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

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General Information

The assignment must be submitted on It's Learning by November 17, 2015, including a zip file containing the report inf PDF format and executable Matlab/Simulink code/Diagrams.

The project Part 2 will be evaluated, so the quality of the answer and of the final presentation (later this year) will be important. Special importance should be given to how the output data is presented.

It is mandatory to give one single answer for each group when it comes to the Project Part 2 solutions.

Any information about the system that might be missing can be asked directly to the TA

System overview

This project is developed based on the project part 1, extending the system to a more realistic approach, including some parts of the electrical system (such as thrust limitations, etc).

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 assignment (Project 1) consists of designing and testing the following systems for a DP positioned drilling rig:

- Detailed environmental loads (wind and current)
- 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, one new initialization file and two new blocks are provided:

- Thruster dynamics
- Measurement noise

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.

1 Detailed environmental loads

The first part discussed 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 are:

- Current
- Wind

The current and wind loads must be calculated as generalized forces on the body frame for all 6 degrees of freedom.

Both environmental models implemented shall use a coefficient table, where:

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

$$F_{Current} = |V_c|^2 \cdot C_c(\alpha_{rc}) \tag{2}$$

where:

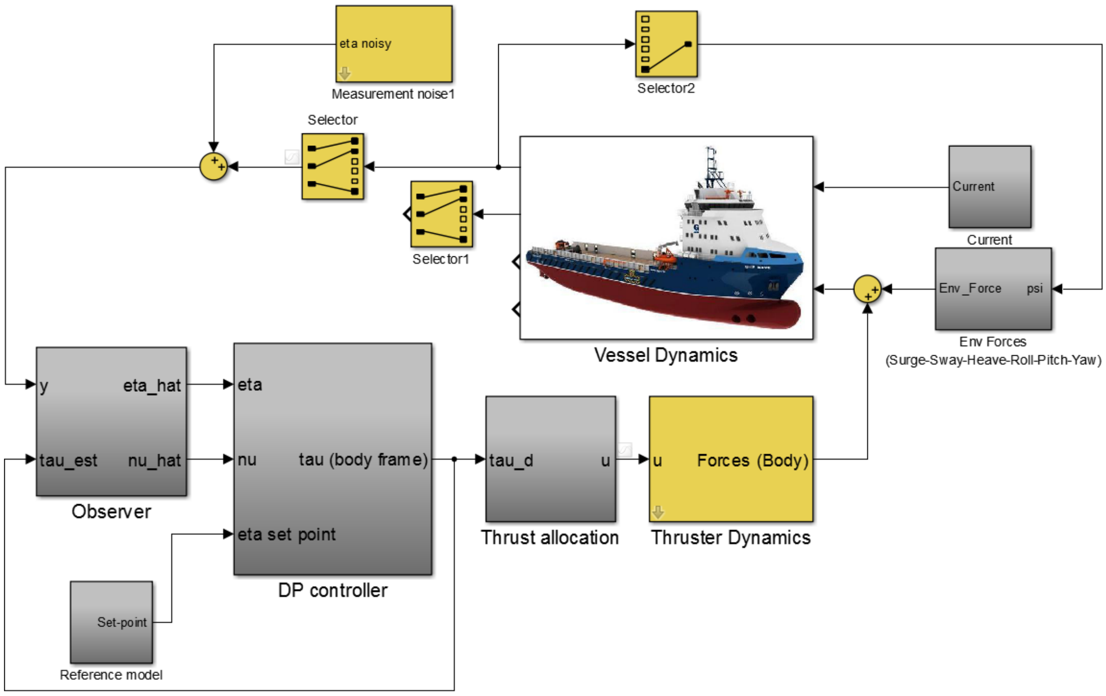

Figure 1: Simulator configuration overview

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

Figure 2 demonstrates how the relative angle is calculated.
The relative incidence angle is given at the appendixes A and B.
*Hint: You may use your wind generator developed on a previous assignment.
The current component is an extension of the model implemented in the project part 1, and should replace it for a more accurate estimative.

Both current and wind shall have a mean component, slow varying component and gust. The direction also must have a slow varying component (but not a gust

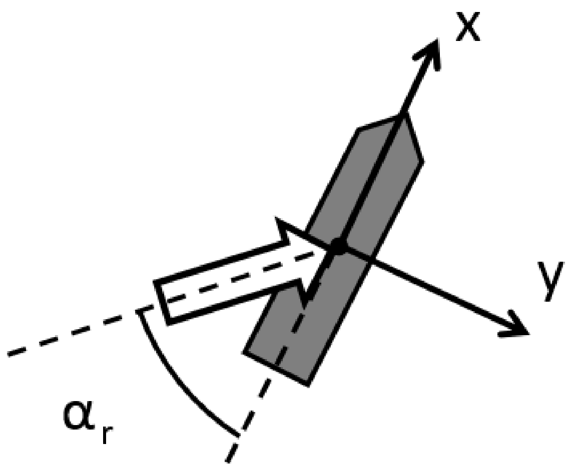

Figure 2: Relative angle calculation

component). The angle variation shall be limited to a maximum of 5 degrees around the mean direction.

