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

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General Information

The solution to the second part of the project must be submitted on Blackboard by November 11, 2018, including a zip-file containing the report in PDF-format and executable MATLAB/Simulink code/diagrams.

The Project Part 2 will be evaluated (same as the 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 come, the important 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 on the simulator, since it's 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.

Assignment Task

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

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

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

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

- Thruster dynamics
- Wave loads

Those two blocks have a few options that shall be adjusted accordingly to the simulated case (by double clicking on the block). The final configuration shall look like as shown of 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.

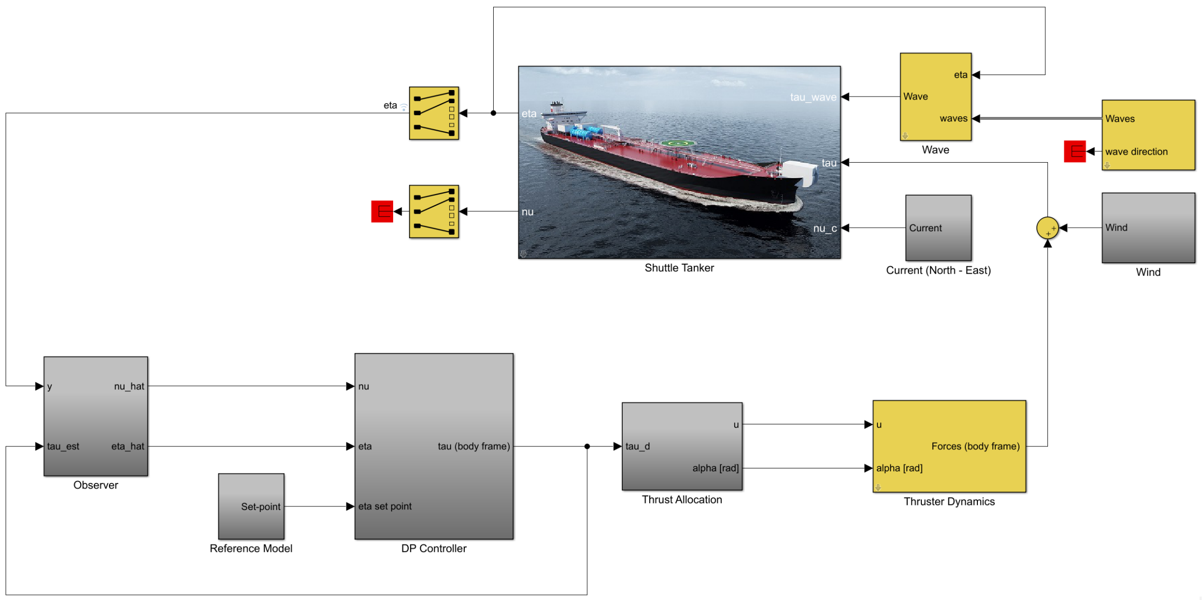

Figure 1: Simulator configuration overview.

1 Detailed Environmental Loads

The first part is the implementation of the environmental loads acting on the vessel hull. Ice loads, mooring lines and other external forces can be disregarded. The only environmental loads that must be taken into account here are:

- Current
- Wind
- Waves

The current block you made in Part 1 can be used also here, and the wind loads must be calculated as generalized forces on the body frame for all 6 degrees of freedom. The Wave loads blocks are given to you, so they can be enabled in the block `Wave` and the wave variables can be change in the block `Waves`.

The wind model implemented shall use a coefficient table, where:

$$F_{Wind} = |V_w|^2 \cdot C_w(\alpha_{rw}), \tag{1}$$

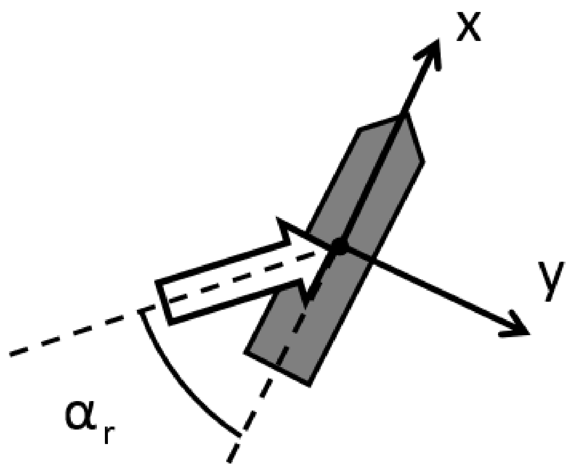

Figure 2: Relative angle calculation.

where:

- F_{Wind} are the generalized wind forces.
- V_w is the wind velocity modulus.
- $C_w(x)$ is the wind coefficient matrix.
- α_{rw} is the relative angle between the wind direction and the vessel heading.

