Sub-meeting 2019

Underwater umbilical management between two robots

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Context

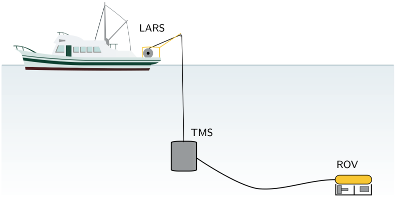
Cables such as tethers and umbilicals used for the execution of underwater missions

Advantages:

- Data transfer
- Power supply
- Mechanical support

Disadvantages:

- Impact on ROV motion/ loss of maneuverability
- Limited range if no winch
- Possible entanglement



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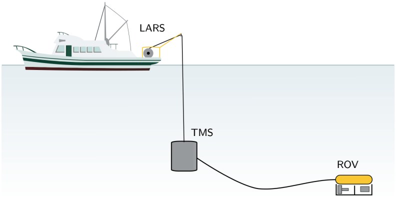
Objective

- Exploration of shallow water and confined environments by mini-ROVs

Challenges

- Strong perturbations
- Low power of mini-ROVs
- Risk of cable entanglement



Research focus on two systems

1st focus: chain of mini-ROVs

- passive cable between two consecutive robots
- how to control the position of the follower robot w.r.t. the leading one through ROV-embedded sensing of the cable
- PhD M. Laranjeira - 2016 - 2019

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2nd focus: tether management between ROV and USV

- Cable rolling up/unwinding thanks to smart winch on USV
- how to reduce the dynamical impact of the cable onto the ROV and to have the USV assist the ROV
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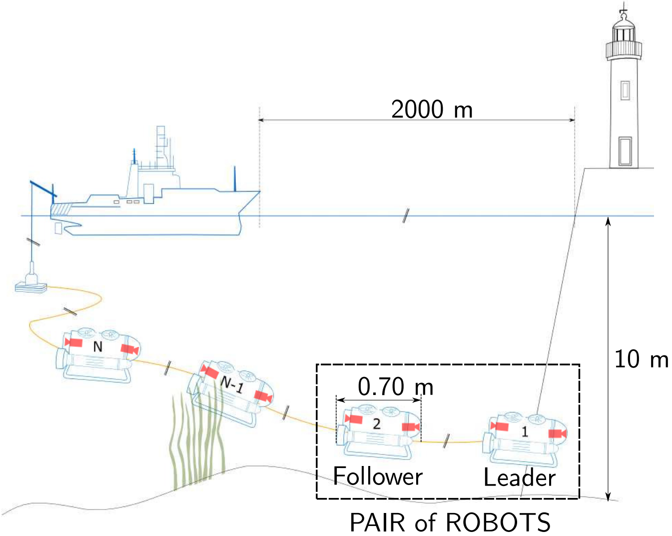
Low cost mini-ROVs

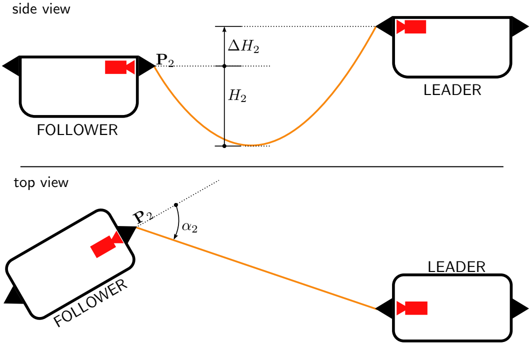
1st focus: Chain of mini-ROVs (PhD M. Laranjeira)

Control the shape of tye umbilical linking two robots, a leader and a follower, through visual sensory feedback

