Performance Analysis of Ship Tracking using PID/Predictive Controller

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***Abstract*: Accurate ship navigation is very essential for saving fuel as well time. In order to achieve accurate tracking in unmanned ship navigation various controllers like PID, Predictive and Adaptive controllers are used. Each one is having its own merits and demerits but the Predictive controller provides better tracking. The only major limitation of Predictive and Adaptive controllers is that they are computationally heavy. In order to reduce the computational time, researches have come up with various matrix inversion techniques [7]. In this work an attempt is made to evaluate the performance of PID and Predictive controllers in terms of tracking efficiency and computational time. Computational result evaluated using mat lab shows that Predictive controller with matrix inversion technique provides better tracking and takes less time.**

***Index terms*- PID, Predictive, matrix inversion**

I. INTRODUCTION

The efficient ship track keeping/course keeping 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 track keeping/course keeping 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.

There are several technique used for ship tracking, namely PID, adaptive and predictive controllers. A .S White [2], has discussed the most widely used PID controller 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.

Juan Martin [4], explains a special type of nonlinear control system called adaptive controller which can alter its gain parameters in accordance with the changing environment. The main advantage of adaptive controllers is that it can adjust its weight functions according to the environmental changes in order to obtain optimal solutions. The only drawback is that it cannot predict the future control outputs which are very crucial in ship navigation. Another type of adaptive controller which is used in ship navigation is Model Reference Adaptive Control (MRAC) system. The general idea behind Model Reference Adaptive Control is to create a closed loop controller with parameters that can be updated to change the response of the system. The output of the system is compared to a desired response from a reference model. The control parameters are updated based on this error.

Eduardo F [5], explains 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 advantage of this controller over adaptive controller is that, it can predict future outputs and can tune the control parameters for future steps, thus reducing heading angle error.

Even though the literature survey indicates that predictive controller is the best method, predictive controllers are computationally intensive [6], but research [7] is going on to reduce the computational time.

This paper compares the tracking efficiency and computational time of PID and predictive controller. Section II discusses the simulation results of PID controller. In Section III, the simulation results of predictive 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. Controller used for simulation is PID controller. 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**.** The Bech's non linear model, which supports 6 degree of freedom and larger rudder angle turns of ship, is used to simulate ship dynamics.

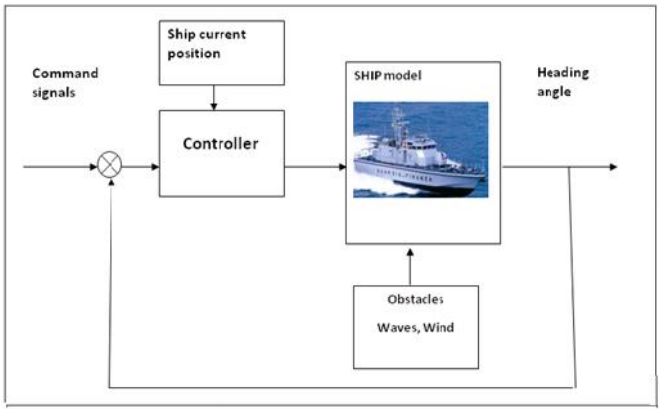

Figure 1: General simulation setup for ship tracking

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. 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.

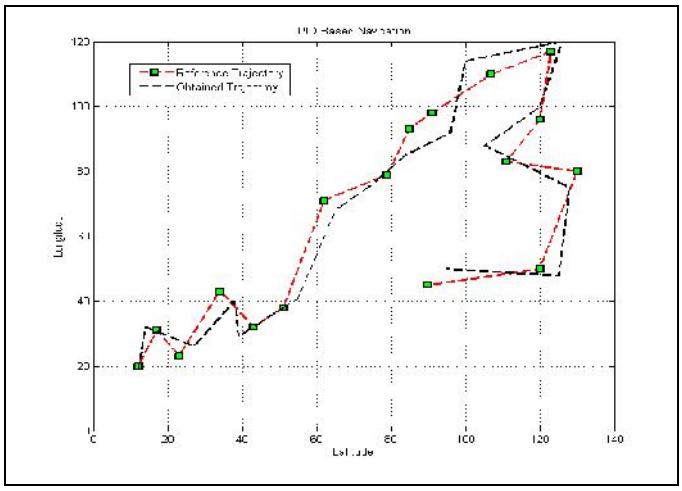

Figure 2: Waypoint Navigation by PID.

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 72 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.

