Intelligent Support System for Ship Steering Control System Based on Network

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Abstract

The important field of research on ship operation is related to the high efficiency of transportation, the convenience of maneuvering ships and the safety of navigation. As a way of practical application for a smart ship based on network system, this paper proposes the intelligent support system for ship steering control system based on TCP/IP and desires to testify the validity of the proposal by applying the fuzzy control model to the steering control system. As the specific study methods, the fuzzy inference was adopted to build the maneuvering models of steersman, and then the network system was implemented using the TCP/IP socket-based programming. Lastly, the miniature model steering control system combined with LIBL (Linguistic Instruction-based Learning) was designed to testify for its effectiveness.

Keywords: Intelligent System, Ship Steering control, Network system, TCP/IP, Fuzzy Inference, LIBL method

1. Introduction

In today's ship navigation, emergent situations where a vessel is within a water hazard or there is a risk of collision due to a nearing traffic vessel increase the task of ship operators, so that the ship operators should promptly execute the judgment and decision on how to control their vessels while continuously take a closer look at the situation development of both their vessels and other ones. The burden of their work would sharply drop if ship maneuvering and job management by network-based remote control are achieved when it comes to the situation where the ship operators observe the exterior conditions by the eye, while reading the information from numerous navigation equipment. Therefore, the studies on intelligent ship or an integrated control system have been actively carried out as part of the efforts to further improve safety and efficiency of ship operation. Moreover, digital ship integrates and manages data measured from a variety of sensors built in ships, making it possible to control ships and navigate autonomously and providing efficient and accurate information on the situation in ship navigation [1][2].

In this paper, as a base study to realize a next-generation intelligent ship, this study will seek ways to put ship steering system to practical use by establishing intelligent steering control system that enables network-based remote monitoring and control. The specific study methods are as follows:
(i) Establishing TCP/IP socket-based programming and network system to remotely control ship steering system on a PC environment; (ii) establishing and applying fuzzy steering maneuvering model to control rudder angle based on fuzzy inference; and (iii) identifying the efficiency by applying a real ship steering system to miniature model steering control system.

2. Network System for Ship Steering System

2.1 Network-based Steering Control System

Figure 1 represents the whole system composition to remotely control ship steering system. The system consists of client, which permits users to monitor the information of heading angle and rudder angle, interprets the related orders and deliver them to servers, server, which controls steering system of miniature ships and the data of heading angle and rudder angle to client, autopilot unit, and miniature steering control system that scales down ship steering system.

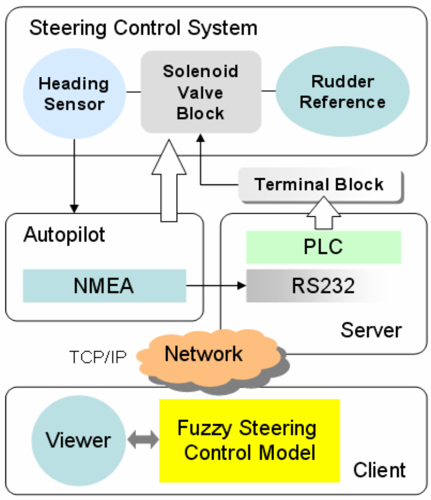


Figure 1. Block diagram of remote steering control system.

When users give an order, client interprets it and delivers the results to server system. Server system moves rudder of steering gear based on delivered data, and moves the ship. In this part, ship's heading angle and rudder angle are detected by heading sensor and rudder reference unit, respectively. The data of heading angle and rudder angle of miniature ship are input through RS232, and the rudder angle of miniature ship is controlled through PLC. Moreover, the system is in charge of providing data of heading angle and rudder angle to client system.

2.2 Composition of Server and Client System

Figure 2 shows the flow diagram of server and client in ship steering networking system, respectively. The heading angle and rudder angle of steering control system are input through PLC and RS232, the results are output and steering system of miniature ship is controlled. Moreover, the link of TCP/IP to client makes it possible to monitor the situation of miniature ship. In client, data of heading angle and rudder angle are displayed on a monitor, and client is in charge of delivering heading and rudder angles to server to remotely control ship steering system.

