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System Configuration of Ship-handling Simulator Based on Distributed Data Processing Network

-With Particular Reference to Twin-Screw and Twin-Rudder Ship-

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분산처리네트워크에 기반한 선박조종 시뮬레이터의 시스템 구축에 관한 연구

-2축2타선박을 대상으로-

손경호* · 김용민** · 양승열** · 홍기영***

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요 약

선박조종시뮬레이터는 해기사의 교육 훈련, 항만 수로 설계 시 안전성 평가, 선박설계 시 조종성능의 검토 등으로 널리 활용되고 있다. 본 논문은 최근 한국해양대학교에서 개발한 선박조종시뮬레이터를 소개하고 개발 과정과 활용에 대하여 논의한다. 본 시뮬레이터는 Operation Panel, Instructor's Console, Ship Dynamics Calculation, 3D Bridge View, 2D Bird's Eye View 및 Navigational Indicators의 6 구성요소로 이루어져 있으며, 이를 위해 8대의 퍼스널 컴퓨터가 배치되어 있다. 모든 구성요소들은 효율적인 정보 교환을 위하여 분산처리네트워크 방식으로 연결되어 있다. 또한, 본 논문은 항만내에서의 저속 시 조종운동 수학모델과 가상현실 모델링에 대해서도 논의한다. 마지막으로, 부산항에 대한 2축2타선박의 접안 조종 시뮬레이션 예를 보여주고 있다.

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1. Introduction

Recently the environment related to ship operation has grown worse than ever. It comes firstly from the rapid growth of ship size. The handling of the giant ship is very critical. At the same time, sea traffic is alarmingly tight in harbour area and near the area. Three important things to give an effect on ship operation can be listed as ship's inherent manoeuvrability, quality of seamanship and environmental characteristics of harbour and port. From the viewpoint of safe operation of ship in harbour areas, harmonization or adaptation of above three elements, namely ship, seaman and environment will be desirable. A possible solution to synthetic judgement on the harmonization or adaption of ship operation, is to depend on man-machine system such as ship-handling simulator.

Ship-handling simulator has been widely utilized for various purposes, such as safety assessment, job training of mariners, waterway design, manoeuvrability analysis of new ship at her planning stage and so on. The levels of ship-handling simulator that can be distinguished are suggested by IMSF and are classified into four categories such as Full Mission, Multi Task, Limited Task and Single Task [1].

In the present paper, the details of ship-handling simulator developed recently by Korea Maritime University are described. The simulator is made up of eight personal computers which serve as six functional parts such as Operation Panel, Instructor's Console, Ship Dynamics Calculation, 3D Bridge View, 2D Bird's Eye View and Navigational Indicators.

All the parts are connected with one another by Distributed Data Processing Network System for transmission and exchange of information with high efficiency. The commercial-based graphic and modeling tools are employed to make virtual reality and real time simulation possible. We also discuss mathematical model of ship manoeuvring at low advance speed or at large drift angles with particular reference to twin-screw and twin-rudder ship. Finally the result of real time simulation of berthing manoeuvre in Pusan Harbour is presented. The present simulator system may be utilized for multi task purpose in a laboratory room.

2. System Configuration and Function

2.1 System Configuration

Fig. 1 shows schematic diagram for realization of ship-handling simulator to be introduced. In the present stage, steering wheel, main engine telegraph and tugs are controled in real time in order that captain handles own-ship in harbour areas. Information on navigation is provided for captain by 3D and 2D visual systems and navigational indicator gauges. Of course external environmental effects by wind and current and target-ship's behavior are also taken into account.

Fig. 2 shows the system composition of the present simulator. The system consists of six

