MIR 2024 Annual Symposium and Robotics Championship

Instituto Superior Técnico

Robotics Championship

Centro Náutico da Marina Parque das Nações

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The MIR Robotics Championship Challenge

During the championship, you will have the opportunity to design a controller for a high-speed Autonomous Surface Vehicle. Your challenge is to drive the ASV the furthest along a straight line while minimizing the tracking error, within a specified time interval, and moderating its speed for lower energy consumption. The formal goal is to design a controller that maximizes the score function

$$\mathcal{J} = \underbrace{\alpha_d D_f}_{\text{distance bonus}} - \underbrace{\alpha_s \int_0^{t_f} \bar{s}(\tau)^2 d\tau}_{\text{speed penalty}} - \underbrace{\alpha_c \int_0^{t_f} c(\tau)^2 d\tau}_{\text{tracking error penalty}} , \quad (1)$$

where α_d, α_s and α_c are positive coefficients that define the weight of each of the components, which are to be defined by the jury before the challenge competition. The function $\bar{s}(\tau)$ is defined as follows,

$$\bar{s}(t) = \begin{cases} s(t) - s_{max} & s(t) > s_{max} \\ 0 & s(t) \leq s_{max} \end{cases} , \quad (2)$$

where $s(t)$ corresponds to the speed of the vehicle at time t and s_{max} is a constant which defines the maximum allowed speed. The function $c(t)$ denotes the cross-track distance at time t between the vehicle and the straight-line path to be followed. The initial position and orientation (at $t = 0$) will define the straight-line path. The function is illustrated in Figure 1 to provide greater intuition.

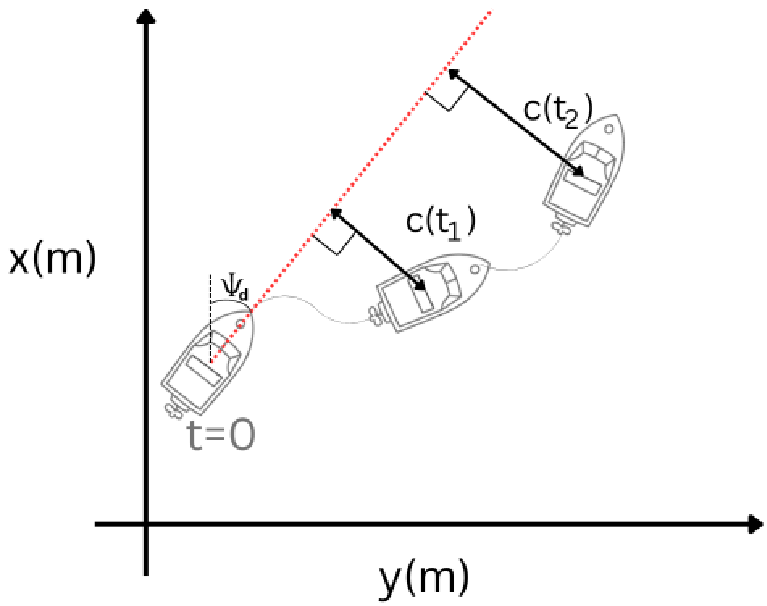

Figure 1: Illustration of the cross-track distance.

Lastly, D_f corresponds to the along-track distance between the initial and final positions of the vehicle.

The controller will run for a limited time interval, after which the score function will be evaluated. You can consider a final time $t_f = 20$ s as a guideline. The exact value will be decided by the jury before the competition starts.

The Platform

The vehicle you will be working with is illustrated in Figure 2.

Figure 2: Autonomous surface vehicle used in the challenge.

The available actuators are a rudder and a propeller. Your controller will provide a value between 0 and 1 to the propeller, which will map to a positive propeller speed. Similarly, you will provide a value between -1 and 1 to the rudder, which will map to a rudder angle. A close-up of the actuators can be seen in Figure 3.

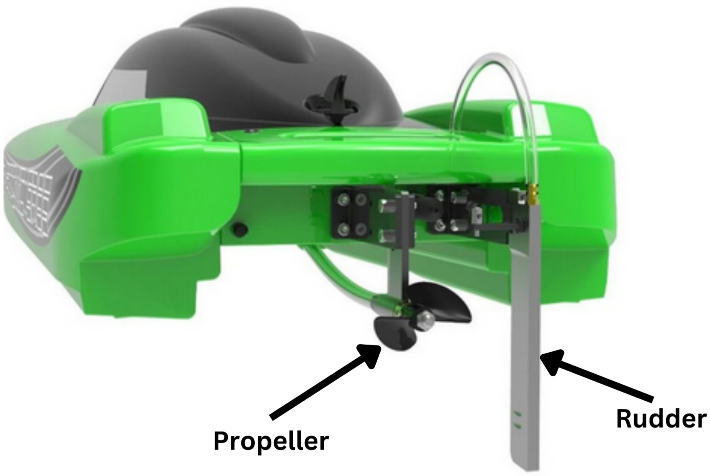

Figure 3: Actuators present on the vehicle.

