Performance Analysis of Ship Tracking using PID/Fuzzy Controller

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***Abstract:*—Accurate ship Path following is an issue of the Marine Navigation Technology. In order to achieve accurate path following in ship navigation various controllers like PID (Proportional-Integral-Derivative), Adaptive and Predictive controllers are used. However, the main problem of ships is the PID controller is that they are set to work under specific conditions. Even though predictive controllers have predictive capability and are giving accurate results but they are computationally complex. In this work an attempt is made to evaluate the performance of Adaptive (Fuzzy logic) and PID controllers in terms of tracking efficiency and computational time. Computational result evaluated using mat lab shows that Adaptive (Fuzzy logic) provides better tracking performance than PID.**

***Keywords*—Fuzzy Logic control, PID, Underactuated Ship Control.**

I. INTRODUCTION

To design a path following for a ship is always a challenging problem. A ship dynamics is influenced by unpredictable environmental disturbances such as waves, winds, change of depth under keel, etc. as well as ship sailing conditions such as speed, loading condition, trim, etc. The efficient ship path following is very important in the ship navigation because it not only save's the time but it also save's the fuel consumption of the ship which is very important parameter to be considered in the ship. But to achieve the efficient path following of ship and as well to generate accurate heading angles, one should have a robust controller which takes into account of sea disturbances, ship hydrodynamics and both internal /external noise parameters into consideration[1].

There are several technique used for ship tracking, namely PID, adaptive and predictive controllers. PID controllers are most widely used for control application. For ship navigation task, the controller coefficients need to be changed due to several reasons like environmental changes (wind, waves, and currents), random disturbances, internal errors etc. To accommodate these changes PID controller coefficients Kp, Ki, Kd, must be tuned accordingly, which demands the support of other controllers (fuzzy, genetic etc.), which in turn increases the complexity of the system. Hence PID controllers are not suitable for Navigation applications [2].

The Model Predictive Controller which is an advanced method of process control, which involves the complex computational operations to predict the behavior of dependent variables (i.e. heading angle outputs) of the modeled dynamic system with respect to changes in the process of independent variables (i.e. way point inputs). The main disadvantage of this controller is computationally complex [3] [4].

At present, ship modeling and control is an issue of high interest in research areas. The control problems are challenging due to the fact that the motion of ships possess six degrees of freedom to be controlled. Usually, the ship has: large time lag, large inertia, nonlinearity and underactuated characteristics; and its motion is strongly influenced by the model parameter perturbations (wind, wave and current flow). So the design of the motion controllers with high performance is always difficult [5].

For the ship modeling, there many ships mathematical models namely nomoto's, bech, and norbin and yang model [1]. These ship models are developed such that they can be controlled by any controller by giving command signal. We used Bech's nonlinear model, which supports 6 degree of freedom and larger rudder angle turns of ship, is used to simulate ship dynamics.

There are some wave mathematical models namely Bretschnieder spectrum, Pierson-Markowitz (P-M) spectrum, Modified Pierson-Markowitz, and JONSWAP spectrum. In order to consider Sea disturbances, modified Pierson-Markowitz Spectrum (P-M) is used which will take into account of both high and low tides.

In such situation, the researchers call the intelligent control theories and try to achieve better results of control. In this paper, we attempt to use the fuzzy control approach to study the ship path following motion under disturbances and the uncertainty of the model [6] [7].

Fuzzy Logic control is a practical alternative for a variety of challenging control applications since it provides a convenient method for constructing nonlinear controllers via the use of appropriate information [8]. So, optimal control laws can be implemented based on ship path following. Fuzzy controllers have been successfully used in many fields and shown extraordinary advantages over traditional control technology, such as nonlinearities, and robustness [9].

By considering above models in this paper an attempt is made to evaluate the performance of ship path following using Fuzzy Logic over PID.

This paper compares the tracking efficiency and computational time of PID and Adaptive (Fuzzy Logic) controller. Section II discusses the simulation results of PID controller. In Section III, the simulation results of adaptive (fuzzy logic) controller is discussed. Section IV gives the results and conclusion of the work.

II. SIMULATION OF PID CONTROLLER

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. The general simulation set up for ship tracking is as shown in figure 1.

