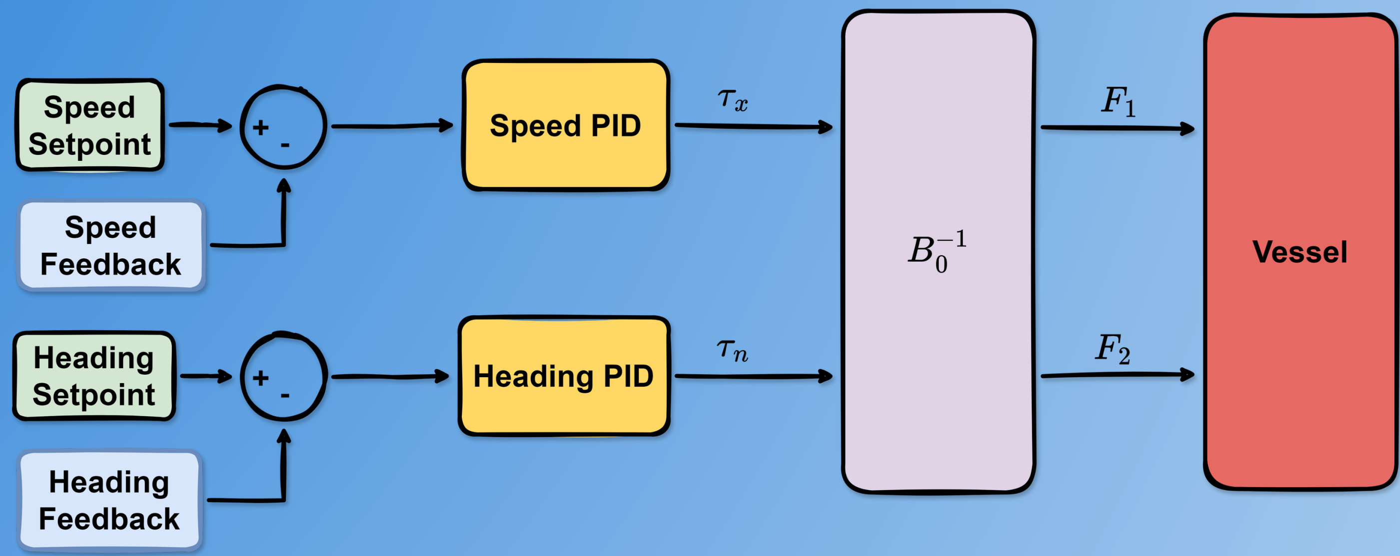
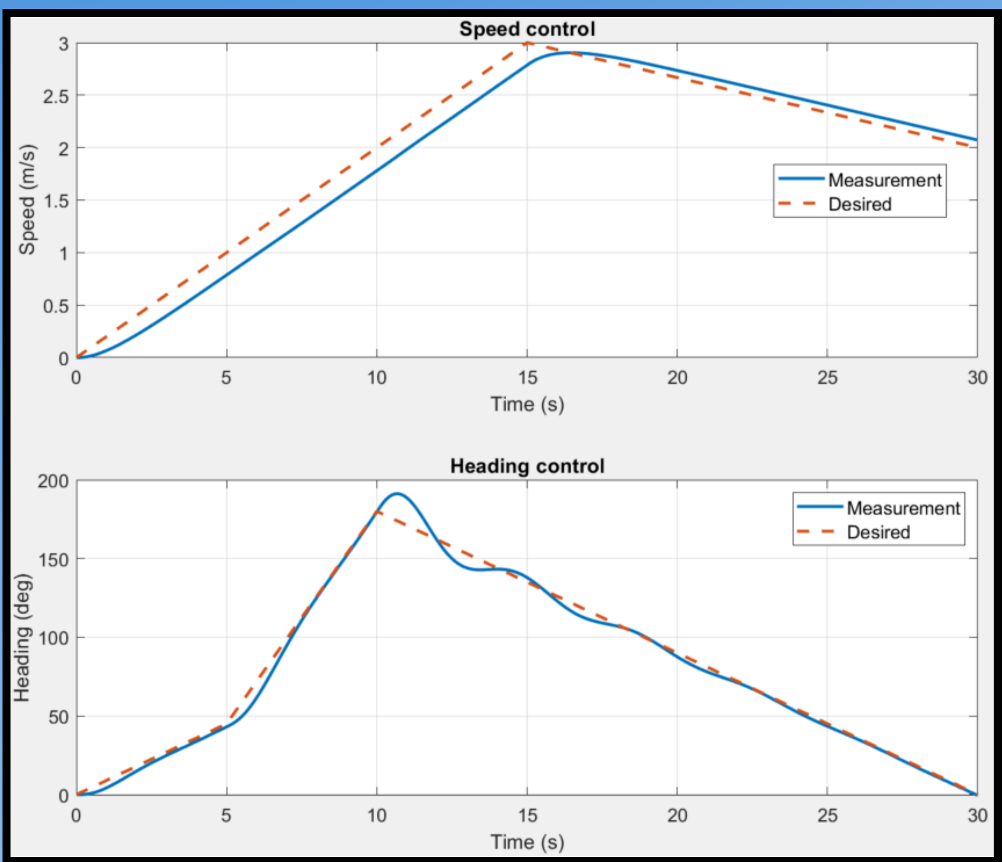
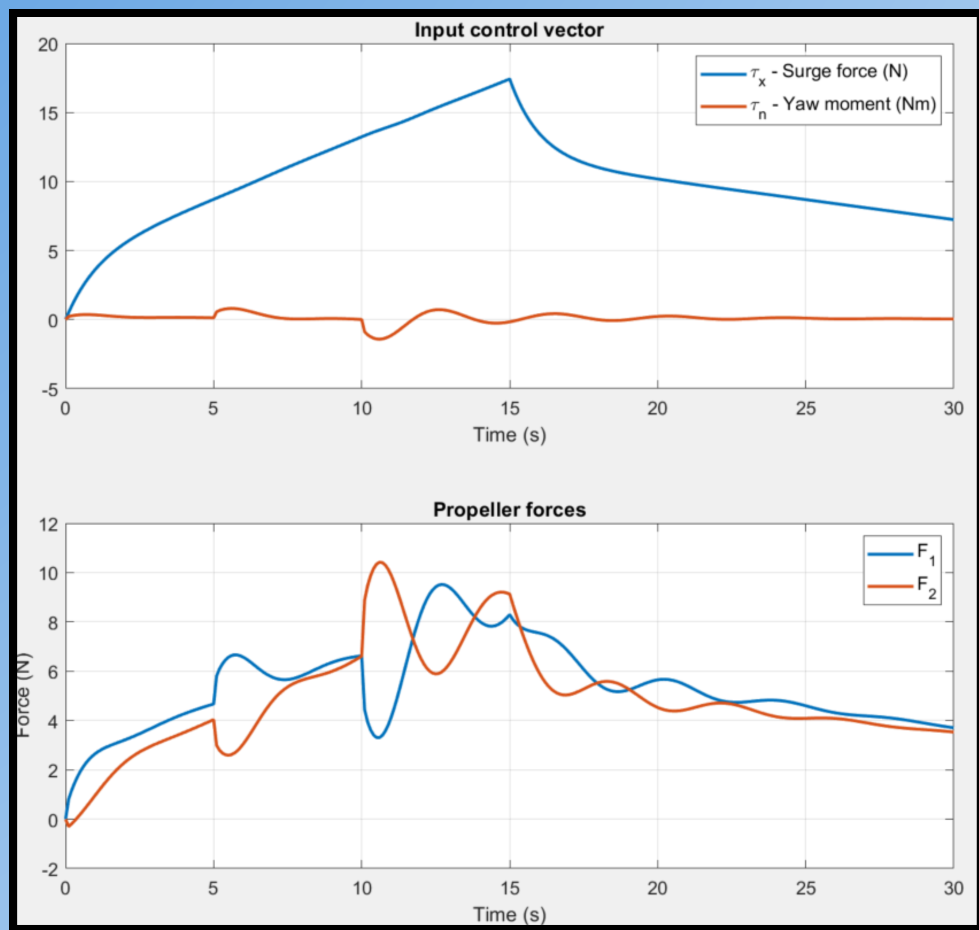