The vehicle is completely instrumented and communicates with a ground station using both i) telemetry radios for bidirectional data transfer, as well as ii) an RC controller and receiver pair for fail-safe reasons (in case of emergency or loss of telemetry/control, the RC controller can be used to stop and disarm the vehicle).

The ASV is equipped with a flight controller (the name comes from the fact that these microcontrollers are usually employed in aerial applications, onboard quadrotors, fixed-wing airplanes, etc.). The flight controller is used as a base for the vehicle control system due to the ease of sensor and actuator integration, built-in safety features, and embedded state estimation algorithms. A Raspberry PI 4 computer is connected to the flight controller and will receive the state estimation, run your controller, and send the computed inputs to the actuators.

The communication setup and configuration of the vehicle and the ground station is presented in Figure 4.

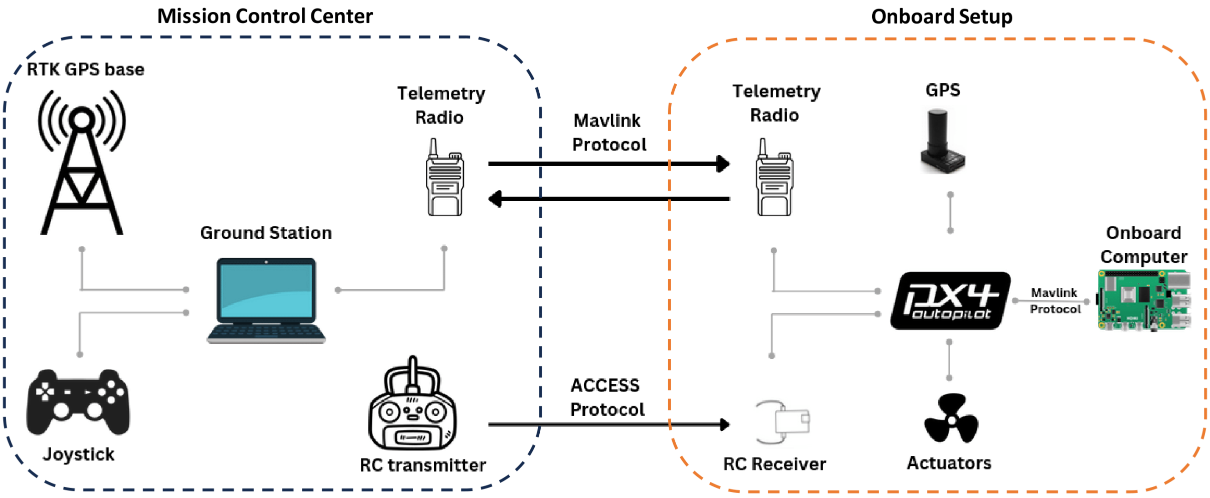

Figure 4: Experimental setup of the ASV and ground control station.

From the ground station, you will start the mission by entering *Offboard mode* (a mode where the flight controller allows the Raspberry PI to send commands to the actuator) and *Arming* the vehicle (this corresponds to allowing the rudder and thruster motor to move). After the mission starts, your controller will take over and will run for the challenge time interval, for now set at 20 seconds.

To read your score and make changes to controller gains or test different controllers, you will need to manually (using the RC controller) bring the ASV close to your team (and to the Wi-Fi router) so that you can connect by SSH (through Wi-Fi) to the onboard Raspberry PI.

A simulation of the environment and vehicle, together with the boilerplate and scaffolding code necessary to run the controller is provided at the MIR Challenge github website. In the simulation you will always have network access to the vehicle and will get the score information on your screen at the moment the time interval ends.

Model of the ASV

A 3 DOF dynamic model was identified for the ASV. Its states are the surge, sway and yaw rate. The surge (u) is defined as the projection of the velocity onto the x axis of the body frame (x_B). Similarly, the sway (v) is defined as the projection of the velocity vector onto the y axis of the body frame (y_B). The yaw rate (r) corresponds to the rate of change of the yaw angle (ψ). The inertial frame is fixed to a point on earth and follows the NED convention. The body frame is fixed to the centre of mass of the vehicle. These are illustrated in Figure 5.

