On a Ship Manoeuvring Simulator Newly Developed by Korea Maritime University

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Abstract

Ship manoeuvring simulator has been widely utilized for training mariners, for assessing safety, for developing harbour and port, and for designing ships. We discuss a ship manoeuvring simulator which has been newly developed by Korea Maritime University. The simulator consists of simulator bridge and control console. All the computers used in the simulator are connected with one another by UDP or TCP network system. All the instruments are connected with interface computer by signal line which is controlled by RS232 communication protocol, or by voltage controlled A/D board. Next the mathematical model of ship manoeuvring motion in harbour areas, and ship and terrain modeling technique are also briefly discussed. Finally using the simulator an experiment of distance cognition and a simulation example of berthing/deberthing manoeuvre are shown.

1. Introduction

Recently the environment related with ship operation has grown worse than ever. It comes firstly from the rapid growth of ship size. The handling of the giant ships is very critical. At the same time, sea traffic is alarmingly tight in harbour areas. Three important things to have an effect on ship operation can be listed as ships inherent manoeuvrability, quality of seaman and environmental features of harbour and port. From the viewpoint of safe operation of ship in harbour areas, harmonization of above three elements, namely ship, human and environment, will be desired. One possible solution to synthetic judgement on the harmonization of ship operation, is to depend on man-machine system such as ship manoeuvring simulator. Nowadays ship manoeuvring simulator has been widely utilized for various purposes, such as safety assessment, maritime education and training, waterway design, manoeuvrability analysis of new ship at her planning stage, and so on. In this paper, we discuss a ship manoeuvring simulator which has

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been newly developed by Korea Maritime University. The simulator is consists of simulator bridge and control console. All the computers used in the simulator are connected with one another by UDP or TCP network system. All the instruments are connected with interface computer by signal line which is controlled by RS232 communication protocol, or by voltage controlled A/D board. Next we also briefly discuss mathematical model of ship manoeuvirng motion, and ship and terrain modeling technique. Finally using the simulator an experiment of distance cognition on visual scene and a simulation example of berthing/deberthing manoeuvre in Busan Harbour are shown.

2. Outline of simulator

2.1 System configuration

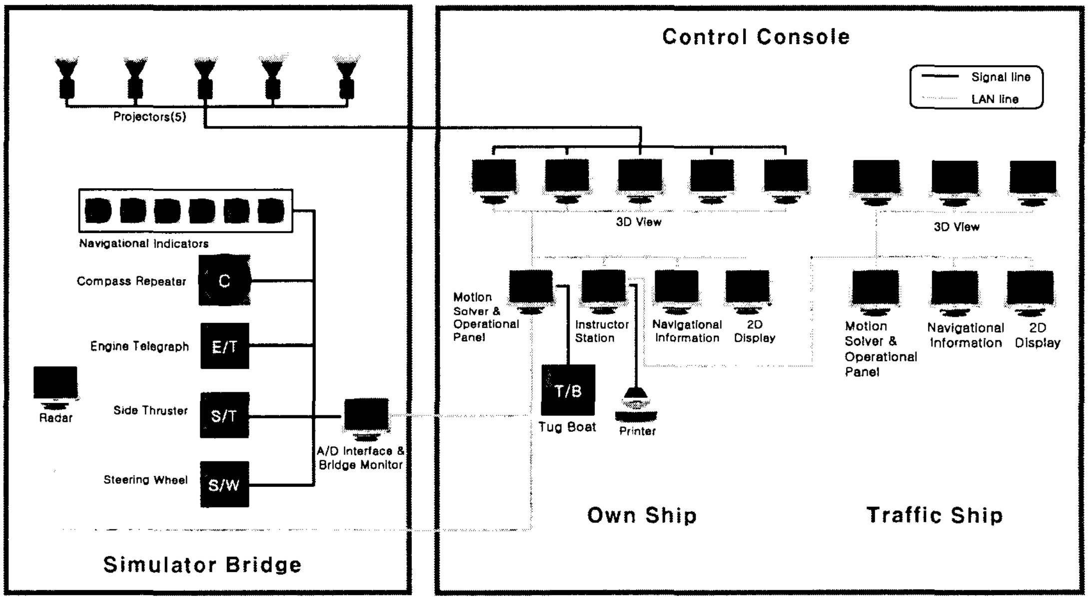
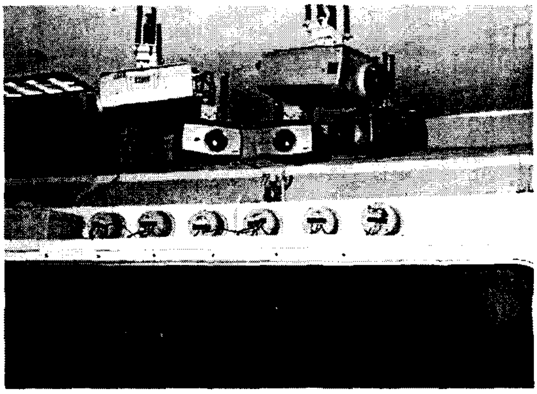
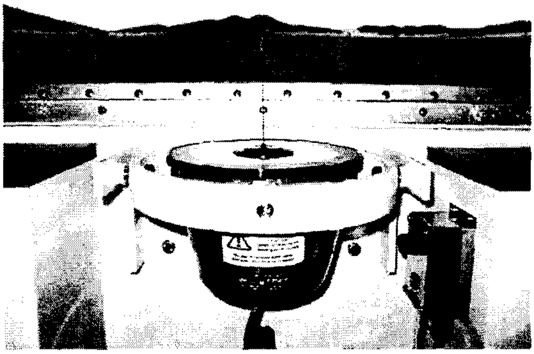


