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Design of Multivariable Fuzzy Control System for Automatic Navigation of Ship

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요 약

본 논문에서는 다변수 퍼지 제어 시스템 이용한 선박의 자동 항해 시스템을 제안한다. 제안된 다변수 퍼지 제어 시스템은 세 개의 입력과 두 개의 출력을 가지는 서브시스템으로 구성되어지며, 제안된 시스템의 효과성을 증명하기 시뮬레이션을 통해 동적인 환경에서도 스스로 장애물을 인식하고 회피할 수 있음을 보였다.

Abstract

In this paper, we propose an automatic navigation system of ship using multivariable fuzzy control system in dynamic sea environment. The proposed multivariable fuzzy control system consists of two subsystems with three inputs and two outputs. The effectiveness of the proposed multivariable fuzzy control system is shown by simulation results.

Key Word : Automaitc Navigation System, Multivariable Fuzzy Control System

1. Introduction

Automation is one of the very important part modern industry societies. The research and development for an automation of various industrial machine and automatic control of dynamic plant have been studied over the last several decades. In particular, many research for vehicle have been progressed[2]-[5]. However, the works of automatic navigation of a ship for obstacle avoidance have been not enough. In the deep sea, this matter is not necessary because ship doesn't limit place. However, in near sea it is very important because it may collide with many other moving or working ships and many obstacle, such as an island or sucken lock. Because of this reason, there have unnecessary economy loss and need many people for safety in near sea. Therefore, to overcome above problems need exact system using intelligent control[1].

One of the more popular new technologies is "intelligent control", which is defined as the combination of control theory, operations research, and artificial intelligent. Among new technologies based on artificial intelligent, fuzzy logic is the popular area. Fuzzy control is one of field for global technological, economical, and manufacturing competitions[1]-[5]. In 1980's, fuzzy control is to be usefully applied the technological field that engineering design, intelligent control, signal filtering, pattern recognition, breakdown diagnosis, and the society field that decision making, the medical, action science, economy, society model, and the nature field that phenomena, geographical features, mode of life cycles, physics & chemical phenomenon[1]. Using technique such a fuzzy is efficient to automation of vehicle. Therefore, this paper used control system that composed with fuzzy logic.

In section 2 the multivariable fuzzy equations for open-loop control system are presented, and some formal properties of the equations are discussed. The design of map and fuzzy ship for navigation are illustrated in section 3. Section 4 of this paper shown modeling of multivariable fuzzy control system and fuzzy algorithms. Simulation results and plotting graphs are illustrated in section 5. The conclusions are given in section 6.

2. The Multivariable Fuzzy Control System Structure of Open-Loop System

In an industrial process a complex system can be decomposed into several interconnected subsystems based on the physical structure of the process. To avoid the computational burden due to the complexity of the global model and yet retain the coupling effects, one may wish to develop a fuzzy model which aggregates those

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parts of the system which are not of immediate concern, and maintain a similar structure for the subunits under consideration. Therefore, in chapter, it is explained a series connection of multivariable open-loop fuzzy systems will be analyzed now.

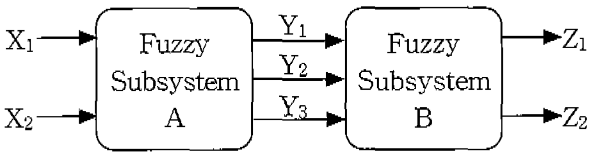


Fig. 1. Series connection of two fuzzy subsystems

A series of connections of two multivariable systems, as shown in Fig. 1, will be described by the following linguistics description.

[Fuzzy Subsystem A:]

$$\{(\text{IF } X_{1(i)} \text{ AND } X_{2(i)} \text{ THEN } Y_{1(i)} \text{ AND } Y_{2(i)} \text{ AND } Y_{3(i)}), (\text{ALSO})\}, \quad i=1,2,3,\cdots,n \tag{1}$$

[Fuzzy Subsystem B:]

$$\{(\text{IF } Y_{1(i)} \text{ AND } Y_{2(i)} \text{ AND } Y_{3(i)} \text{ THEN } Z_{1(i)} \text{ AND } Z_{2(i)}), (\text{ALSO})\}, \quad i=1,2,3,\cdots,n \tag{2}$$

Based on the previous considerations, a vector matrix notation of the subsystems in terms of the fuzzy equations has the following form:

[Fuzzy Subsystem A:]

$$\begin{bmatrix} Y_1 \\ Y_2 \\ Y_3 \end{bmatrix}' = [X_1 \ X_2] * \begin{bmatrix} R^A_{11} & R^A_{12} & R^A_{13} \\ R^A_{21} & R^A_{22} & R^A_{23} \end{bmatrix} \tag{3}$$

where

$$R^A_{kj} = \bigvee_{i=1}^{n} \{X_{k(i)} \wedge Y_{j(i)}\}, \quad k=1,2,3$$

[Fuzzy subsystem B:]

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}' = [Y_1 \ Y_2 \ Y_3] * \begin{bmatrix} R^B_{11} & R^B_{12} \\ R^B_{21} & R^B_{22} \\ R^B_{31} & R^B_{32} \end{bmatrix} \tag{4}$$

where

$$R^B_{kj} = \bigvee_{i=1}^{n} \{Y_{k(i)} \wedge Z_{j(i)}\}, \quad k=1,2,3, \ j=1,2$$

Substituting (3) into (4), the following composite fuzzy system of two multivariable open-loop systems connected in series is obtained:

$$\begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix}' = [X_1 \ X_2] * \begin{bmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{bmatrix} \tag{5}$$

where

$$R_{11} = R^A_{11} \circ R^B_{11} \wedge R^A_{12} \circ R^B_{21} \wedge R^A_{13} \circ R^B_{31}$$
$$R_{12} = R^A_{21} \circ R^B_{11} \wedge R^A_{22} \circ R^B_{21} \wedge R^A_{32} \circ R^B_{31}$$
$$R_{21} = R^A_{11} \circ R^B_{12} \wedge R^A_{12} \circ R^B_{22} \wedge R^A_{13} \circ R^B_{32}$$
$$R_{22} = R^A_{21} \circ R^B_{12} \wedge R^A_{22} \circ R^B_{22} \wedge R^A_{32} \circ R^B_{32}$$

Equation (5) is represented by the structure shown in Fig. 2. The reduced fuzzy model (5) contains the system's structural information. Using (3)-(5), a multivariable series-connected system with a given linguistic description can be analyzed or synthesized.

3. Design of Dynamic Environment

In this paper, the map are designed to 640×480 PCX mode by NEOPAINT program which is one of many excellent graphic program. It is a convenient and simple program to draw graphic. A number of maps to simulate

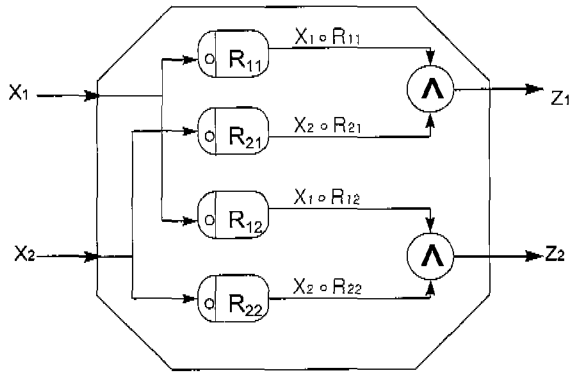


Fig. 2. Multivariable structure of series connection of two fuzzy subsystems

are two an include obstacles each other. In map static obstacles are islands and dynamic obstacles are ships which are moving or working.

Map 1 in Fig. 3 is designed to know how the fuzzy ship move various courses.

(a) map 1

(b) map 2
Fig. 3. Design of map

Map 1 in Fig. 3 is designed to know the decision ability of the fuzzy ship in several courses. The first ship is designed to obstruct the moving of the fuzzy ship at starting position and the second ship is designed to move from the lower right to the upper right at a narrow path and third ship is designed to turn around the coast line.

Map 2 in Fig. 3 is designed to know how the fuzzy ship navigate a wide space which almost never exist the interference of geographic. In this paper, this map is used twice with the different dynamic obstacles. In the first simulation each ship moves toward the center of map, but the initial places of ships are different. The first ship is designed to move to a deep sea and the second ship is designed to move from the lower right place to the upper left place and the third ship is designed to move into a port. In the second simulation, the first is designed to move together the fuzzy ship and the second is designed as the first simulation each ship and the third ship is designed to move form the deep sea to the port

The numerical value (i.e., width, length) of ship is generally made into a rate for the real geographic, but it may have a few errors. A kind of ship assumes not a boat but a vessel. Each coordinate is used to decide the next output of the fuzzy ship.

