Stepwise autonomous path-generation and path-following for an underwater drone

Erlend Torje Berg Lundby
etlundby@stud.ntnu

NTNU

Motivation

Dynamic path and planning is relevant when global position is not available, obstacles and targets are located beyond sensor range and task or mission targets changes during operation. Such a setup is highly relevant in the Vortex project, which aims for competing in the AUV competition Robosub .

In this project, the objective is to develop a path-generation, guidance and control design that ensures that a fully actuated underwater drone step-wise will be able to re-plan and update it's mission objectives, step-wise perform path-planning and path-generation, and control the robot accordingly.

Simulation Model

The 6 DOF non linear model can be described as

$$\dot{\boldsymbol{\eta}} = \mathbf{J}_{\Theta}\boldsymbol{\upsilon} \tag{1a}$$

$$\mathbf{M}\dot{\boldsymbol{\upsilon}} + \mathbf{C}(\boldsymbol{\upsilon})\boldsymbol{\upsilon} + \mathbf{D}(\boldsymbol{\upsilon})\boldsymbol{\upsilon} + \mathbf{g}(\boldsymbol{\eta}) = \boldsymbol{\tau} \tag{1b}$$

Since the path generation and following is limited to two dimensions (constant depth), the Control Design Model (CDM) is reduced to 3 dimensions. Furthermore, the drone is limited to low velocities, hence the CDM is reduced to a linear model:

$$\dot{\boldsymbol{\eta}} = \mathbf{R}_z(\psi)\boldsymbol{\upsilon} \tag{2a}$$

$$\mathbf{M}\dot{\boldsymbol{\upsilon}} + \mathbf{D}\boldsymbol{\upsilon} = \boldsymbol{\tau} \tag{2b}$$

Where $\boldsymbol{M} = \boldsymbol{M_{RB}} + \boldsymbol{M_A}$. In order to calculate $\boldsymbol{M_A}$, the drone was approximated to an oblate spheroid and the coefficients where calculated according to [2].

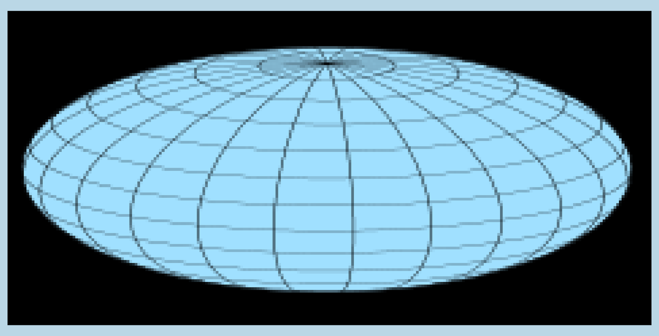


Figure 1: Oblate spheroid

The linear damping term $\boldsymbol{D}$ is calculated according to [3]

References

[1] Roger Skjetne: *The maneuvering problem*, NTNU, Trondheim (2005)

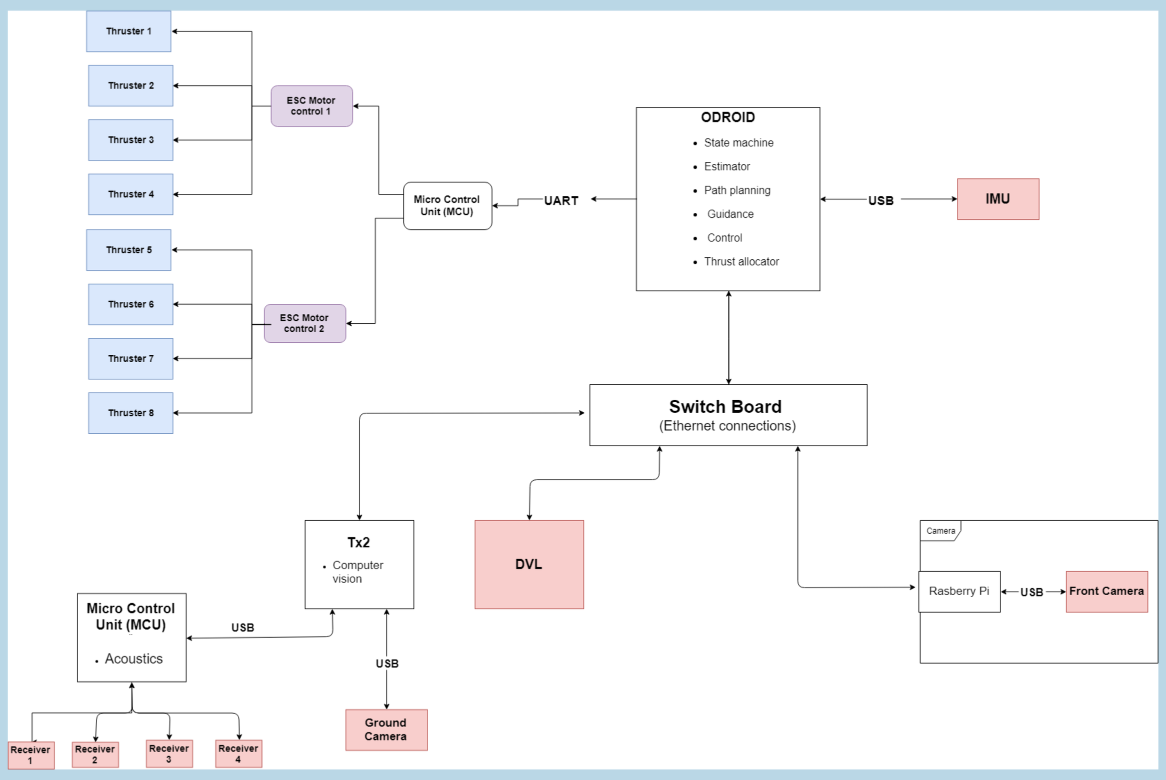
[2] Christopher Earls Brennen *An Internet Book on Fluid Dynamics.*

