Smart Controller for Dynamic Positioning of Ship

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***Abstract:-* The automatic steering of the ship from one place to another along a planned track is a principle of track keeping problem. The heading of the ship must be in such a way that .the distance from the desired track should be minimum. The designing of an accurate track keeping controller is a challenging task, in which the desired heading angle is decided by the current position of the ship and the reference wave point because ship and sea environment are dynamic in nature. This paper discusses the control algorithm for precise tracking keeping even in the presence of sea disturbances with simulation results in MATLAB well supported by hardware results.**

General Terms:- Degrees of freedom, Path tracking.

Keywords:- PD, Nomoto model, Wave spectrum, Controllers, differential motors.

1. INTRODUCTION

Ship course control plays an important role in autonomous navigation. Based on autonomous course keeping problem the rudder angle of a surface vehicle has to be decided. Recently many control approaches are proposed for controlling the vessel such as PID control, PD control, and Predictive control. There are many classical ship modeling techniques such as Nomoto model[1], Norrbin model, Bech Model etc.nomoto model can be used for modeling ship dynamics, which support all six degrees of freedom and can adjust to very small rudder angles. The ship model is simulated for various controllers along with sea disturbance to decide the best among them. Once the best algorithm is found the same algorithm is implemented to control the speed of DC motor in hardware.

To support the simulation results of ship model an autonomous ship is implemented in hardware. For this purpose initially, a ship is built by analyzing the required physical phenomenon. The hardware implementation provides the expected results. As a part of the initial stage, PD control motor is implemented to understand the control algorithm before implementing in the ship. The paper is organized as follows: section 2, discusses the mathematical modeling of Nomoto ship.Section-3, will provide the analysis of Pierson- Markowitz sea wave model and Section-4, provide the detailed physical design of the ship and finally, Section-5, provides and results and conclusion of the work

2. NOMOTO SHIP MODELLING

The controllability, observability and identifiability properties of the first order, second order, and fourth order are discussed in this section. The controllability and observability properties are studied apropos of the state-space model of Nomoto model since the transfer function is employed while representing the observable and controllable properties of system dynamics. The heading angle ( ) obtained from the measurement is readily available to almost all vessels. Controllability is the condition when (,) i.e. system states are controlled using an arbitrary values through the prosecution of the rudder **.** It implies success rate of statthe e-feedback controller. The system is said to be observable if (,) are achieved using measured data . In the second order system, 2 and 3 nearly cancel each other resulting an ill-c in inonditiothe ning problem. Due to this, the first order model is preferred over second order system.

When magnitude and phase plot of the fourth order, second order and first order are considered no much difference between them is observed except that there are some humps in fourth order model. Similarly, disparages in between first order and the second order is somewhat larger. There is negligible coupling effect in between the roll mode and yaw motion resulting in the derivation of second-order system form the fourth order less significant. But the model reduction from second to first order has a significant effect on the sway mode coupling effect on the yaw motion is not negligible. Fig **2.1** is boded plot of fourth order and second order transfer functions.

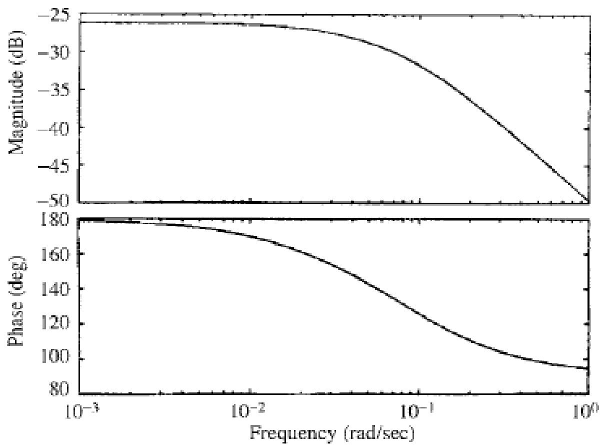


Fig 1: Bode plot of second-order system

3. MODELING OF SEA DISTURBANCES

The sea disturbance is also taken into account while simulating the Nomoto ship model. The undesirable motion of a ship in a seaway is induced by the action of environmental disturbances: waves, wind, and current. However, ocean waves are the dominant environmental disturbances. There are various methods available to model the sea waves the most generally referred standard wave spectrums are:

- Bretschneider spectrum
- Pearson-Markowitz Spectrum
- Modified Pearson-Markowitz Spectrum
- JONSWAP Wave Spectrum

In this section, a detailed analysis of Pearson-Markowitz Spectrum is carried out with MATLAB simulation results.

