Efficient Ship Track Keeping using Predictive PID Controller

Anil Kumar D, Hari Prasad S. A

Abstract: Present day's unmanned surface vehicles are important where human cannot enter. Navigating these unmanned vehicles plays an important role. This work is proposed with an efficient navigation of unmanned vehicle using predictive proportional-integral-derivative (PID) variants controller. Many researchers are working on the ship track keeping efficiency. This work is an attempt made to reach the maximum efficiency in track keeping. PID controllers are very simple but only PID controller is less efficient compare to predictive and fuzzy controller. Fuzzy and neural network based controller complex in nature. The adaptive controllers are also used to keep the ship on track, but the adaptive controller also complex and sometimes fail to maintain the maximum efficiency. Predictive neural, predictive fuzzy also can be used but again complex. Keeping these limitations in mind an efficient ship track keeping using predictive PID variants is developed which is simple compare to predictive fuzzy and predictive neural and efficiency achieved is around 99.98% and this efficiency is compared with simple PID variants controllers.

Keywords: Predictive Controller, Ship Navigation, PID controller

I. INTRODUCTION

The unmanned vehicles are taking an important role in present technology. The unmanned surface vehicles which run in sea are also important to explore the places in the sea. The main important task in unmanned vehicles is navigation. The navigation takes an important role to make the vehicle to reach the proper destination. In navigation keeping the vehicle on track is also important. Having unmanned surface vehicle in sea is very important. It can be used by army to face the enemies. If unmanned vehicles are used with proper path following/navigation saves fuel. These are some of the advantages why unmanned vehicles are important in present technology. The ship navigation and keeping the ship on track is very important, because ship face sea disturbance, obstacles in the sea, sea waves. Considering all these disturbances, challenges are more to keep the ship on track. To keep the vehicle on track several control methods are used such as PID, predictive, and adaptive controllers.

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The PID controller is a simple and most widely used controller which can keep the vehicle on track. The self-tuned PID controllers are most widely used controllers which adjusted with control variable and tune the controller accordingly and try to keep the ship on track [1][2][3].The predictive controller is one of the main controllers which will be used in ship navigation. In this, the path following is done by predicting the particular horizon and try to adjust the heading angle of the ship to keep the ship on track. This technique is used to achieve the maximum efficiency, but to predict and control the heading it takes time and time is also an important parameter in ship navigation [4][5].The adaptive controllers can also be used for ship navigation such that the controller can adapt itself to the environmental and other conditions of the ship and try to keep the ship on track. This controller is also a widely used controller but it is complex system because of adaptiveness in the system the controller system becomes complex and may take more time compare to PID controller to decide the heading angle [6][7]. By observing drawbacks of the above three different controllers, this paper is proposing a new efficient algorithm which improves the efficiency of the control system. The proposed algorithm predicts the heading angle and controlling is done by PID controller. This Predictive PID variants controller is simple which predicts using predictive controller and controls using PID controller. Second section discusses about the predictive controller, third section is about predictive PID controller. The last section discusses about the simulation results of predictive PID controller.

II. PREDICTIVE CONTROLLER

To control and keep the ship on track in sea is very difficult as the sea dynamics keep changing. To consider these dynamic variations of the sea, a predictive controller plays an important role. The PID controller cannot be used for this non-linear behaviour of the sea condition and ship has to overcome all these uncertain conditions and has to be on track. The model predictive controller is used to control multiple inputs and multiple outputs (MIMO) system. In multiple inputs if any changes are found, accordingly the output variable also will be adjusted as per the predictions and measurements. The predictive controller advantages are process model is used to capture the dynamic and static interactions between input, output and disturbances, optimum set points are calculated, and accurate prediction avoids early warnings.

