# TMR4240 Project Part 2:
# Design of a detailed Dynamic Positioning System
# *Control System Design*

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August 2, 2024

## General Information

The solution to the second part of the project must be submitted on Blackboard by November 10, 2024, including a zip-file containing executable MATLAB/Simulink code/diagrams for all simulations performed by you.

Project Part 2 will be evaluated (same as Project Part 1), so the quality of the answer and presentation in the report will be important. Special importance should be given to how the output data is presented.

One single answer will be accepted for each group.

If, for some reasons, some parts cannot be solved, it is important to underline difficulties and thoughts. So, no worries if some difficulties arise, the important thing is to justify the process and underline your attempts to face them, in order to show that you have learned something from it (and tried).

## System Overview

This project is developed based on the Project Part 1, extending the system to a more realistic approach, including some dynamics and limitations on the thrusters.

Don't be afraid to modify the existing components present in the simulator, since its code is being provided for the TMR4240 course and it is intended for the students to modify whatever is necessary to reach the desired goals. If you have modified something, remember to put it into the report.

## Assignment Task

This part consists of designing and testing the following systems for a DP positioned SOV:

- Detailed environmental loads
- Observer (state estimator)
- Filter (if not covered by your observer)
- Controller
- Thruster constraints

You are free to use any reasonable methodology to design the mentioned subsystems.

Also, new wave blocks are provided in the `part2.slx`.

Those two blocks have a few options that shall be adjusted according to the simulated case (by double clicking on the block). The final configuration shall look like as shown in Figure 1. You shall use a fixed-step size solver when simulating Part 2, use either a step size of 0.01 or 0.1.

**NOTE:** The plots asked for in each simulation are a minimum, so if other plots are needed to express your point in discussing the results, add them.

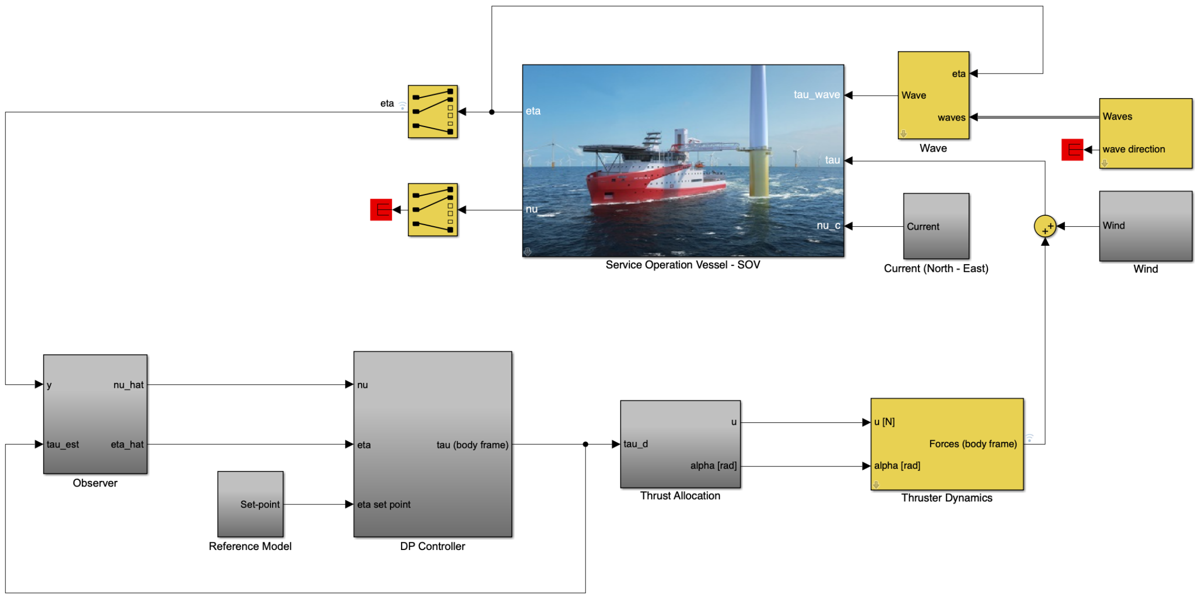


Figure 1: Simulator configuration overview.

# 1 Detailed Environmental Loads

New wave load blocks are given to you in Project Part 2. These can be enabled in the block `Wave` and wave variables can be changed in the block `Waves`.

Further, the current block you made in Project Part 1 can be used as it is, but the wind model shall be expanded to contain more details. In addition to the mean and slowly varying component of the wind speed implemented in Project Part 1, wind gusts must be added. A slowly varying component (but not a gust component) shall also be added to the wind direction. This angle variation shall be limited to a maximum of 5 degrees around the mean direction.