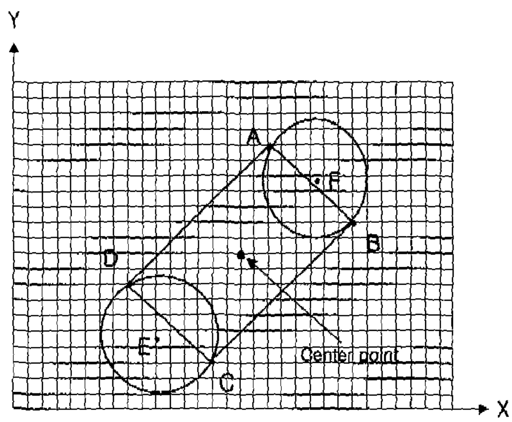


Fig. 4. Design of the fuzzy ship

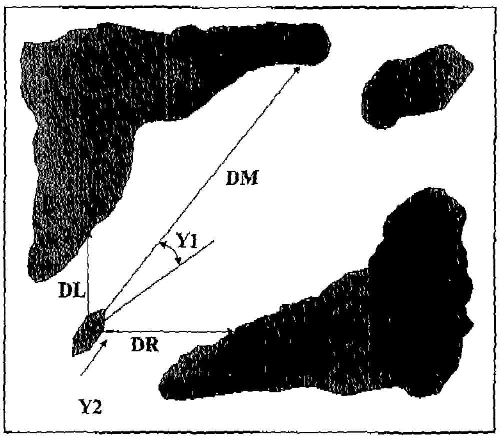


Fig. 5. Input and output variables

Fig. 4 presents points to necessary for design of the fuzzy ship. Each point(A, B, C, D, E, F) is made by the ready-selective center point of the fuzzy ship. These points are converted by trigonometrical function.

In control design of input and output variables are a very significant. According to their numbers, the system is complex or simple and has a good or bad efficiency. Therefore, the design of input and output variables are principal. To move the fuzzy ship need five variables. The following Fig. 5 illustrates input and output variables.

In Fig. 5, DL is a distance from the fuzzy ship to the left obstacle and DM is a distance from the fuzzy ship to the front obstacle and DR is a distance from the fuzzy ship to the right obstacle. Y1 is the delta angle to decide the next direction of the fuzzy ship and Y2 is the margin to move the front ship. Y2 is used to the information to decide the next coordinates of the fuzzy ship. If the fuzzy ship is to be near place of the right obstacle (i.e., island or others ships), it turn to the left at the present place and then it move with the modified direction. If the distance of the front obstacle is long, the fuzzy ship move many distances.

4. Automatic Navigation System

4.1 Modeling of multivariable fuzzy system

Fig. 6 shows the block diagram of multivariable fuzzy control system. This block diagram show to express the simple connection of input and output variables.

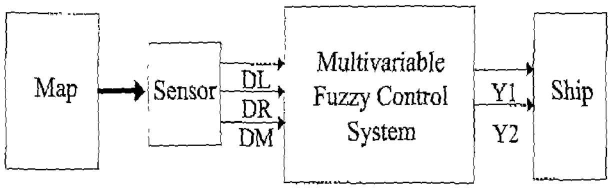


Fig. 6. Block diagram of fuzzy control system

As shown in Fig. 5, the fuzzy ship founds distance of the left obstacle, the right obstacle and the front obstacle by three sensors.

The founded informations are transferred to input of multivariable fuzzy systems. Fig. 7 shows the structure of fuzzy control system.

In Fig. 7, the parameters(DL, DR, DM) are distance of each obstacle. Y1 is the delta angle of ship and Y2 is the information on x and y coordinate of the fuzzy ship. The informations collected from sensors of the fuzzy ship is used to detect the variable numbers of input and output of the fuzzy control system.

The fuzzy control system A collects a difference value of the left obstacle and the right obstacle and it is used to input variables. The output of fuzzy system A modifies the angle of the fuzzy ship and it is used to one of the input variable of fuzzy system B. Y1 is a half of output of the fuzzy control system A and DM which is the distance of the front obstacle of the fuzzy ship is used to the input variable of fuzzy control system B. The output of fuzzy system B determines the next coordinate of ship.

