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Autonomous Ship Maneuvering Control and Its Path Tracking Using Fuzzy Logic and Model Free Adaptive Control

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Abstract: ***Ship Electrical propulsion, is tested using Fuzzy logic and Model-Free Adaptive Control method where the best suited algorithm applied to control the speed and torque of the ship, where it makes ship adaptable to various sea situations. In case of Fuzzy logic, since ship has limited turning radii at specific path planning strategy is developed, where the ship trajectory turns around the way point. In higher order MFAC makes use of previous controlled information to improve the performance by introducing higher order learning law. The dynamic linearization is model free. Robust path planning methods are implemented to achieve the planned path with less delay in time avoiding surge.***

Keywords: Ship Electrical Propulsion, Fuzzy logic, MFAC, Robust path, way points

1. Introduction

Studying the manoeuvrability of ship has great importance in order to avoid collision with unpredictable objects, moreover, it helps in determining ship constraints either in dynamics or control signal commands [1]. Electric ship propulsion motor drive propeller directly which the rotor and propeller have common shaft, the ship electric propulsion is more sensitive to load which have great influence on tracking accuracy [2].

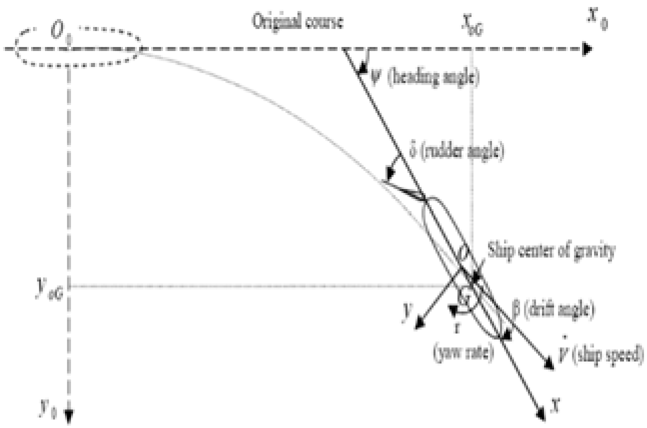
The ship faces two problems, velocity and heading control and limited turning radii [3]. Dynamic equations developed using SSP systems are used. The control design is model-free in MFAC where only input, output data of the system are considered and it makes use of more ship sailing control information, where controller design is made flexible [4].
Defining the way points and its circumference associated, leading to show how the navigation algorithm works including the development of fuzzy control used on board, path planning is robust and straight forward to be implemented on autonomous vehicle following lines and arcs with only storing the list of way points and radii. Here ship dynamics and kinematics has been studied to make the set of equations in surge and sway motions and these forces and moment are driven according to Newton law of motion [5]. Results of fuzzy logic and MFAC are validated to get the best response using reference outputs. The same is validated using Matlab and Simulink as Simulation tool [6].

2. Ship Manuvering Model Analysis

Equations of motion are constructed base on rigid body dynamics to describe the ship motion in 3 degree of freedom.

The three motions are; the longitudinal translation motion 'surge motion' produced by the longitudinal force 'X', The lateral translation motion 'sway motion' produced by the lateral force 'Y' , and the rotational motion around the z-axis 'N', these forces and moment driven according to the Newtonian law of motion.

Earth fixed coordinated system (inertia)'"O_0-x_0 y_0 z_0" and body fixed coordinated system are the two right handed coordinate system" O-x y x" adapted for the ship manoeuvrability analysis. Where Ψ is the angle defined between x-axis original course x_0 .Drift angle (β), defined between direction of speed and x-axis. The equations of motion in the earth fixed coordinate system.



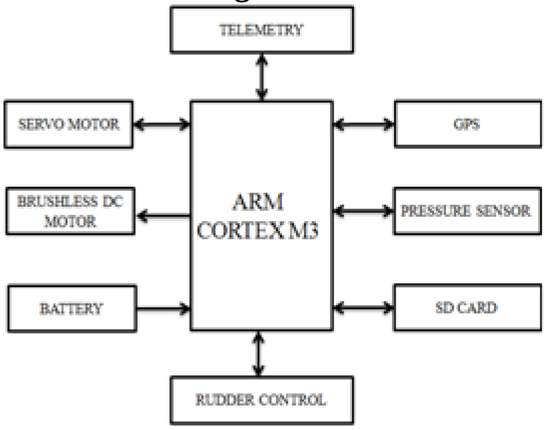
Coordinate System

Maneuvering refers to the study of large amplitude motion of ship in calm seas. Traditionally, heave, roll, and pitch are not considered in maneuvering equations due to their relatively low excitement in calm seas; only planar motion are factored in Maneuvering dynamics are distinctly slower than the other variety of ship motions.