**Hint:** You may use your wind generator developed in a previous assignment.

# 2 Observer

With the measured states from the vessel and knowing the estimated generalized forces over the vessel hull, it is possible to create an observer.

You should implement two different observers, but the observer type/implementation is up to you.

The main measurements available are the vessel position and the controller desired forces (before the thruster dynamics). Keep in mind that the velocity measurements are not usually measured, since they are estimated by your observer. Some vessel data can be found in Appendix B, these can also be found in `supply.mat`.

# 3 Filter

The filter should filter out the measurement noise due to sensor errors. Depending on your observer methodology and tuning, it will not be necessary to pre-filter the signals for the observer, but if the tuning is not done properly, it will be necessary.

# 4 Controller

The controller was implemented in Project Part 1, but feel free to modify your project as much as you want/need. Remember to write about any changes to your system in the project report.

# 5 Thrust Allocation

In the model for Project Part 2, constraints on rotational speed, max thrust and ramp-up time have been added to the "thruster dynamics" block according to the table below. Now, it is your job to update the thrust allocation made in Project Part 1 to take these constraints into consideration.

| Thruster number | Position X | Position Y | Angle [deg] | Rotation [rpm] | Max thrust [kN] | $0 \rightarrow 100\%$ [s] |
|---|---|---|---|---|---|---|
| 1 | 39.3 | 0 | 90 | - | 125 | 8 |
| 2 | 35.6 | 0 | $\alpha_2$ | 2 | 150 | 8 |
| 3 | 31.3 | 0 | 90 | - | 125 | 8 |
| 4 | -28.5 | 5 | $\alpha_4$ | 2 | 300 | 10 |
| 5 | -28.5 | -5 | $\alpha_5$ | 2 | 300 | 10 |

Keep in mind that the thruster angle is given in the body frame, clockwise, with zero pointing to the bow.

**Note:** Thrusters 2, 4 and 5 are azimuth thrusters that can rotate freely. An extended thrust allocation algorithm will give full score, but if you want to it is possible to use optimization algorithms to solve this. Refer to Lecture Dynamic Positioning, Thrust allocation for details of possible optimization algorithms.

# 6 Mandatory Tests

Several tests are required to show that your system is working properly. They are described in the following sections. The 4 initial simulations are to test if your simulator works properly, and the remaining simulation cases aims to have a better understanding of a marine system.

## 6.1 Simulation 1 - Environmental Loads

For the first test, show the vessel behavior when you are under influence of current, wind and waves. For this case, you shall not use thrusters, and the vessel should just drift with the environmental forces.

Simulate for 300 seconds with current from East, with average speed of 0.2 [m/s] and wind from the north, with average speed of 10 [m/s]. Waves from Northeast with a significant wave height $H_s$ of 2.5 [m] and a peak wave period $T_p$ of 9 [s]. Note that the wind and current direction slow variation shall not exceed 5 degrees. Use the same parameters as in Assignment 5.

Plot the position and heading, both as individual results and in an xy-plot, and discuss the results.

## 6.2 Simulation 2 - DP and Thrust Allocation

Disable the environmental forces and plot the desired force calculated by your controller, the force applied by the thruster dynamics and the force set-point for each thruster. The duration that the vessel stays in one position should be long enough to achieve stability before it can move to another setpoint.

Perform the 4 corner DP test from Part 1:

- $\eta_0 = [0\ 0\ 0]$
- $\eta_1 = [50\ 0\ 0]$
- $\eta_2 = [50\ \ -50\ 0]$
- $\eta_3 = [50\ \ -50\ \ -\frac{\pi}{4}]$
- $\eta_4 = [0\ \ -50\ \ -\frac{\pi}{4}]$
- $\eta_5 = [0\ 0\ 0]$

No observer shall be used in this simulation.

Also, make the same simulation for the case where thrusters 2 and 4 are disabled (double click on the thruster dynamics block to enable the fault). The thrust allocation itself also needs to be reconfigured with the disabled thrusters. Compare the results for both cases.

Plot the position and heading until you reach steady state, both as individual results and in an xy-plot. In addition, put the desired trajectory in the individual plots. If the reference model contains velocity trajectories, then plot these with the actual velocities.

## 6.3 Simulation 3 - DP and Environmental Forces

Perform the 4 corner DP test using the environmental conditions presented in Simulation 1 and the thrust allocation from Simulation 2 (without thruster failure). There shall be NO OBSERVER used.

Plot the position and heading until you reach steady state, both as individual results and in an xy-plot. In addition, put the desired trajectory in the individual plots. If the reference model contains velocity trajectories, then plot these with the actual velocities.

