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On Visualization Simulation for Generation of Three Dimensional Sea State

Kyoung-Ho Sohn, Jun-Young Bae**, Yong-Min Kim****

*Korea Maritime University, Pusan, Korea
**Graduate School, Korea Maritime University, Pusan, Korea
***Korea Soft Space Inc., Seoul, Korea

3차원 해상상태 생성을 위한 가시화 시뮬레이션

손경호* · 배준영** · 김용민***

*한국해양대학교 교수, **한국해양대학교 대학원, ***한국 소프트스페이스

Abstract : *Recently a ship manoeuvring simulator has been developed by Korea Maritime University. We are desiring to apply the movement of wave to the visual scene of sea state in the simulator. This paper discusses the calculation method and visualization simulation of three dimensional sea state using OpenGL API, and the possibility to apply calculation result to the simulator.*

Key words : *ship manoeuvring simulator, sea state, OpenGL API*

요 약 : 최근에 한국해양대학교에서는 선박조종시뮬레이터를 개발했다. 이에 따라 시뮬레이터에 해상상태를 적용하기위해 노력중이다. 이 논문에서는 해상에서의 파의 움직임을 표현하는 수학모델과 OpenGL API를 이용하여 해상상태의 가시화 시뮬레이션 및 계산 결과의 시뮬레이터에 적용가능에 대해 논한다.

핵심용어 : 선박조종시뮬레이터, 해상상태, OpenGL API

1. Introduction

Ship operation environment has been growing worse than ever. Nowadays ship manoeuvring simulator has been utilized to many kinds of purpose to assess harmonization of ship, environment and human in connection with ship operation problem.

Recently Korea Maritime University has just developed a ship manoeuvring simulator(sohn, 2002). In order to take the movement of waves in the simulator, It has been endeavoring to generate 3 dimensional sea state. Firstly we make an arrangement for mathematical model necessary to irregular sea wave generation. Secondly we carry out numerical calculation of sea waves with the characteristic of ITTC 1978 wave energy spectrum(Lloyd, 1989). Thirdly we deal with a matter of real time visualization simulation of natural sea state, making use of OpenGL API. Lastly we discuss the possibility to apply calculation result to ship manoeuvring simulator.

* 종신회원, sohnkh@kmaritime.ac.kr 051)410-4303
** newthousands@hhu.ac.kr 051)410-4991
*** trueness@kebi.com 017-328-1236

2. Generation of three dimensional sea state

2.1 Mathematical model

The movement of wave is described with the help of Fig. 1. The elevation of regular wave can be expressed as follows.

$$\zeta = \zeta_0 \cos\,(kX\sin\theta_0 + kY\cos\theta_0 + \omega t) \qquad (1)$$

where

ζ : instantaneous wave elevation
ζ_0 : wave amplitude
k : wave number
ω : circular frequency
θ_0 : wave direction from arbitrary reference axis (Y-axis)
t : time

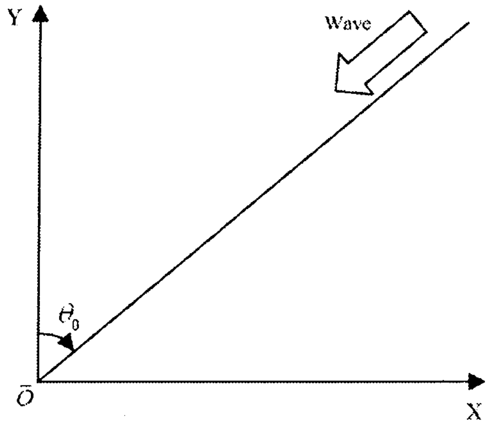

Fig. 1 Coordinate system

Irregular wave may be interpreted as the sum of an infinite number of component regular waves. According to the definition of wave energy spectrum(Lloyd, 1989), the irregular wave elevation may be expressed as follows.

$$\zeta(t) = \sum_{i=1}^{\infty} \sqrt{2S_{\zeta}(\omega_i)\delta\omega} \times \cos k_i X sin\theta_0 + k_i Y \cos\theta_0 + \omega_i t + \varepsilon_i \qquad (2)$$

where

$S_{\zeta}(\omega)$: one-dimensional spectrum

$\delta\omega$: frequency band width

ε : random phase angle $(0 \le \varepsilon \le 2\pi)$

i : sequence number of component waves $(i=1,\ 2,\ 3,\ \cdots,\ \infty)$

Next we should consider wave spreading, which means multi-directional irregular waves. We adopt the wave spreading function as follows.

