An Intelligent Control System for Ship Collision Avoidance

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***Abstract*— The paper aims to develop an intelligent controller to control the ship trajectory. This requires a procedure to acquire the control rules for a moving ship to avoid collision with another moving object and then steer back to reach a certain destination. This objective can be achieved by applying fuzzy logic approach. A linear 4 Th order mathematical model is developed to represent the ship dynamics. The model and the control algorithm are simulated on a PC using C++ language. The obtained results affirmed that the proposed control algorithm is powerful to realize the tracking and regulation objectives.**

***Index Terms*—Intelligent, Control, Fuzzy, Collision Avoidance**

I. INTRODUCTION

Many procedures for improving the performance of control systems are based on the control strategies of human operators have already been published [1-9]. Pierre developed an on-board real—time expert system for controlling engineering systems [1]. Gilles and Pierre [2] proposed approach adopted for developing real-time expert systems by adding real-time functions to AI systems. A fuzzy guidance controller is developed for waypoint following guidance on a small autonomous boat by Vaneck [3]. The present authors have already described a method for the automatic acquisition of control strategy and tactics from operator-generated data using fuzzy neural networks [4, 5]. Cheng and Liu present a new space model for collision avoidance using genetic algorithm [6, 7]. Yu and others designed ship intelligent agent architecture, and proposed seven basic units [8]. Realization of integration technology, of ship collision avoidance system, based on high level architecture, studded by wang and others [9].

Fuzzy logic provides a practical, inexpensive solution for controlling complex or ill-defined systems. The idea of fuzzy sets is introduced by Lotfi Zadeh in his seminal papers published around 1965 [10]. Fuzzy theory is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings, tall, hot, dangerous, a little, very much, and so on.

The main objective of this paper is to acquire the control rules for a moving ship to avoid collision with another moving object and then steer back to reach a certain destination. This objective can be achieved by applying fuzzy controller.

The paper is organized as following; in Section 2, an overview of fuzzy logic system is given. Section 3, is devoted to treat the problem of collision avoidance. In Section 4, a ship collision avoidance system is designed using the fuzzy controller. Section 5, involves the simulation results with external disturbances at the track and without its. In Section 6, comparison and parameters sensitivity analysis are presented. Section 7, involves the Conclusions and suggestions for future work.

II. FUZZY LOGIC

The idea of fuzzy sets introduced by Lotfi Zadeh in his seminal papers published around 1965 [10]. Fuzzy theory is primarily concerned with quantifying and reasoning using natural language in which many words have ambiguous meanings, tall, hot, dangerous, a little, very much, and so on [11].

Fuzzy logic provides a practical, inexpensive solution for controlling complex or ill-defined systems. Despite its contradictory-sounding name, fuzzy logic offers a rigorous framework for solving many types of control problems. Rule-based fuzzy controllers require less code and memory and do not need heavy number-crunching or complex mathematical models to operate. All that is really needed is a practical understanding of the overall system behavior.

Using fuzzy logic to reach a crisp solution to a specific problem usually involves three steps: fuzzifier, fuzzy inference engine, and defuzzifier. Figure l, shows basic configuration of fuzzy logic system with fuzzifier and defuzzifier.

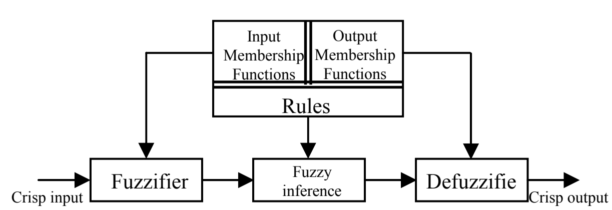

Fig.1 Basic configuration of fuzzy logic system.

The fuzzy logic system with fuzzifier and defuzzifier has many attractive features. First, it is suitable for engineering systems because its inputs and outputs are real-valued variables. Second, it provides a natural framework to incorporate fuzzy - IF -THEN rules form human experts. Third, there is much freedom in the choices of fuzzifier, fuzzy inference engine, and defuzzifier, so that we may obtain the most suitable fuzzy logic system for a particular problem. Finally, we can develop different training algorithms for this fuzzy logic system so that it provides an effective framework to integrate numerical and linguistic information. One of the most commonly used defuzzifier techniques is called the Center of Gravity (COG) or centroid method [12, 13].

