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Development of Maneuvering Simulator for PERESTROIKA Catamaran using Fuzzy Inference Technique

Joon-Tark Lee† · Seok-Jun Ji* · Woo-Jin Choi*

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Abstract : Navigation simulators have been used in many marine schools and marine training centers since the early 1960's. But these simulators were very expensive and were almost limited only in one engine system. In this paper, a catamaran with twin engine system, controlled by two remote control levers and its economic simulator based on a personal computer shall be introduced.

One of the main features of catamaran is to control variously its progressing direction. In the static state, a catamaran can move into all the directions and in the dynamic state, ship can change immediately the heading and speed. Although a good navigator can skillfully operate one engine system, it is difficult to control smoothly the catamaran of twin engine system without any threat for the safety of passengers. Thus, in order to bring up the expert navigators, the development of a simulator which makes the training effective is necessary.

Therefore, in this paper, a Fuzzy Inference Technique based Maneuvering Simulator for catamaran with twin engine system was developed. In general, in order to develop a catamaran simulator for effective training, first of all, its mathematical model must be acquired. According to the acquired system modeling, the dynamics of simulator is determined. But the proposed technique can omit a complex and tedious mathematical modeling procedures by using the fuzzy inference, which dependent upon only experiences of an expert and can design an efficient training program for unskillful navigators. This developed simulator was consisted of two fuzzy inference routines and two remote control levers, and was focused on effective training of navigators for the safe maneuvering to avoid a collision in a harbor.

Key words : Fuzzy Inference, Maneuvering Simulator, Catamaran.

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† Corresponding Author(Dept. of Electrical Electronic & Computer Engineering, Dong-A University), E-mail : jtlee@donga.ac.kr, Tel : 051)200-7740

* Intelligent Control Lab., Dept. of Electrical Engineering, Dong-A University. Hanla Level Co. Ltd. R&D Institute(hlico@chol.com, wjchoiic@donga.ac.kr).

1. Introduction

What is a catamaran? It means a ship with twin hulls and usually a deck or superstructure connecting the hulls. It is equipped with twin engines and two high speed water jet propulsion devices. Operator's main control goal is to bring a catamaran with passengers or cars at the destined harbor quickly and safely.

Then why do we need a simulator such as that? The benefits of this catamaran system are that the ship can go ahead or astern to any direction and make powerful propulsion than one engine. But, twin engines should be controlled by two remote control levers. Futhermore, one lever is used to control the power and the direction of an water jet propulsion at once as Fig. 1. And also, even expert operators with the wide experiences can not understand easily the maneuvering dynamics of ship with two control levers and if an emergency is given, they can not cope immediately with the other operation technique because the safety of passengers is most important. Because of these reasons, without the help of simulator such as a sort of catamaran, any operator cannot show the qualified operation techniques except his preferred operations.

But, unfortunately there were no any recent research about this training lever control apparatus such as catamaran. Even if it is related to catamaran or analogous system, it limited only to the theoretical designs and academic researches which cannot make an operator perfect for actual operations[2]. Additionally well-made conventional simulators were very expensive and were limited nearly in one engine system. In two engines, it needs many times and much money to bring the novice operator without experience up as an expert. Also, it is difficult to obtain the mathematical model of catamaran. Recently, according to the remarkable developments of computer hardware and software, a desktop or portable simulator is realizable.

Therefore, in this paper, an implementation technique of a fuzzy inference based catamaran simulator was introduced. By the application of the fuzzy inference technique, the expert's linguistic know-hows were described as if-then rules about maneuverings can be easily implanted into the developed catamaran simulator. It shall provide us the important informations about how to control twin engine system and its behaviors.

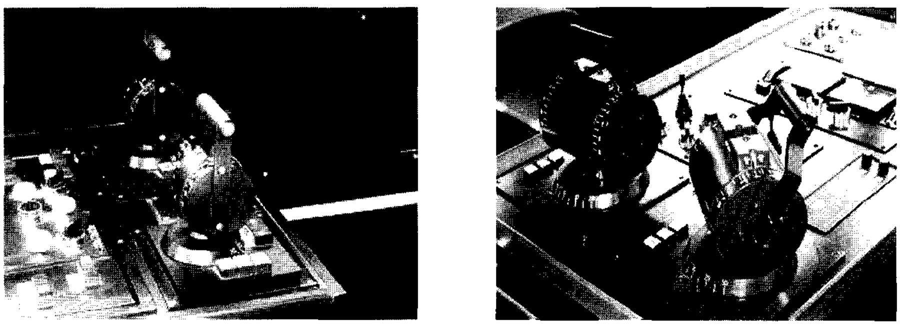


Fig. 1 Various control levers of catamaran.