$$f(\theta_i) = \frac{2}{\pi}\cos^2\theta_i\ , \qquad (-\frac{\pi}{2} \le \theta_i \le \frac{\pi}{2}) \qquad (3)$$

where

θ_i : secondary wave angle from primary wave direction(cf. Fig. 2)

Then the elevation of multi-directional irregular waves can be expressed as follows.

$$\zeta = \sum_{i=1}^{N}\sum_{j=1}^{M} a_{ij} \cos k_{ij} X sin(\theta_0 + \theta_i) + k_{ij} Y cos(\theta_0 + \theta_i) + \omega_{ij} t + \varepsilon_{ij} \qquad (4)$$

where

$a_{ij} = \sqrt{2S_{\zeta}(\omega_{ij}, \theta_i)\delta\omega\delta\theta}$

$S_{\zeta}(\omega, \theta) = S_{\zeta}(\omega) \times f(\theta)$

$\delta\theta$: direction band width

i : sequence number of wave directions $(i=1,\ 2,\ 3,\ \cdots,\ N)$

j : sequence number of component waves at the i-th direction $(j=1,\ 2,\ 3,\ \cdots,\ M)$

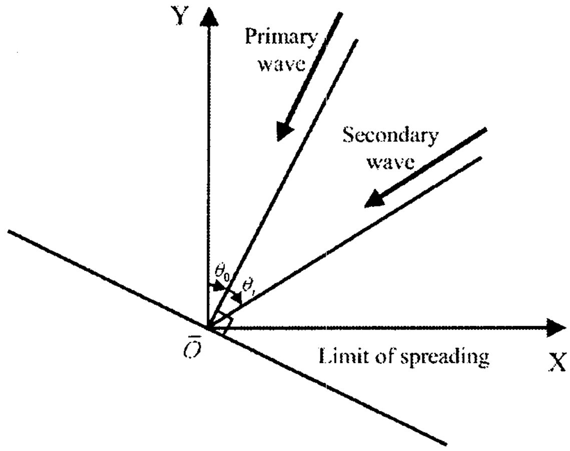

Fig. 2 Multi-directional irregular wave

2.2 Numerical simulation

We adopt ITTC 1978 spectrum as the standard wave energy spectrum, which can be expressed as follows.

$$S_{\zeta}(\omega) = A\omega^{-5} \exp(-B/\omega^4) \qquad (5)$$

$$A = 172.75 \overline{H}_{1/3}^{2} / \overline{T}^{4}$$

$$B = 691 / \overline{T}^{4}$$

where

$\overline{H}_{1/3}$: significant wave height

$\overline{T}$: mean wave period

Fig. 3 shows the ITTC 1978 spectrum curve with Beaufort No. 5, which is the case of $\overline{H}_{1/3}$ = 2.0 m and = 5.46 sec(Lloyd, 1989). In this paper we will simulate the three dimensional sea state with Beaufort No. 5, the spectrum curve of which has been already illustrated in Fig. 3.

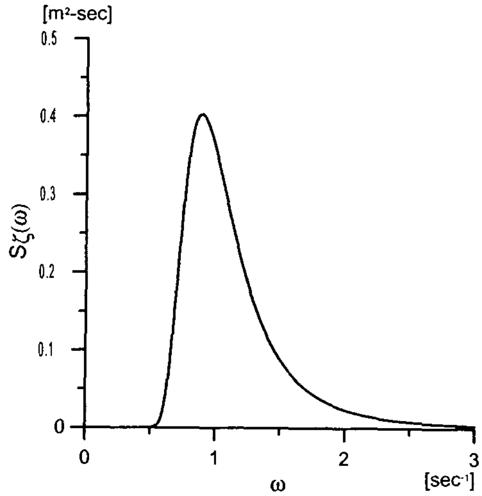

Fig. 3 ITTC 1978 spectrum curve with Beaufort No. 5

The sea area of the numerical simulation is expressed by a number of meshes with 128*128 vertexes, as illustrated in Fig. 4. Adjacent two vertexes are apart from each other by 1 m.

