Improved Method about Particle and Wave Spectrum Modeling Based on the Detection Line

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Abstract. In research field of ocean wave simulation, especially in wave spectrum and the wave direction spectrum, there are irreal problems of narrow and steep in peak of wave and wide and flat in the valley. In this paper, a spectrum of wave synthesis model is proposed which utilizes the Gerstner waveform of wave spectrum combined with LHM direction function to achieve a more realistic simulation of sea surface. In addition, an improved method based on particle and wave spectrum modeling is proposed. In this method, the collision detection technology is used to process the collision between the waves and the ship, and the collision detection algorithm is used to control the number of excitable particles. Experiments demonstrate that the proposed model and method not only have good solution on large-area wave simulation, but also can achieve the realistic effect of forming waves after collision between ships and sea waves.

1. INTRODUCTION
The rise of virtual reality technology has created a new field of research for human-computer interaction, and has enabled many projects to be visually described. Due to restricting about various factors, the simulation of the uncertain marine environment and the simulation of the ship's hull corrosion process in the marine environment have great significance for game development, film production, and naval engineering equipment. The relevant theory and techniques for wave spectrum modeling under different wind levels is introduced by this chapter, and then a solution is proposed, to save the problem of large waves those have narrow and steep peaks, wide and flat troughs, and the effect of ship-wave interactions on crushing waves. An improved method based on particle and wave spectrum modeling is proposed.

2. THE PRESENT SITUATION AND PROBLEMS OF WAVE MODELING METHODS
The wave spectrum modeling method\textsuperscript{[1]} is characterized by a faster modeling speed for large-area waves and more authenticity in sea surface simulation leading to more desirable effect of simulation. Since the one-dimensional ocean wave spectrum simulates the waves by means of a random trigonometric function, the waveform parameters can only be selected based on experience, and the simulated wave effect is neither well controlled, nor can it reflect the wave frequency and wave height of the real wave. The distribution function of the direction\textsuperscript{[2]} of the waves is added to the direction spectrum of the waves, and the influence of the wind on the formation of the waves is taken into account. However, due to the lack of effect of narrow and steep peaks and wide valleys on ocean wave simulations, Gerstner waveforms are introduced in the paper to simulate the sea surface, and the wave spectrum and the LHM direction function are utilized to synthesize more authentic wave effects.

On the other hand, under large-scale sea surface simulations, it is impossible to achieve wave-breaking effects under the interaction between waves and ships. In view of this, collision detection is added on the basis of the original wave simulation method\textsuperscript{[3]}, so that the crushing wave particles formed during the collision between the waves and the ship could not pass through the hull, which is consistent with the actual theory.

3. IMPROVED PARTICLE AND WAVE SPECTRUM MODELING METHOD

3.1. Wave synthesis model based on wave spectrum

According to the afore-said wave modeling analysis, the principle to simulate the waves involves a series of cosine waves with different amplitudes, different frequencies, and wave propagation directions. Therefore, the wave height formula at the instantaneous time point corresponding to a point on the water surface is as follows:

\[ z = z_0 + \sum_{i=1}^{n} A_i \cos[k_i(x_i \cos \theta_i + y_i \sin \theta_i) - \omega t + \phi_i] \]  

Where, \( z_0 \)、\( n \)、\( A_i \)、\( \omega \)、\( k_i \)、\( \theta_i \)、\( \phi_i \) denotes the height of the tide, the number of unit waves, the amplitude, the angular frequency, the wave number, the propagation direction of the wave in the xy plane, and the initial phase angle. The linear wave is applicable for simulating the static sea surface, while the Gerstner wave model can simulate the sea surface with steep peaks and relatively smooth troughs under the action of the wind. According to the principle of the Gerstner wave model, the formula for wave motion can be expressed as:

\[
\begin{align*}
  x &= x_0 + A \sin(kx_0 - \omega t) \\
  z &= z_0 - A \cos(kx_0 - \omega t)
\end{align*}
\]  

Among them, \( k \)、\( \omega \)、\( A \) are expressed as wave number, angular frequency and amplitude.