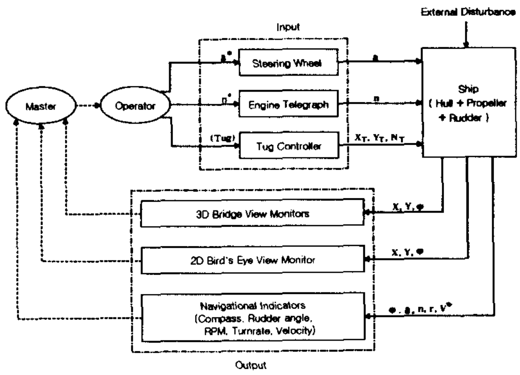

Fig. 1. Schematic diagram for realization of ship-handling simulator

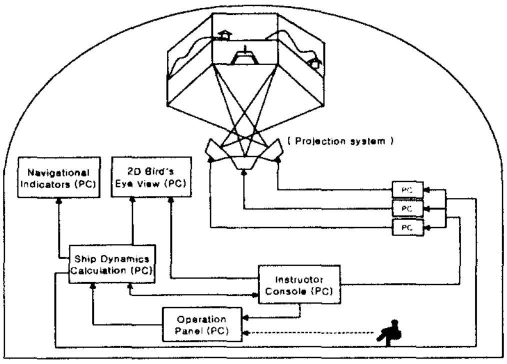

Fig. 2. System composition of present ship-handling simulator

functional parts such as Operation Panel, Instructor's Console, Ship Dynamics Calculation, 3D Bridge View Projection System, 2D Bird's Eye View and Navigational Indicators. Three personal computers and three projectors are employed for 3D Bridge View. Therefore eight personal computers totally are used for configuration of the present simulator.

The distributed data processing network technique is adopted in order that the information data of the functional parts can be exchanged as shown in Fig. 2. There are two network systems using Internet Protocol, in which the information data are transmitted in the form of packets between two applications. They are Transmission Control Protocol(TCP) and User Datagram Protocol (UDP) systems [2]. TCP and UDP provide different kinds of service. TCP provides a highly reliable stream of packets, and so guarantees the accurate data delivery and no error. UDP is a datagram-based protocol that does not always guarantee delivery. The one advantage of UDP is that it requires a minimum of services to move data from one host to another. The adoption of transmission system is dependent upon the applications. We choose UDP for the data transmission from Ship Dynamics Calculation to 3D Bridge View and 2D Bird's Eye View because the quicker service is needed for image generation and renewal. By the same reason, UDP is also adopted between Instructor's Console and 3D and 2D visual systems only when calculation results on target-ship's behavior are transmitted. While TCP is chosen for data transmission between the other parts, in which the higher reliant service is needed than the quicker service.

2.2 Role and Function of Each Part

(1) Operation Panel

Operation Panel part operates rudder, main engine and tug. The operation is performed by steering wheel, engine telegraph and tug controller respectively shown on the monitor with mouse according to the order by captain every moment. Information on the ordered rudder angle, propeller revolutions, and/or tug arrangements and forces are transmitted to Ship Dynamics Calculation. Fig. 3 shows the screen of Operation Panel for twin-screw and twin-rudder ship.

(2) Instructor's Console

Instructor's Console has two main functions. One is to manage the database concerning ships and harbours, and to set the environmental effects such as wind and current, time of day, or weather. The other is to manage target-ships to be controlled. Fig. 4 shows the example of database formats on the screen of Instructor's Console.

(3) Ship Dynamics Calculation

The mathematical model of own-ship's behavior is solved every constant time in the Ship Dynamics Calculation. And information on the calculated results of own-ship's behavior is transmitted to three parts such as 3D Bridge View, 2D Bird's Eye View and Navigational Indicators. In the

