# AEOLUS, the ETH Autonomous Model Sailboat

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## INTRODUCTION

Path planning and control are particularly challenging tasks for a sailboat. In contrast to land vehicles or motorboats, the movement of a sailboat is heavily restricted by the wind direction (Figure 1). This project focuses on the low-level control acting on the rudder and the sails. Specifically, a standard proportional controller and a non-linear controller have been implemented to track a reference heading. Further, special control algorithms that are activated during a tack or a jibe perform fast and smooth maneuvers. The path planner is based on the minimization of the weighted sum of different cost functions and allows for multi-objective optimization of the boat trajectory such as obstacle avoidance, time-to-target minimization and tactical behaviors.

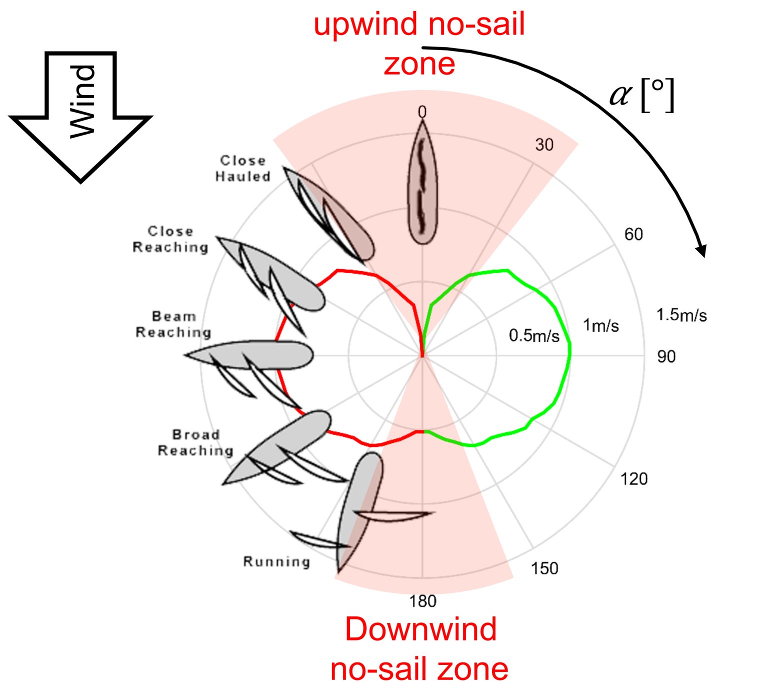


Fig 1: The movement of a sailboat is heavily restricted by the wind direction.

## HARDWARE - SOFTWARE SETUP

AEOLUS is an international one meter class model sailboat whose hardware has been re-designed to sail autonomously. The boat has been equipped with a weather station and an autopilot control unit which communicates with the pre-existing actuators. The architecture is represented in Figure 2. The AIRMAR WS-200WX weather station provides information about the apparent wind and GPS coordinates. The PIXHAWK autopilot board provides IMU readings performs all on board computations and communicates the control imputs to the rudder and electric winch for heading and sail control respectively.