According to the value of the K*A product, different degrees of steep waves can be simulated, as shown in Figure.1.

![Gerstner waveform](image_url)
By using cycloid wave superposition method to simulate the surface of two-dimensional waves, the formula is as follows:

\[
\begin{align*}
    x &= x_0 + \sum_{i=1}^n A_i \cos \theta \sin \left[ k_i (x_i \cos \theta + y_i \sin \theta) - \omega t + \delta \right] \\
y &= y_0 + \sum_{i=1}^n A_i \sin \theta \sin \left[ k_i (x_i \cos \theta + y_i \sin \theta) - \omega t + \delta \right] \\
z &= z_0 - \sum_{i=1}^n A_i \cos \left[ k_i (x_i \cos \theta + y_i \sin \theta) - \omega t + \delta \right]
\end{align*}
\]

(3)

According to the wave linear wave theory, for deep-water waves there are:

\[
k_i = \frac{\omega_i^2}{g}
\]

(4)

The directional spectrum represents the description of the interior energy of the waves distributed over the wave frequency and direction of the waves. The wave direction spectrum function is

\[
S(\omega, \theta) = S(\omega) \cdot G(\omega, \theta) 
\]

(5)

where, \( G(\omega, \theta) \) signifies the direction function of the directional spectrum and \( S(\omega) \) is the wave spectrum. It can be known from this formula that different wave spectrums and direction functions are combined into different directional spectra. The direction function should satisfy the condition below:

\[
\int_{-\pi}^{\pi} S(\omega, \theta) d\theta = S(\omega)
\]

(6)

Longuet-Higgins, Mitsuyasu direction functions are used in this article

\[
N(S) = \frac{1}{2\sqrt{\pi}} \frac{\Gamma(S+1)}{\Gamma(S+0.5)} \int_{-\infty}^{\infty} x^{S-0.5} e^{-x^2} dx
\]

(7)

Among them, \( N(S) \), \( \Gamma(S) \) and \( S \) respectively represent the normalization factor, gamma function, and the acute angle that controls the distribution of the wave directions. The directional spectrum function is combined with the JONSWAP spectrum to generate a two-dimensional surface wave model to obtain the spectrum.

The formula is:

\[
S_{J-LHM}(\omega, \theta) = S_{J}(\omega) \cdot G_{J-LHM}(\omega, \theta)
\]

(8)

As shown in Figure. 2:

Figure 2. \( S_{J-LHM} \) Spectrogram

3.2 The control method based on Excited-flow particle

According to the wave crushing surface construction method, it can be seen that the movement of the point distributed on the detection line and the linkage between the motion loop transmission detection
lines are applied to detect the corresponding wave crushing situation where the wave surface of the sea wave reaches different detection point positions. A detection bounding box is formed on the whole hull using the hull grid distribution detection network. The grid height of the bounding box from top to bottom is divided into different levels, and the wave crushing surface detection line corresponds to its wave breaking situation. In accordance with the different wave conditions of wind, combined with the different height of the detection line of the hull bounding box, the jetting effect of different particle sizes is stimulated so that the effect of the wave splashing is more realistic during the collision between the simulated sea wave and the ship. The hull bounding box detection line and the wave crushing surface detection line coincide with the schematic diagram of the excited agitation flow particle, as shown in Figure 3.

Figure 3. Detection of hull bounding box detection line and broken wave surface detection line

The number of crushing particles generated by the crushing of waves under different wind forces needs to be controlled. The a, b, c and d represent the excited excitatory flow particles with different wave surfaces reaching different positions. The method can give rise to the wave crushing effect. The mutual detection is performed between the detection line \( L_0 \) of the surf wave surface and the height of the detection line \( L_a, L_b, L_c, L_d \) of the hull bounding box. When the wave detection line of the surf reaches the range of different detection lines of the hull bounding box, different levels of excitable flow particles can be triggered. The combination of collision detection of broken wave particles and obstacles makes it impossible for the particles to pass through the hull.