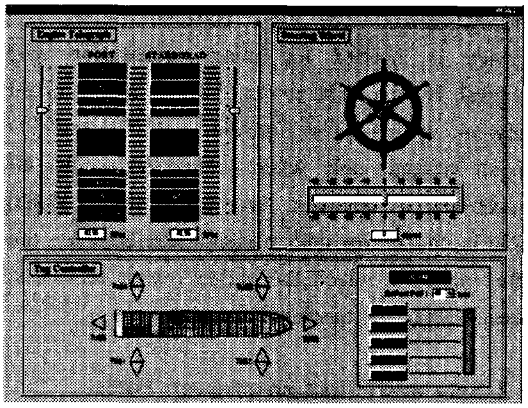

Fig. 3. Screen of Operation Panel for twin-screw and twin-rudder ship

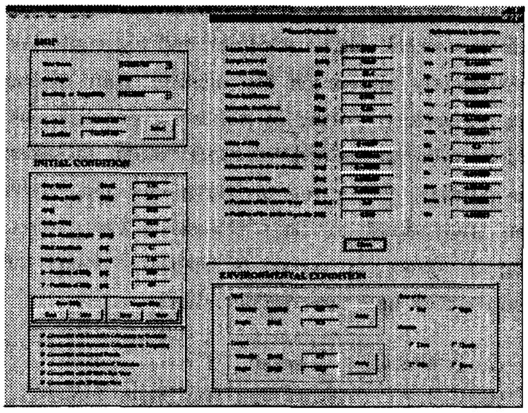

Fig. 4. Database format on Instructor's Console

present simulator, the ship motion is calculated every 0.1 second and information on calculation result is also transmitted to visual systems every 0.1 second as well.

(4) 3D Bridge View

3D Bridge View consists of three personal computers and three projectors, and gives 3D visual image which is the most important for captain to obtain visual information related to ship manoeuvring. 3D visual system includes real time animation of ship manoeuvring behavior in horizontal plane and also that of vertical bow motion as well for high reality. The visual field of each projector screen covers 45 degrees of angle in horizontal and 30 degrees of angle in vertical directions. So total visual field covers 135 degrees of angle in horizontal direction and 30 degrees of angle(10 degrees of elevation and 20 degrees of declination) in vertical direction. The observer's view-point which is specified by coordinate system fixed on ship(body axes), is assumed to be placed at gyro-compass repeater position on longitudinal center line of wheel house.

(5) 2D Bird's Eye View

As shown in Fig. 5, 2D Bird's Eye View provides information on 2D geographical features, and position and track of own-ship and target-ship. The 2D Bird's Eye View can be thought as an alternative of radar function.

(6) Navigational Indicators

Fig. 6 shows navigational information on own-ship's condition, which is depicted in the form of analogue gauges. The gauges consist of heading angle, propeller shaft revolutions, rudder angle, turn rate and velocities. Besides analogue gauges, all information are expressed digitally as well.

