Development of an Integrated STR Control System for Thruster and Direction Control of Remotely Operated Vehicles(ROVs)

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EE582 Adaptive and Learning Systems

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Introduction

Maritime operations stand at the forefront of global exploration, presenting unique challenges in navigation and control. The effectiveness of marine propulsion and guidance systems is paramount, not only for the economic viability of maritime endeavors but also for the safety and environmental impact of these operations. This project is positioned at the cusp of this vital intersection, aiming to engineer a comprehensive control system. Utilizing the computational capabilities of MATLAB, the project is tailored to optimize marine propulsion, addressing the dynamic challenges posed by varying environmental conditions such as directions and velocities of wind and current.

This project focuses on designing an STR controller for effective thruster and direction control of a medium-sized Remotely Operated Vehicle (ROV). Given the complexities of marine navigation, the project emphasizes enhancing the ROV's maneuverability and stability in response to environmental factors such as water currents and wind.

STR controller, a control system approach offers significant improvements over traditional PID (Proportional, Integral, Derivative) controllers. STR controllers are known for their flexibility in handling complex systems and their ability to precisely tune system responses. This project aims to leverage these characteristics to specifically address the challenges in controlling the thruster and directional stability of medium-sized Remotely Operated Vehicles (ROVs). By doing so, it contributes directly to the efficiency and safety of maritime operations.

In addition to navigational precision, another crucial aspect of this project is the focus on energy efficiency. Marine vessels, particularly those involved in transportation and research, require significant amounts of energy. An STR-based control system is expected to optimize propulsion mechanisms, leading to reduced fuel consumption and lower operational costs. This aligns well with the growing global emphasis on sustainable practices in the maritime industry.

Lastly, this report will detail the comprehensive design process of the STR controller, from the theoretical underpinnings to practical implementation. It will include the development of reference model transfer functions, the integration of plant transfer functions, and the formulation of the STR controller to effectively manage both the thruster and directional control of an ROV. Simulation results will be presented to demonstrate the controller's efficacy, along with a discussion on the challenges faced.

Problem Description

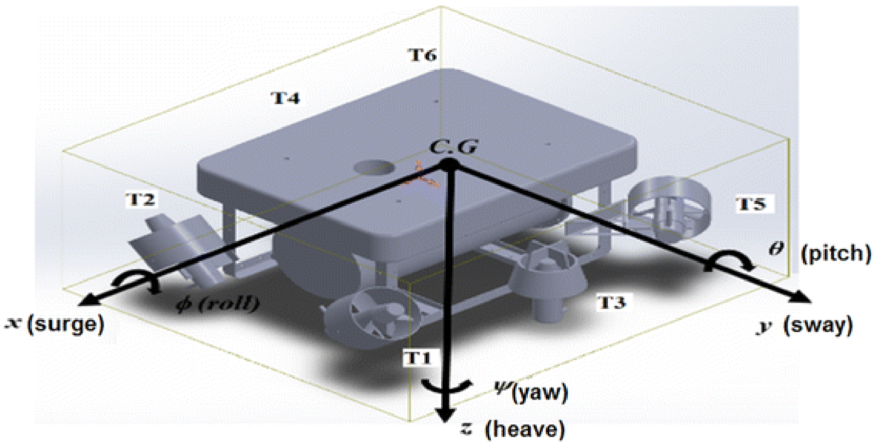
The project is set against the backdrop of an evolving maritime industry, with a focus on enhancing the control mechanisms of a medium-sized Remotely Operated Vehicle (ROV). The primary challenge lies in developing a responsive control system for both the thruster and direction (yaw) mechanisms of the ROV. This system is tasked with optimizing the ROV's navigational efficiency in a dynamic aquatic environment influenced by wind speed, wave speed, and their respective directions. The aim is to achieve a delicate balance ensuring safe and precise navigation through complex marine conditions. The development of such a system is crucial for advancing ROV capabilities in various applications, ranging from underwater exploration to marine infrastructure maintenance.

Assumption

The project is based on the assumption that the ROV's thruster and direction controller operate as a single integrated system. This design means that multiple thrusters will work together to produce a unified effect, ensuring coherent and efficient propulsion and direction control. This approach simplifies the control system architecture, allowing for more straightforward command execution and responsive vehicle handling, particularly in challenging and dynamically changing marine environments.