III. STEERING OF A SHIP WITH INERTIA

The single manipulated variable of the operator's ship is the steering angle u. The equations below are taken to be a simplified model of the ship's dynamics [4] (the reduced order model is used to obtain a simple controller design).

$$T\frac{dw}{dt}+w(t)=ku(t) \quad (1)$$

$$w(t)=\frac{d\theta(t)}{dt} \quad (2)$$

$$\frac{dx}{dt}=|V|\sin\theta(t) \quad (3)$$

$$\frac{dy}{dt}=|V|con\theta(t) \quad (4)$$

$$\theta=\theta'+\eta \quad (5)$$

Where T is the time constant (T=2 sec). V is the velocity of the operator's ship and |V| is the speed, u is the steering angle, w is the angular velocity, θ is the angular deviation from the north, k is a constant (k=2), (x, y) is the Cartesian ship position, and η is external disturbances (from currents and wind).

Figure 2, shows the terms used to describe the position of the operator's ship relative to another ship and the goal. The distance between the ship and the other ship is denoted by D. The angle between the direction of the operator's ship and the direction of the other ship viewed from the operator's ship is denoted by δ_o. In the same way, the angle between the direction of the operator's ship and the direction of the goal viewed from the operator's ship is δ_G. V_R is the relative velocity of the operator's ship (moving at V) with respect to another ship (moving at V_o). The angle formed by V_R and the direction vector of the operator's ship will be referred to as □.

When □ is near zero the other ship is approaching the operator's ship nearly headed on. When □ is positive the other ship should pass in front of the operator's ship, and when □ is negative the other ship should pass behind the operator's ship. As the other ship approaches the operator's ship □ approaches 90 (or -90) degrees: once the two ships have reached maximum proximity their positions begin to diverge, the value of □ increase (or decreases), and the relative distance D is proposed a negative value.

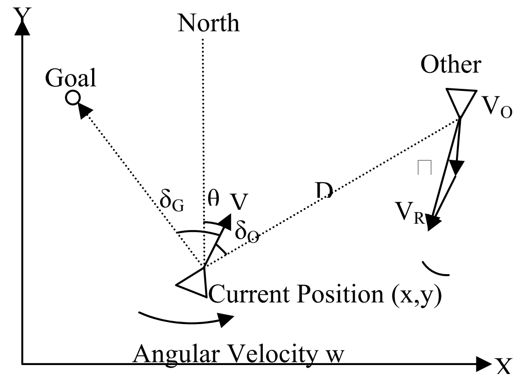

Fig.2 Simulation parameters.

Equations for computation algorithm are:

$$D=\sqrt{(x_1-x')^2+(y_1-y')^2} \quad (6)$$

$$\delta_G=\theta+\tan^{-1}\left(\frac{x_2-x_1}{y_2-y_1}\right) \quad (7)$$

$$\delta_O=\tan^{-1}\left(\frac{x_1-x'}{y_1-y'}\right)-\theta \quad (8)$$

$$\phi=\tan^{-1}\left(\frac{x_1-x'}{y_1-y'}\right)-\beta_{VR} \quad (9)$$

Where: $\beta_{VR}=\tan^{-1}\left(\frac{|V_X+V_{OX}|}{|V_Y+V_{OY}|}\right)$, V is velocity of the operator's ship, V_O is velocity of the other ship, (x_1, y_1) is the Cartesian operator's ship, (x_2, y_2) is the Cartesian goal, and (x', y') is the Cartesian other ship.

The unit of the distance between the ships is defined here to be a dot on the CRT screen. There are 640 x 480 dots on the CRT screen [4].

IV. FUZZY CONTROLLER

We simplify the fuzzy controller structure in order to limit the number of input variables up to two for each table. In this method, we have four fuzzy controllers.

Figure 3, shows the block diagram of the fuzzy controller.