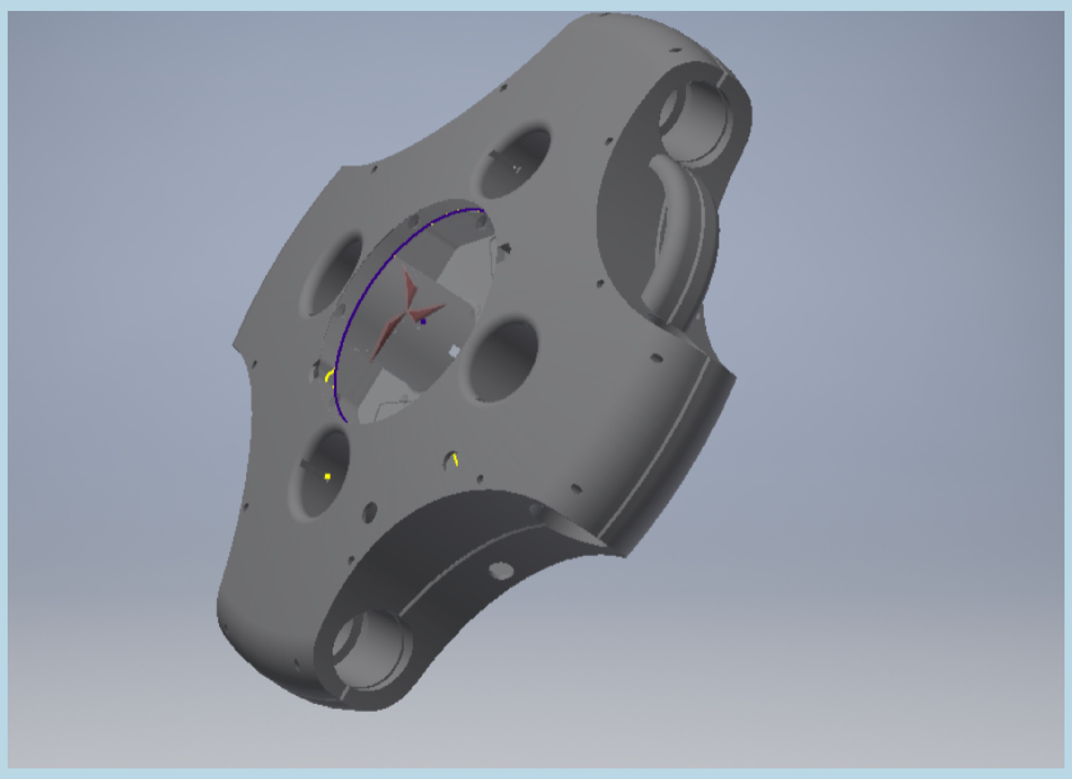
[3] Thor I. Fossen *Handbook of Marine Craft Hydrodynamics and Motion Control.*

Acknowledgements

I would like to thank professor Roger Skjetne for helping me to designing the task according to objectives and limitations of Vortex NTNU. Furthermore, the guidance on maneuvering theory from Prof. Skjetne has been of great help in the process of gaining insight on this field of study.