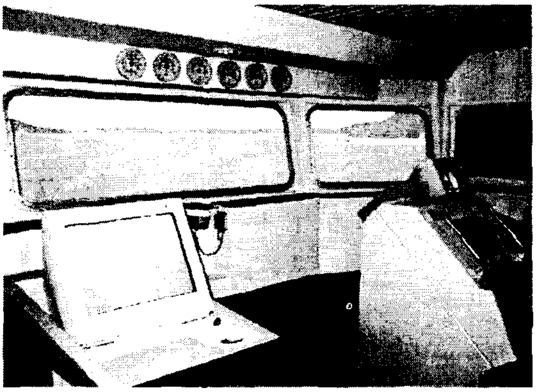
Fig. 1 Schematic of system configuration

Fig. 1 shows schematic of system configuration of present simulator. The simulator bridge consists of various navigational instruments such as steering wheel, side thruster, engine telegraph, compass repeater, navigational indicators, radar, bridge monitor and visual system. The control console consists of two parts. One is for own ship and the other for traffic ship. Three computers used as instructor station and motion solvers of own ship and traffic ship play a role as servers and the other computers as clients. Figs. 2 and 3 show photographs of simulator bridge and control consoles of own ship and traffic ship respectively.



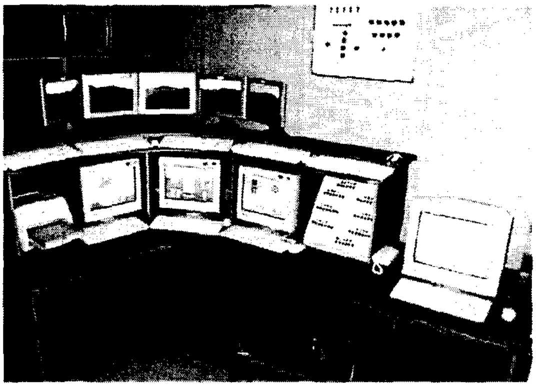


(a) Front of bridge (b) Inside of bridge(center)



(c) Inside of bridge(left) (d) Inside of bridge(right)

Fig. 2 Photograph of simulator bridge



(a) Own ship console (b) Traffic ship console

Fig. 3 Photograph of control console

We adopt the distributed data processing network system, namely UDP or TCP with asynchronous sockets, for data transmission among all the computers[1]. Instructor station is connected with the other computers by TCP for checking the situation of network connection, and also connected with 2D diplay, 3D view and radar by UDP for quicker data transmission. We also choose UDP for data transmission from motion solver to 2D display, 3D view, and radar because the quicker service is requested for image generation and renewal. While TCP is chosen for data transmission between the remaining other computers, in which the higher reliant service is requested than the quicker service. Fig. 4 shows one example of network connection with motion solver and clients.

