Towards controlling Autonomous Underwater Vehicles with faults

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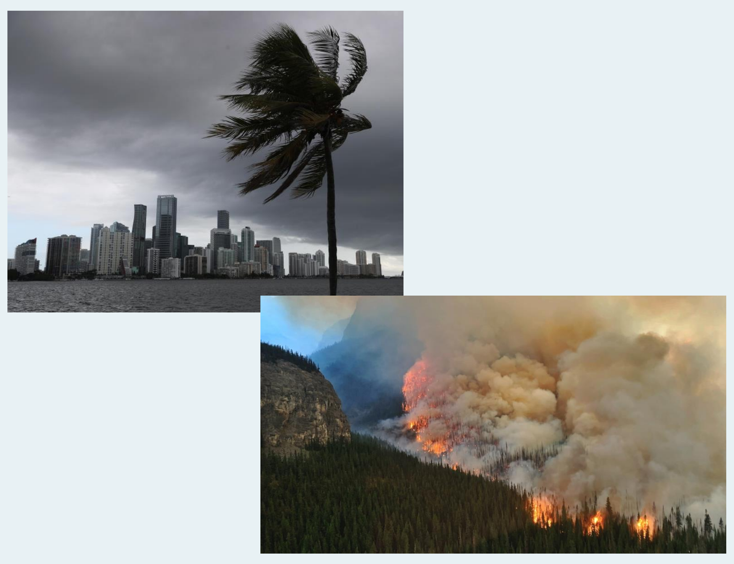
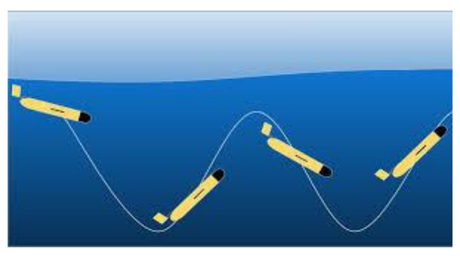
1. Introduction

Extreme weather events require extensive monitoring to be forecast and mitigated against.

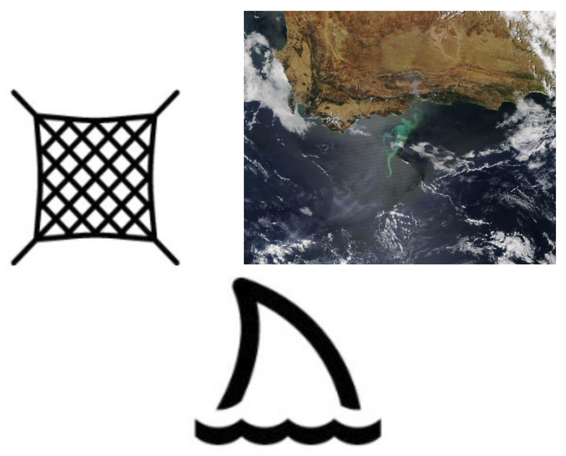


Thousands of **ocean observing devices** are currently deployed.

2. Problem definition and objectives



The **Autonomous Underwater Gliders** are an energy efficient technology to collect oceanographic data. They are deployed for **months-long missions** and are therefore exposed to challenging operating conditions that can lead to **faulty actuators**.

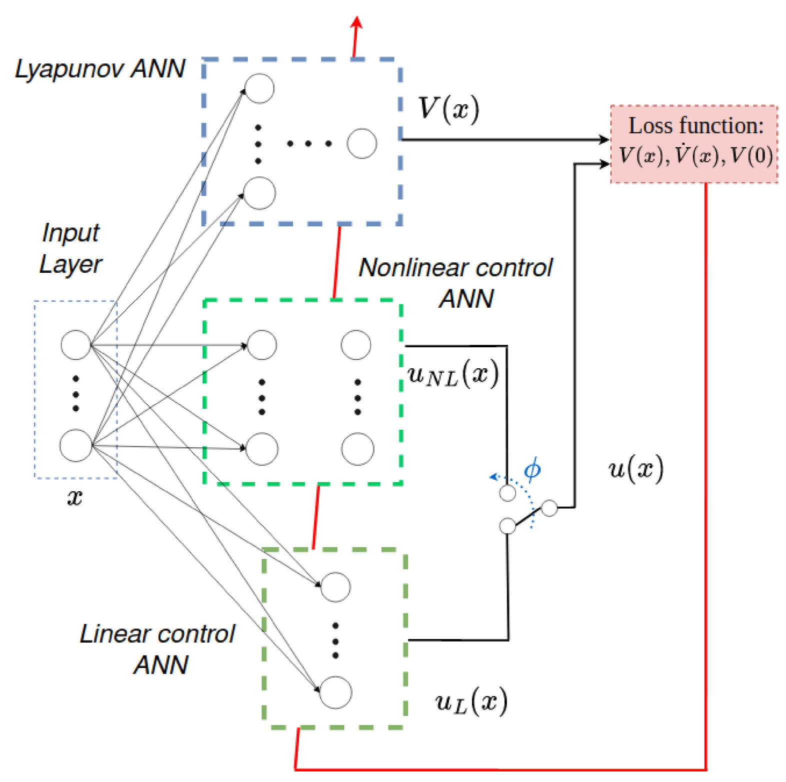


Objectives

1) **Automatically design control systems** based on Machine-Learning techniques;
2) Using **Lyapunov theory** to guarantee the **stability** of the control systems;
3) Design **Fault-Tolerant Control systems** that can recover the vehicles when faults occur.