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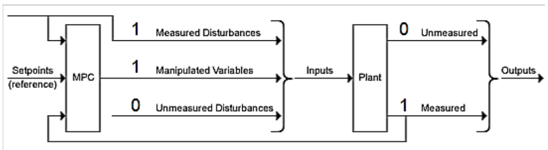

Fig. 1 Predictive Controller Blocks

The predictive controller is implemented using MATLAB Simulink. The model is as shown in the fig. 1. It consists of model predictive controller, plant, disturbance block, input variables. The output variables are controlled variables or manipulated variables (MV), the input variables are measured outputs (MO) as feedback from the system, reference variables as input variables, measured disturbances (MD) as disturbance for the system. The disturbance is the sea wave model which is used as disturbance for ship. The plant in this model is the ship, which is a Nomoto's fourth order model which given as [8]

$$\frac{r}{\delta} = \frac{k(1+T_3 S)(S^2+2\eta\omega_0 S+\omega_0^2)}{(1+T_1)(1+T_2 S)(S^2+2\xi\omega_n S+\omega_n^2)} \quad (1)$$

where, K is the static yaw rate gain and T_1, T_2, T_3 are time constants. The Nomoto model is very simple and linear ship model which is most widely used. It supports all 6 DOF (degrees of freedom). For smaller rudder angle also it performs due to its consideration of all 6 DOF.The sea model used is modified Pierson Moskowitz [9]. The different wave spectrum is considered with frequency, amplitude, phase and direction of propagation. The final spectrum is derived and measured data of wave motions as,

$$S(\omega) = A\omega^{-5}\exp(-B\omega^{-4})\ \mathrm{m^2 s} \quad (2)$$

where, $A = 8.1\mathrm{x}10^{-3}\ g^2$, and $B = 0.74{*}g^4/V$. Here V is the wind speed at a height of 19.4 m over the sea surface, and g is the gravitational constant (9.8 m/s^2). It is assumed that the waves are represented by Gaussian random process and that S (ω) is narrow banded, now, the concept of significant wave height is used to reformulate the PM spectrum as:

$$A = 8.1 * 10^{-3} g^2 \text{ and } B = 0.0323 * \frac{g^2}{H_S^2} = \frac{3.11}{H_S^2}$$

and the maximum value of (ω) is,

$$S_{max}(\omega) = S(\omega_0) = \frac{5A * \exp\left(-\frac{5}{4}\right)}{4B\ \omega_0} \quad (3)$$

where,

$$\omega_0 = \sqrt[4]{\frac{4B}{5}}$$

Fig. 2 shows the P-M wave which is simulated in MATLAB. This wave gives a single wave spectrum, which occurs with ω_0 frequency and it has a height given by the equation (3).

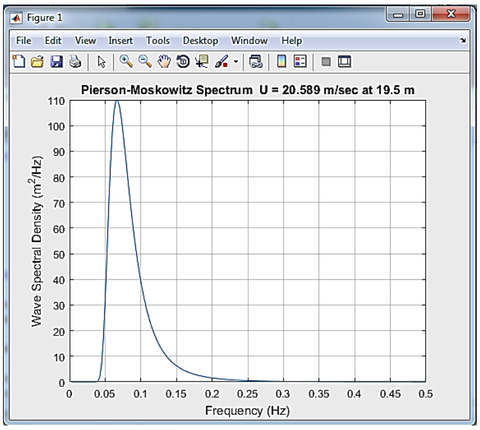

Fig. 2 Pierson-Moskowitz Spectrum

The predictive controller is multivariable with internal dynamic model for prediction process is given as [5][10]

$$\psi(t+1) = \sum_{i=1}^{n} a_{1,i}\psi(t+1-i) + \sum_{i=0}^{m} b_{1,i}\Delta\delta(t-d-i) + \sum_{i=0}^{r_1} C_{1,i}\xi_1(t+1-i) \quad (4)$$

where ψ(t) is the output variable (heading angle), *δ(t)* is the input variable (rudder angle) of the system, 1(t) is a disturbance term which is assumed to be a white Gaussian noise with zero mean, $(d+1)$ is the time delay of the system, $\Delta = 1 - q^{-1}$ is the differencing operator $a_{1,i}$, $b_{1,i}$ b1,i and $c_{i,1}$ are the coefficient n, m and r_1. The predictive controller performs better than PID Controllers.