System Dynamics

The dynamics of a Remotely Operated Vehicle (ROV), essential for effective control are modeled using second-order differential equations. These equations consider factors such as mass, damping, added mass due to water, and external forces like hydrodynamic drag and buoyancy. Understanding these dynamics is critical for our project to design a responsive and efficient STR controller for both thruster (surge) and direction (yaw) control of the ROV.



In this project, we are designing an STR controller for surge and yaw control of the ROV.

Thruster Control Dynamics:

The thrust control dynamic of the ROV is modeled as a second-order system representing surge motion.

The dynamics is represented by the following equation,

$$m\ddot{x} + d\dot{x} + bx = F_{Thrust} + D_{Thrust}$$

where,

m = Mass of the ROV, inclusive of the added mass due to water. It represents the inertia that the control system needs to overcome.

d = Damping coefficient, indicative of hydrodynamic drag. It affects how quickly the ROV can change its speed.

b = Restoring force coefficient, due to buoyancy.

F_{Thrust} = Propulsive force generated by the ROV's thrusters.

D_{Thrust} = Disturbance forces acting on the ROV.

Our aim is to observe the constant Force generated by the ROV, irrespective of the environmental factors like wind and wave current forces acting on it.

Direction Control Dynamics:

Direction or yaw control of the ROV is similarly represented by a second-order system.

The dynamics is represented by the following equation,

$$I\ddot{\theta} + d_{\theta}\dot{\theta} + b_{\theta}\theta = T_{yaw} + D_{yaw}$$

where,

I = Moment of inertia for yaw motion, influencing how the ROV rotates about its vertical axis.

d_{θ} = Rotational damping coefficient, affecting the rotational speed changes.

b_{θ} = Restoring moment

T_{yaw} = Torque produced by differential thrust.

D_{yaw} = Disturbance torques

Our aim is to observe the direction in which ROV remains constant with what we want.

Controller Design

The STR controller design employed in our project is an approach to the control of a medium-sized Remotely Operated Vehicle (ROV), focusing on precise management of both thrust and direction.

The transfer functions for the plant models of our thrust and direction controller are given by,

$$G_{plant\_thrust} = \frac{k_{thrust}(s+1)}{ms^2 + ds + b}$$

$$G_{plant\_dir} = \frac{k_{dir}(s+1)}{I_{yaw}s^2 + d_{yaw}s + b}$$

Where, for the system, we have assumed the following values,
k_{thrust} = 1 N/V, m = 100 Kg, d = 20 Ns/m, b = 10 N

K_{dir} = 2 Nm/V, I_{yaw} = 10 Kg-m^2, d_{yaw} = 5 Nms/rad, b = 8 N-m

The reference model is given by the following equation,

$$G_{ref} = \frac{\omega_n^2}{s^2 + 2\varrho\omega_n + \omega_n^2}$$

Where with $\omega_n = 1$, and $\varrho = 0.7$, we get two reference models for our controller

$$G_{ref\_thrust} = \frac{10}{s^2 + 1.4s + 1}$$

$$G_{ref\_dir} = \frac{4}{s^2 + 1.4s + 1}$$

For our system, we are introducing disturbing external factors as noise to the system.

For thrust(surge) control, the external affecting force are due to the wind and wave current acting on the ROV.

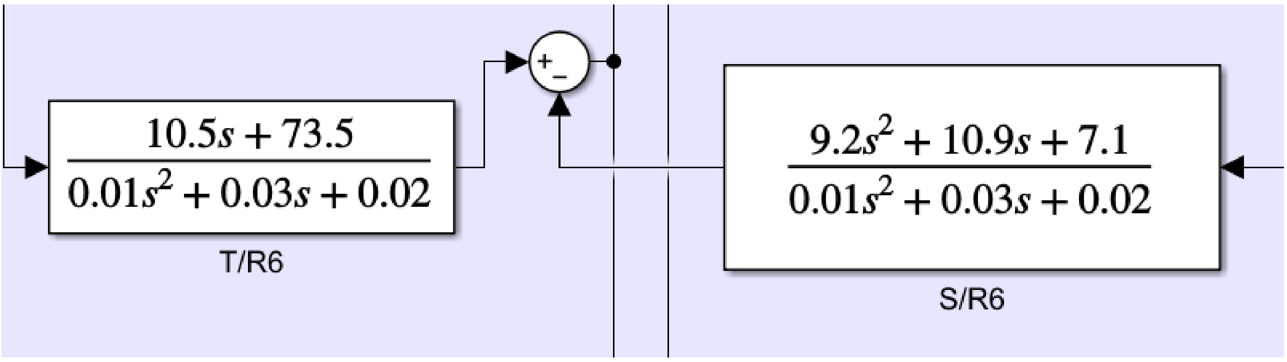
For direction(yaw) control, the external affecting factors are the direction in which the wind, and wave hit the ROV.