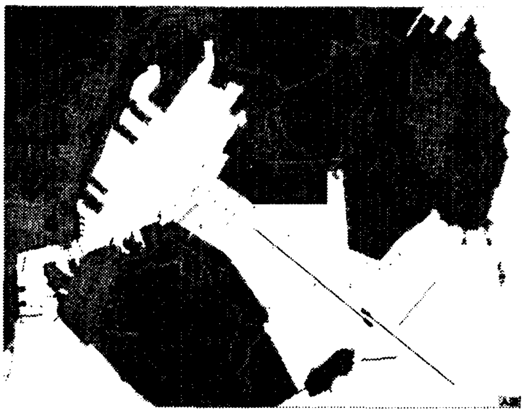

Fig. 5. Screen of 2D Bird's Eye View

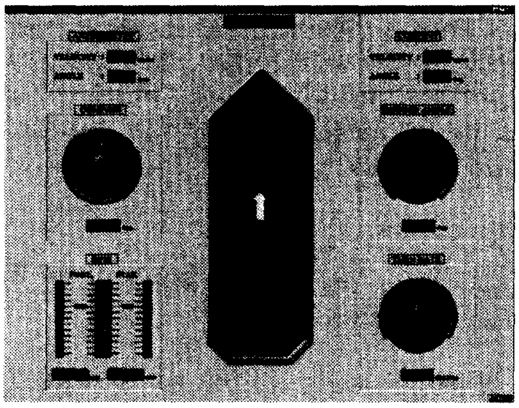

Fig. 6. Screen of Navigational Indicators

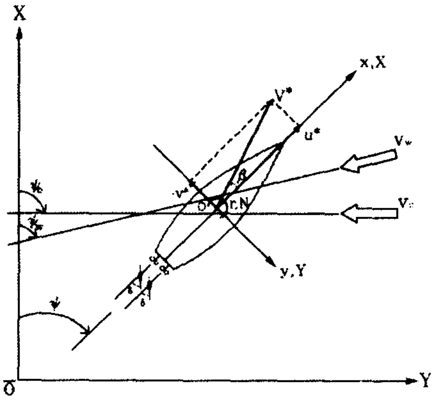

Fig. 7. Coordinate system for describing ship manoeuvring motion

3. Mathematical Model and Virtual Reality

3.1 Ship Manoeuvring Mathematical Model

In general it is customary in manoeuvring studies to consider only the motions in the horizontal plane, namely surge, sway and yaw. Besides horizontal motions, longitudinal motions such as pitch and heave may be requested sometimes for realistic visual scene of the screen of ship-handling simulator. We handle the longitudinal motion separately from manoeuvring motion. To describe the ship motion, a system of body axes($o-xyz$) which are fixed on ship and move relative to space axes($\overline{O}-XYZ$) is employed as shown in Fig. 7. The origin of body axes is located at midship. Following the sign convention of Fig. 7 and assuming that body axes coincide with principal axes of inertia, the basic equations of manoeuvring motion can be written as

$$\begin{aligned} m(\dot{u} - vr - x_G r^2) &= X \\ m(\dot{v} + ur + x_G \dot{r}) &= Y \\ I_{zz}\dot{r} + mx_G(\dot{v} + ur) &= N \end{aligned} \quad \cdots\cdots (1)$$

where m denotes ship's mass, I_{zz} moment of inertia about z axis, u and v denote velocities of ship in x and y directions respectively, r denotes angular velocity of ship about z axis, the dot over parameters of ship motion represents time derivative, x_G distance of the centre of gravity in front of midship. And X and Y denote hydrodynamic forces in the x and y directions respectively, N hydrodynamic yawing moment about midship.

If the added mass and added moment of inertia are taken into account and modular-type model such as MMG model is employed, Eq. (1) will be expressed as follows

$$\begin{aligned} &(m + m_x)\dot{u} - (m + m_y)vr - (mx_G + m_y\alpha)r^2 \\ &= X_H + X_P + X_R + X_T + X_W \\ &(m + m_y)\dot{v} + (m + m_x)ur + (mx_G + m_y\alpha)\dot{r} \\ &= Y_H + Y_P + Y_R + Y_T + Y_W \\ &(I_{zz} + J_{zz})\dot{r} + (mx_G + m_y\alpha)\dot{v} + mx_G ur \\ &= N_H + N_P + N_R + N_T + N_W \end{aligned} \quad \cdots\cdots (2)$$

where the terms with subscripts H, P, R, T and W represent damping forces on hull, propeller forces, rudder forces, tug forces and wind forces respectively, m_x and m_y denote added mass in the x and y directions respectively, J_{zz} added moment of inertia about z axis, and α the distance of the centre of m_y in front of midship.

In order that current forces are taken into consideration, u and v are assumed to be relative velocities to water particles. Then u and v are expressed in terms of absolute velocity components of ship and current velocity as follows

$$\begin{aligned} u &= u^* + V_c\cos(\psi_c - \psi) \\ v &= v^* + V_c\sin(\psi_c - \psi) \\ \dot{u} &= \dot{u}^* + V_c r\sin(\psi_c - \psi) \\ \dot{v} &= \dot{v}^* - V_c r\cos(\psi_c - \psi) \end{aligned} \quad \cdots\cdots (3)$$

where u^* and v^* denote absolute velocities described in space axes $\overline{O}-XYZ$ in Fig. 11. Eqs. (2) and (3) give as follows.

$$\begin{aligned} (m + m_x)\dot{u}^* =& (m + m_y)vr + (mx_G + m_y\alpha)r^2 \\ & - (m + m_x)V_c r\sin(\psi_c - \psi) \\ & + X_H + X_P + X_R + X_T + X_W \\ (m + m_y)\dot{v}^* +& (mx_G + m_y\alpha)\dot{r} \\ =& - (m + m_x)ur \\ & + (m + m_y)V_c r\cos(\psi_c - \psi) \\ & + Y_H + Y_P + Y_R + Y_T + Y_W \\ (I_{zz} + J_{zz})\dot{r} +& (mx_G + m_y\alpha)\dot{v}^* \\ =& - mx_G ur + (mx_G + m_y\alpha) \\ & V_c r\cos(\psi_c - \psi) \\ & + N_H + N_P + N_R + N_T + N_W \end{aligned}$$
$$\cdots\cdots (4)$$

The differential equation Eq. (4) will be solved by computer to predict ship's behaviour.