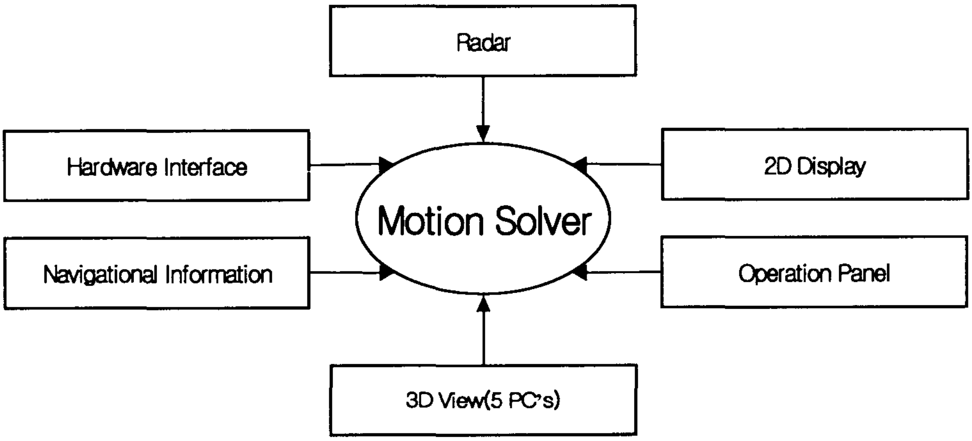


Fig. 4 Example of network connection

2.2 Specification and visual system

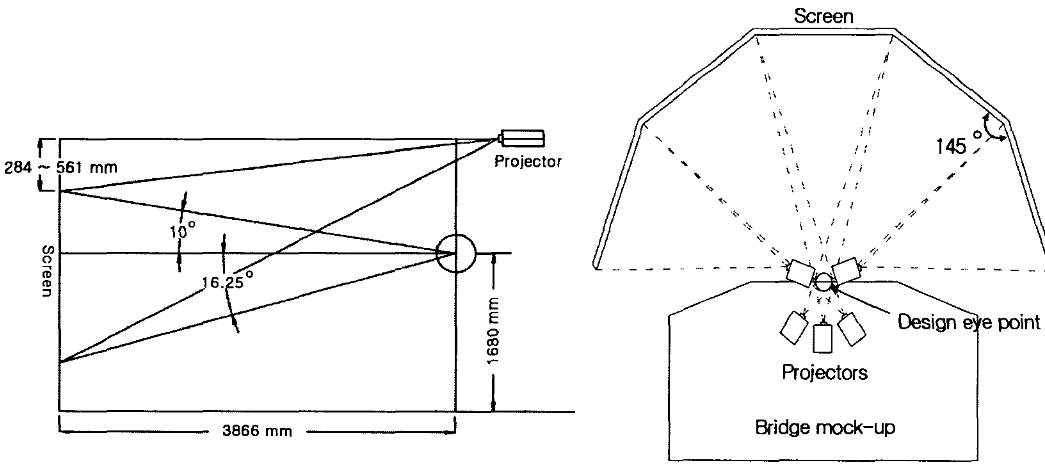
Table 1 Specification

Bridge dimension	W× × H 2.3mD 3.5m 5.1m
Visual display system	Com. Gen. Imagery system LCD Projector 5 channels (Max. 3200 ANSI lumens) Flat screen 120 5 channels (3.87m off from designed POV)
Field of view	Horizontal 175 deg Vertical 26.3 deg (Up 10 deg / Down 16.3 deg)
Designed point of view	Center of compass repeater (1.68m high from floor)

Table 1 shows the specification of present simulator. We adopt front projection system. Table 2 shows Computer Generated Imagery(CGI) system. There is one point to be very important for reality of simulator visual scene. That is frame rate of visual scene. Present simulator has been set to 10 Hz in frame rate at the minimum. Fig 5 shows visual system arrangement. Two projectors, which have been mounted a little forward and used for visuals at left and right ends, are wearing telephoto lenses for the same size of visuals as the others.