We are using constant signal as input signal to the control system.

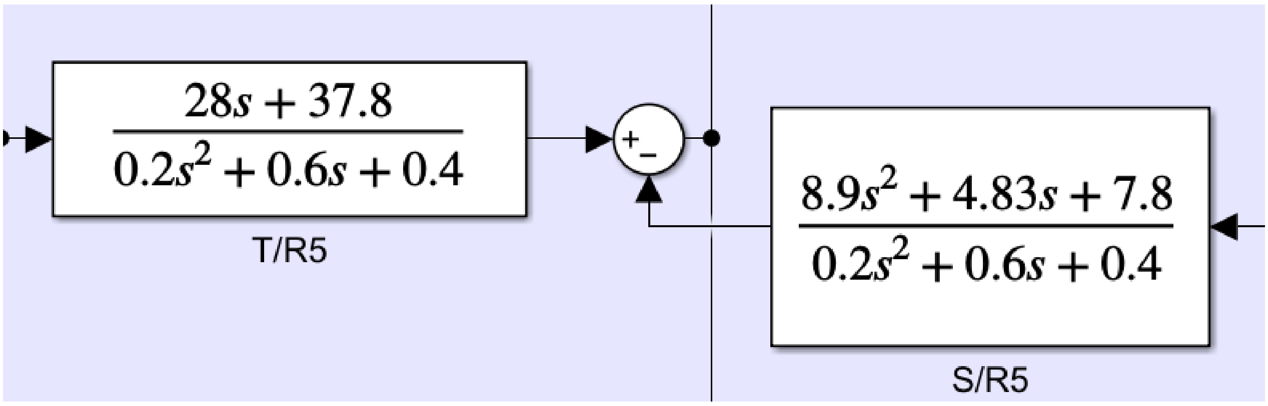
Our aim will be to observe constant force and direction of motion of ROV despite external factors.

Control Law for both surge and yaw control:

For thrust(surge) control:



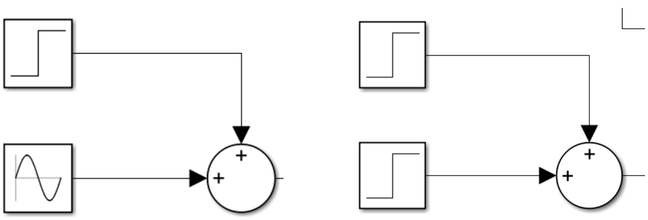
For direction(yaw or rudder) control:



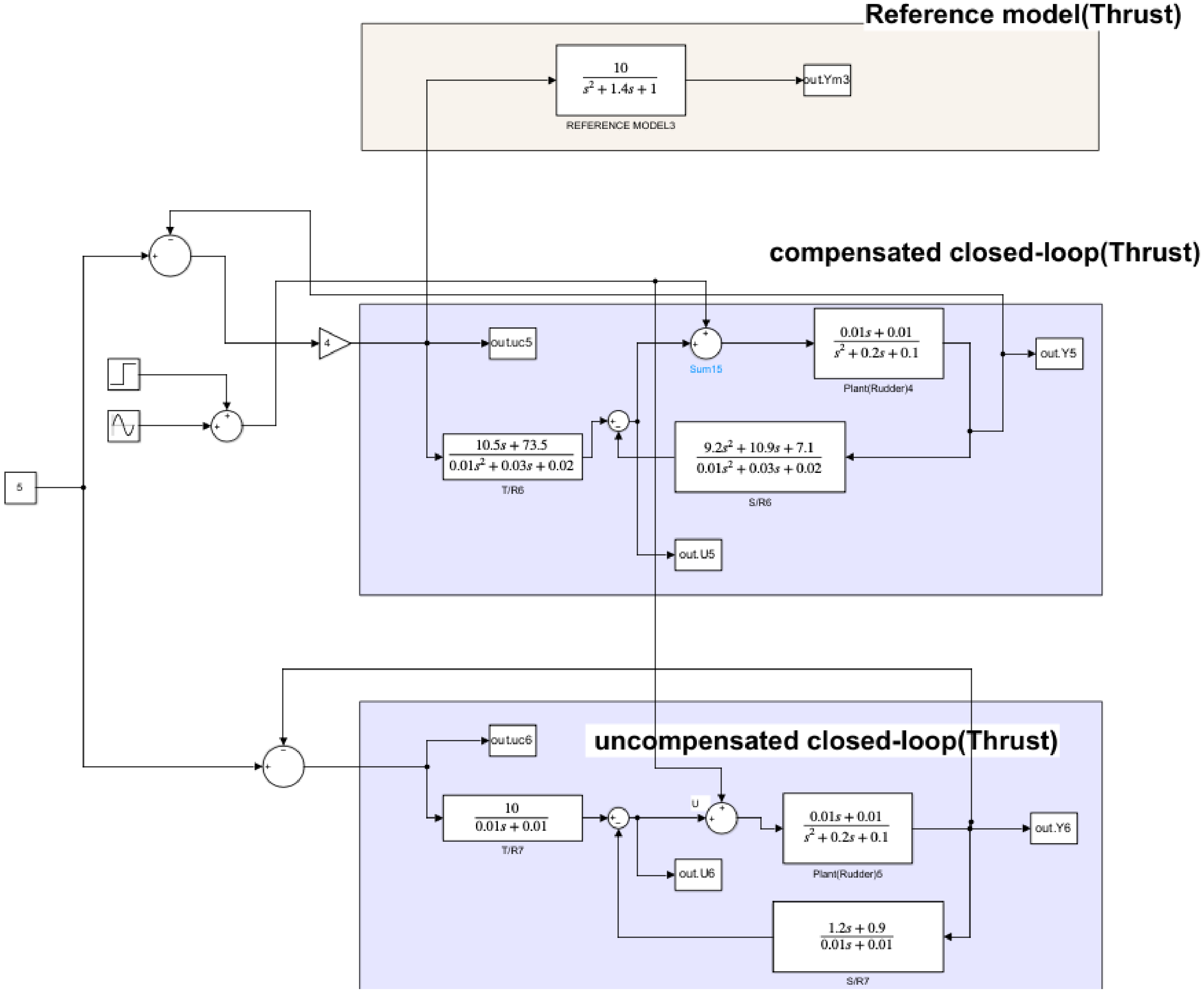
External factors:

We are introducing external forces by wind and wave current using sine and step signal.

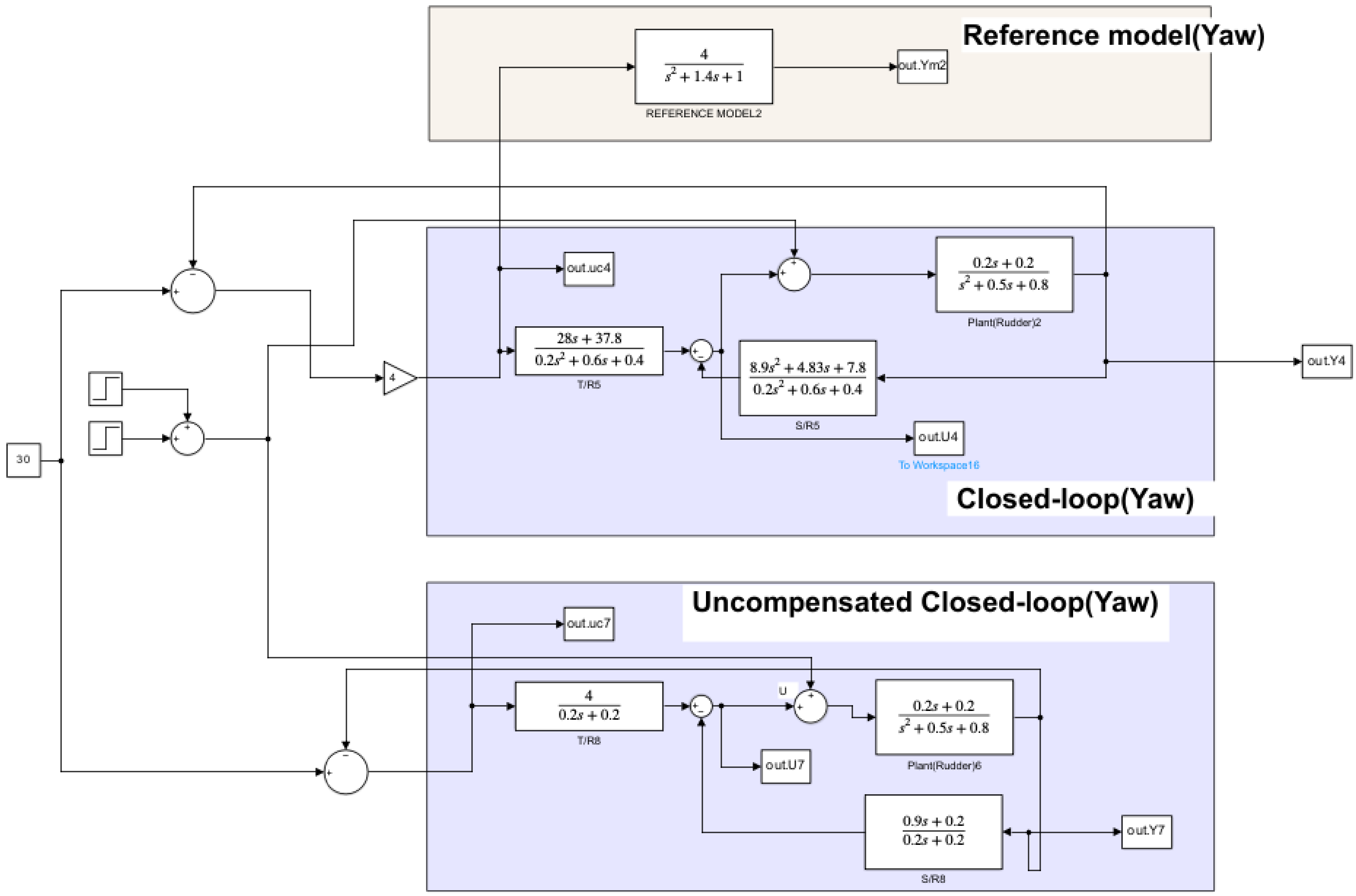
We are introducing angular motion value of the wind and wave current to the system using step signal.