## 6.4 Simulation 4 - Observer selection

Use the same environmental conditions as in Simulation 1. The desired DP force shall be fixed at $[1\ 1\ 1] \cdot 10^4$. Simulate for enough time such that you can choose observer later. Do a new simulation, now without wave forces/moment. We just want you to compare your observer output with the real measurements (before and after wave forces/moment are added to the signal).

Compare the two different observers designed and based on the results, choose the one that had the best results.

## 6.5 Simulation 5 - Capability Plot

Make a thrust utilization plot for the vessel for a fixed weather condition, $U_3 = 12.0$ [m/s], $U_c = 0.2$ [m/s], $H_s = 4.0$ [m] and $T_p = 8.0$ [s].

To make the capability plot, find the average thrust percentage used to keep the vessel stable at $[x_{\mathrm{SP}}\ y_{\mathrm{SP}}] = [0\ 0]$, given that the current, wind and waves are coming from North. Change the environmental direction with increment of 10 degrees. The wind, wave and current directions are co-linear (having the same direction) and vessel heading $\psi_{SP} = 0$ degree.

An example of an average thrust utilization plot, with respect to change in environmental direction, is shown in Figure 2.

A thrust utilization is defined as the sum of the magnitudes of individual actuator forces (for all active actuators) as percentage of the sum of the magnitudes of maximum nominal thrust of all active actuators. The average of thrust utilization is the average value of thrust utilization over the simulation time.

To ensure the safe operation of personnel transfer via the gangway, the vessel position and heading deviation should not exceed 3 [m] and 3 [deg], respectively. Please provide a representation of the thrust utilization plot with this constraint on position and heading deviation. In this context, the thrust utilization curve should not be displayed if position and heading deviation exceed 3 [m] and 3 [deg], respectively.

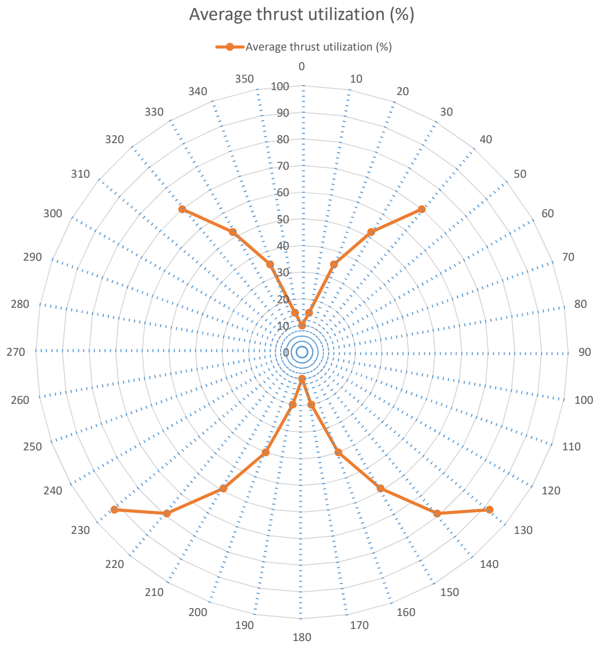


Figure 2: Average thrust utilization plot.

In other words, it is expected that you generate two average thrust utilization plots: one without constraints on deviation, and one including these constraints to present the limits for safe operation of the gangway for the given environmental conditions. Discuss the results.

## 6.6 Simulation 6 - Observer Robustness

Verify if your observers are robust by changing the wave height to 8 [m] and period to 13 [s], use the same current and wind values from Simulation 1. Then plot the vessel position over 1000 seconds, for station keeping at the origin ($\eta_{\mathrm{SP}} = [0\ 0\ 0]$).

## 6.7 Simulation 7 - DP System Functionality

Design your own simulation to showcase the functionality and performance of your DP system. Explain the simulation and its parameters and discuss your results. This simulation will be evaluated based on how well it visualizes the strengths and weaknesses of your DP system.

# 7 Report

The report should include the modeling of the developed systems (equations and/or Simulink diagrams) as well as a discussion about why this method was selected.

It is expected that this report is a mix between a technical report of your implementation and an academic research report.

## Tips

- Even though you are in a group of four students, with a long deadline, remember that you have other duties as well, so don't try to solve this project on the last week (day), it might be surprisingly long.
- Do not try to solve everything at once. When you develop a big system like this one, it is possible that the connections between the blocks might generate unexpected behavior, so, if possible, work block by block.
- One of the goals for this project is to be similar to what you might find in your professional life. With this in mind, remember that it is not only important to develop a good product, but it is also important to present it properly, with a suitable user interface and well written report.