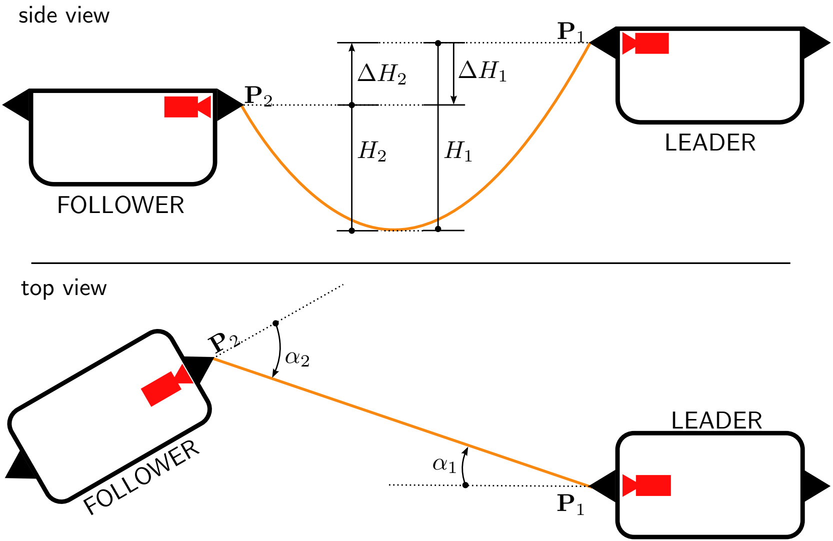


Cable: assumptions

1. The cable has a fixed and known length, uniform color
2. The cable can be modeled by a vertical catenary (slightly negative buoyancy): 3 parameters: height, height difference, and orientation angle.
3. Cameras and attachment points are fixed
4. Robots remain horizontal
5. Pressure sensors give the depth difference between the robots



Cable Modeling: Shape Parameters Symmetry



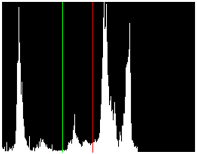
Cable Detection

1.

New image acquisition

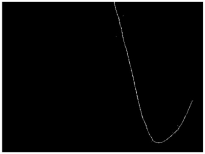
2.

Color segmentation (HSV space)



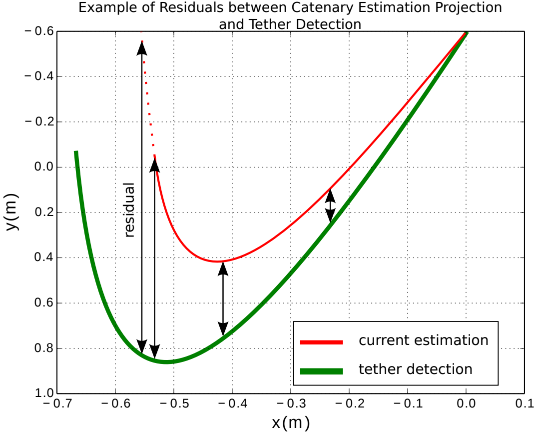
Opening and closing to reduce noise and fill in holes

Skeletization to shrink the points into a curved line

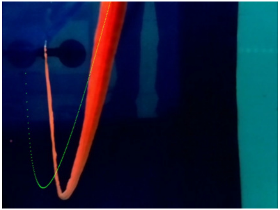


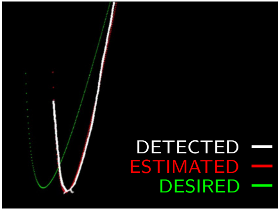
Cable Parameters Etimation: Catenary Curve Fitting

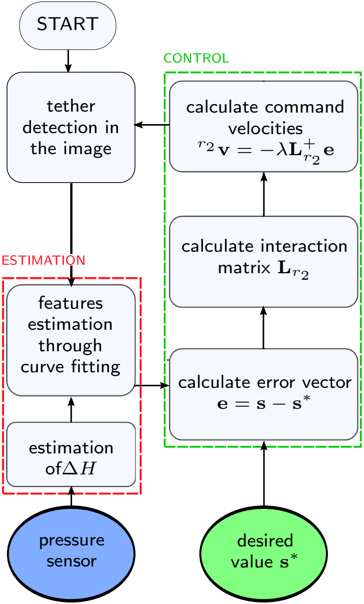
- Fitting procedure based on **Gauss-Newton** algorithm
- Feature vector: $\mathbf{s} = [a, b]^T \in]0,1[\times]0,1[$, with $a = \frac{H}{H_{max}}$ and $b = \sin \alpha$
- Cost function: $\Gamma(\mathbf{s}) = \frac{1}{M} \sum_{i=1}^{M} r_i^2(\mathbf{s})$, with $r_i(\mathbf{s}) = y_i - y(\mathbf{s}, x_i)$



Control scheme: Catenary-based visual servoing







feature vector

$$\mathbf{s} = [a, b, d]^T$$

$$a = \frac{H}{H_{max}}$$

$$b = \sin(\alpha)$$

$$d = \frac{\Delta H + \Delta H_{max}}{2\Delta H_{max}}$$

feature bounds

$$a \in]0, 1[$$

$$b \in]-1, 1[$$

$$d \in]0, 1[$$

Leader and Follower Features Regulation

The feature vector (normalized) is:

$$\mathbf{s}_f = \begin{bmatrix} a_2 \\ b_2 \\ d_2 \\ b_1 \end{bmatrix} = \begin{bmatrix} H_2/H_{max} \\ \sin(\alpha_2) \\ (\Delta H_2 + \Delta H_{max})/(2\Delta H_{max}) \\ \sin(\alpha_1) \end{bmatrix}$$