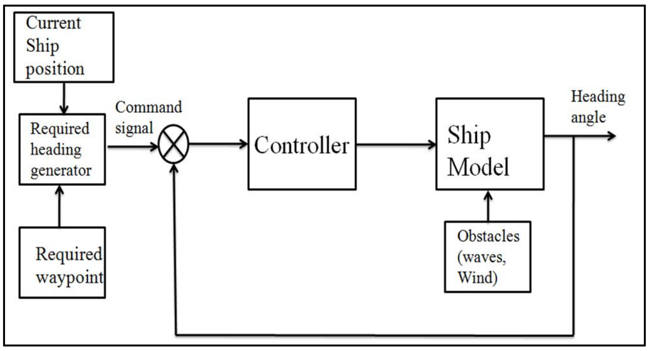

Fig. 1 General simulation setup for ship tracking

Algorithm steps for simulation are given below:

1. Ship parameter declaration i.e. length, speed and nonlinear parameters of the ship.
2. Ship transfer function declaration.
3. Latitude Longitude array initialization.
4. Conversion of coordinates to angles.
5. PID gain and state vector initialization.
6. Random generation of sea disturbance.
7. Addition of noise effect to the output and adding the same to the controller for future calculation
8. Computation of K (heading angle gain) and T (time constant) parameters for next iteration.
9. Conversion of angle to coordinates (x-y axis form).
10. Update state vector.
11. Back to step 6 for continuous monitoring.

Matlab simulation result of PID controller is as shown in figure 2 which exhibits the trajectory of both practical and theoretical way points. One can observe that there is deviation between the obtained trajectory (black) and reference trajectory (red) because of sea wave's disturbances and improper tuning of PID coefficients. The obtained (practical) trajectory is closer to the theoretical reference trajectory by 75 to 85%. If there is an error in choosing the value of coefficients, that is, if tuning is not proper the system performance will be degraded. So tuning of a PID controller is very important.

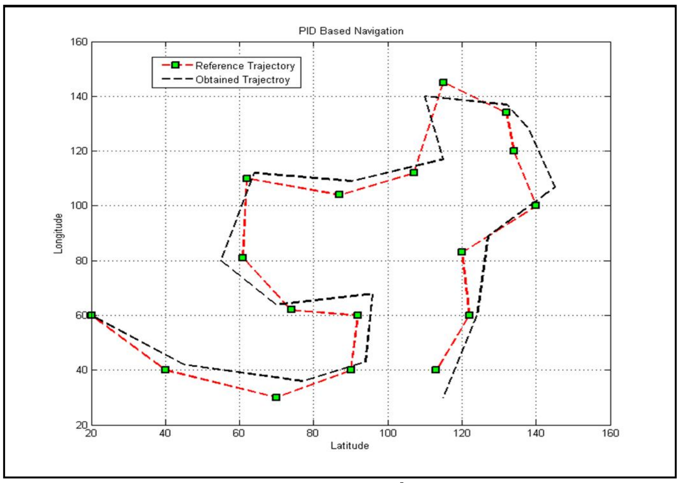

Fig. 2 Waypoint Navigation by PID.

III. SIMULATION OF ADAPTIVE (FUZZY LOGIC) CONTROLLER

A fuzzy control system is a control system based on fuzzy logic—a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively).

The idea of this controller is justified by the two following principles:

• If the error is zero, continue.

• If the error is not zero, turn very quickly to eliminate this error.

The inputs and output are defined as:

$$\delta_e(t) \equiv \{NL, NB, NM, NS, NT, ZE, PT, PS, PM, PB, PL\}$$

$$d\delta_e(t) \equiv \{NL, NB, NM, NS, NT, ZE, PT, PS, PM, PB, PL\}$$

$$u_d(t) \equiv \{NL, NB, NM, NS, NT, ZE, PT, PS, PM, PB, PL\}$$

Triangular distributions in [−1, 1] interval are chosen as membership functions for $\delta_e(t), d\delta_e(t)$and $u_d(t)$.

As per the input waypoint information, rudder angle (reference) inputs for various stages are calculated by finding the slope between the waypoints. These reference angles are given to the Adaptive (Fuzzy Logic) controller to calculate the future heading angles.

The defuzzification laws are chosen as shown in Table I.

Table I. Rule base of Fuzzy Logic Control

Yaw motion		Yaw error										
		NL	NB	NM	NS	NT	ZE	PT	PS	PM	PB	PL
Change in error	PL	ZE	PT	PS	PM	PB	PL	PL	PL	PL	PL	PL
	PB	NT	ZE	PT	PS	PM	PB	PL	PL	PL	PL	PL
	PM	NS	NT	ZE	PT	PS	PM	PB	PL	PL	PL	PL
	PS	NM	NS	NT	ZE	PT	PS	PM	PB	PL	PL	PL
	PT	NB	NM	NS	NT	ZE	PT	PS	PM	PB	PL	PL
	ZE	NL	NB	NM	NS	NT	ZE	PT	PS	PM	PB	PL
	NT	NL	NL	NB	NM	NS	NT	ZE	PT	PS	PM	PB
	NS	NL	NL	NL	NB	NM	NS	NT	ZE	PT	PS	PM
	NM	NL	NL	NL	NL	NB	NM	NS	NT	ZE	PT	PS
	NB	NL	NL	NL	NL	NL	NB	NM	NS	NT	ZE	PT
	NL	NL	NL	NL	NL	NL	NL	NB	NM	NS	NT	ZE

Algorithm steps for simulation are given below:

1. Ship parameter declaration i.e. length, speed and non linear parameters of the ship.
2. Ship transfer function declaration.
3. Latitude Longitude array initialization.
4. Conversion of coordinates to angles.
5. Reference angles are given to fuzzy controller.
6. Based on the error the fuzzy controller generates the rudder angle for ship based on fuzzy rules.
7. Then rudder angle is fed to ship in presence of wave disturbance.
8. The process is continued for continuous monitoring.