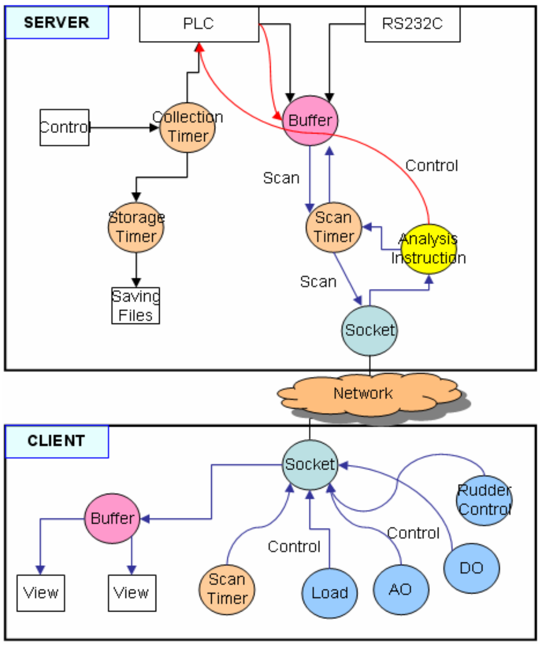


Figure 2. Flow diagram of server and client system.

2.3 NMEA Interface

NMEA (National Marine Electronics Association) is used as a standard for interface protocol of marine-related equipment. NMEA 0183 protocol in GPS is an international standard, so that a majority of GPS devices provide NMEA 0183 interface. This study selected heading and rudder angles of NMEA signal, which are output from FAP-330 autopilot system of Japan's FURUNO. The examples of NMEA Sentence's composition of FURUNO FAP-330 used in this study are as follows:

$PFEC, AGFPA, B, 324, S05.0, 324, N, OT0

Of the letters and figures above, "324" and "S05" means heading angle and rudder angle, respectively.

3. Fuzzy Steering Control Model

3.1 Introduction of LIBL Method

The Linguistic Instruction Based Learning (LIBL) system was first proposed by G.K Park and M. Sugeno. They combined the human's learning capacity based on natural language with the fuzzy theory. Whenever linguistic instructions are made, the LIBL system gets to learn them based on the existing knowledge it has. In fact, the LIBL utilizes natural language to make simple communications with the system. The process of searching meaning elements is required to understand the command of an operator [3][4].

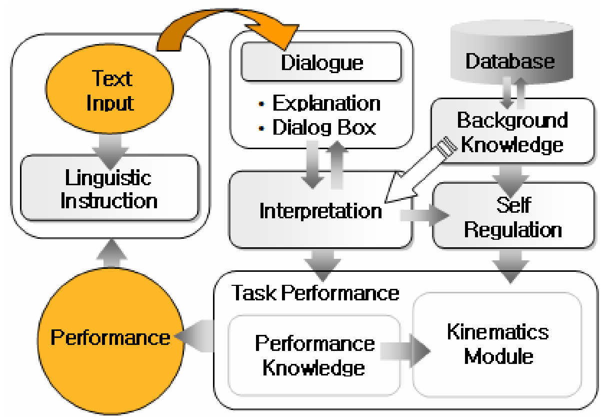


Figure 3. Framework of LIBL system.

3.2 Composition of LIBL Method

1) Linguistic Instruction and Background Knowledge Parts

The linguistic instruction is performed using a keyboard, and its formation is following.

$$L_i = [AP][LH][AW]$$

, where L_i is a instruction, *AP* means fuzzy auxiliary phrases, *HA* means heading angle, *LH* means fuzzy linguistic hedge, *AW* means a fuzzy atomic word, respectively.

When it is applied to the steering control system, the following shows how it works:

L_i = [Follow at (AP_1)][180 degrees (AP_2)][More(LH)][Fast(AW)]

The Background Knowledge Part is divided into the regular database and the knowledge database. In the regular database, the commands regularly used by the system are stored, while in the knowledge database, the evaluation value of the meaning elements are stored to set up the control of the system.