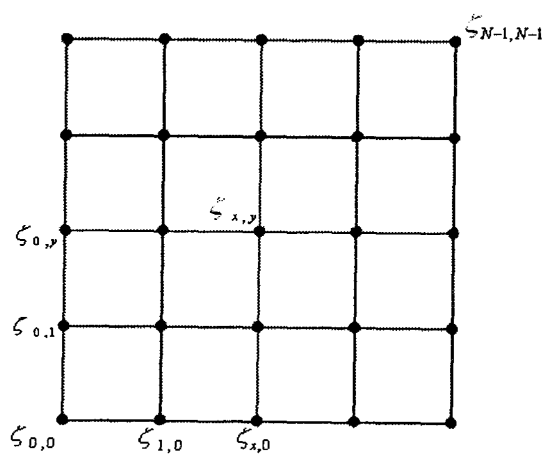

Fig. 4 Meshes for numerical calculation

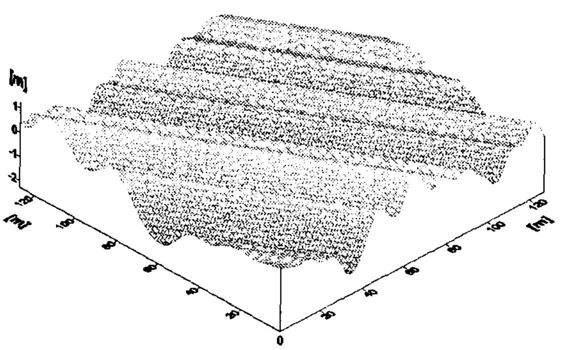

Fig. 5 One-directional irregular wave at some instant (θ_0 = 30 deg)

The results of numerical calculation by Eqs. (2) and (4) are shown in Figs. 5 and 6 respectively. They show one-directional and multi-directional irregular waves at some instant. Fig. 7 shows the instantaneous averages of the third highest calculations of absolute value of double wave elevation at the all vertexes. The calculated result is well agreed with original input data, namely $\overline{H}_{1/3}$ = 2.0 m.

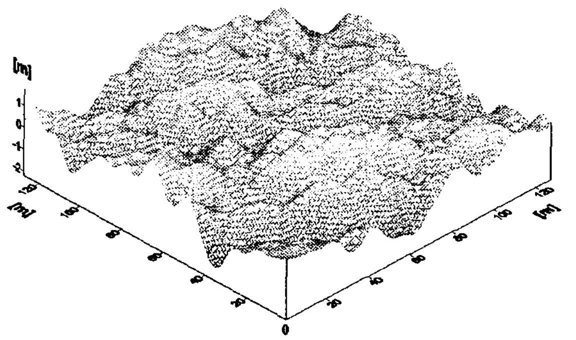

Fig. 6 Multi-directional irregular wave at some instant (θ_0 = 30 deg)

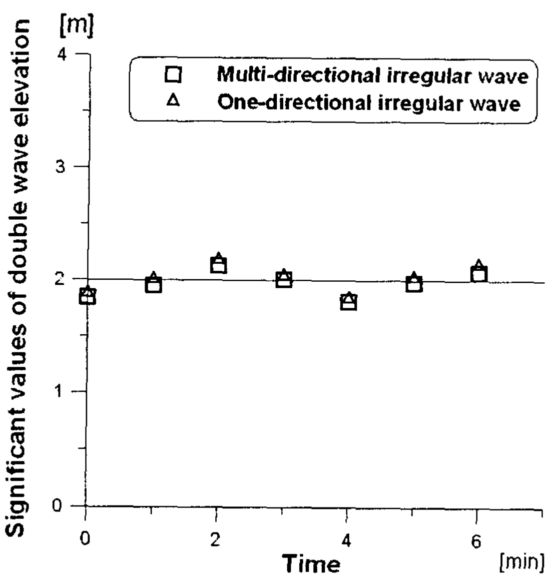

Fig. 7 Instantaneous significant wave height contrarily calculated from simulation result

2.3 Visualization of three dimensional sea state using OpenGL API

In this paper we carry out visualization simulation by personal computer with Geforce 3 TI200 graphic card, which is thought to be not only low-priced but also of good performance. Table 1 shows the specification of the computer and the graphic card used in this paper(http://nvidia.com).

Fig. 8 shows the diagram of programming process using OpenGL API. The programming process is as follows. Firstly some public variables and arrangements are initialized. And the function 'Idle' is executed, which calls 'AnimationMyWater' and 'glutPostRedisplay'.