2. Dynamics of catamaran

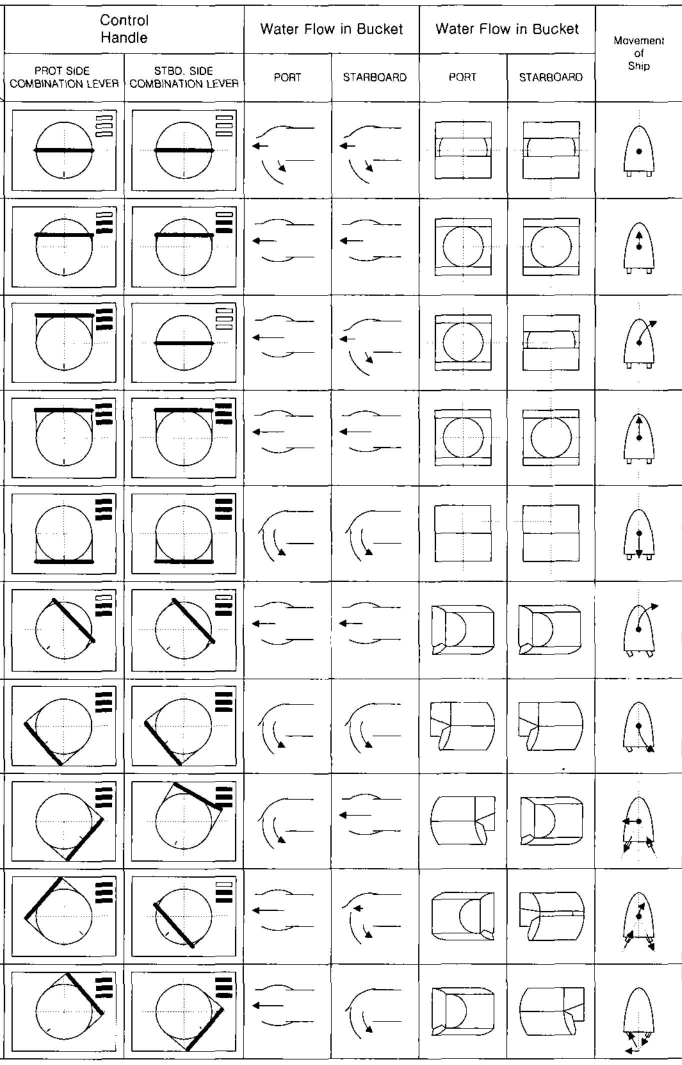
In this paper, the model PERESTROIKA was chosen, and shown in Fig. 2. Its principal specifications are given as Table 1.

What are the basic principles about movements of catamaran? Several operation patterns are shown in Table 2.

Table 1 Principal specifications of PERESTROIKA.

Overall length	36 m
Breadth	11.5 m
Gross Tonnage	279 ton
Draught on cushion	0.5 m
Draught off cushion	2.05m
Cruising speed	46 knot
Number of Passengers	346 person
Route	Busan Jangseungpo Okpo
Duration	45 minute
Main Engine	MTU16V396, HP/rpm : 2,620 / 1,600 2 sets
Maneuvering Lever	Kamewa water jet system

Table 2 Patterns of water jets with two control levers in the various modes.



No.	Mode	ENGINE rpm PORT	ENGINE rpm STBD.
①	Neutral of Port and Starboard	IDLE	IDLE
②	Ahead Half of Port and Starboard	HALF	HALF
③	Ahead Full of Port Neutral of Starboard	FULL	IDLE
④	Ahead Full of Port and Starboard	FULL	FULL
⑤	Astern Full of Port and Starboard	FULL	FULL
⑥	Ahead Half Turn to Starboard	HALF	HALF
⑦	Astern Full Turn to Starboard	FULL	FULL
⑧	Full Move to Horizontal Port Line	FULL	FULL
⑨	To Slantwise Starboard Line	FULL	HALF
⑩	Rotate to Starboard Full	FULL	FULL

Fig. 2 PERESTROIKA Catamaran.

Practically speaking, there are many available cases for operation states of twin levers except Table 2. The operation ranges of each lever are limited as $\pm 30^\circ$ and 10 grade of ahead and astern. Even if the lever states are divided in smallest cases such as maximum, middle and minimum, for each states of propulsion power and direction, the total 81 cases($3 \times 3 \times 3 \times 3$) are available.