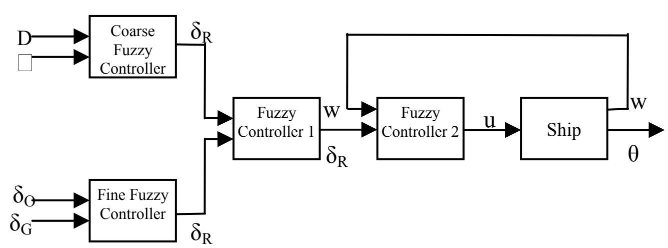

Fig.3 Block diagram of fuzzy controller

The first one is coarse fuzzy controller, it has two inputs (D, □), and one output (δ_{Rl}). Where, the membership functions for the (D, □) are given in figure 4.
Moreover, we use the rules in the table (I).

TABLE I

AVOIDING FUZZY RULES FOR THE δ_{R1}.

δ_{R1}		The angle of relative velocity □		
		Rear	Approaching	Fore
Distance D	Far	A1	A2	A1
	Near	A1	A3	A4
	Gone	A1	A1	A5

The second one is fine fuzzy controller, it has two inputs (δ_O, δ_G), and one output (δ_{R2}). Where, the membership functions for the (δ_O, δ_G) are given in figure 4.
Moreover, we use the rules in the table (II).

TABLE II
AVOIDING FUZZY RULES FOR THE δ_{R2}.

δ_{R2}		Direction δ_O		
		Left	Fore	Right
Goal δ_G	Left	Left	Left	Left
	Fore	Small left	Fore	Small right
	Right	Right	Right	Right

The third one is fuzzy controller l, it has two inputs (δ_{R1}, δ_{R2}), and one output (δ_R). Where, we use the rules in the table (III).

TABLE III
AVOIDING FUZZY RULES FOR THE δ_R

δ_R		**δ_{R1}**				
		A1	A2	A3	A4	A5
δ_{R2}	L	0	1	19	-32	-18
	S.L	0	0	-19	-4	-1
	F	0	9	16	-7	0
	S.R	0	-1	19	4	2
	R	0	0	-19	32	16

The fourth one is fuzzy controller 2, it has two inputs (δ_R, w), and one output (u). We use the rules in the table (IV). Where the command u, go to the ship's model (ship's dynamics (1-4).

TABLE IV
FUZZY CONTROL RULES FOR THE COMMAND u

Command u		Angular velocity w		
		Left	Straight	Right
Direction δ_R	Left	-19.7	-12.8	-10.0
	Fore	2.8	0.0	-2.8
	Right	10.0	12.8	19.7

V. SIMULATION RESULTS

The membership functions for the (D, □, δ_O, δ_G) are given in figure 4.

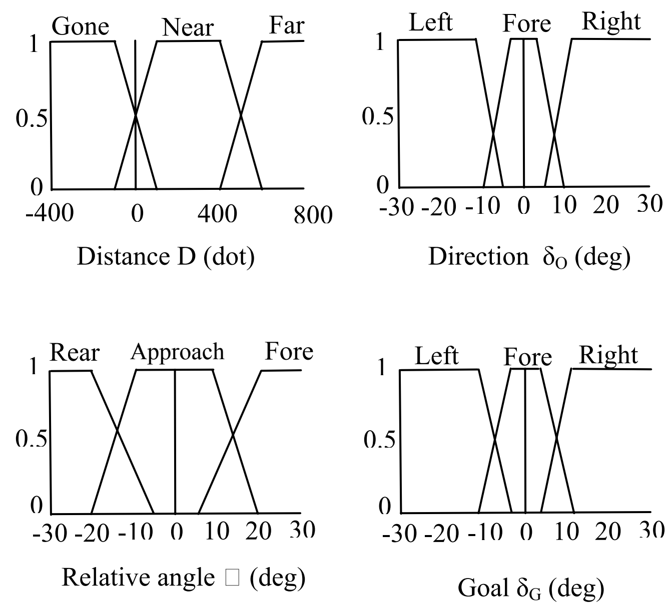

Fig.4 Membership functions for direction command.

Where the membership functions for the (δ_R, w) are given in figure 5.