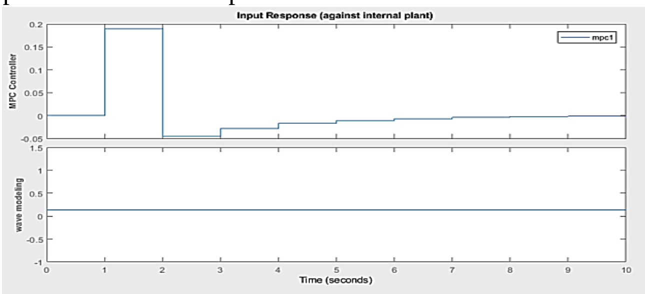

Fig. 3 Input Responses of the Predictive Controller

Fig.3 shows the input response of the predictive controller, one input is given as reference input these are set points of the ship. Another input is the plants feedback to the predictive controller. The sea disturbance is another input to the controller which is wave model. The output of the predictive controller is shown in fig. 4 the output response of the controller.

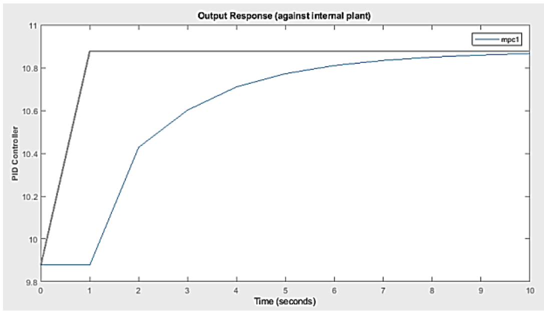

Fig. 4 Output Response of the predictive controller

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III. Predictive PID Controller

The predictive controller plays an important role in predicting and measuring the ship dynamics. The predictor is used take the multiple set points as input heading angles, between present and next set point it divides into 5 steps and these steps are taken as set points for the predictor to predict the error and this predicted output is given to the plant and plant output is given to PID controller. The PID controller is used control the error as per the equation (4)

$$u(k) = K_p e(k) + K_I e(k) + K_D \Delta e(k) \quad (4)$$

where K_P, K_I, and K_D are the proportional, integral, and differentiator constant respectively. The proposed predictive PID is implemented in MATLAB Simulink. The model block diagram is shown in fig. 5.

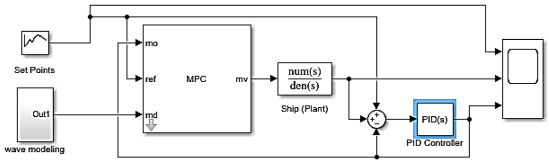

Fig. 5 Predictive PID Controller

The predictive PID controller is implemented with variants of PID like PID, PI and PD. All the three controllers are validated along with predictive controller and the best predictive PID is selected based on the efficiency of the system.

A. Predictive PID

In predictive PID controller the controller part is PID and PID controller is used and tuned as shown in fig. 5. The PID controller equation is given as

$$P + I\frac{1}{s} + D\frac{N}{1+N\frac{1}{s}} \quad (5)$$

where P is proportional, I is integral, and D is derivative. The PID controller implements controller with proportional, integral and derivative actions which are auto tuned and set the value such that the controller can work efficiently.

B. Predictive PI

In predictive PI, only P and I are used with only proportional and integral actions which are auto tuned and set the values for efficient working of the system as shown in fig. 6. The PI controller equation is given as

$$P + I\frac{1}{s} \quad (6)$$

where P is proportional, I is the integral the values can be around 80.6 and 54 respectively. The controller auto tuned for stable system and the above values are set automatically.

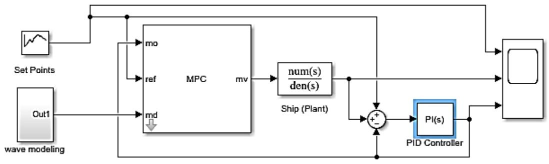

Fig. 6 Predictive PI Controller

C. Predictive PD

The predictive PD controller is using only P and D are used with proportional and derivative actions which are auto tuned and set the values for maximum efficiency as shown in fig. 7. The PD controller equation is given as

$$P + D\frac{N}{1+N\frac{1}{s}} \quad (7)$$

where P is proportional, D is derivative, N is filter coefficient. The tuned values with auto tuning are 80.6 and 0.1 respectively. The filter coefficient is around 500 which set automatically when the controller is tuned. The control system is auto tuned and is a stable system.