Table 2 CGI system

Computer	Pentium IV 2.0 GHz
Graphic card	Garnet GeForce3 Ti 200, 64MB
Operating system	Microsoft Windows NT 4.0
Graphic display software	MultiGen-Paradigm Vega NT
Frame rate	Min. 10 frame/sec



(a) Design of visual system (b) Projector arrangement

Fig. 5 Visual system arrangement

2.3 Interface system

We adopt two interfacing system between hardware and software as illustrated in Fig. 6. One is serial communication system and the other is A/D board controlled by electric voltage. NMEA0183 data protocol for gyro compass repeater and all the navigational indicators is connected with RS422 converter to adapt RS232 communication protocol. And self-developed, internal data protocol for tugboat controller can be directly connected to motion solver computer by RS232 communication protocol. Electric voltage controller for side thruster, engine telegraph and steering wheel is connected to interface computer through A/D board.

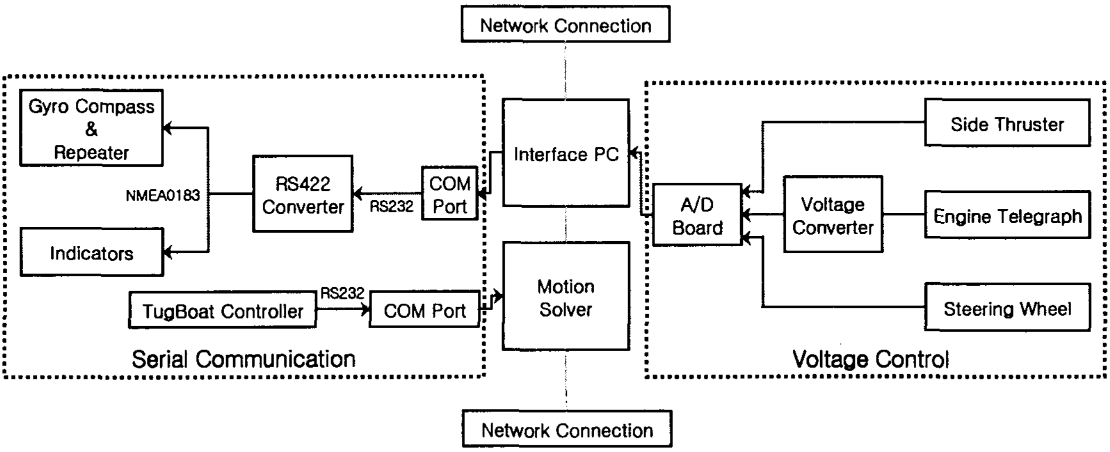


Fig. 6 Interfacing system between hardware and software

2.4 Ship manoeuvring mathematical model

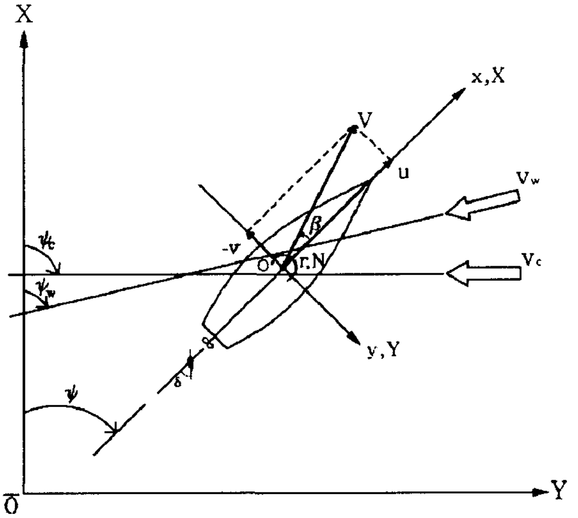


Fig. 7 Coordinate system

In general it is customary in manoeuvring studies to consider the only motion 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 manoeuvring simulator. We handle the longitudinal motion separately from manoeuvring motion. To describe manoeuvring motion, a system of body axes $(o-xyz)$ and space axes $(\bar{O}-XYZ)$ 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

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

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

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

where the terms with subscripts H, P, R, W and T represent damping forces on hull, propeller forces, rudder forces, wind forces and tug 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.