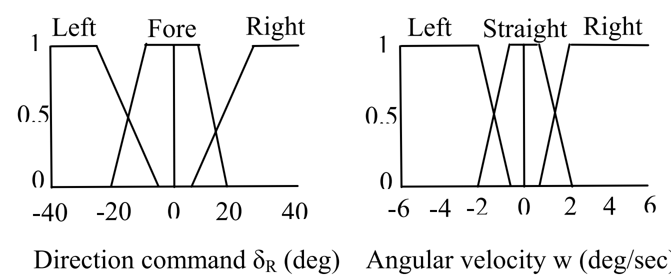

Fig.5 Membership functions for steering command.

Figure 6, shows simulation results with fuzzy controller. Where the other ship comes from 45 (deg) to the left at k = 2, T = 2 and η = 0. Where operator's ship indicated with rectangles. The operator's ship starts to avoid collision at rectangle number ten, and backs to its track at rectangle number thirteen. The maximum proximity is 108 (dot).

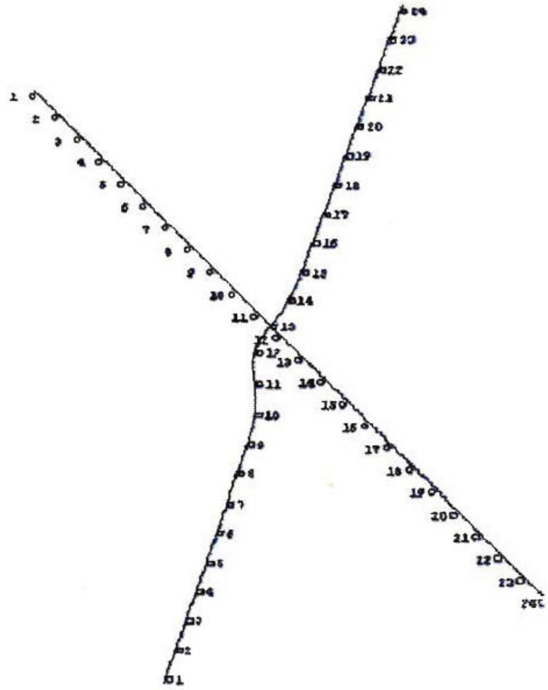

Fig.6 Simulation with fuzzy controller.
The other object comes from 45 (deg) to the left

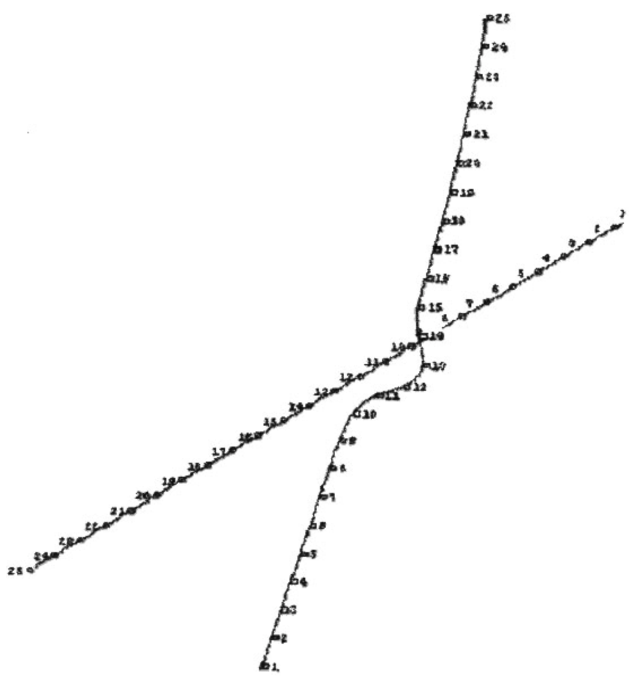

Fig.7 Simulation with fuzzy controller.
The other object comes from 30 (deg) to the right

Figure 7, shows simulation results with fuzzy controller, where the other ship comes from 30 (deg) to the right at $k = 2$, $T = 2$ and $\eta = 0$. The operator's ship starts to avoid collision at rectangle number ten, and backs to its track at rectangle number fifteen. The maximum proximity is 110 (dot).