But these are too rough cases for the effective training and it is also not sufficient to show the plentiful dynamics. Furthermore, it is not effective to summarize 81 fuzzy if-then rules by computer programming. Here, we will introduce the form of forces and directions induced by the water jet.

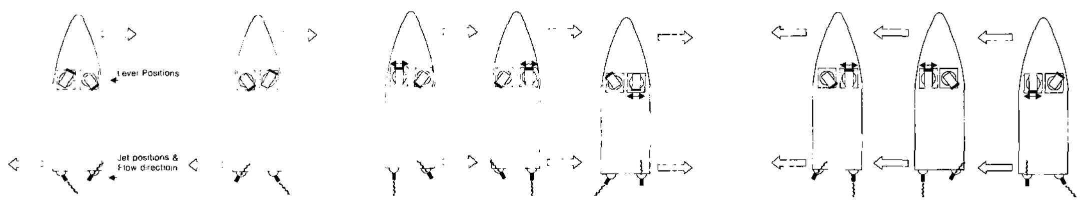
3. Fuzzy rules for catamaran

As Fig. 3, each cases are describing the same movements but the lever control modes by human operator are quite different. This is the unique dynamic features of catamaran. Its system dynamics are determined generally by the control lever position, the water jet position and its water flow direction. Note that the rotation angle of two control levers and that of buckets are different.

Furthermore, the skillful operators′ feelings and the movement of PERESTROIKA catamaran were expressed as these following facts:

1. Operators feel like that the center of catamaran is shifted to the stern, therefore, going astern is more slower than ahead.
2. Operators feel like that the rotation pivot of ship is on the ahead side contrary to the center of ship.
3. When it occurs the fault of one lever, operators must use the other lever only and prevent the accidents.

If an operator want to understand these differences between catamaran and feelings, a simulator must be equipped with a capability of expressing these features. Therefore, in this paper, the resolution principle of two propulsion forces is introduced for the extractions of



(a) Pivoting to starboard (b) Sideways to starboard (c) Sideway to port

Fig. 3 Same movement by different lever controls.

fuzzy rules.

Step 1. It can be calculated the force and direction of water jet according to the control of port side lever. These force and direction are inputted through fuzzy values.(Fig. 4(a))

Step 2. From the force and direction of Step 1, we can determine the motion of the ship by three small increasement factors - (Δx, Δy, $\Delta\theta$), where x and y are the locations, Δx and Δy are each location increments for 2D-display, and θ is the heading of the ship, $\Delta\theta$ is the heading increment for the current heading of the ship.(Fig. 4(a))

Step 3. Above Step 1 and 2 are also repeated in the control of starboard lever.(Fig. 4(b)) From the lever position and the propulsion power, the resultant impressed force to catamaran can be divided into bidirectional forces such as a horizontal force and a vertical one. This physical conversion makes the programming easier.

Step 4. After the addition computation of the motion factors (Δx, Δy, $\Delta\theta$) by the control of port side and starboard side levers(Fig. 4(c)), we can display the catamaran movement using the 4 mode equations as Eq. (1)~(4) with coordinate transformations, zoom-in and zoom-out functions.

1) Rotation mode

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} \quad (1)$$

where, $\theta = \theta + \Delta\theta$

2) Ahead and astern mode:

$$y' = y + \Delta y \quad (2)$$

3) Port and starboard mode:

$$x' = x + \Delta x \quad (3)$$

Table 3 Fuzzy rules related to the control of the port side lever.

(Δx, Δy, $\Delta\theta$)		Propulsion force of the port side water jet				
		NB	NM	ZO	PM	PB
Angle of lever	NB	(NS, NS, PB)	(NVS, NS, PM)	(ZO, ZO, ZO)	(NS, PM, NM)	(NS, PB, NB)
	NM	(NVS, NM, PS)	(NVS, NS, PVS)	(ZO, ZO, ZO)	(NVS, PM, NS)	(NVS, PM, NM)
	ZO	(PVS, NM, NS)	(PVS, NM, NVS)	(ZO, ZO, ZO)	(PS, PM, PS)	①(PS, PM, PM)
	PM	(PS, NM, NM)	(PVS, NS, NS)	(ZO, ZO, ZO)	(PS, PM, PM)	(PS, PM, PB)
	PB	(PS, NS, NB)	(PVS, NS, NM)	(ZO, ZO, ZO)	(PS, PS, PB)	(PS, PM, PVB)

Table 4 Fuzzy rules related to the control of the starboard side lever.