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

where u^* and v^* denote absolute velocities described in space axes $\bar{O}-XYZ$ in Fig. 3, V_c current velocity, and ψ_c current direction. Eqs. (2) and (3) give the following.

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

One of the authors proposed a mathematical model of hull damping forces at low advance speed with large drift angles as follows[2]. The model originated and was modified from Takashina's experimental study[3].

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

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.

$$
\begin{aligned}
u',\ v' &= u,\ v/V \\
r &= r\cdot L/V \\
X_H',\ Y_H' &= X_H,\ Y_H\ /\ 0.5\rho LdV^2 \\
N_H' &= N_H\ /\ 0.5\rho L^2dV^2
\end{aligned}
\tag{6}
$$

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[4]. Hirano also suggested the same mathematical model as Eq. (5) for practical prediction of manoeuvring motion at low advance speed[5]. Expression of $X_P, Y_P, N_P, X_R, Y_R, N_R, X_W, Y_W, N_W, X_T, Y_T$ and N_T is referred to reference[6]. We assume 8 tugs given at the maximum. Hydrodynamic derivatives and many other coefficients appearing in mathematical model can be obtained from a variety of references[4], [7].

2.5 3D Image generation

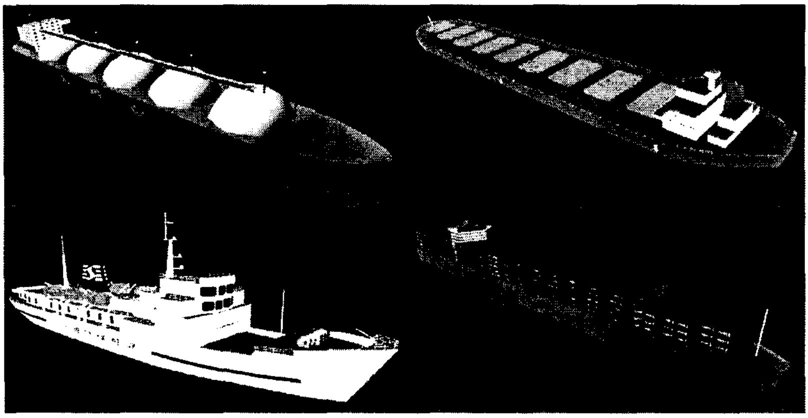


Fig. 9 3D image of ship models

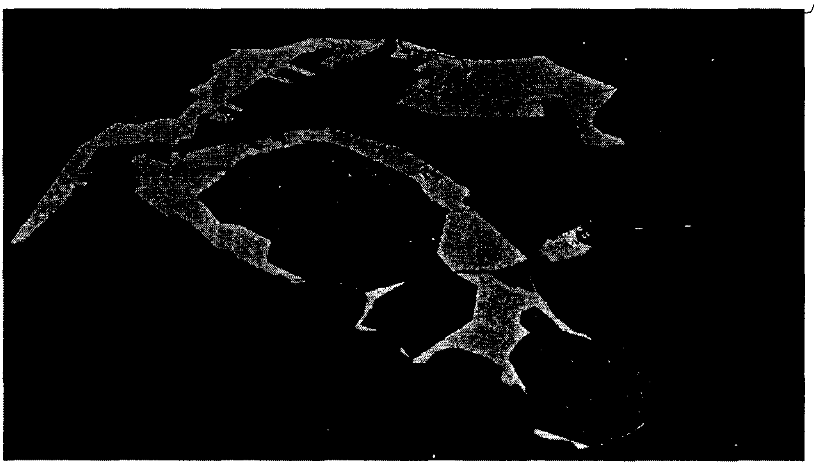


Fig. 10 3D image of Busan Harbour model

It is necessary to generate 3D image database for a large number of objects such as geographical features, ships and the others in order to make VR simulation possible. As 3D modeling tool for this purpose we use MultiGen(MultiGen-Paradigm Inc.), which is based on Open Flight scene description database. Figs. 9 and 10 show examples of 3D image of ship and harbour geographical features respectively.