Control System(Thruster)



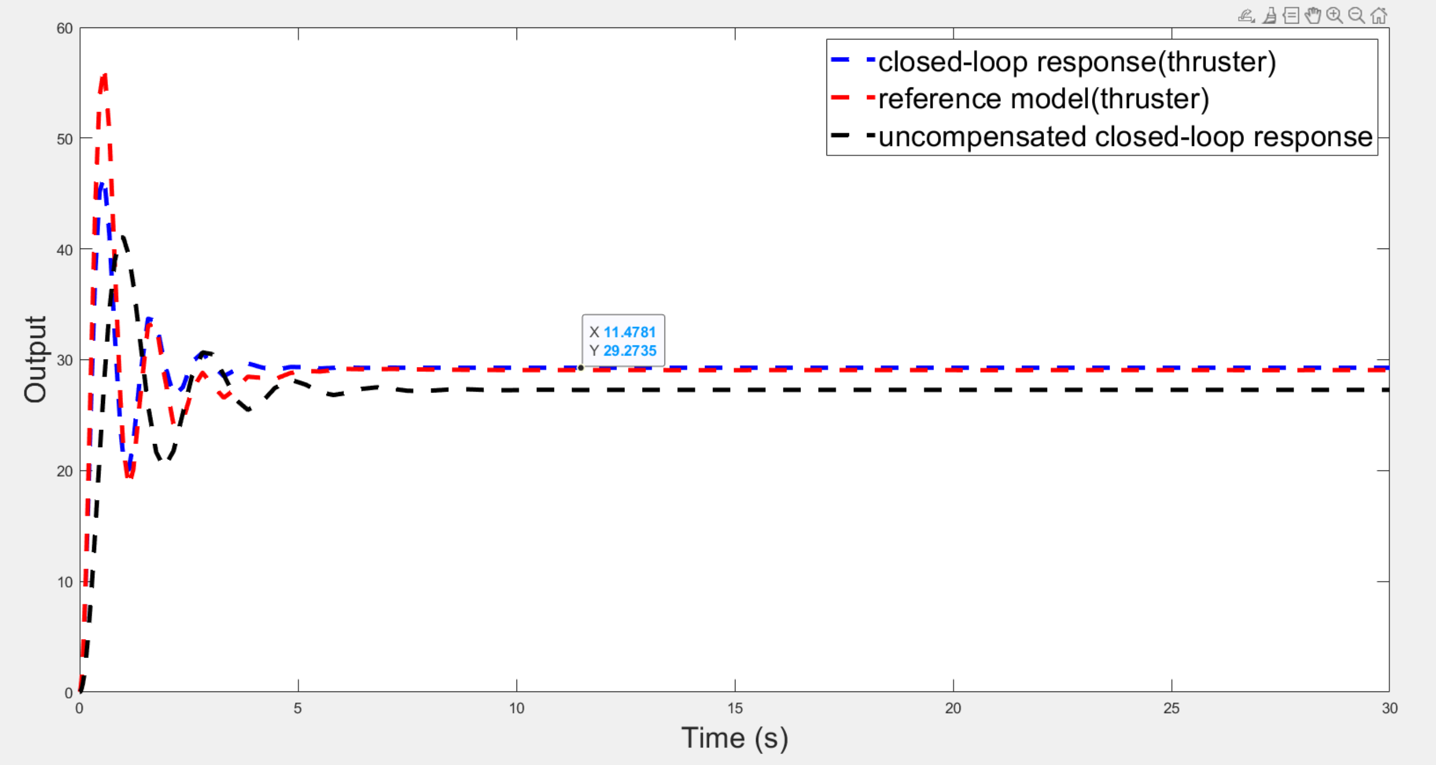
Control System(Yaw, or Rudder)