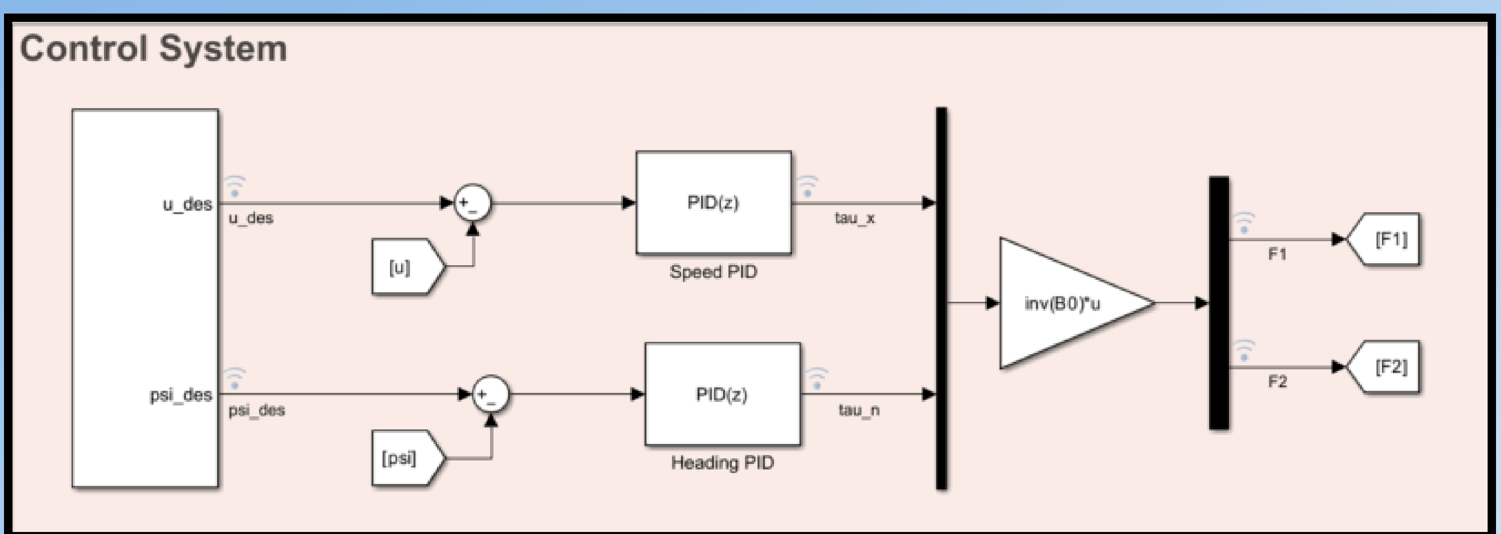
Autonomous Marine Surface Vessel Control