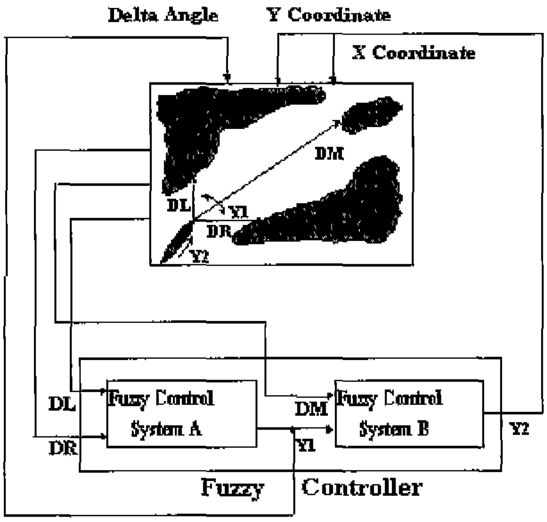
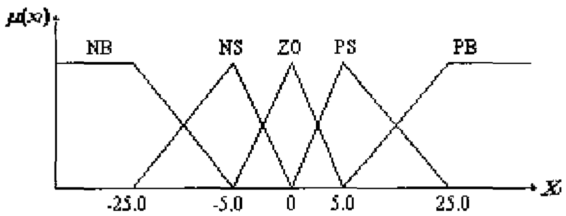


Fig. 7. Structure of the fuzzy control system

4.2 Fuzzy algorithm of navigation system

There are two main factors to move fuzzy ship such as change of angle and distance. Therefore, in this paper, fuzzy control system consists of three inputs and two outputs. Fuzzy algorithms using multivariable fuzzy control system are described by the following :

[Fuzzy System A]



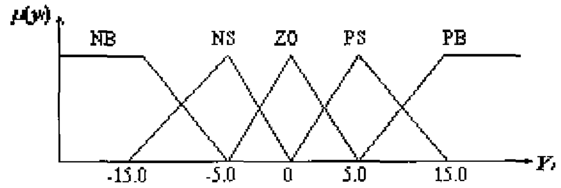


Fig. 8. Input and output membership functions of fuzzy system A

$$X1=DL-D \qquad (6)$$

Fig. 8 shows to present the input and output membership function of fuzzy system which is one of the subfuzzy system of multivariable fuzzy system. X1 which is the input of fuzzy system A is a difference value of DL and DR. Y1 which is the output of that is a delta angle of the fuzzy ship.

The rules are formulated by the following verbal description.

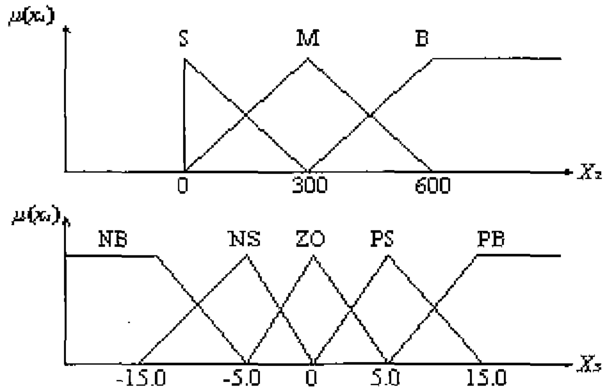
IF X1 = NB THEN Y1 = NB
IF X1 = NS THEN Y1 = NS
IF X1 = ZO THEN Y1 = ZO
IF X1 = PS THEN Y1 = PS
IF X1 = PB THEN Y1 = PB

where NB = negative big, NS = negative small, ZO = zero, PS = positive small, PB = positive big.

If the fuzzy ship is near by the right obstacle, it turns to the left the present place with delta angle. In reverse, if it is near by the left obstacle, it turns to the right from the present place with delta angle. If the fuzzy ship is the middle place of the right obstacle and the left obstacle, it doesn't modify the direction of fuzzy ship. Y1 is a delta angle for navigation of the fuzzy ship and it is calculated by rules.

[Fuzzy System B]

As shown in Fig. 9, the fuzzy control system B has two inputs. One is X2 that is distance in front of ship, the other is X3 that is a half of Y1 which is the output of fuzzy system A. A delta angle is already chosen as the output of fuzzy control system A.