Next we need 3D rendering technique for real time animation. For this application, we use graphic display software Vega NT(MultiGen-Paradigm Inc.), which is based on OpenGL VR simulation. On the basis of OpenFlight file format(FLT file) of object models created by MultiGen, Virtual reality image file, which is denoted as Application Definition File(ADF file), can be generated by Vega NT. And ADF file is linking together with Visual C++ programming.

3. Calibration and simulation

3.1 Distance cognition experiment

Exact cognition of distance to objects on visual scene is very important element in any experiment using simulator. Especially in narrow waterway navigation, there is necessity for not only exact cognition of movement of traffic ship but also exact cognition of distance to traffic ship[8]. We carry out the distance cognition experiment in order to calibrate corresponding relation between the visual scene of present simulator and real scene at sea.

Three examinees participate in the experiment. All of them are students, who have no experience of crew. Before the regular experiment, the examinees have made familiar with distance cognition work through some repeated practice. Experimental scenario is as follows. Own ship is passing in narrow waterway, as which we adopted Designated Area of Inchon Harbour, Korea. And target ship will be made appeared randomly 0.2 to 3 miles ahead. Table 3 shows information on own ship and target ship. The examinees are requested to cognize the distance to target ship on the visual scene of the simulator. At the same time we measure the exact, real distance to target ship on the radar.

Table 3 Information on own ship and target ships adopted in distance cognition experiment

	Kind of ship	L_{pp}(m)	B(m)	D(m)	Height of eye point from sea level(m)	Speed(kt)
Own Ship	Container ship (750 TEU)	175.0	25.4	15.4	17.5	5.96 (Dead slow ahead)
Target ship	Container ship (4,300 TEU)	274.0	32.25	21.7	-	11.75 (Half ahead)
	Bulk carrier (207,000 DWT)	300.0	50.0	25.7	-	8.77 (Half ahead)
	Traning ship (3,700 GT)	93.0	14.5	7.0	-	9.75 (Half ahead)
	Container ship (750 TEU)	175.0	25.4	15.4	-	1021 (Half ahead)

With the experimental data we calculate the probability density distribution of cognitive distance error rate, which is defined as follows.

$$(\text{Cognitive distance error rate}) = \frac{(\text{Estimated distance} - \text{Real distance})}{\text{Real distance}}$$

The distribution of probability density is illustrated in Fig. 11. We can know that though the mean value has a little slanted to the right, the probability density shows almost Gaussian distribution. If sufficient practice has been done, the visual scene of the present simulator can be enough for distance cognition with accuracy.