The function 'AnimationMyWater' calculates the wave elevation in each vertex. The 'glutPostRedisplay' is a kind of 'Callback' function. And this calls 'Display' function. Lastly the function 'Display' initializes camera and light. And this calls 'DrawScene' function. The function 'DrawScene' draws a polygon making use of triangle strip method, and textures faces, and refreshes a screen. The function 'Main' calls all the above mentioned functions and the same process is repeated continuously. Making use of triangle strip method has two merits. One is that only 3 vertexes draw the first triangle, and the second triangle can be drawn by just adding another vertex. This process will be continued to draw many other triangles. The other is that computing time will be saved because of the saved number of vertexes and the faster transmission of information from main memory to graphic card[4].

Table 1 Specification of PC and VGA card

CPU	Intel Pentium4 2.4Ghz
Main MEMORY	256 MB
VGA card	Geforce 3 TI200
VGA MEMORY	64 MB
FILL RATE	2.8 Billion
OPERATIONS/SEC	700 Billion
MEMORY BANDWIDTH	6.4 GB/SEC

Figs. 9 and 10 show the result of visualization simulation of three dimensional sea state with texture, namely captured scene of one-directional and multi-directional irregular waves respectively. We can obtain refresh rate of 12 Hz in simulation of one-directional irregular wave but only 1.4 Hz in that of multi-directional irregular wave. It comes from too long calculating time in case of multi-directional irregular wave. The result of multi-directional irregular wave can not be applied to ship manoeuvring simulator because the refresh rate is too slow. But the result of one-directional irregular wave can be satisfactorily applied to ship manoeuvring simulator in consideration of refresh rate of 10 Hz at the minimum in ship manoeuvring simulator(Sohn, 2002). If generation of multi- directional irregular wave is applied to ship manoeuvring simulator, some other appropriate method has to be devised.

3. Concluding remarks

Through the above mentioned study on visualization simulation of three dimensional sea state, the followings can be drawn.

(1) It is practical and useful to generate the irregular waves using energy spectrum.
(2) Visualization simulation for generation of one-directional irregular wave can be refreshed at 12 Hz, which can be satisfactorily applied to ship manoeuvring simulator.
(3) As far as the present method is concerned, visualization simulation for generation of multi-directional irregular wave can be refreshed at only 1.4 Hz, which is too slow to be applied to ship manoeuvring simulator.

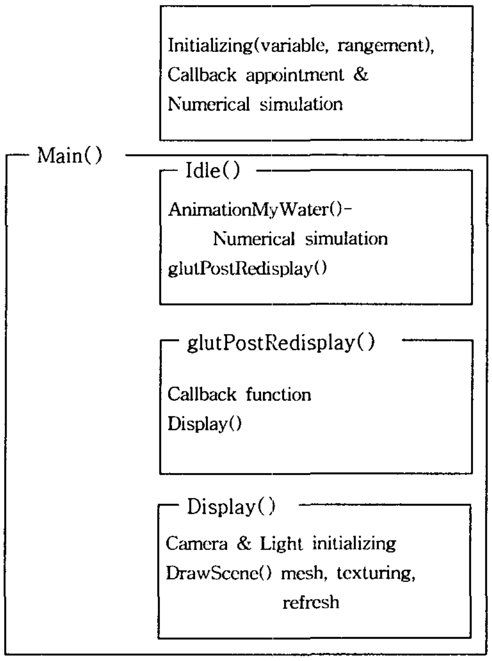

Fig. 8 Diagram of programming process

Fig. 9 Captured scene of one-directional irregular wave with texture

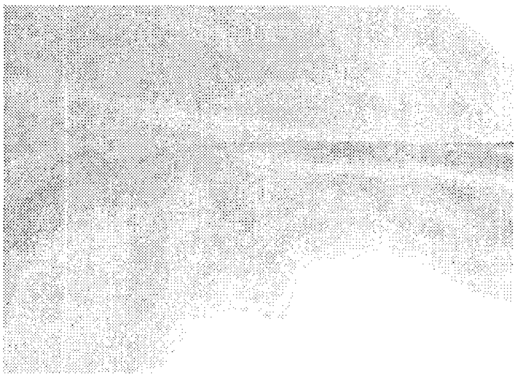

Fig. 10 Captured scene of multi-directional irregular wave with texture

Acknowledgements

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