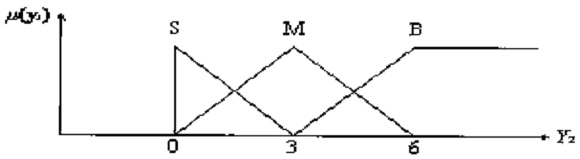


Fig. 9. Membership function of input and output of fuzzy system B

$$X2 = DM \quad (7)$$

$$X3 = |0.5 \times Y1| \quad (8)$$

Thus, the value simply relates to a quantity of distance to move the fuzzy ship. The scope of small membership function is 0 ~ 300, the scope of medium membership function is 300 ~ 600, and the scope of big is from 600 ~ 1000. Where define the maximum of x and y coordinates as each 1000. This value is changed to 640×480 mode by trigonometrical function when the fuzzy ship navigates the proposed map. Y2, which is the output of fuzzy system B is the distance to move to the next coordinate of the fuzzy ship.

X2 \ X3	NB	NS	ZO	PS	PB
S			S	S	S
M			M	M	
B			B	M	

Fig. 10. Rule table of fuzzy system B

Fig. 10 shows the rule table of fuzzy control system B. The rules are described by the following verbal description:

X2 = S AND X3 = ZO THEN Y2 = S
X2 = S AND X3 = PS THEN Y2 = S
X2 = S AND X3 = PB THEN Y2 = S
X2 = M AND X3 = ZO THEN Y2 = M
X2 = M AND X3 = PS THEN Y2 = M
X2 = B AND X3 = PS THEN Y2 = M
X2 = B AND X3 = ZO THEN Y2 = B

where S = small, M = medium, B = big

The whole rules are 15 but in this paper seven rules is used. To use seven rules is sufficient to control the fuzzy ship. The membership function in X2, which is the input of fuzzy control system B use only ZO, PS, PB. Because the absolute value of Y1 transfer to the input of fuzzy control system B and NB, NS of Y1 doesn't need.

If the distance of the front obstacle of the fuzzy ship is small and the delta angle of the fuzzy ship is zero or positive small or positive big, Y2 which determined the next coordinate of the ship is small, because of the short distance of the front obstacle. If DM is the medium distance and the delta angle is zero or positive small, Y2 is medium. This is why the possible distance to move the fuzzy ship is medium. If DM is a large value and the delta angle is positive small, Y2 is to be medium. Because the ship has to rotate greatly. Therefore, when DM is big and X3 is ZO, the Y2 is big. This is to know that the ship moves to far away when the direction of the ship is right.

The form of triangle membership function is irregular. The reason is due to necessitate the delicate and clear control at the narrow place than the wide place. Then the calculated value uses to quantize output of the fuzzy system. A quantization is executed for the sake of convenience of calculation. Analog is continuous value, so difficult to calculate. Therefore it is transformed to digitalize, because digital is a dispersion value. Where use a linear quantization method[6]. Fig. 11 shows the quantization step of output membership function.

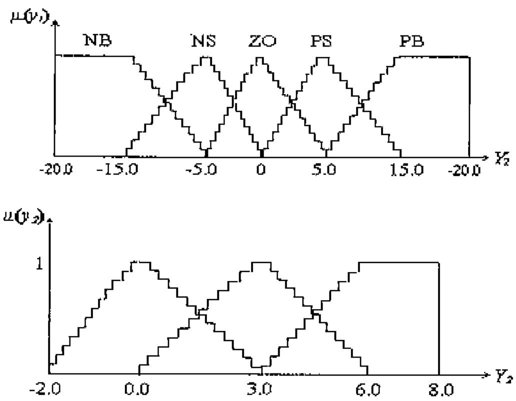
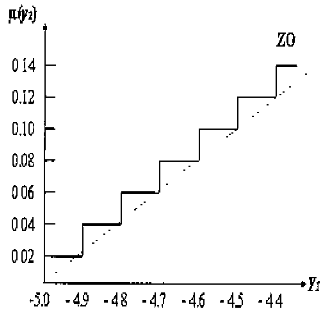


Fig. 11. Quantization of output membership function

The boundary of Y1 to decide the delta angle of the fuzzy ship is [-20, +20] and the boundary of Y2 to decide the next coordinate of that is [-2, +8]. The reason that the minimum boundary of the Y2 decides on -2 is in order to avoid that the fuzzy ship clashes into obstacle when the distance about the front obstacle of the fuzzy ship is very short. Therefore, the fuzzy ship can stop by this negative value at the same place. Here the quantization scale for the output value of fuzzy control system A is selected 0.1 and the fuzzy control system B is selected 0.05.