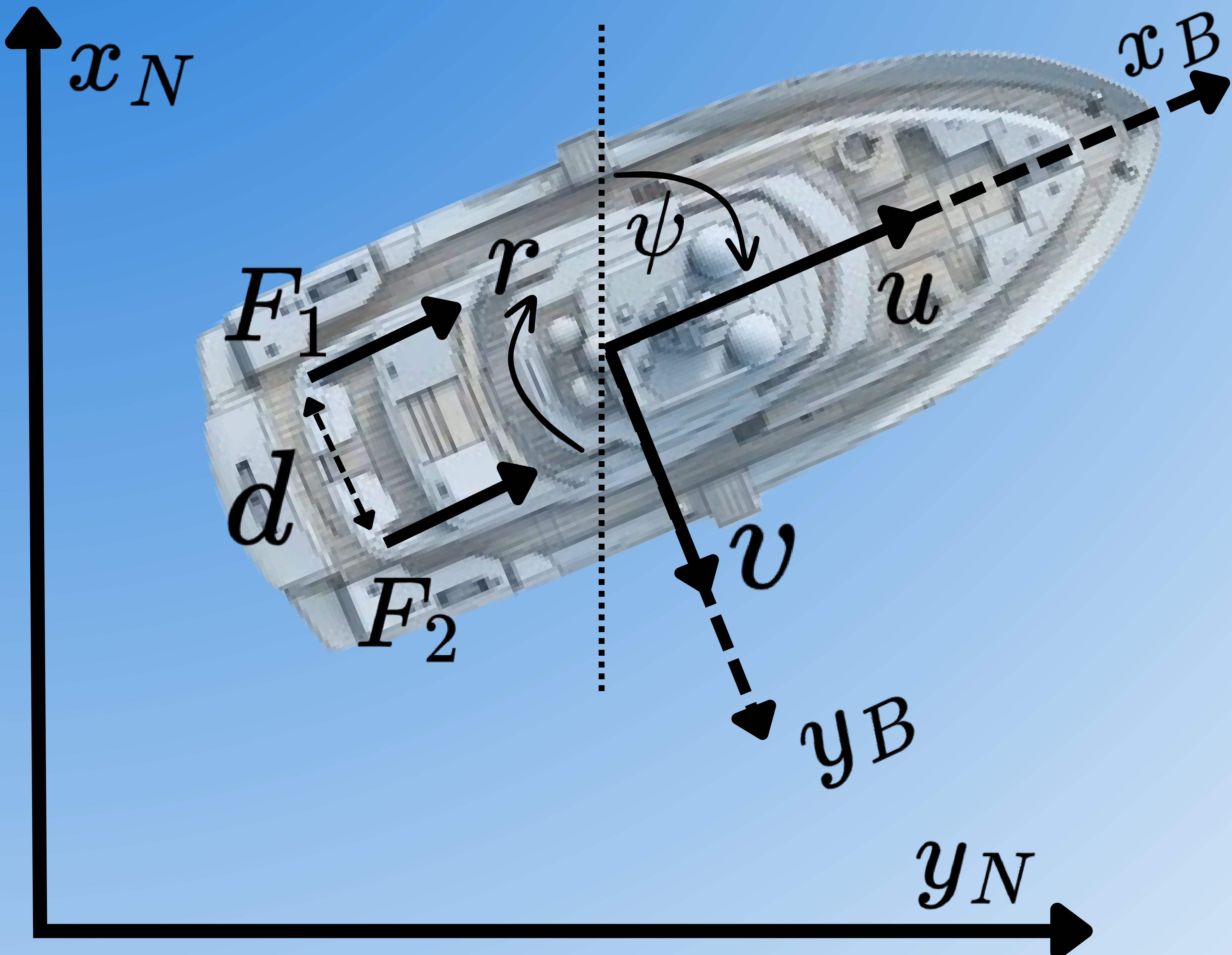


Model

https://github.com/simorxb/autonomous-marine-surface-vessel-control

SIMONE BERTONI
CONTROL LAB

Model – Diagram



Model – Equations – 1

The motion of a ship in the horizontal plane can be described using an inertial frame (x_N, y_N) associated with the sea map and the body-fixed reference frame (x_B, y_B) associated with the ship.

We can use two vectors: $\boldsymbol{\eta} = [x, y, \psi]^T$ and $\boldsymbol{\nu} = [u, v, r]^T$, where (x, y) are the coordinates of the ship's position, ψ is the ship's heading, (u, v) are the linear velocity components x_B and y_B directions, and r is the yaw rate.

The velocity vector determined in the inertial frame (X_N, Y_N) is related to the one in the body-fixed reference frame (X_B, Y_B) by the following kinematic relationship:

$$\dot{\eta} = R(\psi)\boldsymbol{\nu}$$

where $R(\psi)$ is the rotation matrix by angle ψ:

$$R(\psi) = \begin{bmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

and finally the mathematical model of the dynamics:

$$M\dot{\boldsymbol{\nu}} + C(\boldsymbol{\nu})\boldsymbol{\nu} + D(\boldsymbol{\nu})\boldsymbol{\nu} = \boldsymbol{\tau}$$

where M is the inertia matrix, C is the matrix of Coriolis and centripetal terms, D is the damping matrix, and $\boldsymbol{\tau} = [\tau_x, \tau_y, \tau_n]^T$ is the input control vector.

Model – Equations – 2

The inertia matrix M, which includes the hydrodynamic added inertia, can be written as:

$$M = \begin{bmatrix} m_{11} & 0 & 0 \\ 0 & m_{22} & m_{23} \\ 0 & m_{32} & m_{33} \end{bmatrix} = \begin{bmatrix} m - X_{\dot{u}} & 0 & 0 \\ 0 & m - Y_{\dot{v}} & m x_G - Y_{\dot{r}} \\ 0 & m x_G - N_{\dot{v}} & I_z - N_{\dot{r}} \end{bmatrix}$$

where m is the vessel mass, I_z is the moment of inertia about the fixed z-axis of the vessel, and $X_{\dot{u}}, Y_{\dot{v}}, Y_{\dot{r}}, N_{\dot{v}}$, and $N_{\dot{r}}$ are hydrodynamic derivatives.

The matrix of Coriolis and centripetal terms has the form:

$$C = \begin{bmatrix} 0 & 0 & -m_{22}v - m_{23}r \\ 0 & m_{11}u & 0 \\ m_{22}v + m_{23}r & -m_{11}u & 0 \end{bmatrix}$$

For a straight-line stable vessel, D is a positive damping matrix due to linear wave drift and laminar skin friction:

$$D = \begin{bmatrix} -X_u & 0 & 0 \\ 0 & -Y_v & -Y_r \\ 0 & -N_v & -N_r \end{bmatrix}$$

Note that part of this modelling approach has been taken from the article "Control of Dynamic Positioning System with Disturbance
Observer for Autonomous Marine Surface Vessels" by Mirosław Tomera and Kamil Podgórski.

Model – Equations – 3

The parameters for the model are from CyberShip I which is a model of a shipdeveloped in the Department
of Engineering Cybernetics, Norwegian University of Science and Technology (NTNU):

$$M = \begin{bmatrix} 26.4272 & 0 & 0 \\ 0 & 51.3671 & -0.7372 \\ 0 & -0.7372 & 1.2645 \end{bmatrix}$$

$$D = \begin{bmatrix} 4.3411 & 0 & 0 \\ 0 & 6.2983 & 0 \\ 0 & 0 & 1.2577 \end{bmatrix}$$

The model used here has a simplified thruster system respect to CyberShip I, shown in the diagram above. Based on the diagram, we have $\boldsymbol{\tau} = B[F_1, F2]^T$, where:

$$B = \begin{bmatrix} 1 & 1 \\ 0 & 0 \\ \frac{d}{2} & -\frac{d}{2} \end{bmatrix}$$