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, and if some measurement that is not provided is necessary, contact the TA for further instructions.

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.

When an observer is designed, you usually don't have the exact data about the vessel (for instance, you don't know exactly the mass matrix, nor the linear drag matrix), which is usually estimated trought scale experiments or numerical simulation (e.g.: CFD models, etc). You should use the data in appendix 3 for your observer implementation.

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 demanded loads 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]	Max thrust[kN]
1	30	0	90	74
2	-30	5	10	118
3	27	0	90	74
4	-30	-5	-10	118
5	-27	0	90	74

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

6 Mandatory tests and report

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 and wind. For this case, you may ignore the thrusters effect.

Simulate for 100s with current from East, with average speed of 1m/s and wind from the north, with average speed of 20m/s. Note that the direction slow variation shall not exceed 5 degrees. Use the same parameters as in assignment 5, exercise 2.1.

Plot the vessel position over time 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. Run this simulation for as long as it is necessary to achieve stability.

The initial position should be $\eta_0 = [0\ 0\ 0]$ and the final setpoint should be $\eta_{SP} = [10\ 2\ \pi/2]$

The measurements should be disabled and no observer shall be used in this simulation.

Also, make the same simulation for the case where the thruster number 3 is disabled (double click on the thruster dynamics block to enable the fault). Compare the results for both cases.

6.3 Simulation 3 - DP and environmental forces

Simulate this system using the environmental conditions presented in simulation 1 and the DP in simulation two (without thruster failure). there shall be no noise in the system, neither use any observer.

6.4 Simulation 4 - Observer selection

Enable the noisy signal (double click in the noise block) and use the same environmental conditions as in simulation 1. The DP desired force shall be fixed at $[1\ 1\ 1] \cdot 10^4$. We just want to compare your observer output with the real measurements (before and after the noise is added to the signal).

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

6.5 Simulation 5 - Complete simulation

With the selected observer, run a complete simulation, including noise, DP system and the environmental conditions.

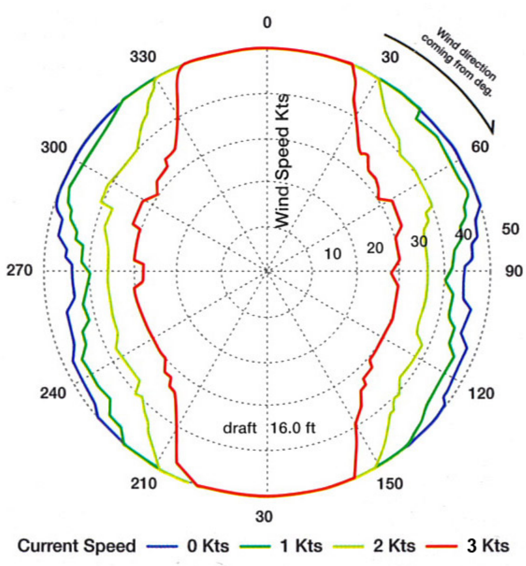

Figure 3: Capability plot

The wind $U_3 = 15m/s$, coming from Northwest and current $U_C = 1m/s$ coming from Northeast.

The initial position should be $\eta_0 = [0\ 0\ 0]$ and the desired setpoint $\eta_{SP} = [100\ 50\ pi/6]$. Use as much time as needed.

6.6 Simulation 6 - Capability plot

Make a capability plot for this vessel, for currents of $U_C = 0$, $U_C = 0.5$, $U_C = 1$ and $U_C = 1.5$.

To make the capability plot, find the maximum wind speed that your system is capable to keep the vessel stable ($\eta_{SP} = [000]$), given the current, parallel to the wind, for the wind incidence angle every 10 degrees ($\alpha_w = 0 : 10 : 360\ deg$). An example of the capability plot is shown in figure 3.

6.7 Simulation 7 - Observer robustness

Verify if your observers are robust: Include a gain of 10 after your noise block and plot the vessel position over 1000s, for station keeping at the origin ($\eta_{SP} = [000]$).

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 behaviour, 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.
- Since this simulator is a work in progress, remember that it might misbehave. If you have any sign of a software bug (not caused by you), contact the TA immediately, so you save time.