Maneuvering by definition is large amplitude motion, nonlinear viscous forces cannot be excluded from the equations of motion.

The mathematical model separates the force experienced by the hull, propeller, and rudder and also includes the interaction effects between the components of model.

3. General Block Diagram



ARM CORTEX M3: path tracking and collision avoidance algorithm is been implemented using this controller ARM cortex M3 and it is powered using DC battery.

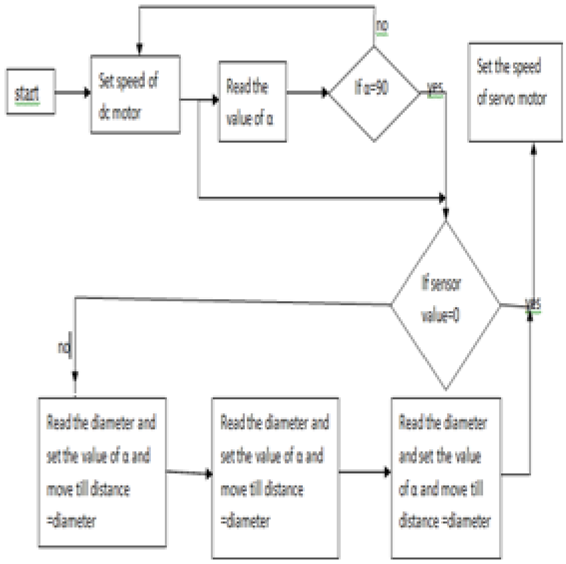
Servo Motor: servo motor controls the rudder angle, which in turn controls the direction of the ship.

Brushless DC motor: brushless DC motor is used to run the propeller, and speed of the ship is been controlled by controlling the speed of this motor.

In the main hull, an Arm cortex M3 is placed to control the ship path and direction. There are two motors (brushless DC motor and servo motor) used in this ship, where one is to control speed of the ship and other one foe direction. Ultrasonic sensor used in this model to identify the distance and diameter of collision. Water pressure sensor is been place to the sides of the hull to sense the water pressure in order to avoid the ship sliding. SD card to save the waypoints set by the telemetry.

4. Algorithm and Flow Chart

- The pins of the control boards are initialized for sensors and motors.
- Speed of the brushless motor is set (speed at which the ship should move).
- Rudder angle is read (direction of the ship is decided by rudder angle).
- Based on the rudder angle set the speed of servo motor, which controls the rudder movement.
- Based on the rudder angle ship moves. During right or left dc motor speed will be reset (reduced).
- Sensor values will be monitored each time when the rudder angle is read.

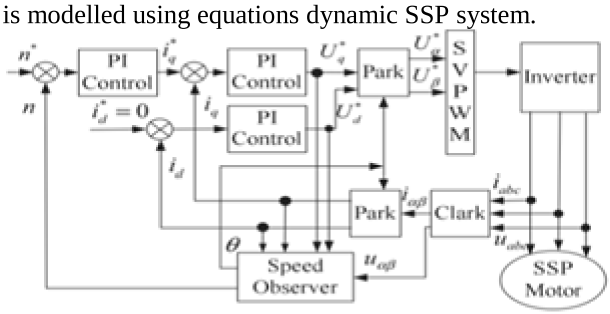


Model Implementation in MATLAB

Simulation of the ship maneuvre behaviour by changing the ship control parameter is achieved by simulink software program. As consequences three modules were built to express the ship subsystems representing the ship hull, propeller, rudder modules.

The ship electrical propulsion motor control system was established under the matlab environment .The parameters used here are three phase current and the torque.