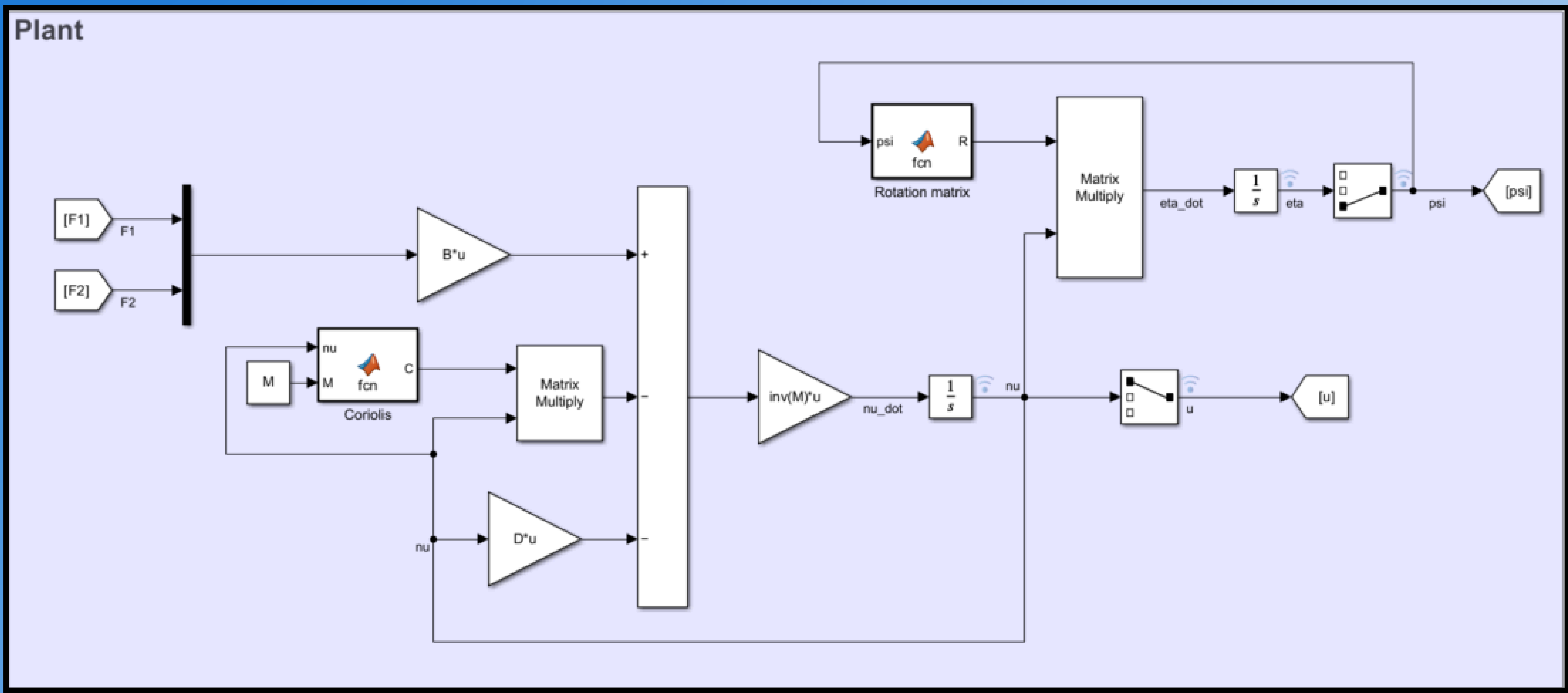
with $d = 0.4$m. To implement the dynamic model in Simulink we need to use:

$$\dot{\boldsymbol{\nu}} = M^{-1}(\boldsymbol{\tau} - C(\boldsymbol{\nu})\boldsymbol{\nu} - D(\boldsymbol{\nu})\boldsymbol{\nu})$$

and

$$\dot{\eta} = R(\psi)\nu$$

Vessel – Simulink Model



SurfaceVesselModel ▸ Coriolis

```matlab
function C = fcn(nu, M)

% Get u, v, r from nu
u = nu(1);
v = nu(2);
r = nu(3);

% Calculate C
C = [0, 0, -M(2,2)*v - M(2,3)*r;
     0, M(1,1)*u, 0;
     M(2,2)*v + M(2,3)*r, -M(1,1)*u, 0];
```

SurfaceVesselModel ▸ Rotation matrix

```matlab
function R = fcn(psi)

% Calculate R
R = [cos(psi), -sin(psi), 0; sin(psi), cos(psi), 0; 0, 0, 1];
```

Control Approach

We have two control levers and we're interested in controlling the longitudinal speed (u) and the heading (ψ).

We recall:

$$\tau_x = (F_1 + F_2)$$
$$\tau_n = (F_1 - F_2)\frac{d}{2}$$

and we know that τ_x and τ_n have only an impact respectively on the longitudinal speed (u) and the heading (ψ).

Now we can design two decoupled controllers and once we have computed τ_x and τ_n we can find F_1 and F_2 from:

$$\begin{bmatrix} F_1 \\ F2 \end{bmatrix} = B_0^{-1} \begin{bmatrix} \tau_x \\ \tau_n \end{bmatrix}$$