3.3 Particle and obstacle collision detection method

In order to better detect the water particles, the obstacles are described by a set of polygons. Applying a regular polygon to the surface of the obstacle can facilitate the detection of collisions between water particles and obstacles. After colliding the waves with obstacles, whether the water particles collide with the polygon during the movement process is detected. Further integrating the actual movement of the water particles with the actual movement after the collision of the waves, it fundamentally translates into the problem of detecting whether the movement path of the water particles will collide with the polygon during the movement for a period of time.

The trajectory of the wave water particles at different moments can be represented by the initial position of the particle, the velocity vector and the time step. As the time step of the wave particles is rather short, the problems related to the collision detection between the wave particles and the obstacles are converted into the detection problems of the line segments intersecting the polygons.

Whether the collision between the wave particles and the obstacle is judged as follows:

1. By calculating the dot product of the variation \( P \cdot P \) of the position of the particle within a short period of time and the plane normal vector \( n \), and the vector \( P \cdot P \) and plane method of the particle at any point in the plane from the initial position of the particle to the detection triangle and the product of the vector \( n \), the positive and negative values of the dot product can be calculated. If the dot product result is positive, the wave particle will intersect with its triangle face, and if the value is negative, it will not intersect with its triangle face.

2. The ray triangular intersection algorithm proposed by Moller is introduced to determine whether the ray and the triangular surface where the wave particles are located intersect at a certain time interval within a given time interval. The specific method is as follows:
(a) Assuming that the starting position of the ray is \( P \), the vector is \( V \), and the time \( t \) is greater than or equal to 0, any point on the ray can be marked as: \( P = P + tV \).

(b) Let \((w,u,v)\) be the coordinates of the center of gravity of the triangle, then in the range of this triangle, \( P \) can be expressed as: \( P = wV + uV + vV \), where the sum of \( u,v,w \) is 1, \( V,V,V \) means three Vertex coordinates.

(c) Substituting the ray equation to the triangular row formula yields:
\[
\overrightarrow{P_0} + t\overrightarrow{V} = (1 - u - v)\overrightarrow{V_0} + u\overrightarrow{V_1} + v\overrightarrow{V_2}.
\]
The values of \( t, u, \) and \( v \) can be calculated using the Cramer method. The conditions that the intersection points need to satisfy within the triangle are: \( u \leq 1, 0 \leq V \leq 1, 0 \leq u + v \leq 1 \).

According to the above judgment method, if the ray of the particle's motion path intersects with the triangular face, the intersection point of the returned ray and the triangular face can be calculated, as shown in Figure 4. The corresponding coordinates of the intersection point \( O \) can be obtained by \( t, P \) and the defined ray vector in the previous step. After that, the relationship between the distance \( P_o \) from the original position of the particle to the intersection point, and then the distance \( P_oP \), from the particle at a certain moment in time are further compared. If \( P_o \) is less than \( P_oP \), the wave particles intersect with the triangle. Finally, the variation of the acceleration, velocity, and position after the collision of the wave particles can be derived.

After the particles collide with obstacles, they begin to move in different directions, as shown in Figure 5. Let the normal vector of the obstacle surface regular polygon be \( \vec{n}, \vec{p}, \vec{P} \), \( \vec{P} \) be the position of the particle at time \( t \) and \( t + \Delta t \), and the particle's running speed at \( t + \Delta t \) will be \( V_{t+\Delta t} \). In order to improve the calculation accuracy, the improved Euler method is applied. This method can achieve second-order accuracy. The improved position expression for calculating the particle motion to the next moment is:
\[
P_{t+\Delta t} = P_t + \frac{1}{2}(V_t + V_{t+\Delta t}) \cdot \Delta t
\]
so that the trajectory of the particle during collision is more realistic and simultaneous, it is also more in line with kinematic theory.

Finally, combining the \( S_{\omega,\theta}(\omega,\theta) \) wave direction spectrum with the wave effect formed by the excitable flow particles under the wave breaking detection line, and the collision detection between the wave particles and the ship, the simulation results of a relatively realistic ocean environment are formed.
4. EXPERIMENTAL RESULTS AND ANALYSIS

The experimental environment of this article is as follows: The computer hardware environment is: Intel(R) Xeon(R) E5-1620 V3 (3.50GHz), Quad core, 8.0GB memory, Nvidia Quadro k620 2.0G; Computer application software environment: Windows7 64-bit system, Matlab R2012b, Unity 3D 5.5.1.