The ship electrical propulsion motor control diagram. And it is modelled using equations dynamic SSP system.



$$\begin{cases} \dot{i}_d = -\frac{R_s}{L_d} i_d + \frac{\omega L_q}{L_d} i_q + \frac{u_d}{L_d} \\ \dot{i}_q = -\frac{R_s}{L_q} i_q - \frac{\omega L_d}{L_q} i_d + \frac{u_q}{L_q} - \frac{\omega\varphi}{L_q} \end{cases}$$

$$\dot{\omega} = \frac{1}{J}(T_e - F\omega - T_L)$$

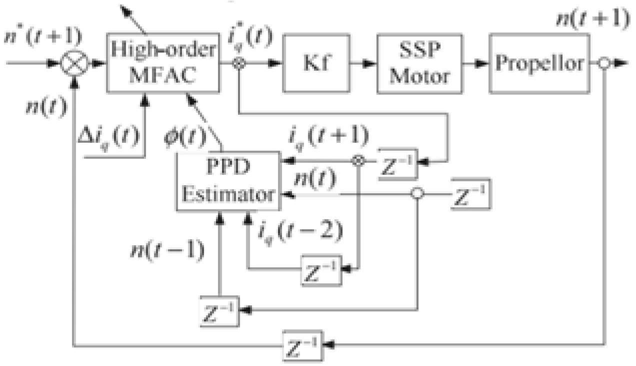
Where the propeller torque obtained to be

$$T_L = \mathrm{sgn}(\omega)\frac{K_T}{4\pi^2}\rho D^5 \omega^2$$

Here we control torque of the motor .By the principle of electromagnetic energy conversion.

$$T_e(i_a, i_b, i_c, \theta) = P\frac{\partial W_m(\psi, \theta)}{\partial \theta}$$

Improved propulsion motor control diagram



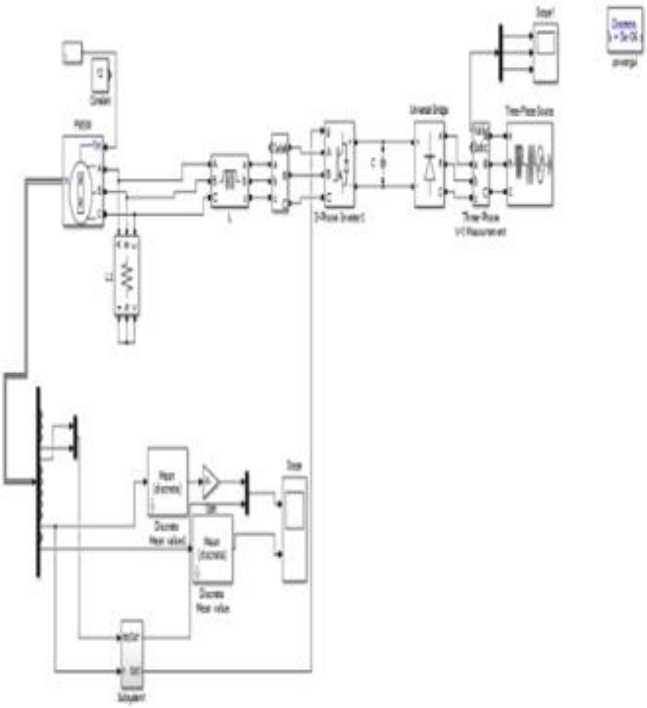
The load torque loop and magnetic flux loop, inverter and the propeller of the ship electrical propulsion motor can be regarded as generalized controlled object .And current loop is simplified by the proportional component (Kf).

Higher order MFAC control system is being to control the ship propulsion. Where n(t) is speed and i_q (t) is the stator phase current.