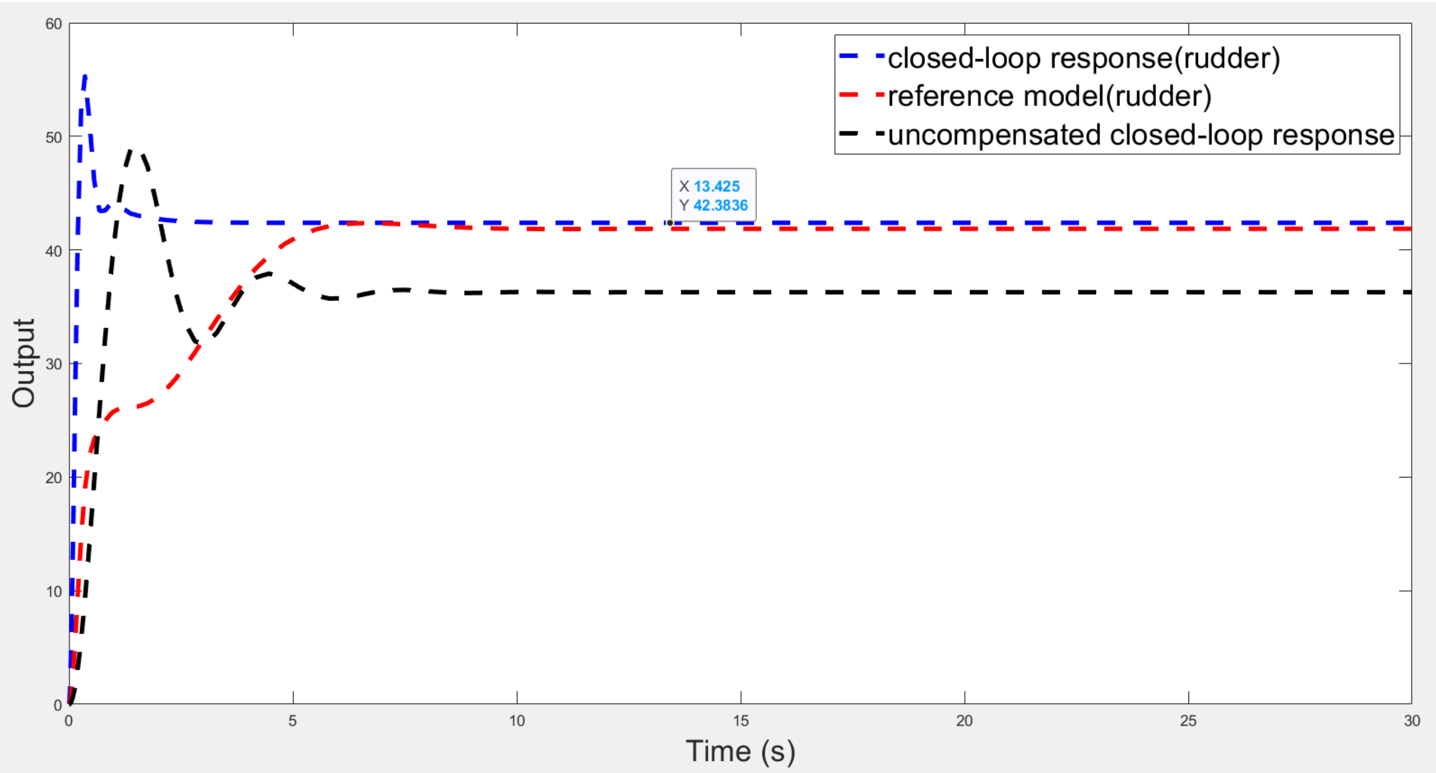


The output of both the plant controller is fed back to the input to reduce error.