Appendix A - Current coefficients

α	C_x	C_y	C_z	C_θ	C_ϕ	C_ψ
0	11786	0	0	0	33000.8	0
10	13751	24354	0	-68191.2	38502.8	-571850
20	15322	46496	0	-130188.8	42901.6	-947490
30	16304	70808	0	-198262.4	45651.2	-1270900
40	16304	95206	0	-266576.8	45651.2	-1501300
50	14339	121710	0	-340788	40149.2	-1447700
60	11000	146070	0	-408996	30800	-1179900
70	7268.3	164050	0	-459340	20351.24	-858400
80	3143	174920	0	-489776	8800.4	-500840
90	-1374.8	179300	0	-502040	-3849.44	-107140
100	-5107.6	174850	0	-489580	-14301.28	214290
110	-8839.1	166060	0	-464968	-24749.48	518280
120	-11982	150570	0	-421596	-33549.6	607860
130	-14339	126300	0	-353640	-40149.2	947490
140	-14537	97417	0	-272767.6	-40703.6	947490
150	-12376	68636	0	-192180.8	-34652.8	750880
160	-10410	42066	0	-117784.8	-29148	518470
170	-9427.9	19898	0	-55714.4	-26398.12	249180
180	-9231.9	0	0	0	-25849.32	0
190	-9427.9	-19898	0	55714.4	-26398.12	-249180
200	-10410	-42066	0	117784.8	-29148	-518470
210	-12376	-68636	0	192180.8	-34652.8	-750880
220	-14537	-97417	0	272767.6	-40703.6	-947490
230	-14339	-126300	0	353640	-40149.2	-947490
240	-11982	-150570	0	421596	-33549.6	-607860
250	-8839.1	-166060	0	464968	-24749.48	-518280
260	-5107.6	-174850	0	489580	-14301.28	-214290
270	-1374.8	-179300	0	502040	-3849.44	107140
280	3143	-174920	0	489776	8800.4	500840
290	7268.3	-164050	0	459340	20351.24	858400
300	11000	-146070	0	408996	30800	1179900
310	14339	-121710	0	340788	40149.2	1447700
320	16304	-95206	0	266576.8	45651.2	1501300
330	16304	-70808	0	198262.4	45651.2	1270900
340	15322	-46496	0	130188.8	42901.6	947490
350	13751	-24354	0	68191.2	38502.8	571850
360	11786	0	0	0	33000.8	0

Appendix B - Wind coefficients

α	C_x	C_y	C_z	C_θ	C_ϕ	C_ψ
0	248.37	0	0	0	-2355.232759	0
10	265.19	61.332	0	275.994	-2514.732759	551.1
20	224.13	136.22	0	612.99	-2125.37069	661.56
30	149.03	238.76	0	1074.42	-1413.215517	451.37
40	134.36	319.42	0	1437.39	-1274.103448	212.51
50	96.8	380.5	0	1712.25	-917.9310345	-23.578
60	41.364	396.1	0	1782.45	-392.2448276	1168.3
70	16.477	372.96	0	1678.32	-156.2474138	2376.3
80	0.30412	376.5	0	1694.25	-2.883896552	3511.9
90	-3.723	390.01	0	1755.045	35.30431034	4610.4
100	-24.879	386.63	0	1739.835	235.9215517	4769.5
110	-61.281	393.76	0	1771.92	581.112931	5921.9
120	-108.5	408.66	0	1838.97	1028.87931	6542.8
130	-169.35	393.26	0	1769.67	1605.905172	6805.2
140	-206.63	276.93	0	1246.185	1959.422414	6751.5
150	-201.99	200.64	0	902.88	1915.422414	6190.1
160	-196.51	124.71	0	561.195	1863.456897	3758.8
170	-181.53	56.27	0	253.215	1721.405172	1905.6
180	-208.22	0	0	0	1974.5	0
190	-181.53	-56.27	0	-253.215	1721.405172	-1905.6
200	-196.51	-124.71	0	-561.195	1863.456897	-3758.8
210	-201.99	-200.64	0	-902.88	1915.422414	-6190.1
220	-206.63	-276.93	0	-1246.185	1959.422414	-6751.5
230	-169.35	-393.26	0	-1769.67	1605.905172	-6805.2
240	-108.5	-408.66	0	-1838.97	1028.87931	-6542.8
250	-61.281	-393.76	0	-1771.92	581.112931	-5921.9
260	-24.879	-386.63	0	-1739.835	235.9215517	-4769.5
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280	0.30412	-376.5	0	-1694.25	-2.883896552	-3511.9
290	16.477	-372.96	0	-1678.32	-156.2474138	-2376.3
300	41.364	-396.1	0	-1782.45	-392.2448276	-1168.3
310	96.8	-380.5	0	-1712.25	-917.9310345	23.578
320	134.36	-319.42	0	-1437.39	-1274.103448	-212.51
330	149.03	-238.76	0	-1074.42	-1413.215517	-451.37
340	224.13	-136.22	0	-612.99	-2125.37069	-661.56
350	265.19	-61.332	0	-275.994	-2514.732759	-551.1
360	248.37	0	0	0	-2355.232759	0

Appendix C - Observer data

Mass matrix (Rigid body + Added mass):

$$M = \begin{bmatrix} 7e6 & 0 & 0 \\ 0 & 11e6 & 0 \\ 0 & 0 & 3e9 \end{bmatrix} \tag{3}$$

Damping matrix:

$$D = \begin{bmatrix} 1.7e5 & 0 & 0 \\ 0 & 1.4e5 & 0 \\ 0 & 0 & 6.4e7 \end{bmatrix} \tag{4}$$