Figure 2 demonstrates how the relative angle is calculated. The relative incidence angle is given in the Appendices A.

The wind model shall have a mean component and a slowly varying component, in addition to a gust component. The direction also must have a slow varying component (but not a gust component). The angle variation shall be limited to a maximum of 5 degrees around the mean direction.

Hint: You may use your wind generator developed on 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 `S175.mat`.

3 Filter

The filter should filter out the measurement noise due to sensors 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.

5 Thrust Allocation

The thrust allocation algorithm shall be implemented in this block. This block will receive the desired thrust from the DP controller and shall translate it to individual thrust set-point for each thruster.

Keep in mind that this system is over-actuated, so it is possible to optimize the thrusters set-point to minimize power consumption.

Regardless of the thrust allocation algorithm picked by your group, at least the following data shall be necessary:

Thruster number	Position X	Position Y	Angle [deg]	Rotation [rpm]	Max thrust [kN]	$0 \rightarrow 100\%$ [s]
1	77	0	90	-	420	8
2	74	0	90	-	420	8
3	70	0	α_3	2	500	8
4	-65	0	90	-	260	8
5	-72	5	α_5	2	1100	12
6	-72	-5	α_6	2	1100	12

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

Note: Thruster 3, 5 and 6 are azimuth thrusters that can freely rotate.

6 Mandatory Tests

Several tests are required to show that your system is working properly. They are described in the following sections. The 5 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 have only under influence of current, wind and waves. For this case, you shall not use thrusters.

Simulate for 300 seconds with current from East, with average speed of 1 [m/s] and wind from the north, with average speed of 15 [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 vessel position 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:

- $\eta_0 = [0\ 0\ 0]$
- $\eta_1 = [50\ 0\ 0]$
- $\eta_2 = [50\ \ -50\ 0]$
- $\eta_3 = [0\ \ -50\ \ -\pi/2]$
- $\eta_4 = [0\ 0\ \ -\pi/2]$

No observer shall be used in this simulation.

Also, make the same simulation for the case where the thruster number 2 and 5 are disabled (double click on the thruster dynamics block to enable the fault). Compare the results for both cases.

Plot the setpoint, reference (desired) position, and the vessel position/velocity.

6.3 Simulation 3 - DP and Environmental Forces

Simulate this system using the environmental conditions presented in Simulation 1 and the DP controller in Simulation 2 (without thruster failure). There shall be no observer used.

Plot position and velocity.

6.4 Simulation 4 - Observer selection

Use the same environmental conditions as in Simulation 1. The DP desired 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 - Complete Simulation

With the selected observer, run a 4 corner DP test, including DP system and the environmental conditions.

Use the same environmental conditions as in Simulation 1.

Plot the setpoint, reference (desired) position, and the vessel position/velocity.

6.6 Simulation 6 - Capability Plot

Make a thrust utilization plot for the vessel for a fixed weather condition, $U_3 = 20$ [m/s], $U_c = 1$ [m/s], $H_s = 5$ [m] and $T_p = 10$ [s].

To make the capability plot, find the average thrust percentage used to keep the vessel stable at $[x_{\text{SP}}\ y_{\text{SP}}] = [0\ 0]$, 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 collinear (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 3.