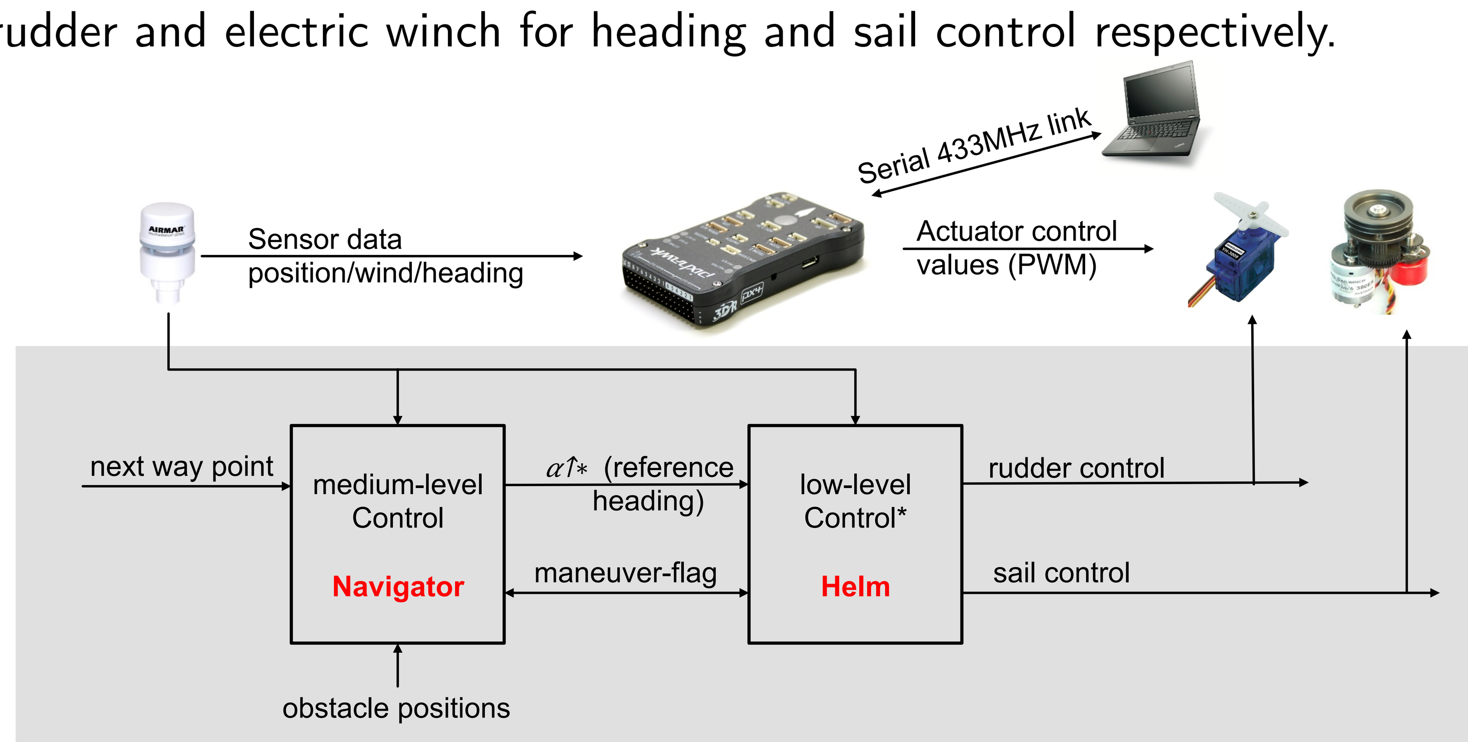


Fig 2: The integration of software and hardware on board AEOLUS.

The software structure emulates the typical task division between navigator/tactician and helmsman on real sailboats. The low level control follows a reference heading angle provided by the path planner which computes it using information about the target, current wind conditions and obstacle coordinates.

## LOW LEVEL CONTROL

The low level controller controls the rudder and sails independently. The rudder controller is in charge to follow a prescribed heading angle. When no maneuvers are required we deploy a nonlinear control law of the form $\delta = K(e)e$ [1], where $e$ is the heading error, $\delta$ is the steering input and $K(e) = 0.35/(1+0.35|e|)$. The control law changes during tack and jibe maneuvers, where we have two options. A more aggressive "dedicated controller" $K(e) = 0.74/(1+0.1|e|)$ or a LQR controller computed using a model identified from experiments. Figure 3 shows a comparison of the two options.