3. Method – Neural Lyapunov Control

In 1892 Alexandr Lyapunov paved the way to the stability analysis of dynamic systems. He postulated that if one can find a function satisfying three basic properties, the system is guaranteed to be stable.
The issue is that, so far, **no systematic way** to obtain **Lyapunov functions** has been **discovered**.

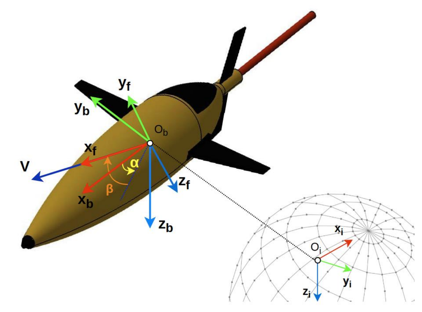


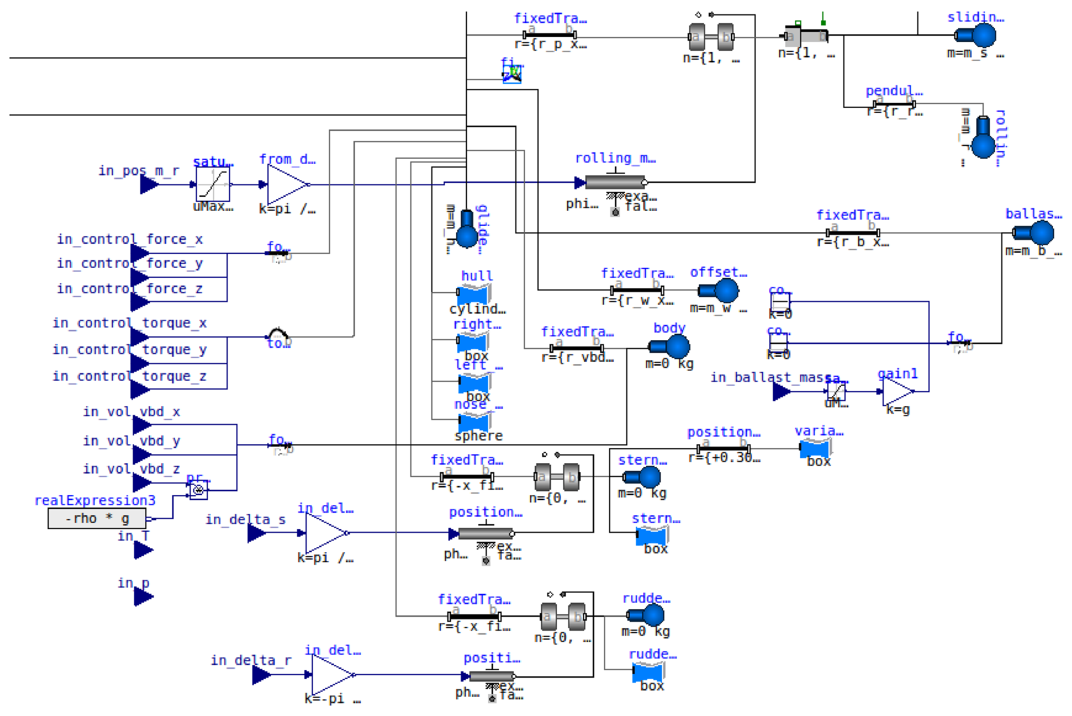
Neural Lyapunov Control architecture:

The system is based on **three Artificial Neural Networks** (ANN): one resembles a Lyapunov function, while the other two represent a linear and a nonlinear control laws. The control system is trained to obtain a function that satisfies the theoretical Lyapunov properties. The correctness of the obtained **result** is then **certified** by means of a symbolic solver.

4. Method - OpenMAUV Simulator

A **simulator** to be used to test the control architecture over a **variety** of **Autonomous Underwater Vehicles** and **Unmanned Surface Vehicles** was designed.





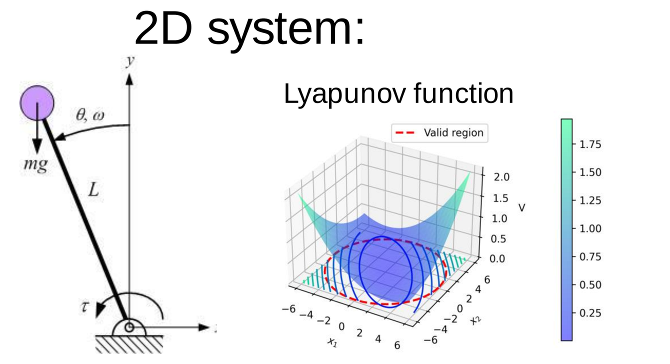
Features

- Multibody dynamics systems;
- **Object-oriented** architecture;
- Included hydrodynamic effects.