2) The Interpretation Part

The Interpretation Part creates the evaluation rules depending on the trends of meaning elements.

(i) Selection of Meaning Elements

In order to make a decision on system response results, the steering gear control system has the three meaning elements and three trends each. The three meaning elements include ΔmR_θ referring to other rudder angle; ΔmT_S referring to the arrival time; and ΔmS_θ referring to stability status. The three trends include increase (+), maintenance (0) and decrease (-). The equation (1) shows the selection result of meaning elements. Refer to the followings:

$$L_i = (LH_i)(\Delta mR_\theta(+)\ and\ \Delta mT_S(-)) \qquad (1)$$

, where LH_i refers to linguistic hedge, $\Delta mR_\theta(+)$ refers to increase in rudder angle and ΔmT_S (-) refers to decrease in arrival time respectively.

Figure 4 displays the process of selecting trends of the meaning elements to evaluate linguistic instructions of operators.

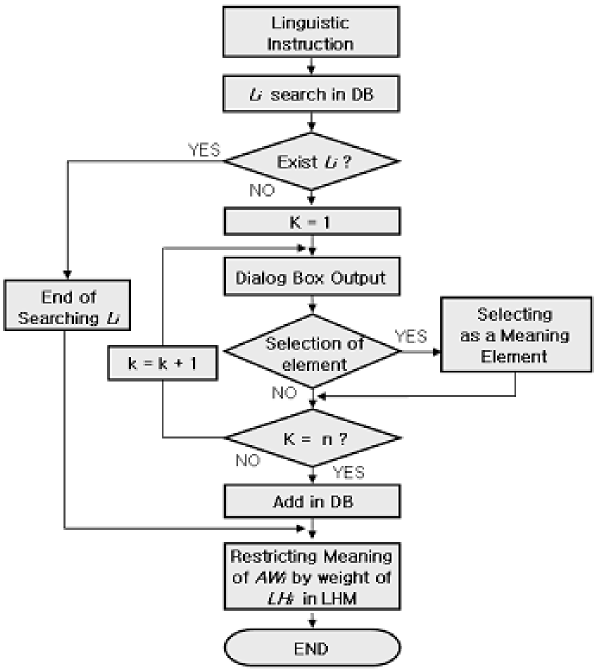


Figure 4. Selection process of meaning elements.

In Figure 4, *n* means the number of meaning elements. In case of the steering control system, if *n*=3, LHM means a pre-defined linguistic hedge module. First of all, when the linguistic instruction of the ship operator is entered through the dialogue box, the comparing and checking process is launched to decide whether the concerned linguistic instruction exists in the database. If the matching linguistic instruction is not found, the conversation with the operator is conducted to determine meaning elements, and the new linguistic instruction is added to the database. Likewise, when meaning elements are determined, a search is conducted to find out whether the entered linguistic instructions contain linguistic hedge. If it is found that the linguistic hedge exists, weight value is allocated according to concerned linguistic hedge. If the concerned linguistic instruction exists in the existing database, searching linguistic instructions is stopped, and weight value is allocated depending on linguistic hedge. As described above, the meaning elements and trends of the linguistic instructions of the ship operator are searched and compared, and the evaluation rules are created accordingly.

(ii) Generation of Evaluation Rules

When each meaning element and its trend are found for linguistic instruction, the Background Knowledge Part is utilized to generate evaluation rules by element and trend. The fuzzy membership function of the premise used by a meaning element includes SMALL, MED, and BIG. In the consequence, three fuzzy membership functions by the trend of the meaning element should be ready in response to membership functions of the premise. Fig. 5 displays an example of evaluation rule when $\Delta mR_\theta(+)$, a meaning element referring the increase of heading angle to starboard, is chosen.