3.1.1 Hull damping forces

Sohn [3] suggested a mathematical model of hull damping forces at low advance speed and at large drift angles. The model was originally based on Fourier series expansion by Takashina's experiment [4]. In the present simulator we employ the model, which are as follows.

(1) In case ship's speed is not zero

$$\begin{aligned} X_H =& 0.5\rho L d V^2\{X_{uu}' u'|u'| + X_{vr}' v' r'\} \\ Y_H =& 0.5\rho L d V^2\{Y_v' v' + Y_{ur}' u' r' + Y_{vv}' v'|v'| \\ & + Y_{vr}' v'|r'| + Y_{urr}' u' r'|r'|\} \\ N_H =& 0.5\rho L^2 d V^2\{N_v' v' + N_{uv}' u' v' + N_r' r' \\ & + N_{vvr}' v'^2 r' + N_{uvrr}' u' v' r'^2 + N_{rr}' r'|r'|\} \end{aligned}$$
$$\cdots\cdots (5)$$

where ρ is density of water, L and d denote length between perpendiculars and mean draft respectively. And the parameters of ship motion and the hull damping forces are non-dimensionalised as follows.

$$\begin{aligned} u', v' &= u, v / V \\ r' &= r \cdot L / V \\ X_H', Y_H' &= X_H, Y_H / 0.5\rho L d V^2 \\ N_H' &= N_H / 0.5\rho L^2 d V^2 \end{aligned} \quad \cdots\cdots (6)$$

In this model, the low advance speed effects are reflected on some terms in which u' is added. In case of normal advance speed, which is relatively high advance speed, the value of u' becomes almost 1.0, then Eq. (5) exactly coincides with Inoue model [5]. Hirano [6] also suggested the same mathematical model for practical prediction of manoeuvring motion at low advance speed. Mikelis [7] suggested a similar model for prediction of backing motion.

(2) In case ship's speed is zero (turning motion only at the one position)

$$\begin{aligned} X_H &= 0 \\ Y_H &= 0 \\ N_H &= 0.5\rho L^4 d N_{rr}' r|r| \end{aligned} \quad \cdots\cdots (7)$$

The mathematical model expressed by Eqs. (5) and (7) is simple but can be utilized very practically for harbour manoeuvring motion at low advance speed and also for normal manoeuvring motion at relatively high advance speed.

3.1.2 Propeller forces

In the present paper we employ twin-screw and twin-rudder ship. The propeller forces are expressed as follows

$$\begin{aligned} X_P &= (1 - t)(T^{(p)} + T^{(s)}) \\ Y_P &= \Delta Y_P \approx 0 \\ N_P &= (1 - t)(T^{(p)} - T^{(s)})\frac{b_p}{2} + \Delta N_P \\ &\approx (1 - t)(T^{(p)} - T^{(s)})\frac{b_p}{2} \end{aligned} \quad \cdots\cdots (8)$$

where the subscripts (s), (p) represent starboard and port sides respectively, t denotes thrust deduction factor, nk T thrust and b_p distance between two propellers, and ΔY_P and ΔN_P propeller induced sway force and yaw moment respectively. In single-screw case nk ΔY_P and ΔN_P are taken into account in the second quadrant only, namely $u > 0$ and $n < 0$ (n : number of revolutions of propeller per second). While in case of twin-screw ΔY_P and ΔN_P are assumed negligible because the direction of any one propeller is always different from that of the other. Thrust T must cover the whole region of propeller operation, namely four quadrants composed by combination of inflow velocity to propeller and number of revolutions of propeller.

3.1.3 Rudder forces

The rudder forces of twin-screw and twin-rudder ship are expressed as follows

$$\begin{aligned} X_R &= -(1-t_R)(F_N^{(p)}+F_N^{(s)})\sin\delta \\ Y_R &= -(1+a_H)(F_N^{(p)}+F_N^{(s)})\cos\delta \\ N_R &= -(x_R+a_H x_H)(F_N^{(p)}+F_N^{(s)})\cos\delta \\ &\quad -(1-t_R)\frac{b_R}{2}(F_N^{(p)}-F_N^{(s)})\sin\delta \end{aligned} \tag{9}$$

where δ represents rudder angle, F_N rudder normal force, x_R the x coordinate of rudder location, and the coefficients t_R, a_H and x_H are correction factors to adapt the open-water characteristics of rudder to behind-hull condition. F_N is expressed as follows

$$F_N = \frac{1}{2}\rho A_R V_R^2 f_a \sin\alpha_R \tag{10}$$

where A_R is submerged area of rudder, V_R effective inflow velocity over the rudder, α_R effective angle of attack, and f_a lift slope of open-rudder. The expression of V_R or α_R should be slightly different according to manoeuvring condition, namely combination of surge velocity, propeller revolutions and/or slip ratio.