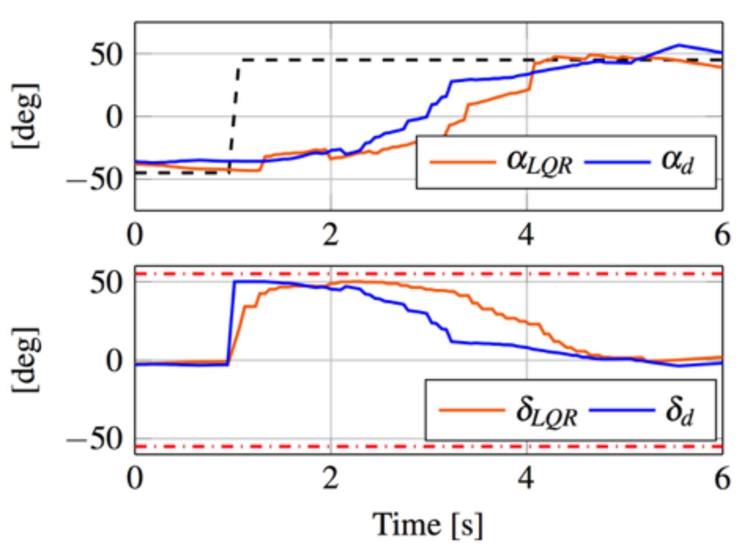


Fig 3: A comparison between the dedicated controller and the LQR controller for a tack maneuver obtained experimental data.

## PATH PLANNER

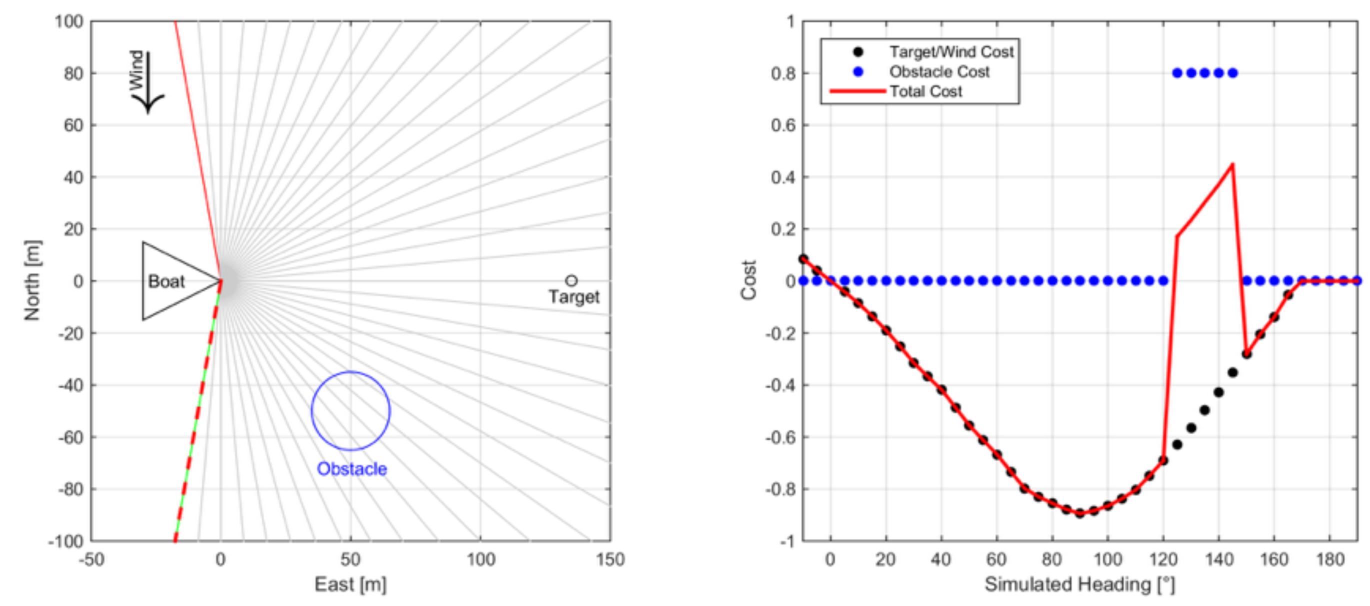


Fig 4: A simple example of the cost function method for path planning.