Interaction matrix obtained from the kinematics relationship between the motion of the cable attachment point and the variations of the cable features:

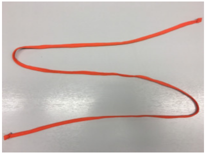
$$\dot{\mathbf{s}}_f = \begin{bmatrix} \mathbf{L}_{r_2,1} \\ \mathbf{L}_{r_2,2} \end{bmatrix} {}^{r_2}\mathbf{v} = \mathbf{L}_{r_2,f}{}^{r_2}\mathbf{v}$$

The follower robot velocity commands are calculated through:

$${}^{r_2}\mathbf{v} = -\lambda \mathbf{L}^{+}_{r_2,f}\mathbf{e}_f$$

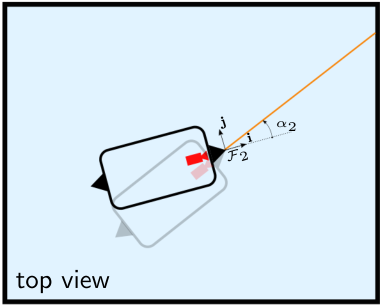
where $\mathbf{e}_f = \mathbf{s}_f - \mathbf{s}^*_f$ and $\mathbf{s}^*_f$ is the desired feature vector

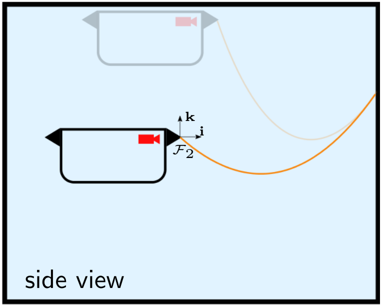
Experimental Setup



tether prototype
$L = 1.50\text{m}$, $\emptyset = 0.01\text{m}$, mass $= 50\text{g}$

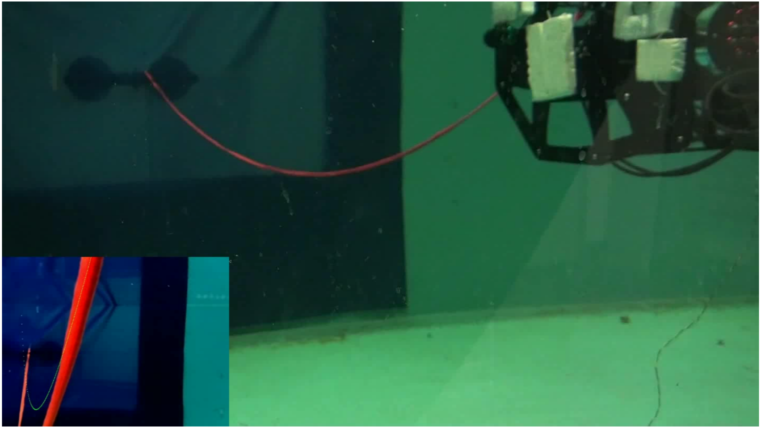
experimental platform
BlueROV1, 6DOF





max velocities 0.3 m/s, 0.2 rad/s

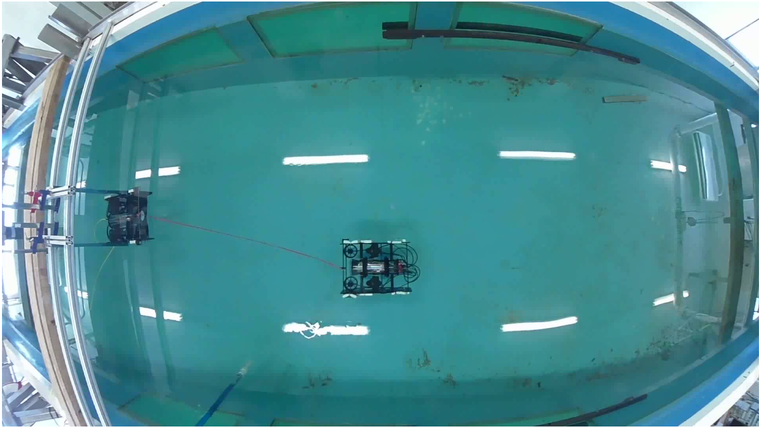
Experiments: regulation of follower features only



PI controller: ${}^{r_2}\mathbf{v} = -\lambda_P \mathbf{L}^+_{r_2,2}\mathbf{e}_2 - \lambda_I \mathbf{L}^+_{r_2,2} \sum \mathbf{e}_2$