3.1.4 External forces

The wind forces and moment are predicted by Isherwood's regression formulas [8]. The expression of calculation is referred to Reference.

In ship-handling operation near to mooring position, the assistance of tugs is necessary. We assume 6 tugs placed at maximum and tug heading kept fixed at 90 deg with respect to the ship centerline as shown in Fig. 8. The tug forces are expressed as follows

$$\begin{aligned} X_T &= F_{t5} - F_{t6} \\ Y_T &= -F_{t1} - F_{t2} + F_{t3} + F_{t4} \\ N_T &= (F_{t1} - F_{t4})\, l_a + (F_{t3} - F_{t2})\, l_f \end{aligned} \tag{14}$$

where F_{t1}, F_{t2}, ⋯ represent tug forces applied to predetermined position of ship, and l_a and l_f denote distances from midship to applied positions of stern and bow tug forces respectively, of which the values are $0.4L$ together.

3.1.5 Movements of propeller and rudder

The number of propeller shaft revolutions is assumed to respond to the ordered one through the main engine telegraph as follows

$$T_M \dot{n} + n = \begin{cases} n^* & : (n^* < 0 \ \ or \ \ n_i < n^*) \\ n_i & : (0 \le n^* \le n_i) \end{cases} \tag{15}$$

where n^* represents the ordered one through main engine telegraph, n_i the idling one, and T_M the time constant of main engine. The idling number of propeller shaft revolutions, n_i is approximately expressed as follows [9]

$$n_i \approx \frac{0.7\,u(1-w_P)}{P} \tag{16}$$

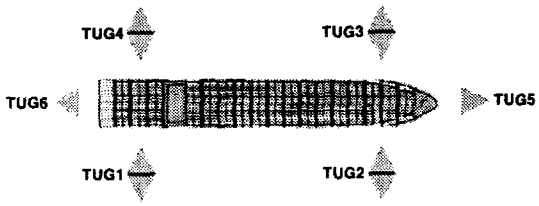

Fig. 8. Towing arrangements

where P represents propeller pitch and w_p wake fraction.

The mathematical model for the dynamics of eletro-hydraulic steering gear is expressed as follows

$$
\begin{aligned}
T_E \dot{\delta} + \delta &= \delta^* \quad : \ (|\delta^* - \delta| \le T_E |\dot{\delta}_{max}|) \\
\dot{\delta} &= sign(\delta^* - \delta)|\dot{\delta}_{max}| \quad : \ (|\delta^* - \delta| > T_E |\dot{\delta}_{max}|)
\end{aligned}
\qquad \cdots\cdots\cdots (17)
$$

where δ^* is the ordered rudder angle, T_E the time constant of steering gear, and $\dot{\delta}_{max}$ maximum rudder rate.

3.2 3D Image Generation and Real Time VR Simulation

It is necessary to generate 3D image database for a large numbers of objects such as geographical features, ships and many others in order to make VR simulation possible. As a 3D modeling tool for this purpose we use MultiGen Creator(MultiGen-Paradigm Inc.) which is based on OpenFlight scene description database format. Fig. 9 shows modeling procedure for 3D image generation of harbour geographical features and ship. Figs. 10 and 11 show the examples of 3D image and hierarchical visual database of Pusan Harbour and ship models. It is the same as above to generatate images of many other objects such as gantry crane, lighthouse, buoy, land scene and so on.