Figure 8, shows simulation results with fuzzy controller, where the other ship is head on at $k = 2$, $T = 2$ and $\eta = 0$. The operator's ship starts to avoid collision at rectangle number two, and backs to its track at rectangle number twenty-four. The maximum proximity is 185 (dot).

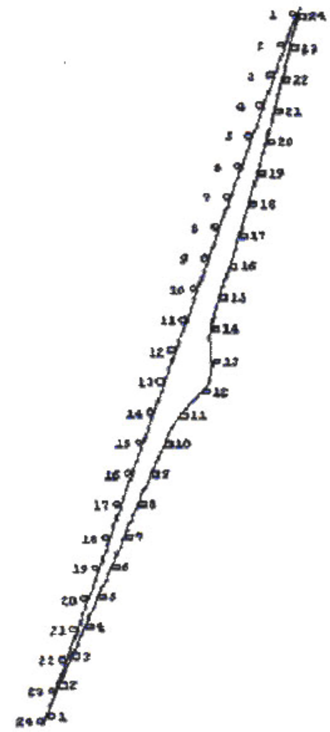

Fig.8 Simulation with fuzzy controller.
The other object is on head.

In the preview simulations, we used $\eta = 0$, but we will suppose $\eta \neq 0 \rightarrow \theta=\theta' + \eta$ and $\eta \leq (0.1 \text{ maximum } \theta)$.

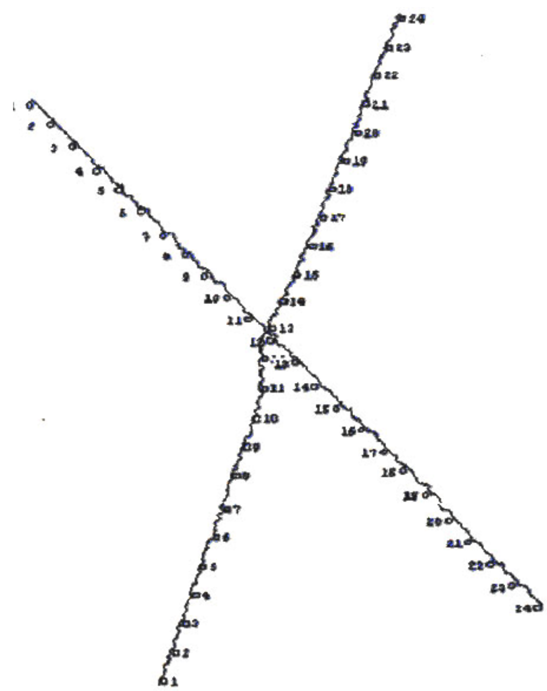

Fig.9 Simulation with fuzzy controller $\eta \neq 0$.
The other object comes from 45 (deg) to the left

Figure 9, shows simulation with fuzzy controller, where the other ship comes from 45 (deg) to the left at k = 2, T = 2 and η≠ 0. Where operator's ship indicated with rectangles. The operator's ship starts to avoid collision at rectangle number ten, and backs to its track at rectangle number thirteen. The maximum proximity is 88 (dot).