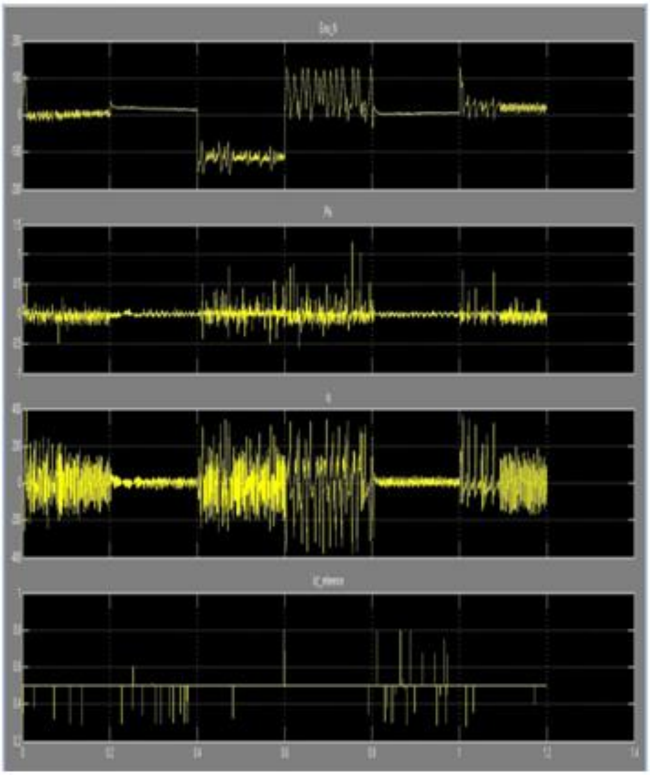
Here we give previously calculated speed (n(t-1)), current(i_q(t-2)), and future estimated current (i_q(t+1))and present speed (n(t)). These values is been given to the PPD estimator, which acts as the feedback to the controller, which in turn regulates the flux φ(t).

In the simulation environment both fuzzy logic and MFAC logic are tested, using the quadrature current as the input and torque as the output. Here we get better response in fuzzy logic, Where the output response almost reaches the desired reference output. whereas in MFAC there is a distortions and takes time to settle down.

Simulink environment created to test fuzzy logic subsystem and model predictive controller