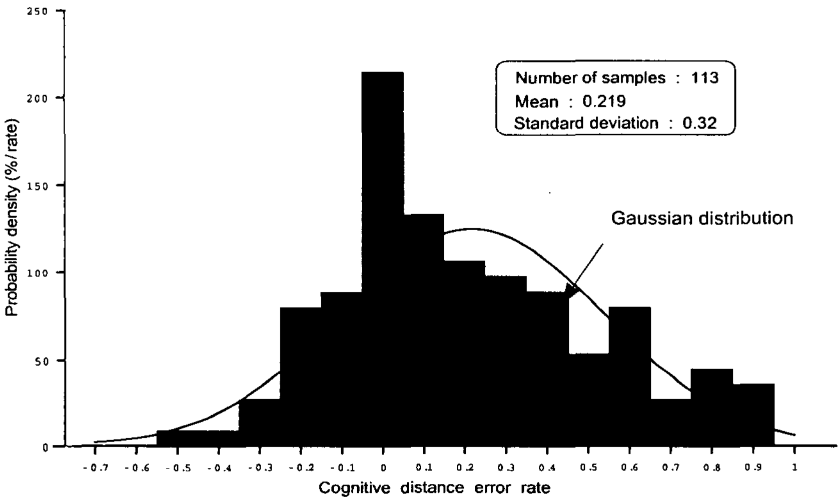


Fig. 11 Probability density distribution of cognition distance error rate

3.2 Berthing/deberthing simulation

Table 4 Principal particulars of container ship(4,300 TEU)

Hull			
Length over all	L_{OA}	(m)	288.0
Length bet. per.	L_{PP}	(m)	274.0
Breadth	B	(m)	32.25
Depth	D	(m)	21.7
Draft	d	(m)	13.5
Trim	τ	(m)	0
Block coef.	C_B		0.65
Prismatic coef.	C_P		0.66
Radius of gyration about z-axis			0.24
Longitudinal center of gravity from midship			- 0.026

Rudder			
Area	A_R	(m^2)	57.3
Height	H	(m)	10.9
Aspect ratio	λ		1.758
Area ratio	A_R / Ld		1/64.6
Propeller			
Diameter	D	(m)	7.8
Pitch ratio	P/D		1.13
Expanded area ratio			1.0
Number of blades			6

One example of berthing/deberthing manoeuvre in Busan Harbour using the present simulator, is introduced. Full container ship in 4,300 TEU class is chosen for own ship. Principal particulars of the ship are shown in Table 4. Simulation scenario is that the pilot gets on board ship near breakwaters of Busan Harbour in order to make the ship alongside Kamman Container Wharf. Initial approach speed of the ship is 5.9 kt(dead slow ahead), and her heading is faced toward the passage inside breakwaters. External environment effect such as wind and current are not considered.

Fig. 12 shows initial bridge view at Busan Harbour entrance, where the pilot gets on board ship. Approached near to mooring position at Kamman Container wharf, the assistance of 2 tugs(bow and stern tugs) are given. Fig. 13 shows view of mooring at the Kamman Container Wharf of Busan Port. In this case the observers position has been changed to out-of-ship. This function is intended in order that operator may see ships side entirely when ship comes near the Wharf. Fig. 14 shows ships track plotted at the intervals of 100 seconds during berthing/deberthing manoeuvre. According to the pilot who has been participated in this simulation, berthing/deberthing manoeuvre can be carried out on the same level with real operation.

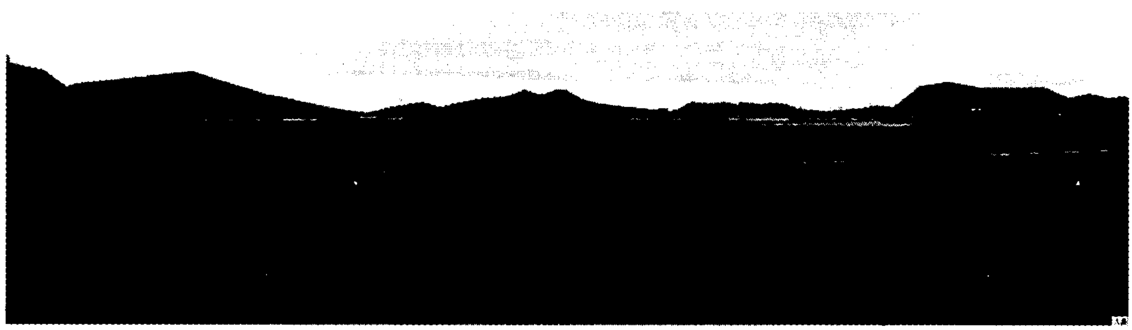


Fig. 12 Initial bridge view at Busan Harbour entrance, where the pilot gets on board ship