III.SIMULATION OF PREDICTIVE CONTROLLER

Model Predictive Control (MPC) is a multivariable control algorithm that uses an internal dynamic model of the process, a history of past control moves and an optimization function over the receding prediction horizon, to calculate the optimum control moves. If the system includes large time delays and higher order dynamics, MPC controllers performs better than PID controllers. The simulation is carried by using predictive controller, based on CARIMA (Controlled Autoregressive Integrated Moving Average Model) model.

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. Transferring ship model into CARIMA model [1].
4. Latitude Longitude array initialization.
5. Conversion of coordinates to angles.
6. State vector initialization.
7. Random generation of sea disturbance.
8. Calculation of predictor and desired heading angle [7].
9. Addition of noise effect to the output and adding the same to the controller for future calculation.
10. Computation of predictive controller parameters for next iteration.
11. Conversion of angle to coordinates(x-y axis form).
12. Update state vector.
13. Back to step 7 for continuous monitoring.

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 predictive controller to calculate the future heading angles.

Matlab Simulation result of Predictive controller is as shown in Figure 3 which exhibits the trajectory of both practical and theoretical way points. The reference waypoints are randomly chosen by the user. By utilizing MPC (self-tuning) recursive method, the obtained (practical) trajectory is closer to the theoretical reference trajectory by 92 to 95%.

The difference between the obtained trajectory and reference trajectory is due to the effect of sea disturbances.

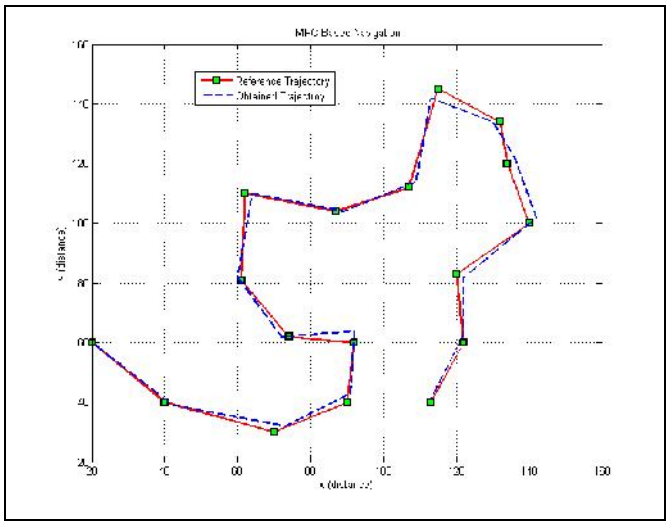

Figure 3: Waypoint Navigation by MPC.

IV. CONCLUSION

Matlab simulation results of both PID and MPC 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 MPC trajectory. From the plot it is clear that, MPC 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 MPC controller is better than PID controllers.

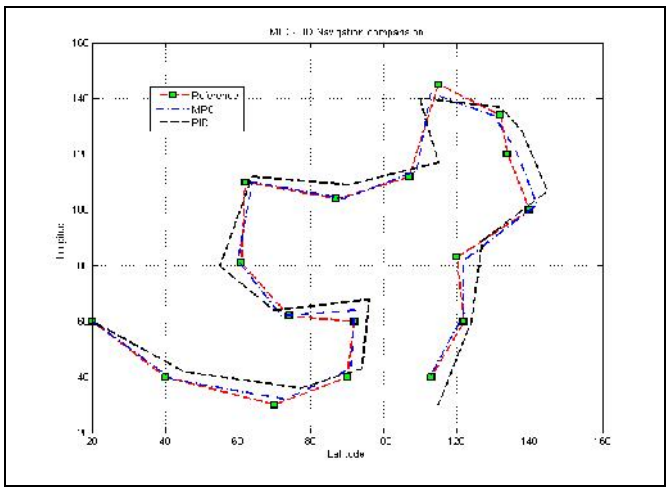

Figure 4: comparison of MPC-PID based navigation.

The table 1 shows the performance and timing comparison between MPC and PID controllers.

Table 1: Performance Comparison between MPC and PID

	Computational time		Obtained Deviation From Reference (Accuracy)
	Profiler	**Tic Toc**	
PID	1.785	1.798	75-85%
MPC	2.885	2.851	92-96%
MPC-Reduced	2.314	2.243	91-94%

From the Table-1 PID controller takes less computation time compared to predictive controller but the tracking performance is not to the expected level. The computational time of predictive controllers depends on the number of way points as well the prediction steps. The computational time increases with the increase of number of prediction steps and way points. By using suitable Matrix inversion method, the computational time can be further reduced.

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