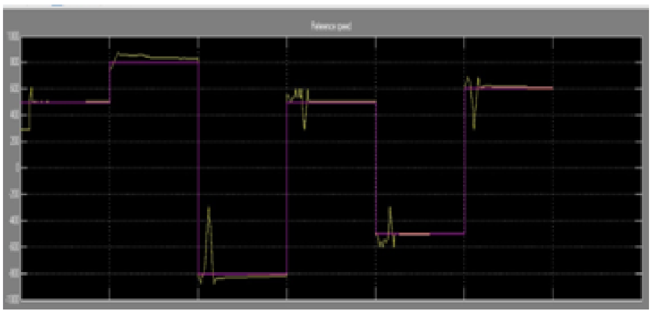


Input output parameter response given by

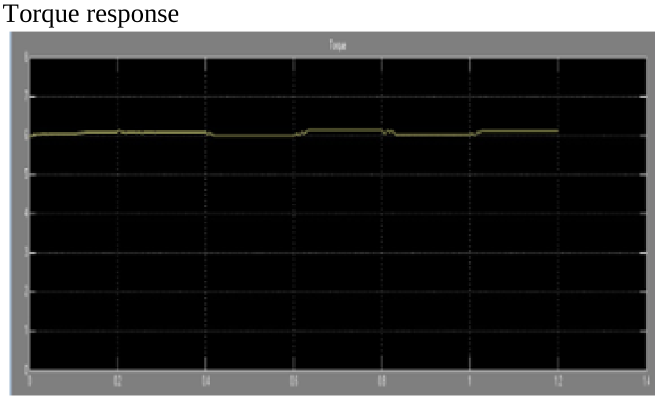


Motor reference speed response and Torque response of fuzzy control

Motor reference



Torque response



Motor reference speed response and Torque response of model predictive control

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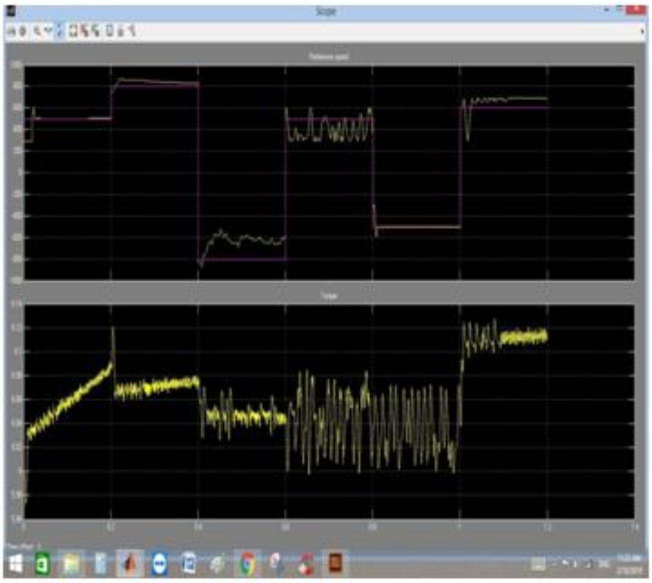
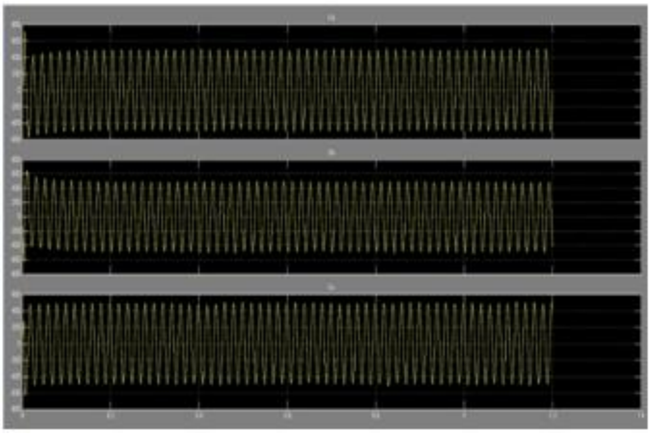


Three phase voltage given to motor as input Va, Vb ,Vc



Ship Motion Module

The motion module represents the euler's equations of motion, inputs to the module are the 3 degree of freedom hydrodynamic forces and moments

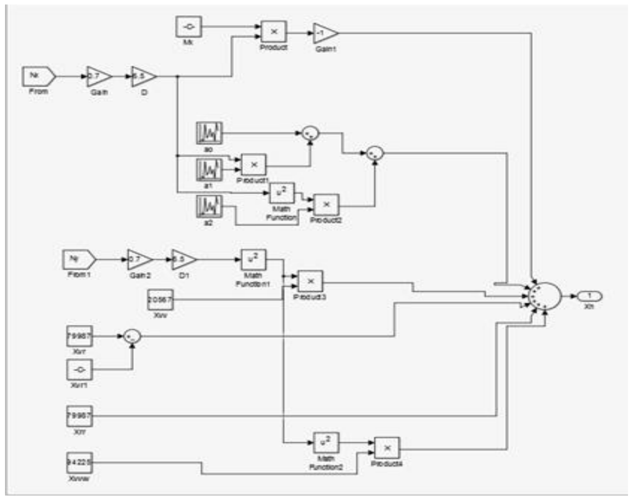
Hull subsystems

Above block diagram is the representation of the hydrodynamic derivatives model that represents the hull characteristics such as hull form geometry. Where the components due to sway motion and the yaw due to yaw movement is been proposed. Where

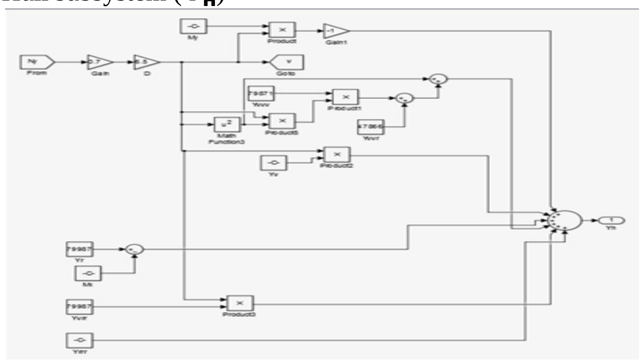
X-> is the momentum due to hull in surge axis.

Y-> is the momentum due to hull in sway axis.