(Δx, Δy, $\Delta\theta$)		Propulsion force of the starboard side water jet				
		NB	NM	ZO	PM	PB
Angle of lever	NB	(NS, NS, PB)	(NVS, NS, PM)	(ZO, ZO, ZO)	(NS, PS, NB)	(NS, PM, NVB)
	NM	(NS, NM, PM)	(NVS, NS, PS)	(ZO, ZO, ZO)	(NS, PM, NM)	(NS, PM, NB)
	ZO	(NVS, NM, PS)	(NVS, NM, PVS)	(ZO, ZO, ZO)	(NS, PM, NS)	(NS, PM, NM)
	PM	②(PVS, NM, NS)	(PVS, NS, NVS)	(ZO, ZO, ZO)	(PVS, PM, PS)	(PVS, PM, PM)
	PB	(PS, NS, NB)	(PVS, NS, NM)	(ZO, ZO, ZO)	(PS, PM, PM)	(PS, PB, PB)

4) Scale mode:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = SF \times \begin{pmatrix} x \\ y \end{pmatrix} \quad (4)$$

where, SF means a scale factor of real number.

The acquired fuzzy rules were summarized in the following Table 3 and 4[1],[3],[4]. Fuzzy rules determine the increasements(Δx, Δy, $\Delta\theta$) from the angle and the propulsion force of the lever.

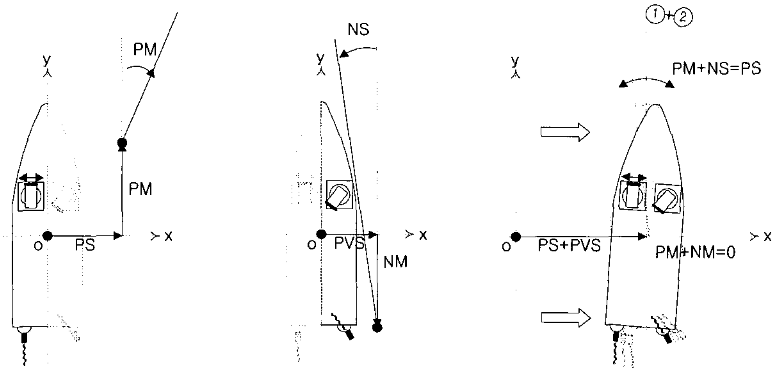
For a graphical example, consider the case of "sideways to starboard" as Fig. 4. The result ① obtained from the Table 3 and the one ② obtained from the Table 4 are given by the fuzzy inference occurred by the predetermined water jet force. By the fuzzy addition of two inference results, the resultant direction of the catamaran movement can be determined as Fig. 4.

4. Catamaran simulator based on fuzzy inference system

The hardware schematic diagram of the developed catamaran simulator consists of twin control levers, A/D card and 32 bit personal computer with the maneuvering simulation program as Fig. 5.

Input of each control lever is converted into the voltage by the potentiometer, and this analog voltage is again converted into the digital value by A/D card. According to the value of the levers, the ship moves at the position (x, y) with the heading angle θ.

And the program of the simulator had been designed by assuming three virtual scenarios. The simulator also can be operated by two modes: the one is to manipulate directly the control levers with the potentiometer and the other is to operate indirectly through the keyboard. To feel the actual maneuvering sense, the one is preferred to the other. Status of each control levers are also displayed in the bottom of the monitor, so it can be referenced by an operator. Left menu panel consists of three virtual scenarios, the resultant A/D conversion data of potentiometer and the key definitions for the operation. In order to verify the performance of this simulator, three scenarios similar to the real



(a) port side:①. (b) starboard side:②. (c) resultant motion:①+②.