Next we need 3D rendering technique for real time animation. For this application, we use

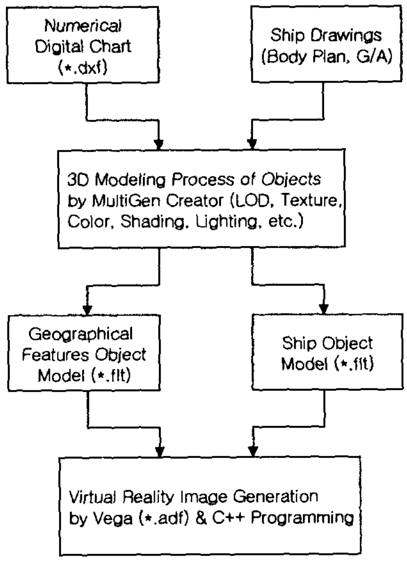

Fig. 9. Image generation procedure for geographical features and ship

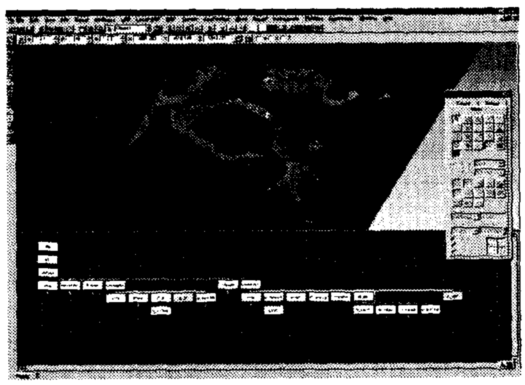

Fig. 10. 3D image and hierarchical visual database of Pusan Harbour model

graphic modeling software Vega(MultiGen-Paradigm Inc) which is based on OpenGL VR modeling. On the basis of OpenFlight file format(FLT file) of object models created by MultiGen, Virtual reality image file denoted as Application Definition File(ADF file) can be generated by Vega. ADF file consists of dynamic(or moving objects such as own-ship or target-ship) and static objects(or fixed objects such as geographical features). Dy-

Fig. 11. 3D image and hierarchical visual database of ship model

namic objects can be movable in real time according to information on own-ship or target- ship's position and heading angle calculated in real time. Vega also has many other rendering functions such as setting visible environment effects.

4. Real Time Simulation Example

We introduce one example of berthing manoeuvre in Pusan Harbour using the present simulator. Middle class container ship with twin-screws and twin-rudders is chosen for own-ship and target-ship as well. Principal particulars of the ship are given in Table 1. Manoeuvring operation is performed every moment with visual information system consisting of 3D and 2D Views and Navigational Indicators.

Simulation scenario is that the pilot gets on board ship a little bit outside from breakwaters of Pusan Harbour in order to make the ship alongside Chasongdae Container Wharf. Initial approach speed of the ship is 5.96 *kt* (dead slow ahead) at near the breakwater, and her heading is faced toward the passage inside breakwaters. As external environment effects we assume absolute wind speed(V_W) of 10 *m*/sec at the angle(ψ_W) of 45 deg and current speed(V_c) of 0.5 *kt* at the angle(ψ_c) of 180 deg.

Table 1. Principal particulars of twin-screw twin-rudder ship

Hull			
Length over all	L_{OA}	(m)	188.0
Length bet. per.	L_{pp}	(m)	175.0
Breadth	B	(m)	25.4
Depth	D	(m)	15.4
Draft	d	(m)	8.5
Trim	τ	(m)	1.0
Block coef.	C_B		0.559
Prismatic coef.	C_P		0.58
Distance between 2 propellers			0.3B
Angle of bossing to horizontal		(deg)	90
Radius of gyration about z-axis	k_z / L_{pp}		0.24
Longitudinal center of gravity from midship	x_G / L_{pp}		-0.018
Twin-rudder			
Area	A_R	(m^2)	13.345
Height	H	(m)	5.44
Aspect ratio	λ		1.833
Area ratio	A_R/Ld		1/55.73
Twin-propeller			
Diameter	D	(m)	4.6
Pitch Ratio	P/D		1.055
Expanded area ratio			0.73
Number of Blades			5
Turning direction (looking from stern)			outboard

Fig. 12 shows initial bridge view at the position near breakwaters of Pusan Harbour entrance where the pilot gets on board ship. Fig. 13 shows actual front-view from bridge mock-up of present simulator. Near to the mooring position at Chasongdae Container Wharf the assistance of 2 tugs(bow and stern tugs) are given. The Fig. 14 shows bridge view of mooring at the Wharf. Fig. 15 shows the 2D display of tracks of own-ship