Robotic Platform





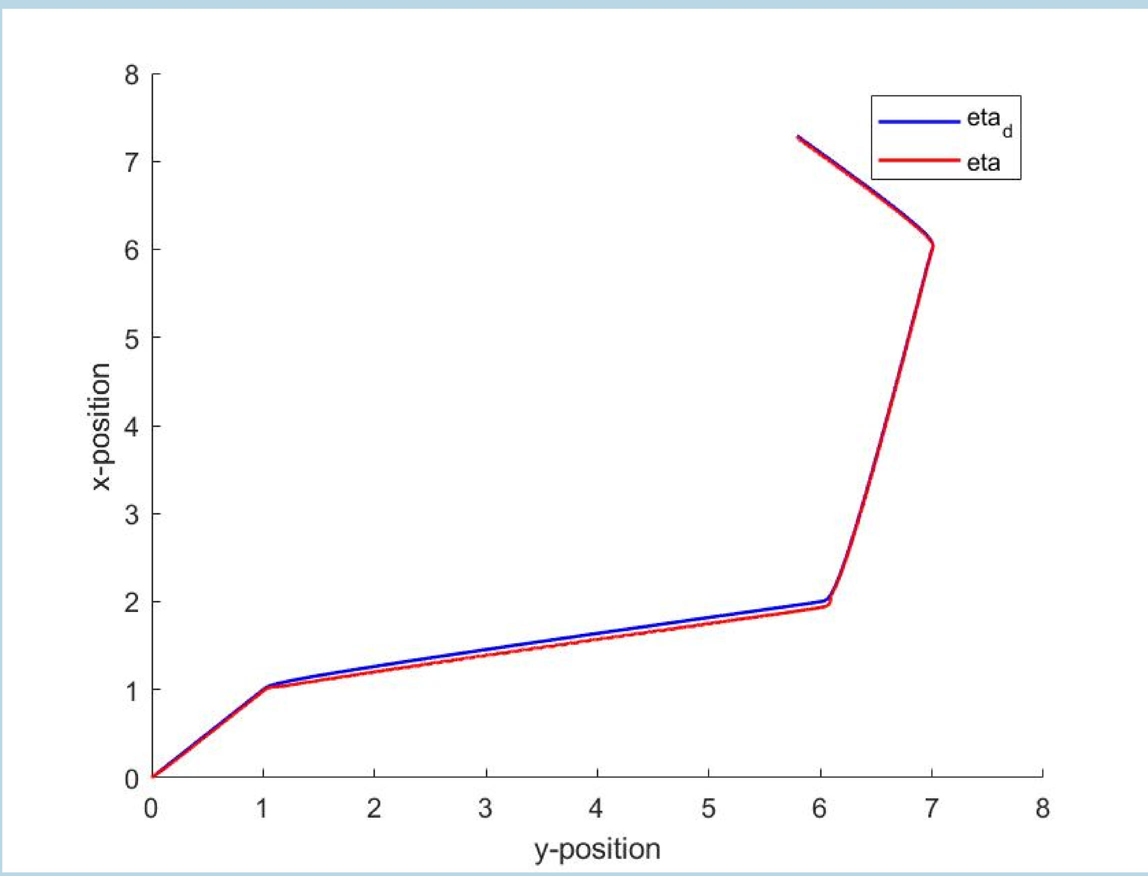
The robotic platform **Manta** is a complex design in terms of both hardware and software. It is developed by the student organization **Vortex NTNU**, which is an interdisciplinary coorperation between engineering students at NTNU.