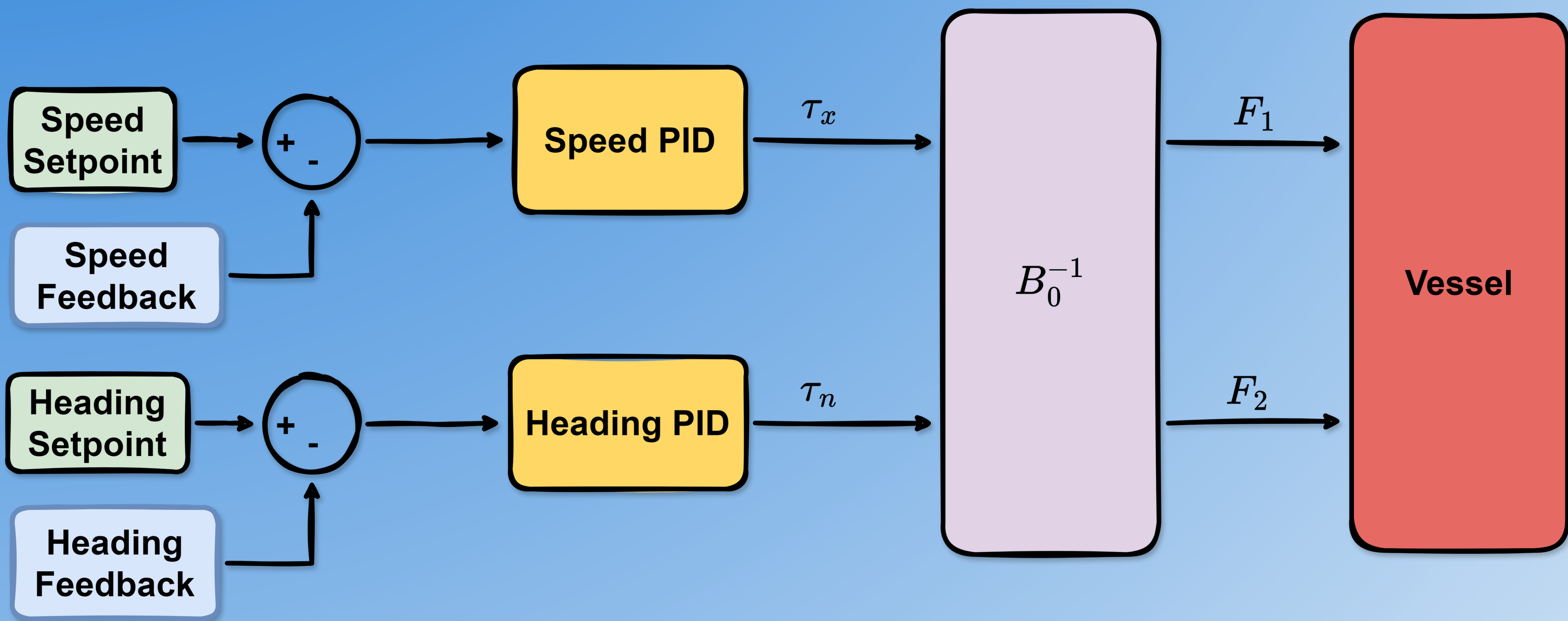
where

$$B_0 = \begin{bmatrix} 1 & 1 \\ \frac{d}{2} & -\frac{d}{2} \end{bmatrix}$$

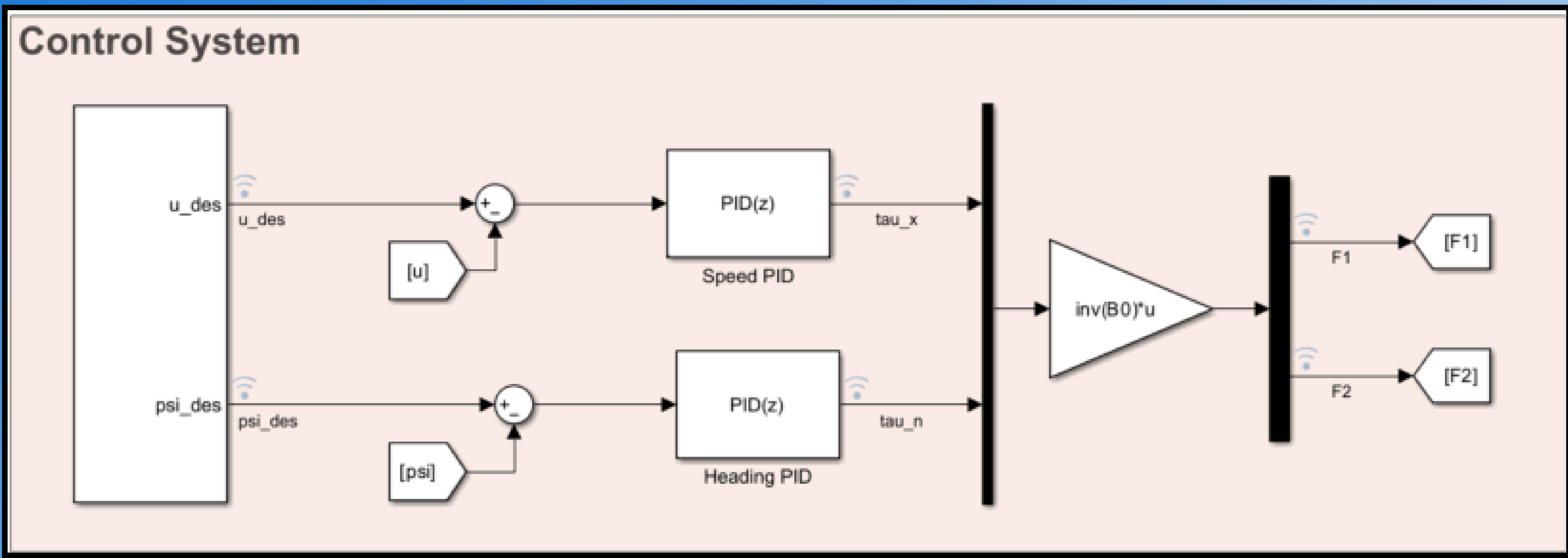
This is a way to decouple the control approach and turn a MIMO problem into several SISO problems.