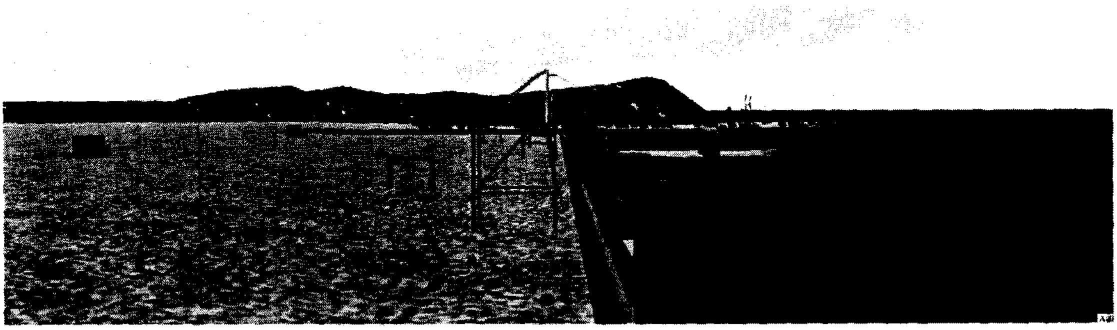
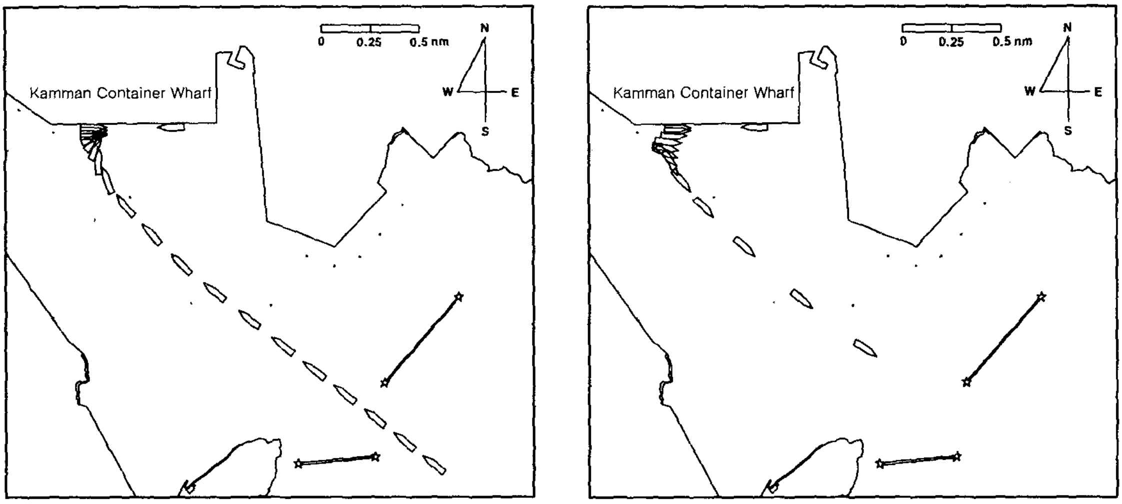


Fig. 13 View of mooring at Kamman Container Wharf of Busan Port
(Observers position has been changed to out-of-ship)



(a) Berthing (b) Deberthing

Fig. 14 Ships track during berthing/deberthing manoeuvre

4. Concluding Remarks

In this study a ship manoeuvring simulator newly developed by Korea Maritime University has been introduced and outlined. Using the simulator, experiment on distance cognition of traffic ship on the visual scene and real time simulation of berthing/deberthing manoeuvre have been shown. The developed simulator can be utilized mainly as a facility for following research and education.

(1) Design and evaluation of manoeuvring performance of new ship.
(2) Safety assessment for new design and management of harbour.

(3) Validation of newly developed navigation-support-system devices.

(4) Manoeuvring difficulty test of prototype and assumed ships under any particular circumstance.

(5) Investigation into cause of sea casualty through reproducing ship collision or other situation.

(6) Ship-human-environment harmonization analysis and synthesis on many other manoeuvring problems.

(7) Maritime education and training(MET) in shiphandling, berthing/deberthing, watch keeping, teamwork management, etc.

Acknowledgements

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