Meaning elements can be limited by linguistic hedge in the way of reflecting the value of W_{LH_i} on the evaluation rule. Use the equation (2) to calculate ΔH, the value of movement of parameter in the consequence, and prepare the evaluation rule limited by linguistic hedge.

$$\Delta H = W_{LHi} \cdot \Delta R \qquad (2)$$

, where the maximum movement of the consequence of the evaluation rules by linguistic hedge is set at $\Delta R = 5.0$.

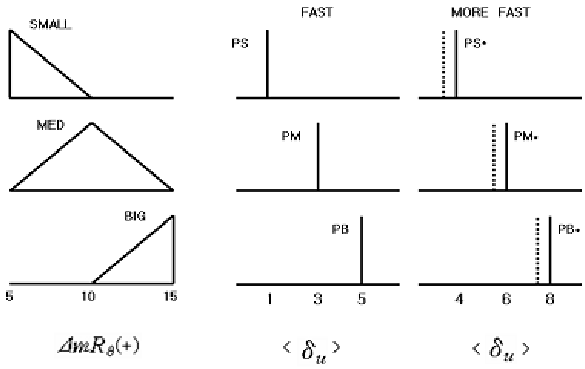


Figure 5. Composition of fuzzy evaluation rules.

The movement of the consequence caused by linguistic hedge [MORE]($W_{LH_i} = 0.6$) is $\Delta H = 0.6 \cdot \Delta R$, and [MORE FAST], the changed membership function of the consequence is prepared. As Figure 5 indicates, the final consequences of the evaluation rule, which is reflected by the linguistic hedge effects, are PS*, PM*, and PB* respectively. When weight value is allocated, the weight value per linguistic hedge is following:

[(None, 0.0), (A Little, 0.2), (Some 0.4), (Further 0.6), (More, 0.8), (Very, 1.0)]

The evaluation rule applicable to meaning elements has a single input/output fuzzy inference engine. For instance, increase in rudder angle, $\Delta mR_\theta(+)$ has the following rules.

If $\Delta mR_\theta(+)$ is SMALL, then δ_u is PS
If $\Delta mR_\theta(+)$ is MED, then δ_u is PM
If $\Delta mR_\theta(+)$ is BIG, then δ_u is PB

, where MED means medium, PS means positive small, PM means positive medium, and PB means positive big.

3) Self-regulation Part

Uses the linguistic instruction earned according to evaluation rules and calculate the additional rudder angle δ_u. Calculate the steering angle δ and δ_u by applying the primary control rule indicating a steering control model by steersman and combine them to conduct self-regulation.

When a linguistic instruction is made, calculate the final rudder angle δ^* based on Equation (3).

$$\delta^* = \delta + \delta_u \tag{3}$$

4) Task Performance Part

In this paper, the system's task is actually performed, and it includes Performance Knowledge and Kinematics Module corresponding to a controller and a plant respectively in a control system. In case of the steering control system, the Performance Knowledge and Kinematics Module are in response to the steersman control model and ship dynamics respectively.

In general, the steersman control model utilizes the results of the research and analysis of the experiences of skilled steersmen and creates a rudder angle control model based on the results and the fuzzy interference model. In general, the block diagram of a regular steering control system is as below in Figure 6.

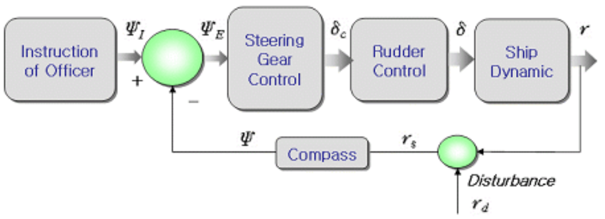
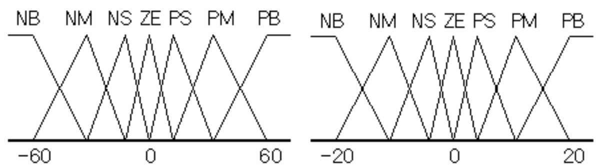
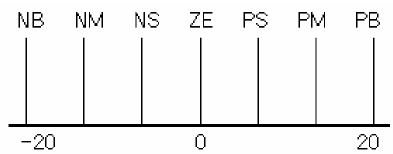


Figure 6. Block diagram of steering control system.