According to the ocean wave spectrum method and the sea wave synthesis method improved by the directional spectrum in the paper, the wave surface effect generated by this method is simulated by Matlab. The a and b directions are 0 degrees and the wind speed is 4, while the c and d are 90 degrees and the wind speed. Following a comparison of the 10 wave simulation results, the simulation results are shown in Figure.6.

(a) Wave spectrum method     (b) Method of this article

(c) Wave spectrum method     (d) Method of this article

Figure 6. Comparison of wave spectrum method and method simulation

Through the analysis of Figure.6, the effect of sea wave spectrum wave simulation under different direction angles and different wind speeds, the sea wave's peak and wave peak density also grow as the wind speed increases. In the process of simulating the ocean wave, applying the wave effect of the superposition of different unit wave numbers will affect the frame rate of the ocean wave simulation, as shown in TABLE I. With the same wind speed, length of wind area, and number of grids, the average drawing frame rate will decrease with the increase of the number of unit waves.

Table 1. scene simulation frame rate.

| Same sea wave condition sample | Unit wave number | Resolution (frames) | Average frame rate (frames/second) |
|-------------------------------|------------------|---------------------|----------------------------------|
| 1                             | 16               | 256 x 128           | 85                               |
| 2                             | 52               | 256 x 128           | 31                               |
| 2                             | 16               | 256 x 128           | 80                               |
| 2                             | 52               | 256 x 128           | 28                               |

Different resolution grid numbers are adopted, that is, by using the CPU real-time dynamic computational grid method in the selection of number of 180 unit waves, the average drawing frame rate (FPS) and the CPU share rate for the ocean wave drawing are respectively the same as the time. The efficiency is then compared, as shown in Figure.7 and Figure.8.
Figure 7. Relationship between grid resolution and average drawing frame rate

Figure 8. Relationship Between CPU Share and Consumption Time

According to the data analysis in Figure 7 and Figure 8, the resolution of 180 grids and 512*384 are utilized to approach the system's operating limit. The different wind speeds and direction angles in the wave scenario to be simulated are set by \( f_{\text{wave}}(\omega, \theta) \), and the appropriate 120 grids and 256*192 resolutions are applied simultaneously, and the average frame rate and CPU share satisfying the simulation effect are achieved. Real simulation modeling of waves.

Figure 9 shows the effect of modeling and modeling of ocean waves at different wind speeds, different direction angles, and a suitable number of unit waves.

(a) Directional angle: 0, wind speed: 4 (b) Directional angle: 90, wind speed: 4
(c) Direction angle: 0, wind speed: 10 (d) Directional angle: 90, wind speed: 10

Figure 9. Directional spectrum of different direction angles and wind speed

Based on the improved particle and wave spectrum model in the paper, Q controls the intensity and quantity of the excitable stream particle emission with the detection line based on the wave spectrum synthesis method. After collision between the waves and the ship, Q makes the particles conform to different The effect of colliding with the waves under conditions is shown in Figure 10.
5. CONCLUSION
The mainstream wave modeling method and wave breaking modeling method are studied in this paper, and a modeling method based on particle and wave spectrum is proposed. Firstly, the direction spectrum of the waves makes the simulation of the waves more realistic. However, due to the lack of a narrow and steep wave trough and flat effect on the sea wave simulation, the Gerstner waveform is used and the sea wave spectrum and the LHM direction function are used to simulate the sea surface. Experiments show that this method can achieve narrow and steep peaks and wide and flat valleys. Secondly, the collision detection was added on the basis of the original sea wave simulation, so that the crushing wave particles formed during the collision between the sea wave and the ship could not cross the hull, which was in line with the actual theory. However, based on this, particle system was added to simulate the wave breaking the effect of wave-induced waves, and the amount of real-time particle injection was controlled according to the inspection of the waves.

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