Hull subsystem (X_H)



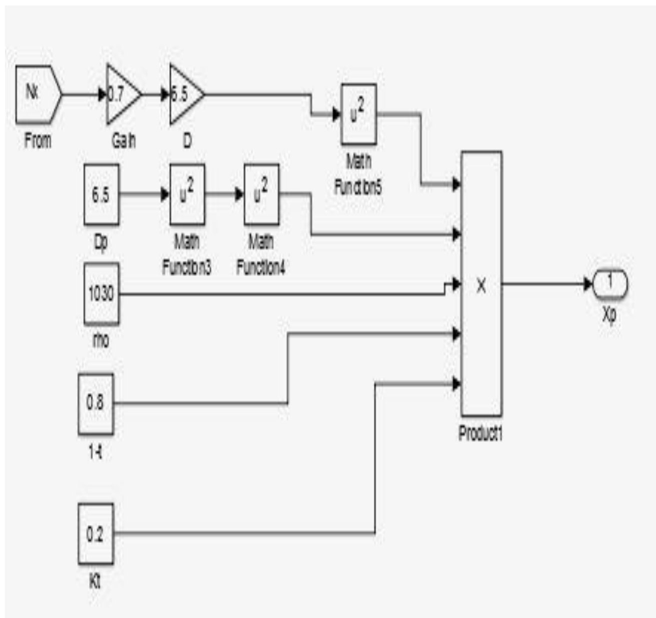
Hull subsystem ($\mathbf{Y_H}$)



Propeller subsystem

Here propulsive forces is been represented, where forces are dependent upon accurate representation of trust geometry, wake, lifting and drag propulsion-hull-rudder interaction. Here yaw effect on the propeller is negligible hence neglected.

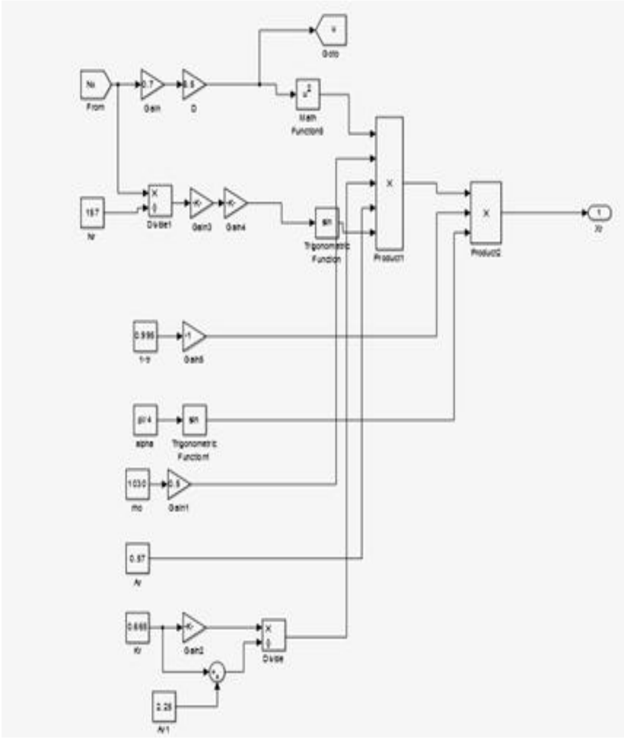
X_p -> is the momentum due to propeller in surge axis.



Rudder subsystems

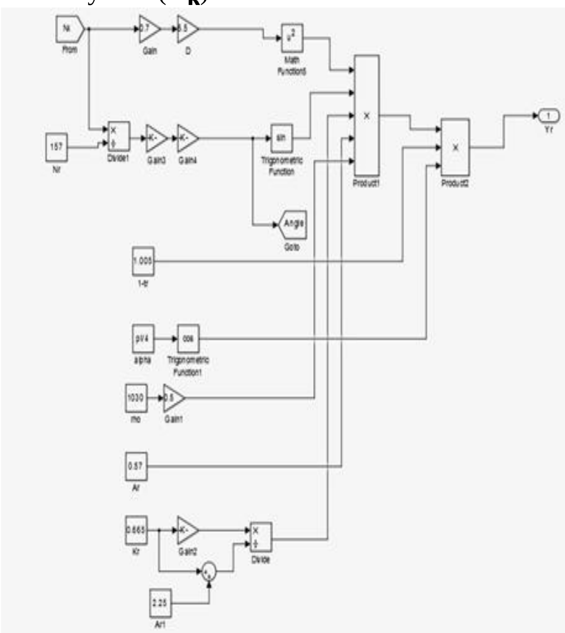
In rudder subsystems ship motions and moments are gr4eatly influenced by the interaction between rudder to hull and rudder to propeller.