The error (ψ_E) between the set direction (ψ_I) and the current direction (ψ) is used as input value of the premise. In this way, the rudder angle (δ) of the consequence can be inferred, and the controlled output (r) is calculated. The membership functions used for the premise and consequence for simulation are as below in Figure 7.



(a) Membership functions of ψ_E and $\Delta\psi_E$ [deg.]



(b) Membership functions of δ [deg.]

Figure 7. Membership functions of ψ_E, $\Delta\psi_E$ and δ.

The steersman control model designed based on experiences of steersman consists with 13 control rules like the following ones.

If ψ_E is PB and $\Delta\psi_E$ is ZO then δ is PB
If ψ_E is ZO and $\Delta\psi_E$ is NB then δ is NB
If ψ_E is NB and $\Delta\psi_E$ is ZO then δ is NB

, where PB means positive big, ZO means zero, and NB means negative big.

The consequence of control and evaluation rules adopts the fuzzy singleton. Mamdani's inference method was used for inference method. The center of gravity (COG) method was used as the defuzzification method [5-7].

4. Composition of Steering Control System

4.1 Basic Composition of Steering Control System

Under steering control system, when a linguistic instruction of operator is input, the meaning of the linguistic instruction of operator is identified in the linguistic instruction-based system, so the rudder angel is appropriately controlled. In general, steersman use fuzzy inference based on their rudder controlling experience to constitute a rudder control model of a steersman. Figure 8 represents a basic block diagram of LIBL-based steering system.

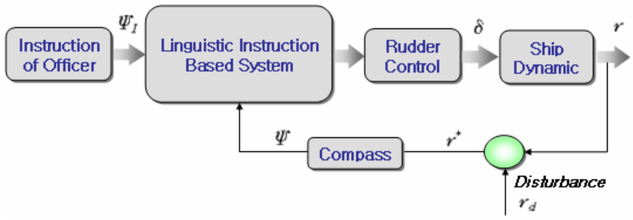


Figure 8. Block diagram of steering control system with LIBL.

Equation of ship's heading angle applied in this study is as follows [8]:

$$r = R\sqrt{v_t}\cdot\delta^*$$
$$\Psi = \int_0^t r^* dt, \quad r^* = r + r_d$$
$$\delta^* = \delta + \delta_u$$

It determines the rate of turn and heading value by adding the result of fuzzy inference through linguistic instruction to rudder angle. In addition, *r* represents the rate of turn by rudder bending, *R* is calibrating constant (0.01), *vt* means ship speed, δ means inferential rudder angle steered by steersman model, δ_u means rudder angle by linguistic instruction, δ^* refers to aggregated rudder angle of δ and δ_u rate of yaw due to the interference of wind or wave, and ψ means current direction, respectively.

4.2 Autopilot and System Control Units

The compositions of autopilot unit and system control equipment in steering control system are shown in picture 9. There are heading sensor, which delivers ship's heading angle data to processor unit, rudder reference unit, which delivers rudder angle data to processor unit, and processor unit, which computes each data input from heading sensor, rudder reference unit, and control unit, and takes a signal to solenoid valve block, a final output. Control unit contains display part of heading angle and rudder angle data, and is an operation part of automatic steering gear with features to set up heading angle data in navigation with automatic steering gear in automatic steering navigation.

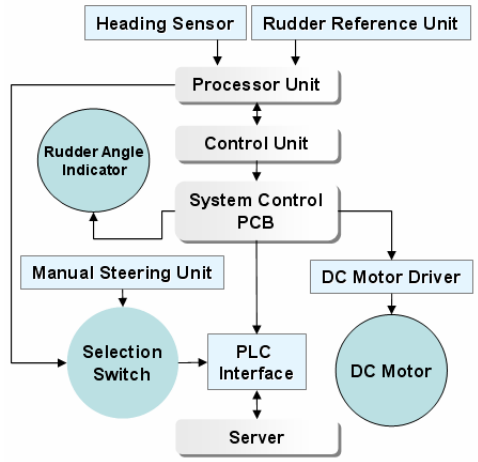


Figure 9. Composition of system control units.