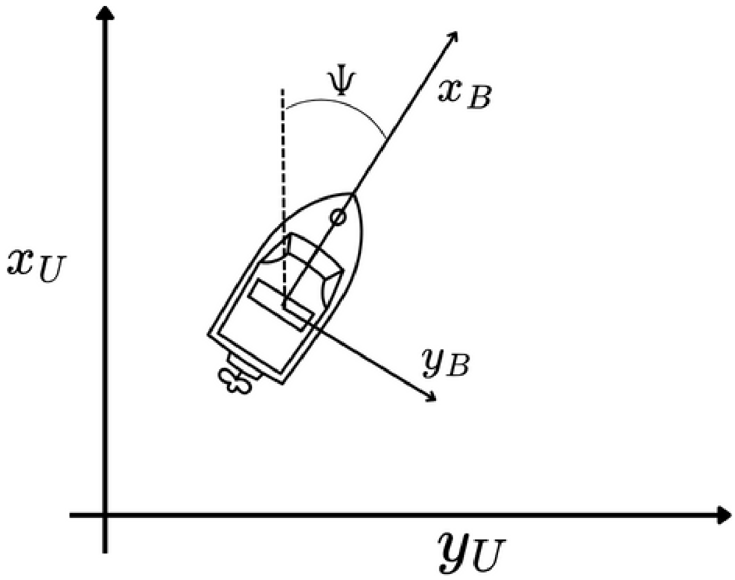

Figure 5: Coordinate frames.

Considering the states mentioned above, the following model of the vehicle was identified:

$$\begin{aligned}
\dot{u} &= a_1 vr + a_2 u + a_3 u^2 + E_T \cdot \mathsf{u}_T + a_7 u|r| + a_8 u^2 |r| \\
\dot{v} &= b_1 ru + b_2 v + b_3 v|v| + b_4 u \cdot \sin(\delta_{rud}) + b_5 u^2 \cdot \sin(\delta_{rud}) \\
\dot{r} &= c_1 vu + c_2 r + c_3 r|r| + c_4 u^2 \cdot \sin(\delta_{rud}) + c_5 \cdot \sin(\delta_{rud}) \cdot \mathsf{u}_T + c_6 ur + c_7 u^2
\end{aligned} \tag{3}$$

where u_T corresponds to the motor input (between 0 and 1), the rudder angle in degrees is given by:

$$\delta_{rud} = d_1 \mathsf{u}_R \tag{4}$$

where u_R is the rudder input (between -1 and 1). Finally, the thrust efficiency (E_T) corresponds to:

$$E_T = a_4 \left[1 - \exp\left(\frac{-a_5 u^2 - a_6}{|r| + 10^{-12}} \right) \right]. \tag{5}$$

Parameters of the model

The following tables have the parameters identified for the model presented in the previous section. These parameters are defined such that the surge (u) and sway (v) are expressed in m/s and the yaw rate (r) is expressed in rad/s.

a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
1.1965	-0.6218	-0.0216	16.4	0.0976	0.5056	-0.1154	-0.0025

Table 1: Identified parameters: surge dynamics.

b_1	b_2	b_3	b_4	b_5
-0.1885	-4.4450	-0.1937	-0.3681	-0.1363

Table 2: Identified parameters: sway dynamics.

c_1	c_2	c_3	c_4	c_5	c_6	c_7
2.1225	-0.8592	-0.0963	2.2910	-5.5000	-1.9001	0.0123

Table 3: Identified parameters: yaw rate dynamics.

d_1
60.000

Table 4: Identified parameters: mapping from rudder input to angle (in degrees).

Important notes and food for thought

- Although a model has been identified, it is not perfect and coefficients might change from ASV to ASV, so your controller should be robust to small variation in the system parameters.
- Think about assumptions you can formulate and system simplifications you can perform that lead to a simpler model from which to design simple controllers. Recall that models for controller design don't need to be of the same accuracy as the simulation models.
- Due to implementation issues, the ASV dynamic model implemented in the simulation provided is NOT exactly the same as presented in this document (it is slightly simplified).
- Again, **DO NOT** assume a perfect model, and try to simplify the one given taking into account the task you will be addressing.
- You should strive for simplicity in designing your controller. A code length of 20 lines of code should be more than enough.
- The dynamic model provided has 3 DOF, however the ASV only has 2 actuators.
- If possible, design the controller such that variations of the identified parameters are easily incorporated in the controller code.
- Structure your code so that changing control gains is a quick and easy operation. You will have to make these gain changes often, especially as you fine tune your controller in the day of the MIR Robotics Championship Challenge.

GOOD LUCK AND HAVE FUN!!!