3.1 Pierson-Markowitz Spectrum (P-M)

The Pierson-Markowitz [12] was developed to forecast Storm waves at a single point in fully developed seas with no swell This relates the parameters A and B to the average wind speed at 19.5m above the sea surface as

1 $$A = 8.1\,X\,10^{-3}\,g^2 \quad B = \frac{0.74g}{V_{19.5}}$$

2 $$S_{\varepsilon}(w) = \frac{8.1X10^{-3}g^2}{w^5}\exp\left(\frac{-\frac{0.74}{V_{19.5}}}{w^4}\right)\ [m^2 s]$$

The P-M wave spectrum in terms of the wave height and wave frequency is as given below

$$S(\omega) = \frac{8.1\,X\,10^{-3}g^2}{\omega^5}\exp\left(-\frac{3.11}{h_{1/3}^2\omega^4}\right)$$ 3

This wave spectrum is narrow band. The energy is mainly concentrated at a certain band. The equal frequency division the method is used to select limited harmonic waves to simulate the wave.

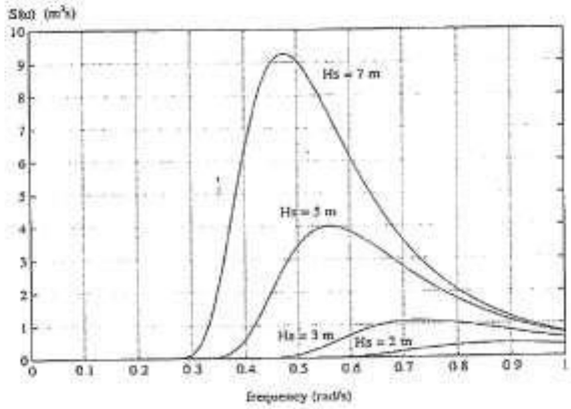


Fig 2: Pierson-Moskowitz spectrum at wind velocity 21 m/sec

4. PHYSICAL DESIGN OF SHIP

The design consists of the dual hull. In case of the dual hull, the C G (center of gravity) is maintained in between the two hulls which make it more efficient in counteracting the wave. Using single hull Centre of Gravity and Centre of Pressure vary continuously due to random motion of currents, so we have preferred dual hull design. Buoyancy theorem states that the height of the object floating should be less than the circumference of it. The ship designs using balsa wood which is flexible and has lightweight. The ship remains stable even in the presence of waves of height one feet. Once the ship is designed as per the required dimensions it is coated with wall

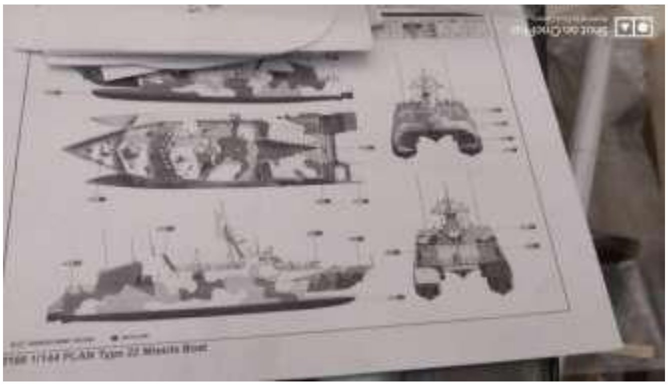


Fig 3: Design of dual hull ship

putty for waterproofing and the abnormal surface extensions are removed by sanding. Later a layer red oxide is coated to fill the tiny gaps created during construction.

Fig 4: Ship Model

5. CONTROLLER ANALYSIS

The aim of using a P-D controller is to increase the stability of the system by improving control since it has an ability to predict the future error of the system response. In order to avoid effects of the sudden change in the value of the error signal, the derivative is taken from the output response of the system variable instead of the error signal. Therefore, D mode is designed to be proportional to the change of the output Variable to prevent the sudden changes occurring in the control output resulting from sudden changes in the error signal. In addition, D directly amplifies process noise therefore D-only control is not used. From the simulation results, we observe that the response time is fast in case of PD controller used in track-keeping of the ship.