Where X_R -> is the moment due to rudder in surge axis.
Y_R -> is the moment due to rudder in sway axis.
Rudder subsystem (X_R)



Here propulsive forces is been represented , where forces are dependent upon accurate representation of trust geometry, wake, lifting and drag propulsion-hull-rudder interaction

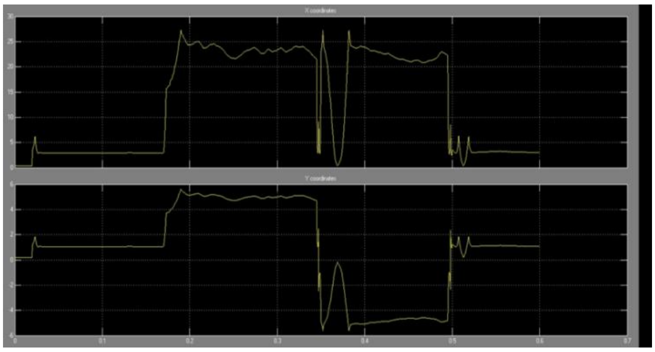
Rudder subsystem ($\mathbf{Y_R}$)



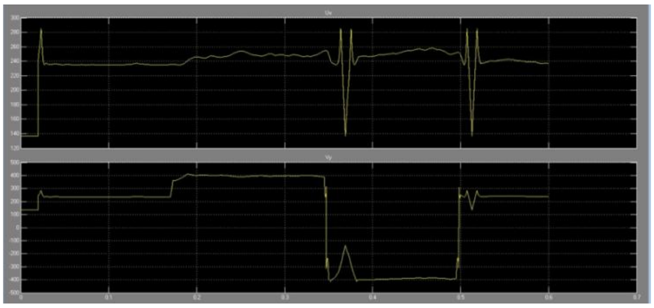
Tracing the reference path

The ship is made to move on the reference path keeping the propeller speed constant and varying rudder speed .

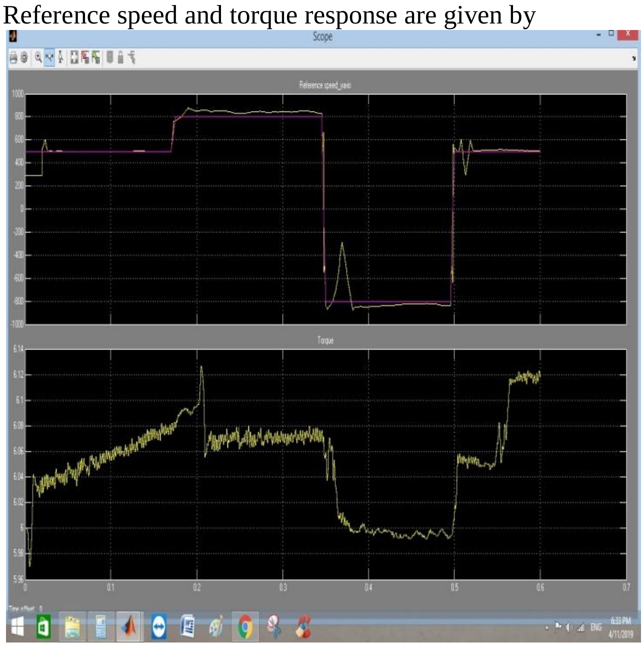
Where x and y coordinates are



U – velocity in x axis (propeller), v- velocity in y axis (rudder) are shown in the response below.



Reference speed and torque response are given by



5. Conclusions

Here we have considered speed error, wave current and rudder angle as input where we are controlling torque of the ship. Where as in the base paper [10] it's velocity and force that is taken and speed will be controlled. Output parameter is 'reference quadrature axis current. Parameters such as speed ,rudder angle(α) and quadrature axis current are taken as input. Based on the response of fuzzy logic and model predictive control logic, autonomous ship can be controlled and navigated unmanly using both the logics.

But the settling time taken by the fuzzy logic is less than that of the model predictive controller.

Hence system which is under fuzzy control is more stable compared to model predictive controller.

In this ship model, a sea disturbances in sway and surge directions are considered, if any sea disturbance encountered in the yaw direction then model might not get through it. The model is taking a delay to get adapted to sea situation when collision is encountered hence future work on yaw direction control and adapting control could be undertaken.

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