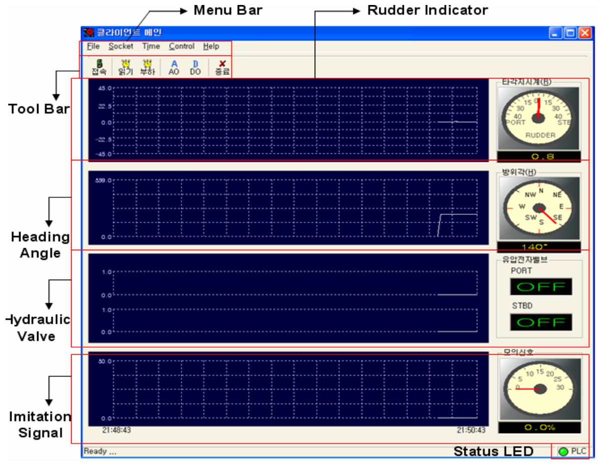


Figure 11. Main screen of simulator.

5. Simulation Results

In order to establish network-based steering control system, this simulation set the steering system of miniature ships of real ones to control rudder through PC interface. System interface was realized using OpenGL/VC++ 6.0 (MFC), and the system was materialized through RS232 and PLC to control steering system of miniature ships.

5.1 Network-based Steering Control System

The composition of miniature ship system used in this study is shown in figure 10. The system consists of a miniature ship, hydraulic power steering system structure, an autopilot system, and PC to control ship's rudder.

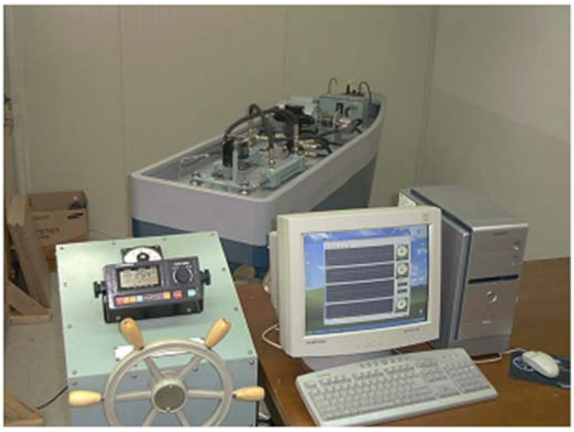


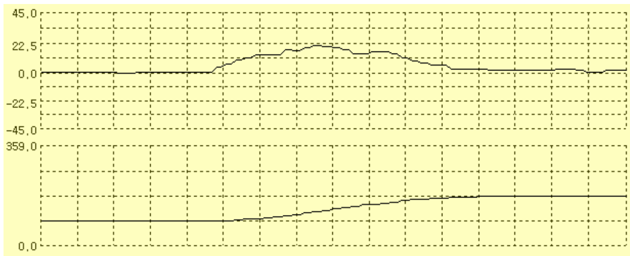
Figure 10. Composition of miniature ship system.

5.2 Composition of Simulator Interface

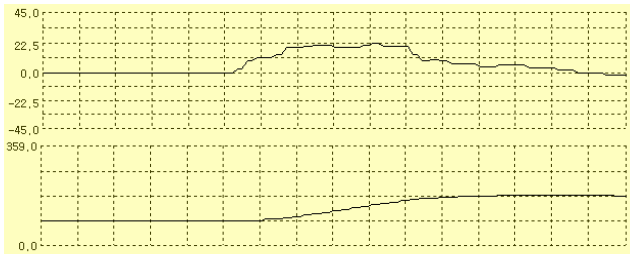
Figure 11 represents the main screen of a remote steering gear control simulator. It is designed to directly control steering gear of miniature ship, and it is set up to monitor rudder angle, heading angle, and hydraulic signal.