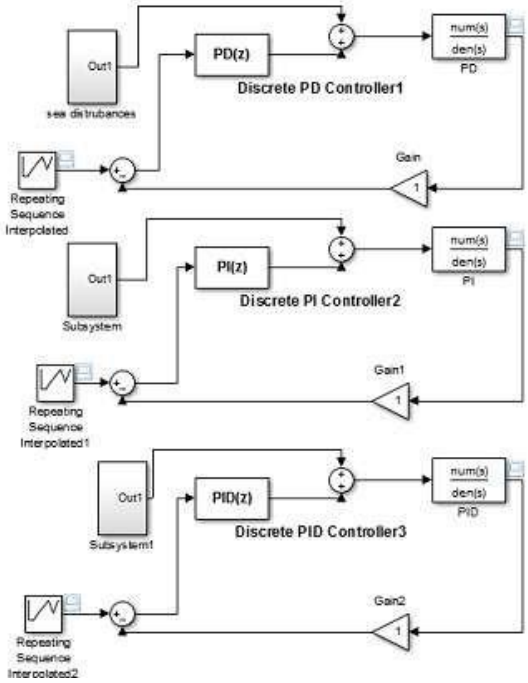
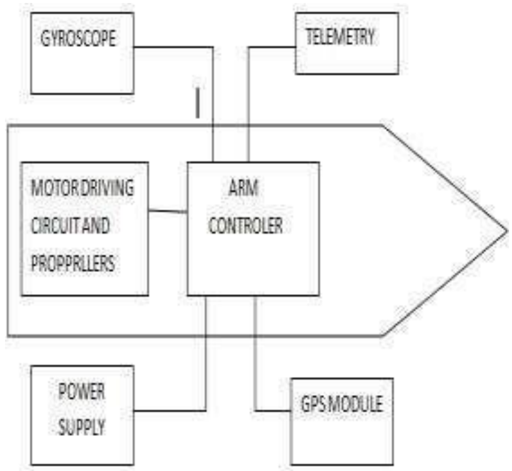


Fig 5: Simulink Model for PD, PI, PID controller

6. PROPOSED SYSTEM



6.1 *Gyroscope*

It works on the principle of Coriolis acceleration. Imagine that there is a fork-like structure, that is constant back and forth motion. It is held in place using piezoelectric crystals. Whenever you try to tilt this arrangement, the crystals experience a force in the direction of inclination. This is a caused as a result of the inertia of the moving fork. The crystals thus produce a current and this current amplified.

6.2 *Telemetry*

An ideal module to set the remote sensing connection module between APM and ground station. It features small volume, cost-effective, wider transmission range, and it allows us to do things that other data transmission modules can't do.

6.3 *GPS Module*

The Ublox latest 8series module providing a convenient method of mounting the compass away from sources of interference that may be present in the confines of the vehicle.

6.4 *Motor driving circuit*

It consists of Brushless DC motors and ESC (Electronic Speed Controller). The BLDC motors are those without the mechanical commutation of the brushed DC motor. BLDC motor is powered by direct current and has electronic commutation system instead of the mechanical brushes and commutators used in brushed DC motor.

ESC is an electronic circuit used to vary the speed, direction of a brushless DC motor. It works on PWM.

6.5 *ARM Controller*

The Pixhawk module contains STM32 ARM M4 microcontrollers and provision for interfacing variousperipherals such as GPS, telemetry and for other output devices. This controller is used to handle data more efficiently since a number of peripherals are used.

7. RESULTS AND CONCLUSION

7.1 Simulation Results

The model introduced in section 5 is used to simulate in real dynamics of the ship. Considering the Nomoto ship model and sea disturbances PD, PID, PI algorithms are simulated.

From the above result, it is observed that PD controller has a better steady-state response when compared to the other controllers. The error rate is also less in case of PD controller; hence it is most suitable for track-keeping of the autonomous ship. The purple line represents reference tracking path and the yellow line is the output response of the controller's w.r.t reference path. Hence we can observe that in the topmost graph of PD algorithm the deviation from the reference path is very less.