Matlab Simulation result of Adaptive (Fuzzy Logic) controller is as shown in Figure 3which exhibits the trajectory of both practical and theoretical way points. The reference waypoints are randomly chosen by the user. By utilizing Fuzzy Logic method, the obtained (practical) trajectory is closer to the theoretical reference trajectory by 92to 95%. The difference between the obtained trajectory and reference trajectory is due to the effect of sea disturbances.

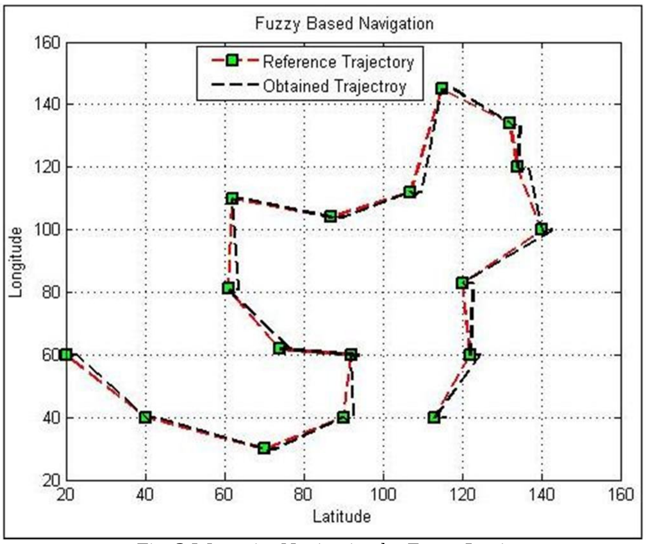

Fig. 3 Waypoint Navigation by Fuzzy Logic.

IV. CONCLUSION

Matlab simulation results of both PID and Fuzzy are compared and the plots of the same are as shown in figure 4. Red color indicates the Reference trajectory, black color indicates the obtained PID trajectory, and blue color indicates the obtained Fuzzy Logic trajectory. From the plot it is clear that, Fuzzy Logic controller results are closer to reference trajectory (91-96%), and PID based controller has more deviation from reference trajectory (75-85%). So performance of the Adaptive (Fuzzy Logic) controller is better than PID controllers.

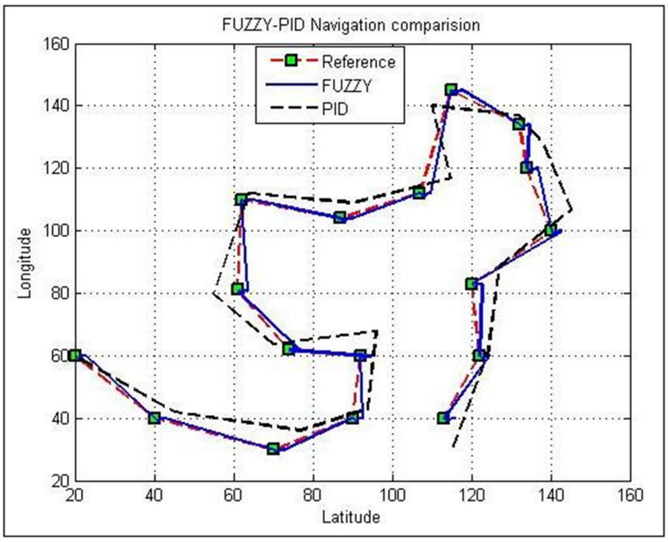

Fig. 4 comparison of Fuzzy Logic-PID based navigation.

From the Table-2 PID controller takes almost same computation time compared to Adaptive (Fuzzy Logic) controller but the tracking performance is not to the expected level. The computational time of Adaptive (Fuzzy Logic) controllers depends on the number of way points as well the

Fuzzy rules. The computational time increases with the increase of number of Fuzzy rules and way points.

Table 2: Performance Comparison between Fuzzy and PID

	Computational time		Obtained Deviation From Reference (Accuracy)
	Profiler	Tic Toc	
PID	1.685	1.698	75-85%
Fuzzy Logic(rules 9)	1.4395	1.4355	91-94%
Fuzzy Logic(rules 11)	1.5256	1.5253	92-95%
Fuzzy Logic(rules 13)	1.7178	1.7181	93-95%

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