface space, which has strong adaptability, but has the problem of large real-time interaction error. This research will explore the solution to these problems.

2. Principle of ocean surface dynamic simulation
Due to the influence of tides, tsunamis and other factors, waves will form on the surface of the ocean. The effect of wind can also lead to changes in the ocean surface. Ocean surface simulation involves two main parameters, one is to determine the range, and the other is to set the highest resolution. In the simulation process, assuming that M represents the number of low resolution ocean surface image frames, the super-resolution model can be obtained according to equation (1).
\[ L_k = DB_k^{(2)}M_kB_k^{(1)}H + N_k, \] (1)

where, \( H \) is the unknown original high-resolution dynamic ocean surface image, and \( L_k \) is the low resolution dynamic ocean surface image observed in each frame.

According to the detection range of sonar, the horizontal calculation sea area is divided into uniform grid with longitude and latitude as the division standard, and the dynamic layered step size is set in the vertical direction according to the characteristics of the sea area to establish the three-dimensional grid framework of the water body. In this paper, the finite difference method is used to discretize the governing equation in the form of grid nodes on the three-dimensional frame. The value of function variable is assigned to the grid nodes, and the derivative of the variable is replaced by the difference quotient of the function value on the nodes. The differential relationship between the variables of the governing equation is transformed into the algebraic relationship among the finite grid nodes, and then the three-dimensional ocean numerical model is established.

3. Optimization method of dynamic ocean surface simulation

Aiming at the problem of large real-time interaction error caused by the inability to describe the changes of ocean surface in detail in the process of dynamic ocean surface simulation, a dynamic ocean surface simulation strategy based on 3D sonar image algorithm is proposed.

3.1. Optimal registration of sonar image

In the process of realistic dynamic ocean surface simulation, the iteration times of adjacent points of two adjacent ocean surface images are calculated, and all sonar images of ocean surface are matched and combined interactively. According to the edge coordinate information between the adjacent image frames, the stacking part between the two sonar images is determined, two ocean surface sonar images beyond the overlap threshold range are registered by the classical ICP algorithm. The specific process is as follows.

We will calculate the number of iterations of adjacent points as equation (2) and equation (3).

\[ q_j = \begin{bmatrix} u_j & v_j & w_j & s_j \end{bmatrix}, \] (2)

\[ \min \sum_{i=1}^{N} \left\| x_i - (Ry_j + t) \right\|^2, \] (3)

where, \( R \) is the 3x3 rotation matrix, \( t \) is the 3x1 translation vector, and \( N \) is the number of points.

The fusion steps based on ICP algorithm are as follows.

Step 1. Judge the overlap between two ocean surface sonar images.

\[ \min \sum_{i,j} \left( \text{angle}\left( R'R^{i,j} \left( R^j \right)^T \right) \right) + \left\| R't'^{i,j} + t' - t_j \right\|, \] (4)

Step 2. Registration of two ocean surface sonar images.

Symbols \( i_1, i_2 \) represent two sonar points, which belong to different sonar data frames and have the same position or direction. If the distance represented by \( d(i_1, i_2) \) is less than the threshold, equation (5) can be used to complete the registration of two sonar images on the ocean surface.

\[ d\left(i_1, i_2\right) = \frac{dw_{i_1}dDR_{i_1} + dw_{i_2}dDR_{i_2}}{dw_{i_1} + dw_{i_2}}, \] (5)

To sum up, in the process of realistic dynamic ocean surface simulation, the number of adjacent point iterations of two adjacent ocean surface images is calculated, and all ocean surface sonar images are paired and combined with each other. According to the boundary coordinate information between the most adjacent image frames, the overlap between the two sonar images is judged. Combining with
the classic ICP algorithm, two sonar images beyond the overlapping threshold range are registered, which provides a sound basis for realistic dynamic ocean surface simulation.

3.2. Wave generation method
The statistical model and FFT algorithm are used to generate detailed wave simulation results. Firstly, the wave height at time $t$ is defined as $h(x, t)$, and $x$ represents the point on the horizon. Secondly, the superposition statistical model is obtained by FFT as equation (6).

$$ h(x, t) = \sum_k \overline{h}(k, t) \exp(ik \cdot x), $$ (6)

Processed by FFT we get the height of discrete points at sea level. At time $t$, the amplitude of the wave is as equation (7).

$$ h(x, t) = \sum_k \overline{h}(k, t) \exp(ik \cdot x), $$ (7)

4. Simulation results
In order to prove the effectiveness of the dynamic ocean surface simulation method based on 3D sonar image algorithm, simulation experiments are carried out in the hardware environment: p4 double cores 2.8GHz CPU, 2GB Memory, Window XP OS. The improved algorithm and the traditional algorithm are used to simulate the ocean surface under different natural conditions, and the simulation results of the two algorithms are compared. The comparison results are shown in figure 1 to figure 6.

Figure 1. Simulation of microwave ripples on ocean surface by improved algorithm.

Figure 2. Simulation of microwave ripples on ocean surface by traditional algorithm.

Figure 3. Medium wave ocean surface simulated by improved algorithm.

Figure 4. Medium wave ocean surface simulated by traditional algorithm.
Figure 5. Large wave ocean surface simulated by improved algorithm.

Figure 6. Large wave ocean surface simulated by traditional algorithm.

It can be seen from the figure that the effect of the improved algorithm for dynamic ocean surface simulation is better than that of the traditional algorithm, mainly because the improved algorithm first calculates the number of iterations of adjacent points of two adjacent ocean surface images, and then matches and combines all the dynamic ocean surface sonar images. According to the boundary coordinate information between the most adjacent image frames, the overlapping part between the two sonar images is judged, and the fusion algorithm is used to register the two sonar images beyond the overlapping threshold range, so as to ensure the effect of realistic dynamic ocean surface simulation.

5. Summary
In order to solve the problem of large real-time interaction error caused by the fact that the current algorithms can not simulate the changes of ocean surface in detail, a realistic dynamic ocean surface simulation method based on three-dimensional sonar image algorithm is proposed. Firstly, the iteration times of adjacent points of two adjacent ocean surface images are calculated, and all the dynamic ocean surface sonar images are paired and combined with each other. According to the boundary coordinate information between the most adjacent image frames, the overlap between the two sonar images is determined, and the two ocean surface sonar images beyond the overlap threshold range are registered by ICP fusion algorithm. On this basis, the statistical model and FFT based wave generation method are used to simulate the realistic dynamic ocean surface. The simulation results show that the dynamic ocean surface simulation method based on 3D sonar image algorithm has high simulation accuracy and ideal effect.

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