5.3 Result Examination

Under network-based ship steering control system, when related linguistic instruction is made to an established client system, the system appropriately controls rudder angle to follow an established heading angle. Figure 12 shows the results of heading angle following in FURUNO FAP-330 autopilot system used in this test and remote steering control system in which the system interprets the order made by a ship operator, controls ruder, and follows heading angle. The results of output are illustrated by taking example of following the 180˚ heading from 90˚ heading. In this figure, in terms of remote steering control, order is a linguistic instruction in the form of "Turn to 180˚ more rapidly." As shown in (a) of figure 12, autopilot system reveals a stable 180˚ following, and remote control shown in (b) reveals a speedier 180˚ following than that of autopilot system since the order takes the form of "more rapidly."



(a) Autopilot (FURUNO FAP-330)



(b) Remote steering control system

Figure 12. Results of autopilot and remote steering system.

6. Conclusion

As part of studies on establishing intelligent ship, this study used miniature steering control system of a real one to establish TCP/IP-based intelligent steering control system. The study employs LIBL system using natural language based on human learning methods to examine efficiency of the system in order to establish intelligent steering control system. In terms of specific findings, this study suggested the network composition and linguistic instruction method to remotely control steering gear, used fuzzy inference to establish steering maneuvering model based on a common experience of steersman, and suggested evaluation rules to amend the rules of steersman's maneuvering model. Moreover, it set up miniature steering control system to remotely control rudder through the network to establish remote steering control system by linguistic instruction, and identified the possible applicability of the system by comparing and analyzing FURUNO FAP-330 system.

However, a sufficient consideration of network delay and analysis on the form of more efficient linguistic instruction is required. Moreover, more accurate establishment of intelligent control system is also required by considering the factors influencing steering since this study did not consider the exterior environmental impact factors to ship steering such as wind, wave, and weather conditions, and it is essential to conduct studies accompanying tests on real ships rather than miniature steering control system.

Acknowledgement

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Reference

1. Y.K. Lim, J.W. Park and Y.C. Choi, “A Research for Digital-ship”, *Journal of Ships & Ocean Engineering*, vol. 33, pp. 15-20, 2002
2. N.S. Son and S.Y. Kim, “Development of a Supporting System for Safe Navigation Using Voice Control and Guidance”, *Journal of Ships & Ocean Engineering*, vol. 33, pp. 117-125, 2002.
3. G.K. Park, K.Y. Seo, J.Y. Jong and N.K. Im, “Intelligent ship’s steering control system based on voice instructions”, *Proceedings of the 6th international symposium on advanced intelligent systems*, vol. 6, pp. 795-800, 2005.
4. G.K. Park and K.Y. Seo, “Intelligent Ship's Steering Gear Control System Using Linguistic Instruction”, *Korea Fuzzy and Intelligent systems Society*, Vol. 12, No. 5, pp. 417-423, 2002.
5. G.K. Park and M. Sugeno, “Learning Based on Linguistic Instruction using Fuzzy Theory”, *Journal of Japan Society for Fuzzy Theory and Systems*, vol. 4, No. 6 pp. 1164-1181, 1992.
6. G.K. Park and M. Sugeno, “An Approach to Linguistic Instruction Based Learning”, *International J. of Uncertainty, Fuzziness and Knowledge Based Systems*, vol. 1, No. 2, pp. 1956, 1993.
7. M. Fujii, T. Furuhashi, “A Proposal of Extraction of Intentions in Linguistic Instructions Using Fuzzy Classifier System”, *Journal of Japan Society for Fuzzy Theory and Systems*, Vol. 11, No. 1, pp. 92-98, 1999.
8. K.H. Sohn, G.W. Lee, G. Lim, J.C. Bae, “A Study on the Prediction of Propulsive Energy Loss Related to Automatic Steering of Ships”, *International Symposium on VTS & IBS ’95*, November 2-3, 1995.