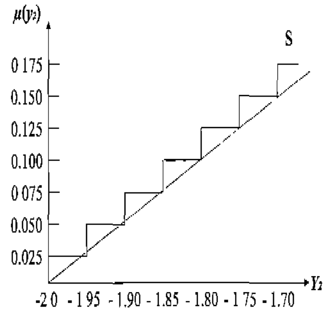


Fig. 12. Scaling of membership function

For example, the quantization scale of the ZO and S, which are in the output membership functions of fuzzy control system A and fuzzy control system B, are shown in Fig. 12.

The composition method using this paper is used mamdani's max-min implication[7].

[Max-Min composition]

$$\mu_Y(y) = \max_{(x_1, x_2)\in f^{-1}(y)} \{ \mathrm{Min}[\mu_{X_1}(x_1), \mu_{X_2}(x_2)]\} \qquad (9)$$

The defuzzification use the COG(Center Of Gravity) method.

[COG method]

$$\bar{y} = \int \frac{\sum_{i=0}^{N} \mu_Y(y) \cdot y \, dy}{\sum_{i=0}^{N} \mu_Y(y) \, dy} \qquad (10)$$

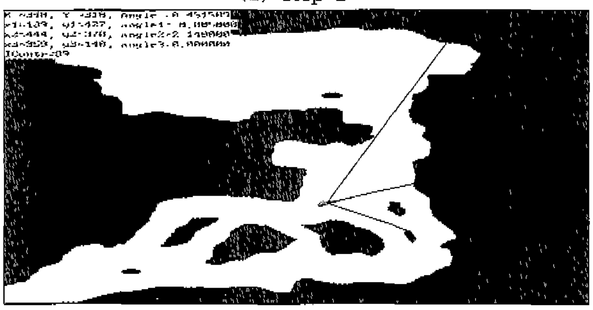
5. Simulation

The fuzzy ship using the multivariable fuzzy control systems, navigates like the following two maps(Fig. 13, Fig. 14). Each map has the result presented by four steps. Step 1 shows the initial point of each map, step 2 shows when the fuzzy ship meets the first moving obstacle. The step 3 and step 4 show when the fuzzy ship meets the second and third moving obstacles respectively.

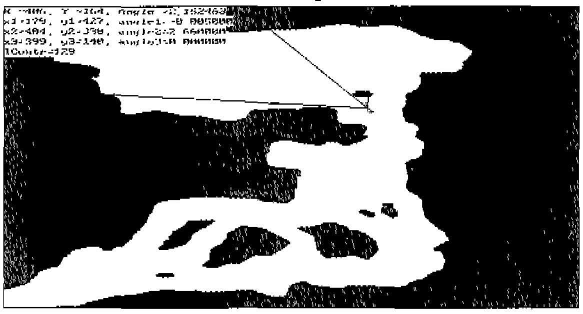
Fig. 13 is designed in order to know how the fuzzy ship move several courses. Step 1 is figure to present the initial point of the fuzzy ship and the middle sensor of that finds the first obstacle. Because DM of the fuzzy ship very short, the fuzzy ship very slowly moves to the front and the marks of that is nearby presented in step 2. At this time, the speed of fuzzy ship is slow, but when the fuzzy ship escapes from this path, it moves speedy. Step 2 shows when the fuzzy ship arrives at various courses. As shown step 2, because DL of the fuzzy ship is shorter than DR, the fuzzy ship move to the right and then it navigates the middle course. In the result, the course is to be a optimal path which the distance short the most.