The minimum functional requirements and optimality criteria for a path planning algorithm applicable to a sailboat are:

- Sail fully autonomously to a target point (waypoint navigation); optimize speed of the boat and account for the "no-sail zone".
- Avoid static and predefined obstacles.
- Tactical considerations in order to remain competitive in a regatta.

Notice that in most model sailboats, including Aeolus, the real-time embedded computational capabilities are significantly limited.

In order to fulfill the above requirements while coping with the limited computational resources we deploy a cost function method [2]. A cost is associated to each potential heading angle. The cost function takes into account:

- The progress towards the target.
- The presence of obstacles.
- The sailing constraints (e.g. no sail zone)
- The time spent for maneuvering.
- Tactical considerations

The cost function is evaluated in real time on board based on the available measurements and the optimal heading angle is fed to the low level controller as a reference. Figure 5 shows experimental results for the path planner [3].

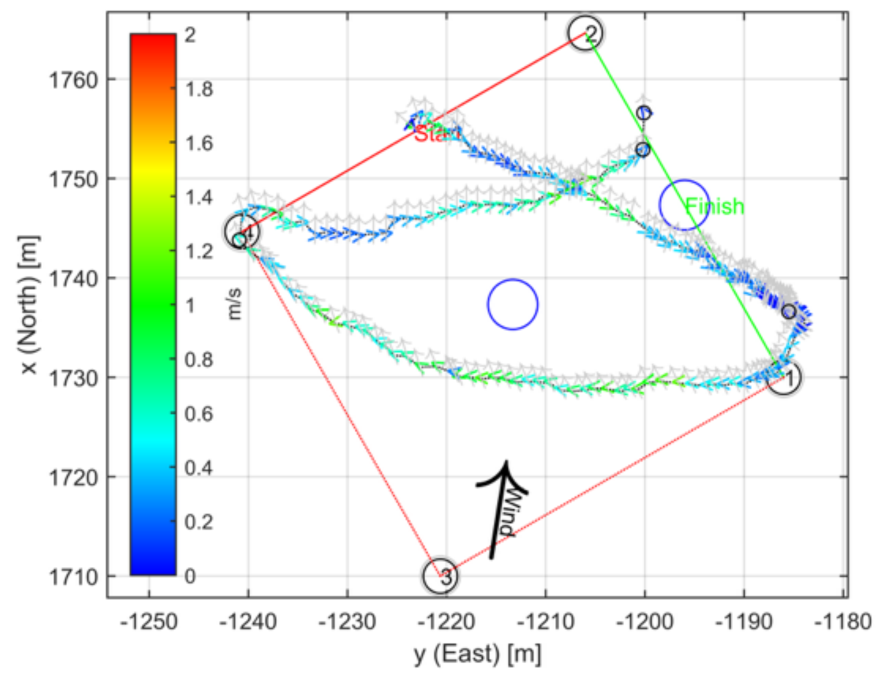


Fig 5: Field result from a lake test at Lake Zurich, Switzerland. Arrows indicate the wind direction and colors are the longitudinal velocity of the boat. The blue circles represent obstacles. The boat starts' between buoy 2 and 4 and sails upwind to buoy 1, then downwind to buoy 4 and finally beam reach to the finish line.

## ACKNOWLEDGEMENTS

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## REFERENCES

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[2] V.Guo,M.Romero,S.-H.Ieng,F.Plumet,R.Benosman,andB.Gas,"Reactivepathplanning for autonomous sailboat using an omni-directional camera for obstacle detection," in *Proc. of the IEEE International Conference on Mechatronics, Istanbul, Turkey*, April 13-15 2011.

[3] J. Wirz, M. Tranzatto, A. Liniger, M. Colombino, H. Hesse and S. Grammatico, "AEOLUS, the ETH auto nomous model sailboat."