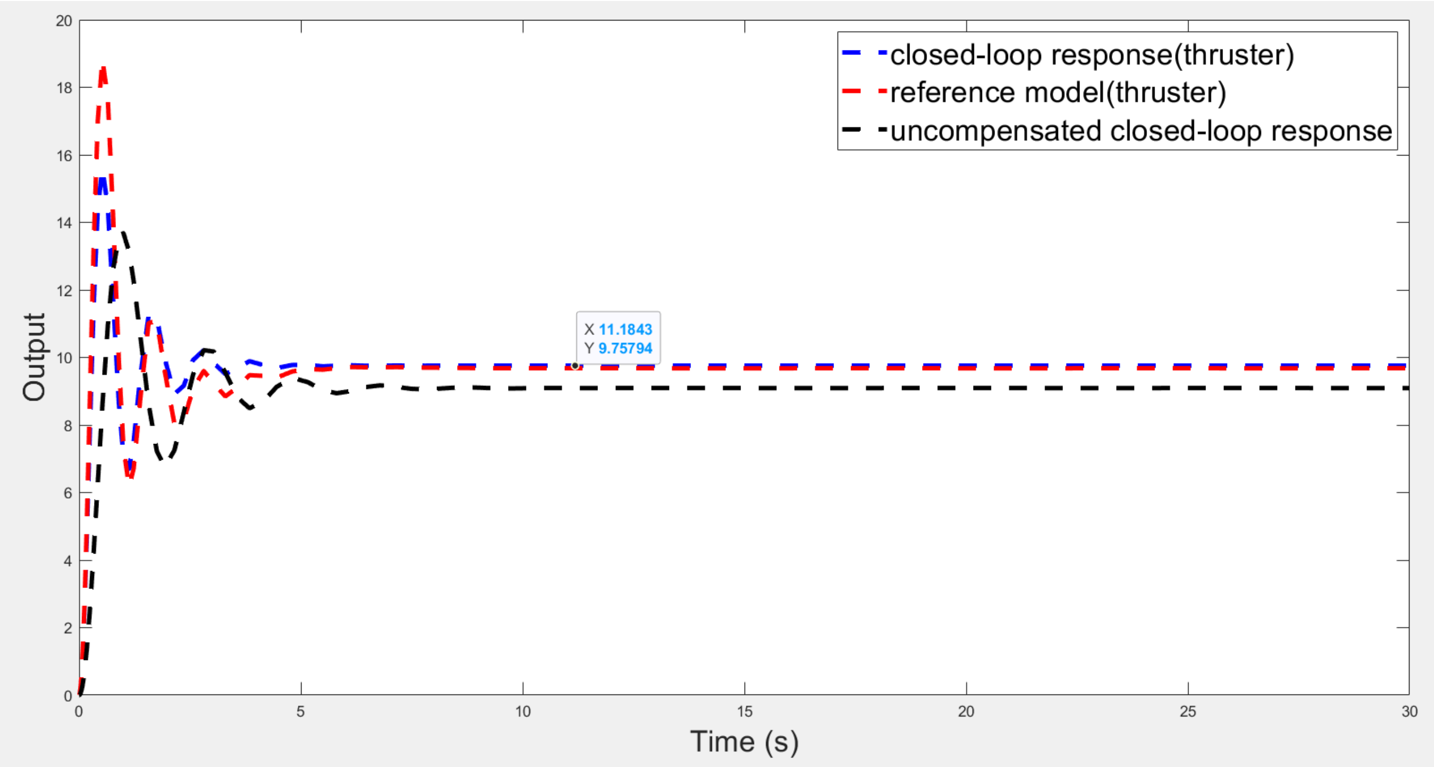
Simulation Result:

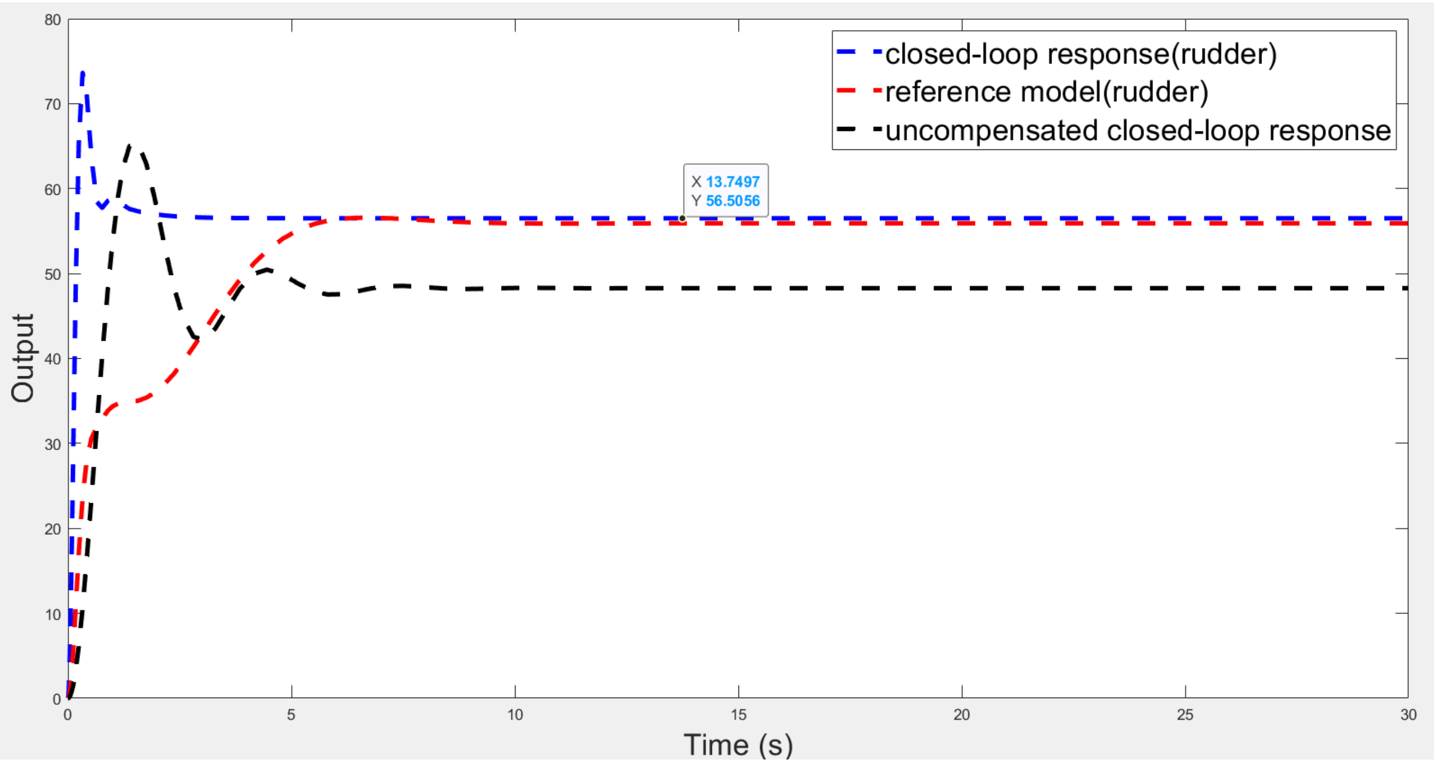
1. To maintain a constant thrust force of 30 N, and angle of 45, despite external forces acting on it.





2. To maintain a constant thrust force of 10 N, and angle of 60, despite external forces acting on it.





Observation:

In observing the performance of our STR control system, it can be noted that the initial response of the ROV exhibits a higher-than-anticipated overshoot, indicating an aggressive control action at the onset. However, following this transient phase, the system rapidly adjusts and closely aligns with the desired trajectory. The post-overshoot behavior of the ROV's control system settles down within a satisfactory 5% error margin. This observation suggests that the STR controller is highly responsive to control commands, but fine-tuning of the initial parameters is required to dampen the initial exuberance and achieve a smoother convergence to the target response from the outset.

Conclusion:

The control system has been designed to ensure responsive and efficient maneuvering under a spectrum of environmental conditions. The STR controller has demonstrated satisfactory performance in maintaining the desired course and speed. The successful application of this control strategy underscores its potential for future explorations in the complex and demanding realm of underwater robotics.

Challenges Faced:

During this project, one of the principal challenges faced was the early-stage reliance on a Proportional-Derivative (PD) control strategy, which proved somewhat difficult for achieving the nuanced response required for our ROV's thrust and direction control. Despite several attempts at tuning, the PD controller fell short in terms of performance. The system struggled to maintain stability, exhibiting persistent oscillations, and failing to conform to our precision criteria. This led to the transition to STR controller.