(a) step 1

(b) step 2



(c) step 3

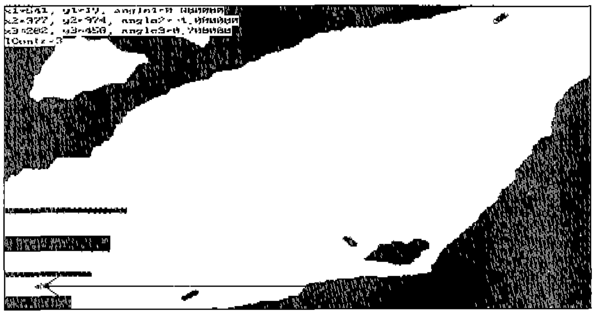


(d) step 4

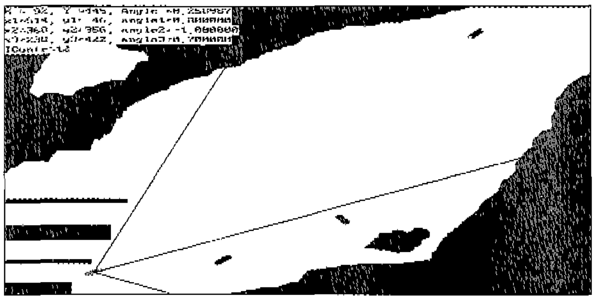
Fig. 13. Simulation result of map 1

Step 3 shows when the fuzzy ship is navigating the middle of course. The right beam of fuzzy ship finds the second obstacle which moves to the middle of map, but it is no matter. Because the fuzzy ship avoids the place before the obstacle arrive at there. Step 4 is a figure before the fuzzy ship nearly collides with other ship. DR of the fuzzy is very short and the mark of fuzzy ship also is very close, but the fuzzy ship perfectly avoids the obstacle which orbits the coastline. Therefore, this simulation also has the satisfied result.

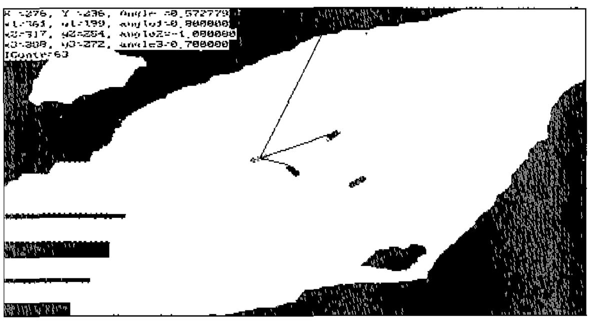
Fig. 14 shows a course of the fuzzy ship, which moves from a port to a deep sea. Step 1 is a figure before the fuzzy ship starts the navigation. Step 2 illustrates when the fuzzy ship leave a port. The fuzzy ship rapidly navigates a course because DM, which decides the next distance of the fuzzy ship are long. This mark is presented with the wide interval in step 3. Step 3 shows that ship meet with two obstacles that is moving from the lower right and the upper right at the center. The direction of fuzzy ship is modifies to avoid the obstacles, but the distance isn't big because the difference of DM and DR is similar and then the fuzzy ship avoid the obstacles in safety. The result is step 4. The fuzzy ship already avoids the ship risen from the lower right and then it navigates without collision with the third obstacle which come from a deep sea. This simulation also has a good result.



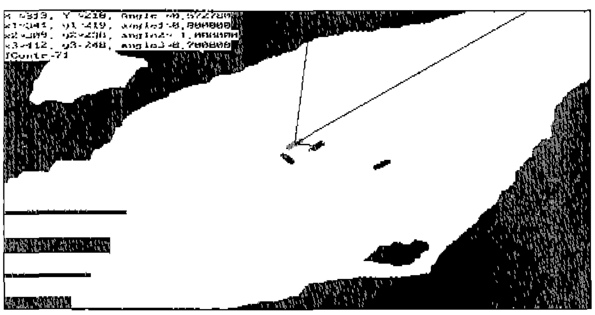
(a) step 1



(b) step 2



(c) step 3



(d) step 4

Fig. 14. Simulation result of map 2

6. Conclusion

This paper proposed multivariable fuzzy control system which has a exact decision ability and control technique. The proposed multivariable fuzzy control system was used to automatic navigation of ship with dynamic environment.

As shown the results, the ship with multivariable fuzzy control system navigated the various course by itself. The proposed multivariable fuzzy control system was proved that they have a good ability in dynamic environment. Two simulations were shown good results, which were responded to a sudden obstacle. The fuzzy ship successfully navigated without collision the maps proposed in this paper. Also, the fuzzy ship had different results at map with the same geographic. This was because the dynamic environment of map differed.

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