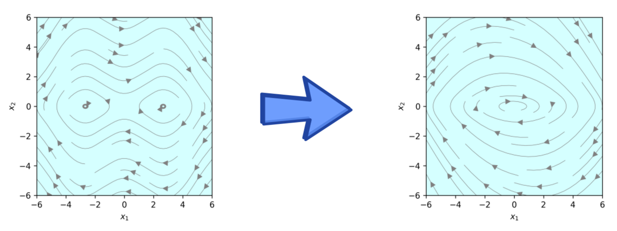
5. Results

5.1) Neural control

2D system:

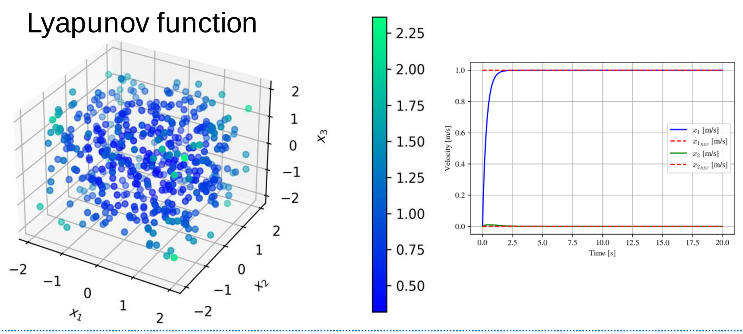


From unstable to stable dynamics



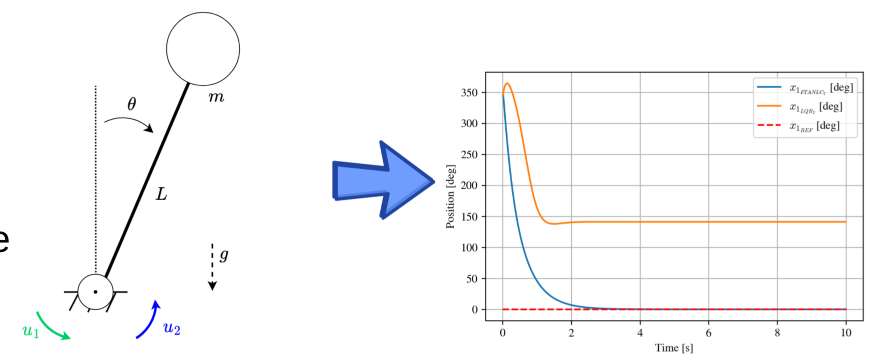
3D system:

Control of different speed setpoints



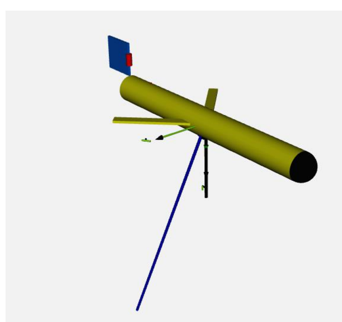
5.2) Neural control of faulty systems

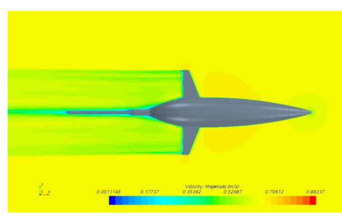
2D system with redundancy: a pendulum with two motors at the hinge.



When one actuator undergoes a fault, classical techniques (LQR) cannot stabilise the system anymore, while the Neural Control is fault-insensitive.

5.3) Simulator verification[1]





Quantity	Seawing reference [8]	OpenModelica	Relative error
Radius [m]	100.83	93.88	6.89%
Angle attack [°]	1.267	1.258	0.71%
Sides angle [°]	-1.283	-1.396	8.81%
V [m/s]	0.490	0.491	0.2 %
Yaw angular rate [rad/s]	0.0039	0.0033	15.39%
Pitch angle [°]	-13.703	-13.011	5.05%
Roll angle [°]	-35.641	-35.643	0.01%

6. Conclusion

- Lyapunov functions were synthesized for up to 3-dimensional systems;
- Stabilising control laws were obtained for simple systems with faults;
- Different types of underwater gliders were simulated with sufficient accuracy.

Future steps will entail:

- Simulator validation with real deployment-data;
- Application of the Neural Lyapunov Control method to faulty autonomous vehicles;
- Deployment of control on real underwater vehicles.

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[1] "Open-source Simulation of Underwater Gliders", D. Grande, L. Huang, C. Harris, P. Wu, G. Thomas, E. Anderlini

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