Fig. 4 Direction of the catamaran movement

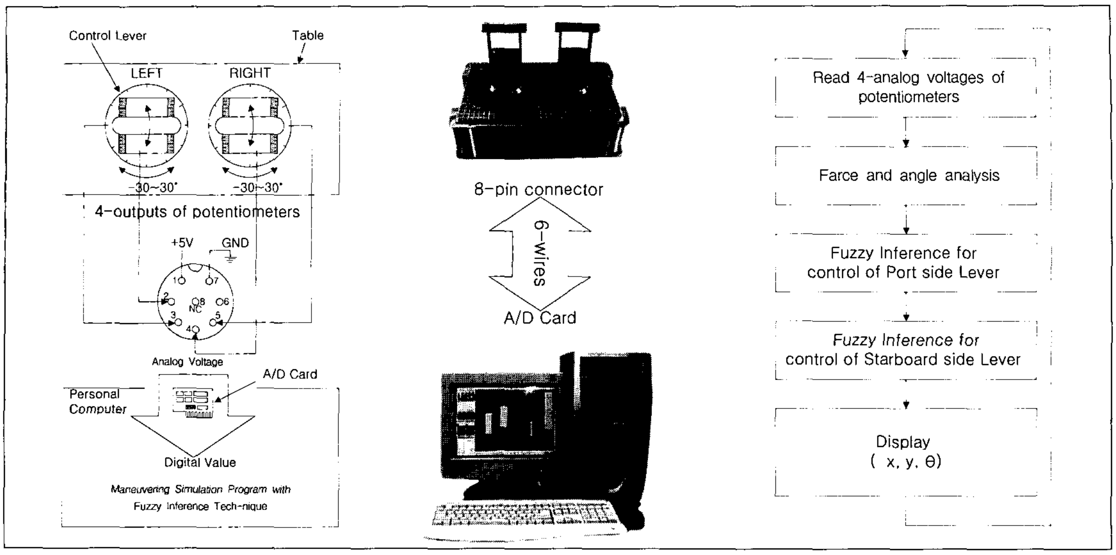


Fig. 5 Wiring diagram and flowchart of simulator.

sistuations in Busan seaport were postulated as follows.

Scenario 1. Come alongside the coast pier. - Operator learns the sideway control methods like Fig. 4. See Fig. 6.

Scenario 2. Pass the Young-do bridge safely. - Operator must control the catamaran without coming into collision with the bridge. Especially, the operator must learn the lever operation with only one lever to cope with emergency such as the failure of lever. See Fig. 7.

Scenario 3. Pilot freely at Busan south port. - Operator can see the relative movement of land. See Fig. 8.

These catamaran simulations were successful for the basic training and the transcendental intuition under three postulated scenarios. But, consider that the actual situation at sea may be different from the operation patterns of catamaran simulator.

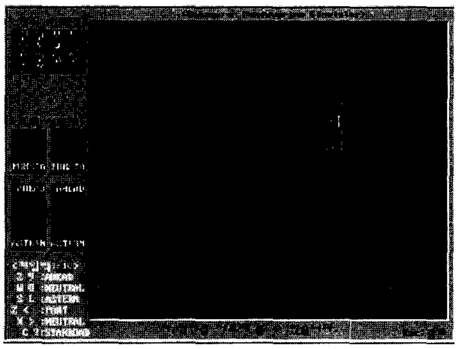


Fig. 6 Scenario 1.

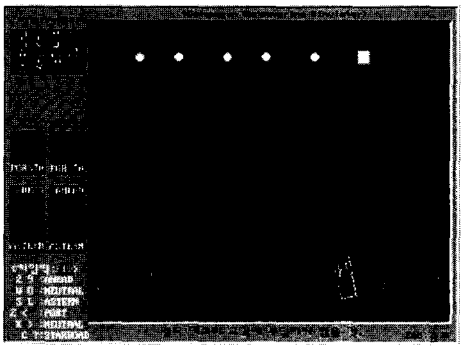


Fig. 7 Scenario 2.

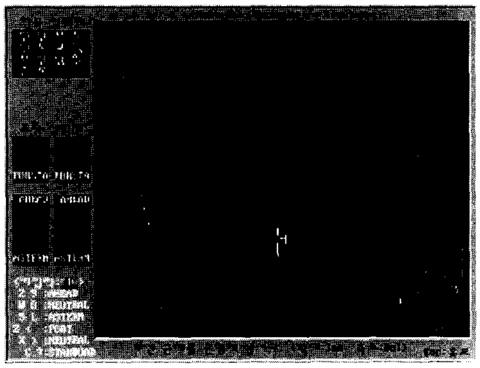


Fig. 8 Scenario 3.

5. Conclusion

The twin engine system, so called the catamaran controlled by two remote control levers and its economic simulator based on the personal computer with an Analog to Digital(A/D) converter was developed. This simulator is based on the fuzzy inference system of model-free approach. By using this simulator, a series of catamaran maneuvering training can be performed easily on the desk even in any places including the office. And we expect that three scenarios shall be helpful to ship operators who want to master the operation of the catamaran.

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