	H_2(m)	α_2	ΔH_2(m)
desired	0.25	25°	0.10

Experiments: regulation of follower and leader features



PI controller: ${}^{r_2}\mathbf{v} = -\lambda_P \mathbf{L}^{+}_{r_2,f}\mathbf{e}_2 - \lambda_I \mathbf{L}^{+}_{r_2,f}\sum \mathbf{e}_2$

	H_2(m)	α_2	ΔH_2(m)	α_2
desired	0.2	$-20°$	0.10	$-20°$

Discussion

Results

- Feasibility OK
- Residual oscillation
  - Thruster deadband / water disturbances
  - Single thruster for lateral motion (straight configuration)
  - $\Rightarrow$ use of vectorial thruster configuration
  - $\Rightarrow$ use of predictive controller with hydrodynamics model

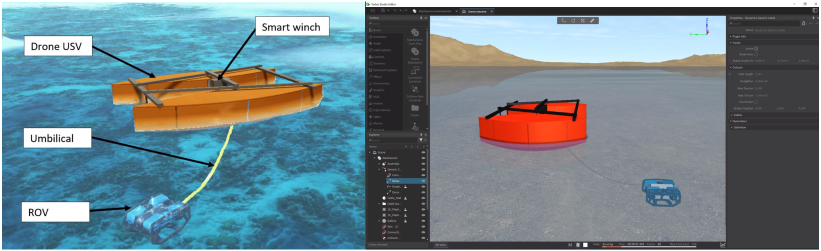
Applications

- Tethering positioning w.r.t. offshore structures/ tank edges
- Exploration of
  - coastal zones
  - cluttered areas: underwater caves and submerged mining sites

Extension

- Extension of the cable model
- Use of additional sensors such as 3-D accelerometers
- Extension to more than two robots
- High level navigation controller - trajectory planning

2nd focus: USV-ROV cable length management



choice of cable: identification of bending and torsion stiffness
weighing cable: semi-stretched configuration

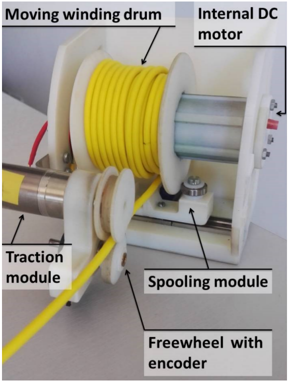
Simulation of cable dynamic impact onto ROV with Vortex™ (CM labs)
$\Rightarrow$ evaluate the dynamical impact of the differents types of cable onto the ROV

2nd focus: USV-ROV cable length management

Challenges

- Low cost force sensor
  - at cable attachment point to the ROV
  - at the winch
- Smart winch with control of cable length
- Wire cable adapted sheath for rolling up

prototype built with additive manufacturing

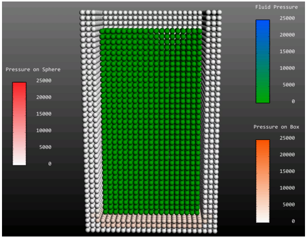


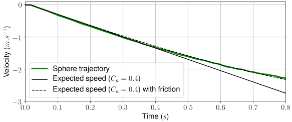
Other activities: simulation

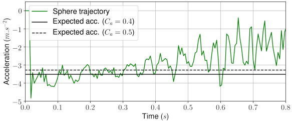
Use of adapted smoothed particle hydrodynamics (SPH) methods
SSSPH project: Submerged Solid using SPH
Cooperation with Centroid PIC company (USA)

- simulate realistic movements of underwater vehicles taking into account fluid-solid interaction
- vehicle's hydrodynamic parameter estimation
  - added mass, linear/quadratic damping coefficients
- check hydrostatics: pressure with depth, pressure around solid,
- check hydrodynamics: sphere fall into water, velocity, acceleration over time.

open software architecture for swarm robotics







What's next?

- Propose research projects in the idea of the Mundus master project titled **MIR - Marine and Maritime Intelligent Robotics** (submitted in Feb.)
  - knowledge in marine processes
  - dynamical modeling of marine mobile systems
  - artificial intelligence to develop behaviour autonomy of marine systems
  - non linear control techniques applied to marine sytems

  3 labs of the University of Toulon involved: LIS, MIO, Cosmer
  4 main MIR partners: Univ. Toulon, NTNU, IST, UJI
  More than 50 associate partners around the world.
  Strong support from IFREMER, Pole Mer and local companies.
- Develop cooperation with foreign research institutes/companies in marine robotics

1. develop decision-making autonomy of marine robots
2. design of bio-inspired amphibious robots

http://cosmer.univ-tln.fr/en/