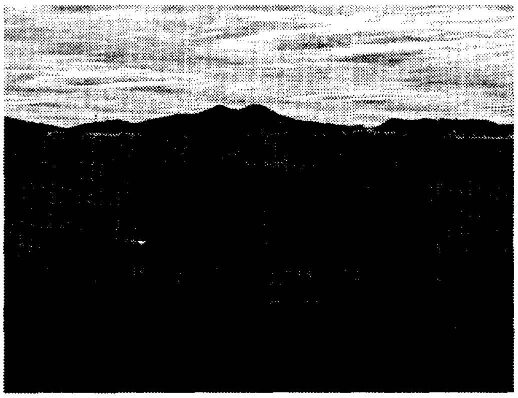

Fig. 12. Captured 3D view from bridge of the ship at the position near breakwaters of Pusan Harbour entrance, where the pilot gets on board ship

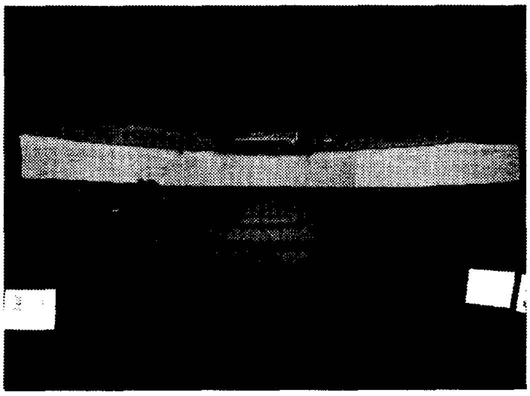

Fig. 13. Actual front-view from bridge mock-up of present simulator

Fig. 14. Bridge view of mooring at Chasongdae Container Wharf of Pusan Port

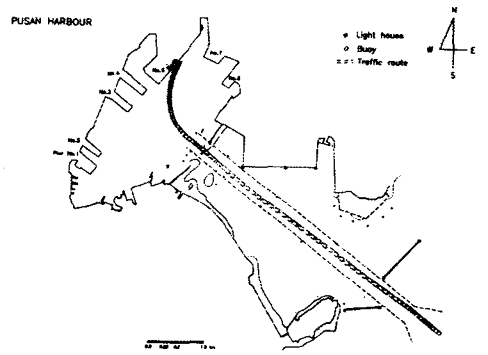

Fig. 15. 2D Display of tracks of ownship during berthing manoeuvre

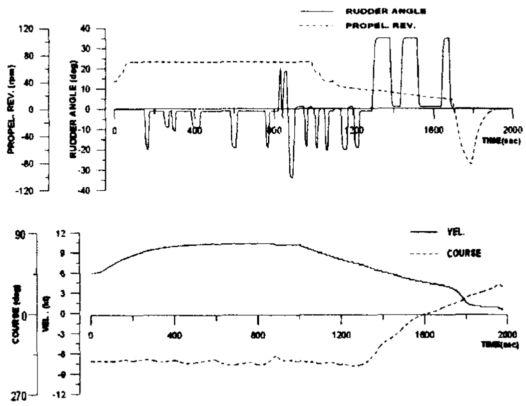

Fig. 16. Time histories of motion parameters of own-ship during berthing manoeuvre

and target-ship during berthing manoeuvre. Fig. 16 shows time histories of motion parameters of own-ship during berthing manoeuvre.

5. Concluding Remarks

In this study a ship-handling simulator for multi task purpose in a laboratory room has been developed and introduced. The simulator consists of many personal computers(as of now 8 PCs) which are connected by distributed data processing network system each other. The mathematical model describing ship motion covers any situation during berthing manoeuvre in harbour areas. The commercial-based graphic and modeling tools are employed to make VR simulation possible with effect. An example of real time simulation of berthing manoeuvre with twin-screw and twin-rudder container ship in Pusan Harbour has been introduced. And the simulation results are shown. As a next phase of study we will extend present simulator technique to developing full mission bridge simulator or collision reappearance simulator for analyzing devices of the causes of marine casualties.

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