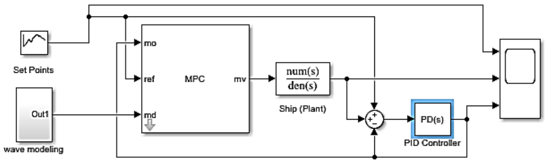

Fig. 7 Predictive PD Controller

IV. Simulation Results

The simulation results are compared with only predictive controller, predictive PID, predictive PI and predictive PD controller. The fig. 8 shows that the predictive controller output. The figure shows the trajectory of the ship.

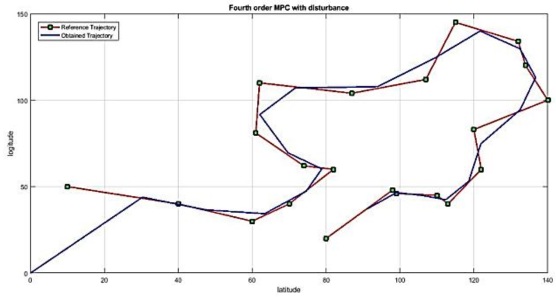

Fig. 8 Trajectory of Predictive Controller

The fig. 9 shows the trajectory of predictive PID. In this the efficiency of the ship track keeping is improved compared to the only predictive controller. Fig. 10 and 11 shows the predictive PI and PD controller respectively. In predictive PD controller the highest efficiency is achieved.

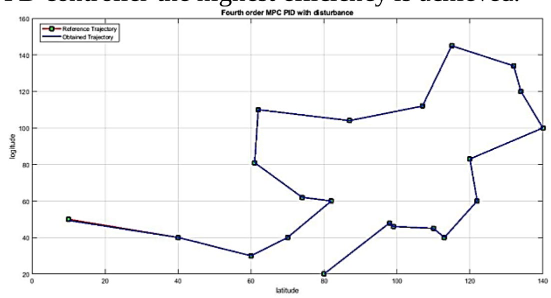

Fig. 9 Trajectory of Predictive PID

The table 1 shows the comparison of all the controllers. The efficiency of each system is given.

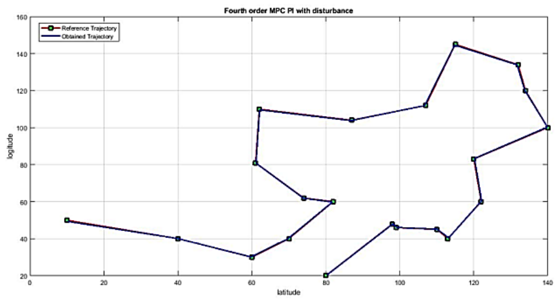

Fig. 10 Trajectory of Predictive PI

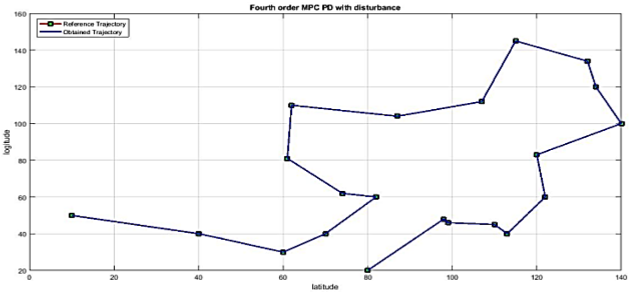

Fig. 11 Trajectory of Predictive PD

Table 1 Comparison of Predictive and Predictive PID variants

Different Controllers	Efficiency (in %)	Execution Time (in Seconds)
Predictive PID Controller	99.93	5.7
Predictive PD Controller	99.98	5.7
Predictive PI Controller	99.88	5.7
Predictive Controller	92.9	5.3

It is observed that the predictive PD controller is most efficient controller. Almost all the controllers take same execution time except the predictive controller. The predictive controller takes around 0.4 seconds less time to execute compared to predictive PID variants controllers. The execution time of the system is not considered in this work, the focus is given to the performance with respect to efficiency. The efficiency of the system is improved by implementing predictive PID controller.

V.CONCLUSIONS

The predictive PID and PID variants is implemented and the efficiency of each variant is compared. The predictive PD based controller is more efficient when compared to other variants, it is observed around 99.98%. The predictive PD based controller is the best controller which can used for ship track keeping and as well as to keep the ship on track. Further, the work can be carried out to implement the hardware and real time test can be conducted for the proposed system.

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