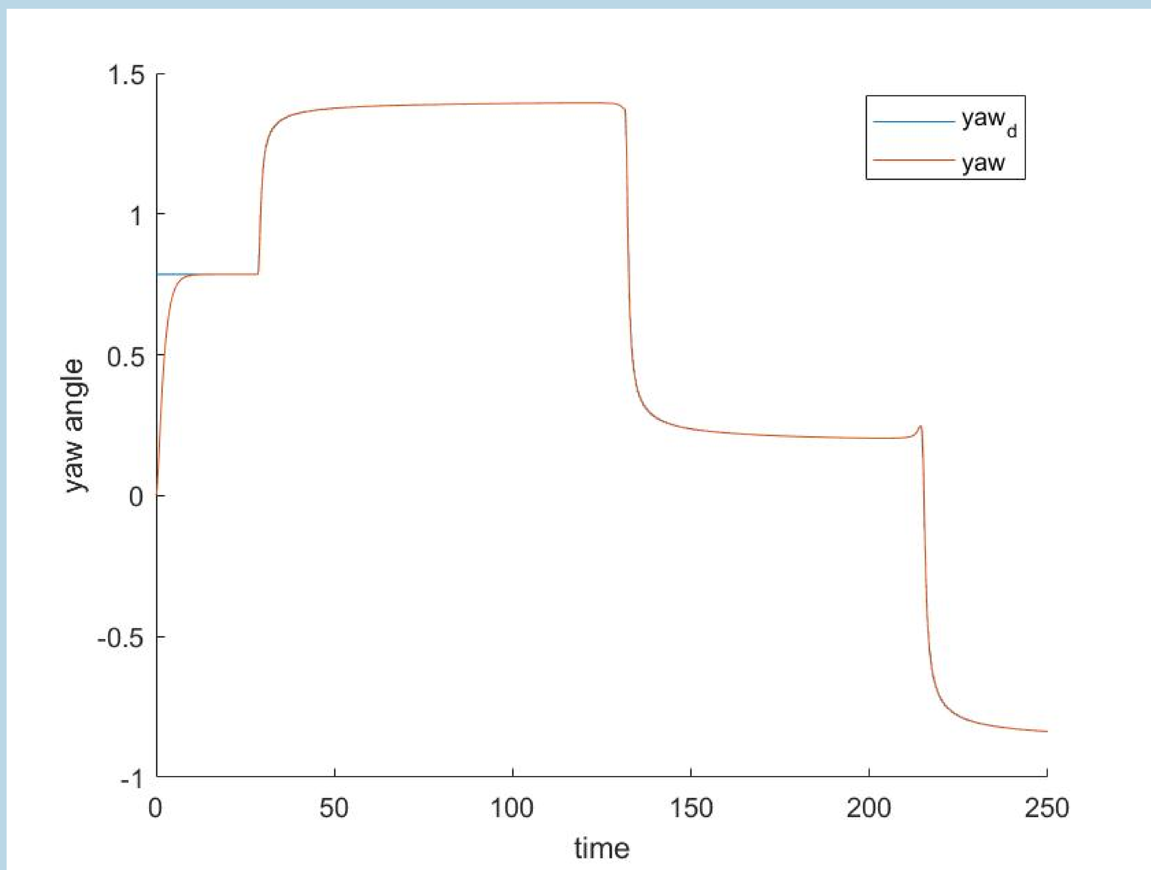
Actuators: Eight *thrusters* placed in a configuration that makes Manta *fully actuated.*

Sensors: Two *Cameras*, one directed down and one directed forward. One *IMU* that measures spesific force, angular rate and magnetic field components. One *DVL* that measures velocity in 3DOF relative to the bottom. Four *Microphones* that measures direction of a acoustic signal.

Method and simulations

The autonomous system is composed of three main modules. A *Path planner* that generates way-points to follow, a *Path generator* that generates continuous path and path derivatives up to third derivative. This module should ensure smooth path following that the dynamics of the vessel can follow. Third, there is the *Controller* in which calculate thrust so that the vessel follow desired path.





Path planning is carried out locally, and new way-points are generated when targets are detected by front camera or ground camera. Due to the lack of information as localization in a global map, we are not able to plan the entire mission before it is carried out. However, clues such as arrows on the bottom, gates in front and acoustic pingers that indicates direction are found along the track to help navigate through the task environment.

Path generation and following In order to generate paths that are possible to follow, parametrized paths $\eta_d(\theta)$ are generated. Furthermore, the path parameter speed $\dot{\theta}$ is forced to follow a speed assignment $\nu_s(\theta, t)$. This way of formulating the control problem is based on the *Manevering problem*, presented in [1].

- **Geometric task:** For any continuous function $\theta(t)$ force the output y to converge to the desired path $y_d(\theta)$,
$$\lim_{t\to\infty} |y(t) - y_d(\theta(t))| = 0 \tag{3}$$
- **Dynamic task:** Follow desired dynamics. In this case, follow speed assignment: textbfSpeed assignment: Force the path speed $\dot{\theta}$ to converge to a desired speed $\upsilon_s(\theta, t)$,
$$\lim_{t\to\infty} |\dot{\theta}(t) - \upsilon_s(\theta, t)| = 0 \tag{4}$$

The separation of the tasks implies that the two main tasks can be approached individually, and thus the tasks can be designed in a manner that the vessel dynamics and actuators can handle. A *guidance* module is used to dereference the geometric and dynamic tasks to a controller.

Controller used is a *Backstepping controller* which guarantees Lyapunov stability for the system.