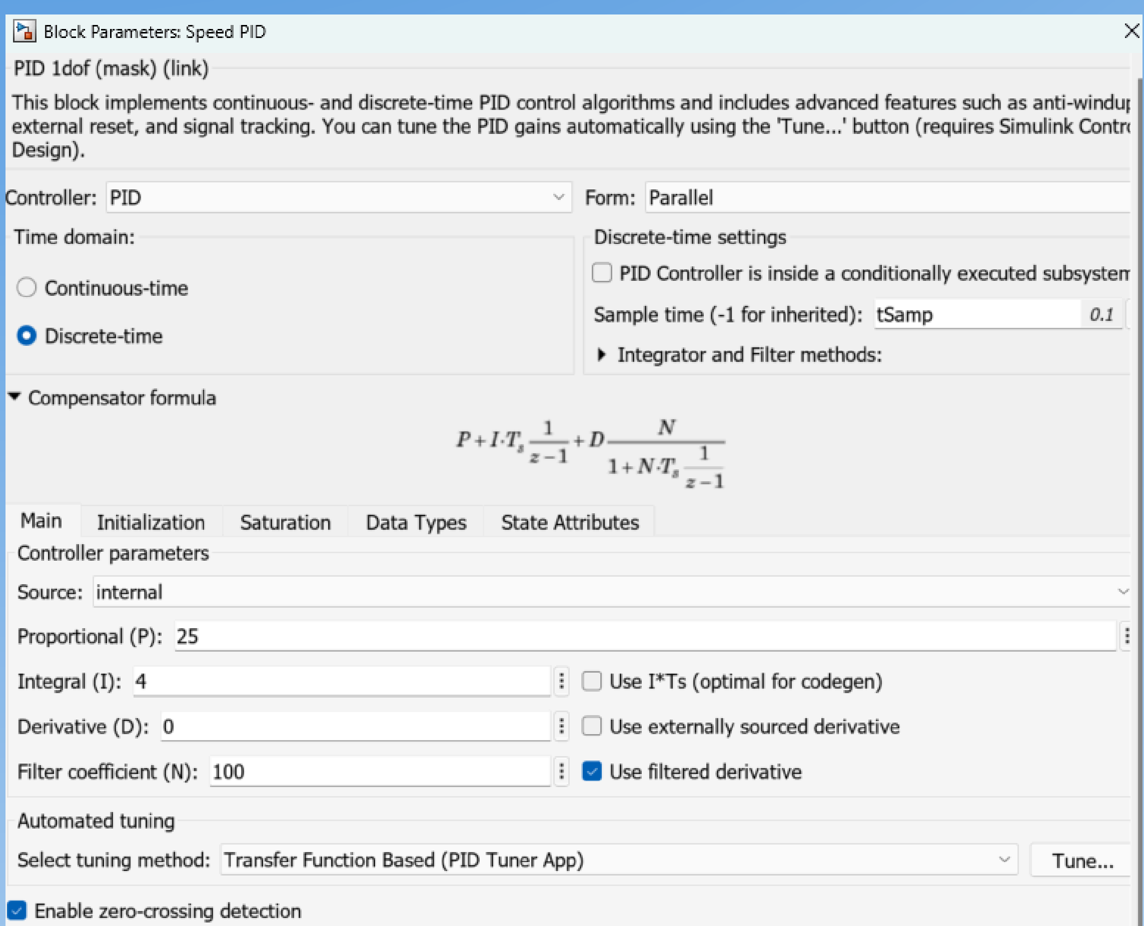
But there is no free lunch. The two loops are still interacting and they "disturb" each other, it may be difficult to stabilize them.