## General Project Report Requirements

The project should be written in a short report. After project part 1, the report will be updated with project part 2. It means that at the end there is only one report. The following sections should be presented (dependent on which Project part):

- Introduction (to the problem)
- Process plant model
  - Mathematical model of the controlled vessel
- Control plant model
  - Simplified mathematical model of the vessel
- Current model
- Wind model
- Wave model (only part 2)
- Reference model
- Observer design (only in part 2)

  - The type of observer chosen and the reason for your choice
  - How do you tune your observer, how do you calculate the observer gain?
- Thrust allocation (thruster constraints only in part 2)
- Controller design
  - What type of controller you choose and state the reason for your choice
  - How you tune the controller, how do you calculate the controller gain?
- Simulation results
  - Present different simulation scenarios
  - Scenario 1 $\rightarrow$ n: plot necessary plots
  - Discuss the simulation results for the different scenarios. Does your controller fulfill the control objective? If not, discuss the reason. For example, have you tried to push the controller/observer/reference gains higher, and what was the consequence of doing that?
- Conclusion (only in part 2)
  - Summary of the project
    * What have you done in the project?
    * Have you achieved the requirements from the project?
  - Provide an overview of
    * The new knowledge or information discovered (Any take-away from the project?)
    * Are there any limitations in your project?
    * Is there any way to improve the project? (to overcome the limitation)
- Appendix describing how you worked as a group, including how the work/responsibilities was distributed, who was responsible for what, and any issues you may have a encountered.

It is noted that the content of the report from Project part 1 will only contain the relevant sections and does not need to have the conclusion section. However, Project part 1 report should contain the discussion(s) to the simulation(s) performed for Part 1. The report after Project part 2 will contain all sections and the results from simulations in Project part 2.

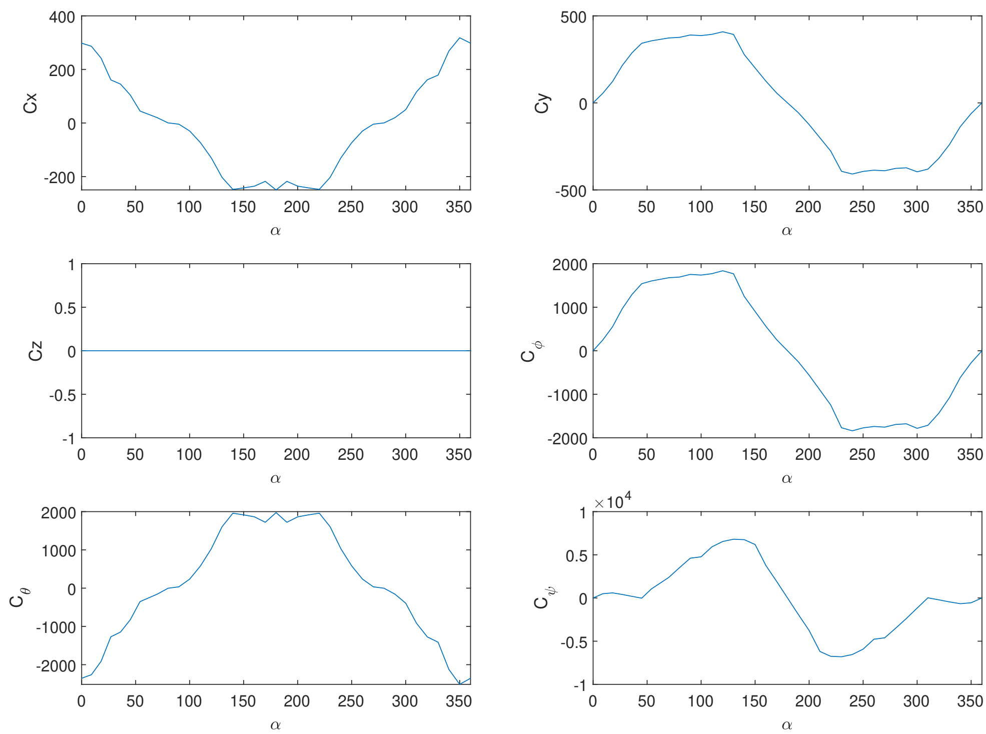


Figure 3: Wind coefficients.

# A Wind coefficients

Wind coefficients are shown in Fig. 3. Wind coefficient can be obtained by running the script `windCoefficients.m` given as the attachment in the project.

# B Observer Data

Mass matrix (rigid body + added mass):

$$M = M_{RB} + M_A = \begin{bmatrix} 7.0101e6 & 0 & 0 \\ 0 & 8.5190e6 & 4.7187e5 \\ 0 & 4.7187e5 & 3.7973e9 \end{bmatrix} \tag{1}$$

Damping matrix:

$$D = \begin{bmatrix} 2.6486e5 & 0 & 0 \\ 0 & 8.8164e5 & 0 \\ 0 & 0 & 3.3774e8 \end{bmatrix} \tag{2}$$