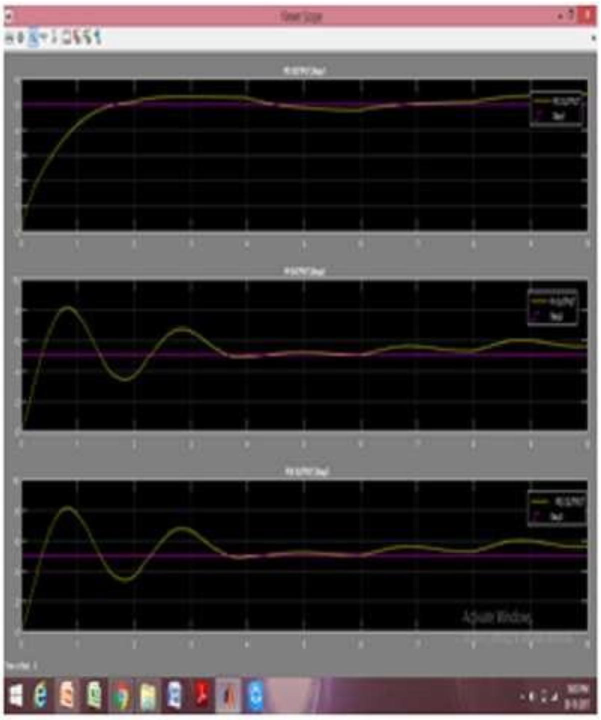


Fig 6: simulation results of PD, PI, PID based ship model

7.2 PD controlled motor

PD controlled DC motor is designed using hall sensor and Arduino. The control algorithm takes the difference between two successive samples and compares it with the reference rpm (in this case 1500).Hall sensor retrieves the rpm values.

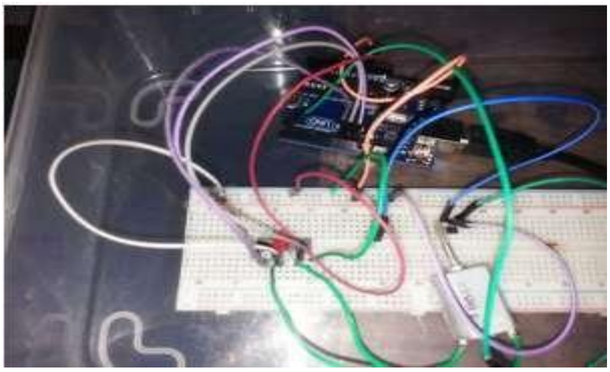


Fig 7: Implementation of PD controlled DC motor

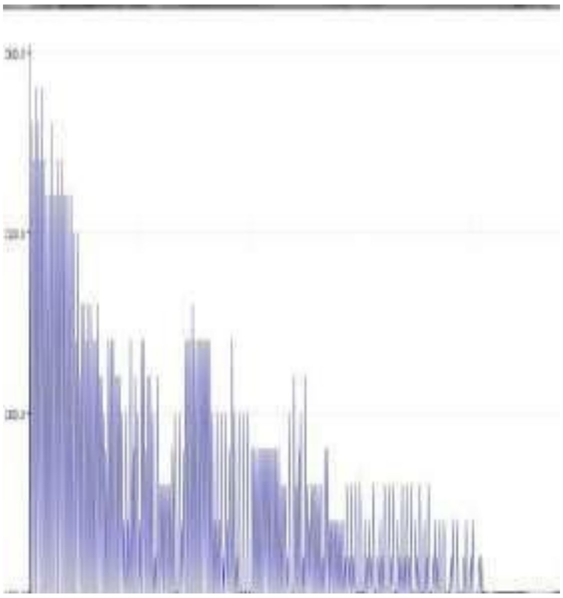


Fig 8: Results obtained from com port of Arduino

7.3 Hardware Implementation of Autonomous Ship

Initially, the ship is run using an RF transmitter for testing and also to fix the waypoints. In order to check whether the ship is moving according to the desired path, it is practically tested in a lake by using a long rope as a reference path which is held joining all the waypoints.

It is observed that under the static condition the ship maintains the desired track. In the presence of environmental disturbances the ship is allowed to deviate from the desired path within a prefixed bandwidth and the control, algorithm navigates the ship back on to the waypoint from which it deviated, further the ship follows the desired path. In this way, the system is able to counteract environmental disturbances and is to have two degrees of freedom. This is achieved with the help of differentially controlled motors.

Fig 9: Real-time model

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