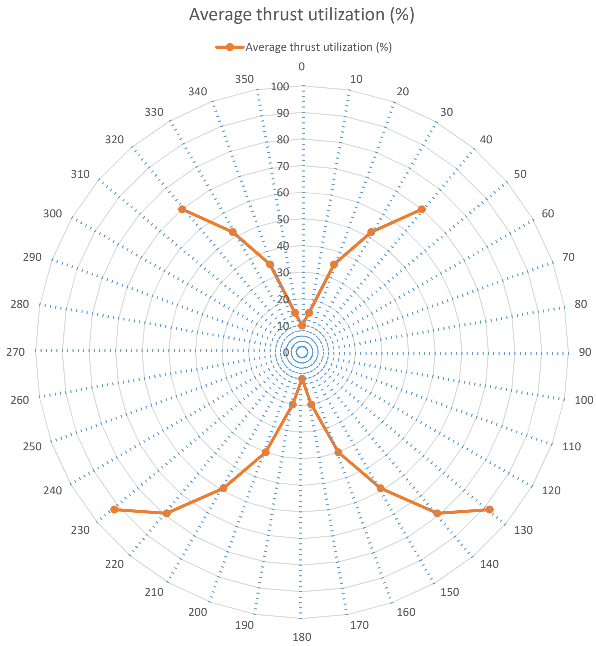

Figure 3: Average thrust utilization plot.

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 simulation time.

6.7 Simulation 7 - Observer Robustness

Verify if your observers are robust by changing the wave height to 8 [m] and period to 6.5 [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 ($\eta_{\text{SP}} = [0\ 0\ 0]$).

7 Report

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

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

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.
- Personally, I would start by the simpler blocks, like thrust allocation. Also, blocks like the state estimator might be overlook initially, since it is possible to provide the actual position values to the vessel, (which is even better than the best sensor in the market).
- 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
  - Mathematic model of the controlled vessel
- Control plant model
  - Simplified mathematic model of the vessel
- Observer design
  - What type of observer you choose and state the reason for your choice
  - How do you tune your the observer, how do you calculate the observer gain?
- 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
  - Discussion on the simulation results for different scenarios. The most important aspect is whether the chosen controller has fulfill the control objective? If not, state the reason.
- Conclusion:
  - 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?)
    * Is there any limitations in your project?
    * Is there anyway to improve the project? (to overcome the limitation)

It is noted that the content of the report of the Project part 1 will contain only 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.

A Wind coefficients

α	C_X	C_Y	C_N
0	1000,308	0	0
10	1017,407	494,0309	-22019,7
20	1094,354	1093,926	-45874,3
30	1111,453	1834,972	-65141,5
40	1034,506	2505,442	-75233,8
50	931,9108	3105,337	-73398,9
60	760,918	3599,368	-60554,1
70	547,177	3952,247	-44956,8
80	307,787	4093,399	-25689,6
90	68,39712	4234,55	-4587,43
100	-170,993	4199,262	12844,8
110	-401,833	4022,823	30277,04
120	-572,826	3740,52	44956,81
130	-786,567	3281,777	52296,7
140	-974,659	2576,018	54131,67
150	-1068,71	1834,972	47709,27
160	-1085,8	1093,926	36699,44
170	-1043,06	494,0309	20184,69
180	-1008,86	0	0
190	-1043,06	-494,031	-20184,7
200	-1085,8	-1093,93	-36699,4
210	-1068,71	-1834,97	-47709,3
220	-974,659	-2576,02	-54131,7
230	-786,567	-3281,78	-52296,7
240	-572,826	-3740,52	-44956,8
250	-401,833	-4022,82	-30277
260	-170,993	-4199,26	-12844,8
270	68,39712	-4234,55	4587,43
280	307,787	-4093,4	25689,61
290	547,177	-3952,25	44956,81
300	760,918	-3599,37	60554,07
310	931,9108	-3105,34	73398,87
320	1034,506	-2505,44	75233,85
330	1111,453	-1834,97	65141,5
340	1094,354	-1093,93	45874,3
350	1017,407	-494,031	22019,66
360	1000,308	0	0

B Observer Data

Mass matrix (rigid body + added mass):

$$M = \begin{bmatrix} 2.6e7 & 0 & 0 \\ 0 & 3.6e7 & 0 \\ 0 & 0 & 7.2e10 \end{bmatrix} \tag{2}$$

Damping matrix:

$$D = \begin{bmatrix} 4.9e5 & 0 & 0 \\ 0 & 4.1e6 & 0 \\ 0 & 0 & 9.7e9 \end{bmatrix} \tag{3}$$