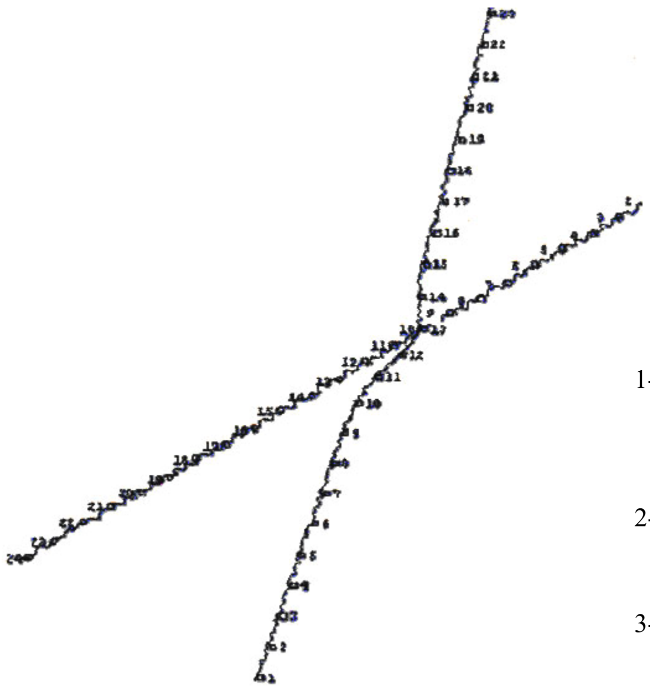

Fig.10 Simulation with fuzzy controller η ≠ 0.
The other object comes from 30 (deg) to the right

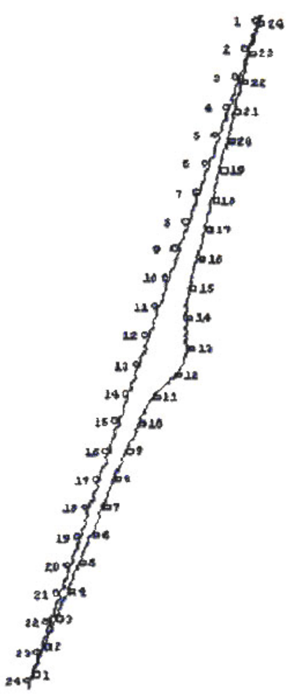

Fig.11 Simulation with fuzzy controller η ≠ 0.
The other object is on head.

Figure 10, shows simulation with fuzzy controller, where the other ship comes from 30 (deg) to the right at k = 2, T = 2 and η ≠ 0. The operator's ship starts to avoid collision at rectangle number ten, and backs to its track at rectangle number fourteen. The maximum proximity is 56 (dot).
Figure 11, shows simulation with fuzzy controller, where the other ship is head on at k = 2, T = 2 and η ≠ 0. The operator's ship starts to avoid collision at rectangle number two, and backs to its track at rectangle number twenty-four. The maximum proximity is 160 (dot) η < 0.05 maximum θ. In this case, the ship cannot avoid collision when η > 0.05 so η must be <0.05.

VI. COMPARISON AND PARAMETERS SENSITIVITY ANALYSIS

We comparison between expert and fuzzy controllers. Sensitivity analysis for system parameters is achieved to find the best design parameters.
We select as performance measure criterion, three factors:

1- 1- the maximum proximity (minimum risk of collision) (minimum) $D=\sqrt{(x_1-x')^2+(y_1-y')^2}$ (10)

2- 2- minimum energy= $\left(\int u^2 dt \quad or \quad \sum_{i=0}^{n} u^2 \Delta t\right)$ (11)

3- 3- smoothing in direction = $\sum_j \left[\theta(j)-\theta(j-1)\right]^2$ (12)

in table (V), we compare between control approaches in (maximum proximity, sum of energy, number of rules and smoothing in direction) at k=2, T=2, η=0, and the other ship comes from 45 (deg) to the left.

TABLE V
COMPARISON BETWEEN CONTROL APPROACHES (η=0)

Control approach	Maximum proximity	Sun of energy	Number of rules	Smoothing in direction
Expert controller	90	$89*10^2$	90	195
Fuzzy controller	108	$96*10^2$	52	182

From the table (V), we find fuzzy controller has the best maximum proximity, smaller number of rules (simple controller), and smoothing in direction.

VII. CONCLUSIONS

In this paper, a fuzzy controller is used to control the direction and steering of ship. The system under consideration to be controlled is a moving ship to avoid collision with another moving object and then steer back to reach a certain destination. The system is studied with disturbances (currents and wind effect) and without it.

We find that the fuzzy controller is powerful. Where the number of obtained rules is limited and the ship back smooth to the track after collision avoidance. Minimum risk of collision (maximum proximity) is reasonable, and dependency on navigator is reduced to very limited level because the variables are determined automatically, also it is appropriate for real time because processor computes the variables. Suggestion for future, the work may be deal with multiple object avoidance, or multivariable case (direction and speed).

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