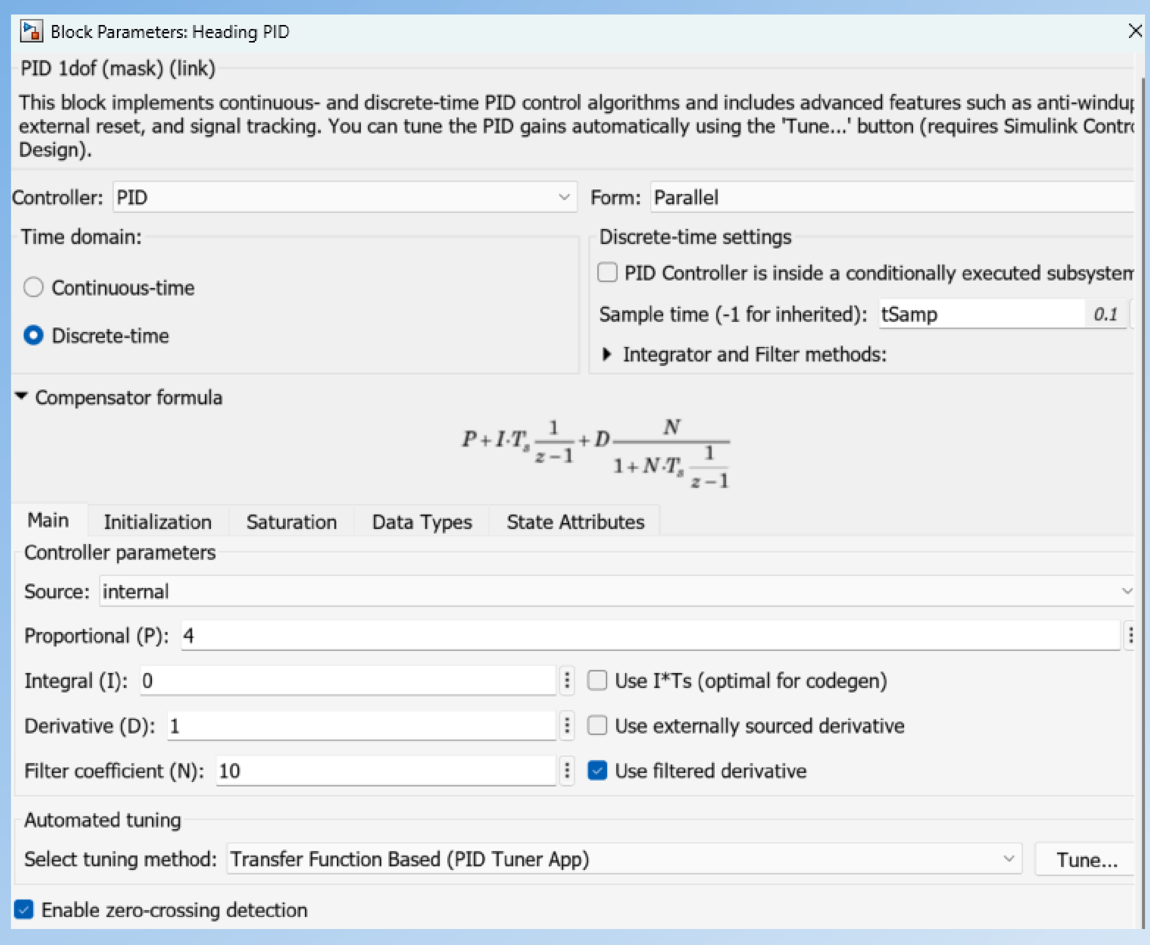
Control Architecture



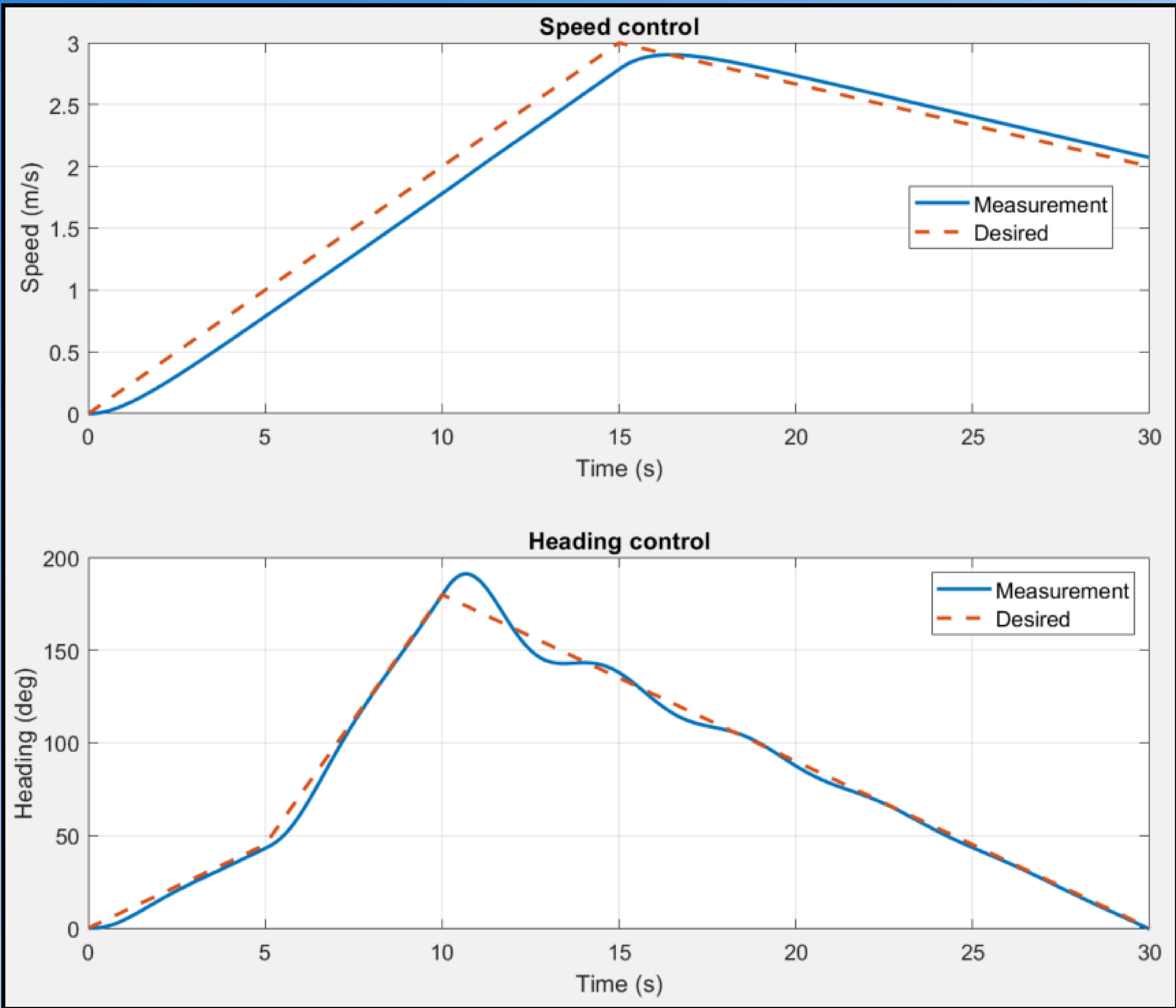
Control – Simulink Model



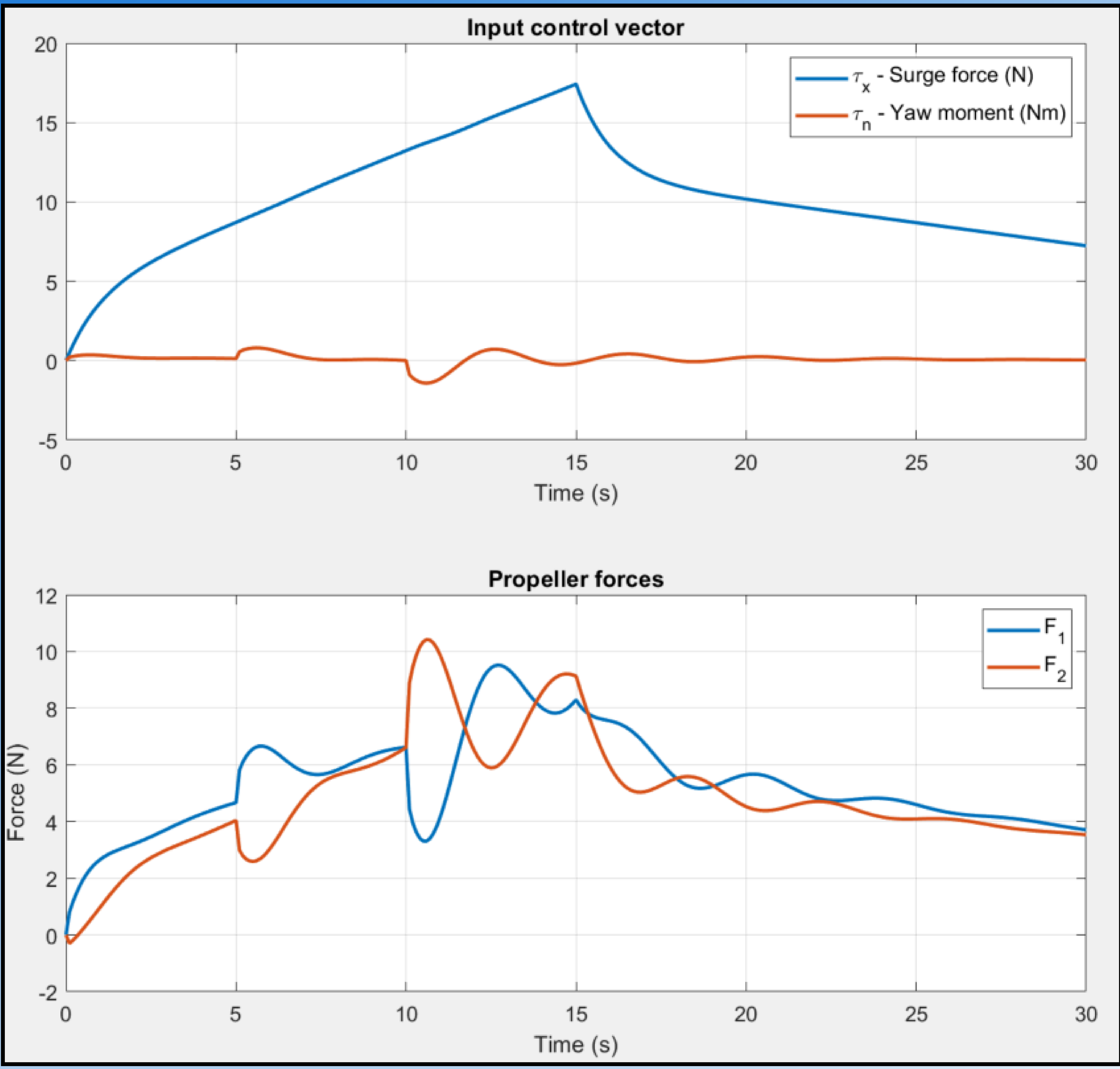




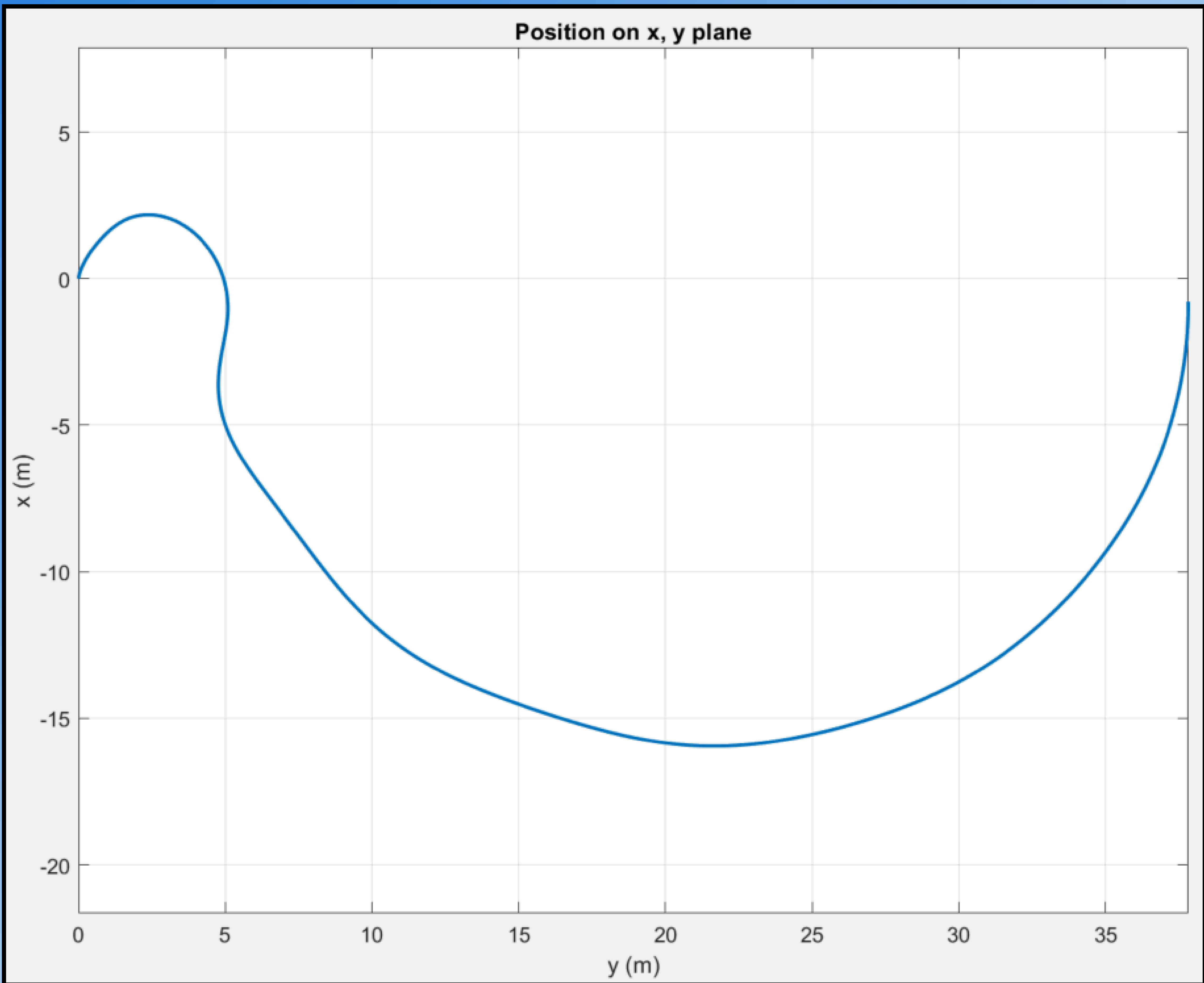
Simulation – Speed and Heading Control



Simulation – Input Control Vector and Propellers



Simulation – Position on x, y Plane



PID Controller Course

https://simonebertonilab.com

Understand the control theory

★★★★★ *April 28, 2024*

I think the most important thing is to understand the meaning behind the mathematical formula. I guess this is the mission of Simone in this course and from my point of view he fully achivied this target. I hope to see in the future other courses (e.g advanced controls) structered in the same way with the same passion and examples.

Thank you Simone. Show less

Emidio Verified

★★★★★

Very helpful and practical

Yoav Golan

I enjoyed this course very much. I learned a lot of practical knowledge in a short time. Simone is very clear and teaches well, thank you! In the future, I would be very interested if Simone added a course with more subjects, such as cascading controllers, rate limiting, and how the controllers look in actual code. Thanks again!

★★★★★

Intuitive and Practical

Ranya Badawi

Simone's explanation of PID control was very intuitive. This is a great starter course to gain a fundamental understanding and some practical knowledge of PID controllers. I highly recommend it. For future topics, I'd be interested in frequency response, transfer functions, Bode plots (including phase/gain margin), Nyquist plots, and stability.

★★★★★

Very good sharing of experience

Romy Domingo Bompart Ballache

I have background in control system for power electronics, I see every lesson very useful.

Great course

★★★★★ *April 15, 2024*

Right to the point, easy to follow and very practical. I missed the zero/pole placement and phase margin analysis. It would also be interesting if you could provide other plants examples. Anyway, a great course to help designing and tuning a PID controller.

Leonardo Starling Verified

A different way to learn PID !

★★★★★ *May 31, 2023*

The teacher explains PID in a clear way adding his experience there where formulas alone cannot do much. Furthermore, each topic covered is included in a practical example to better fix ideas.

Michele De Palma