Self-management of the umbilical of a ROV for underwater exploration

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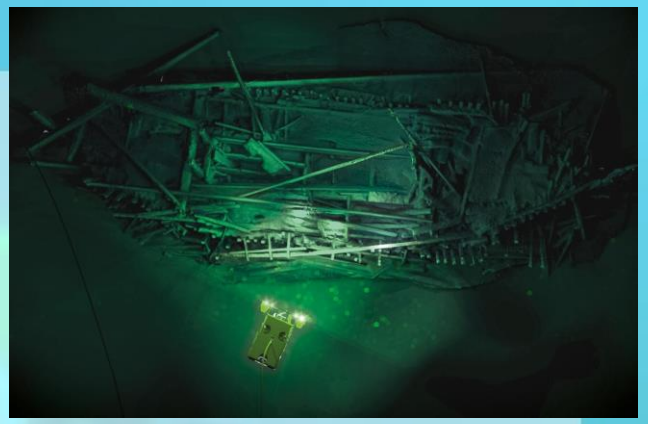
Context

The ROVs are used to collect information and perform operations in difficult areas:

- oceanographic exploration,
- wreck inspection and underwater archaeological research,
- maintenance of underwater infrastructures,
- risk areas for divers,
- …

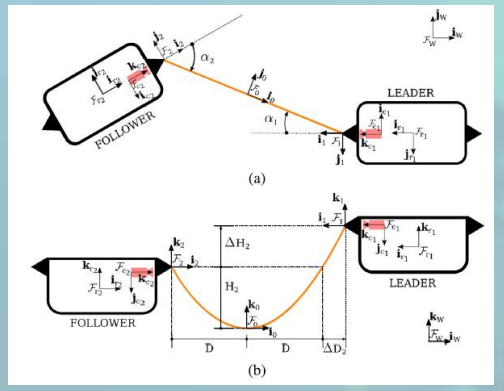
However,

- **they are generally deployed to perform individual tasks,**
- **Their umbilicals have as many advantages as disadvantages.**

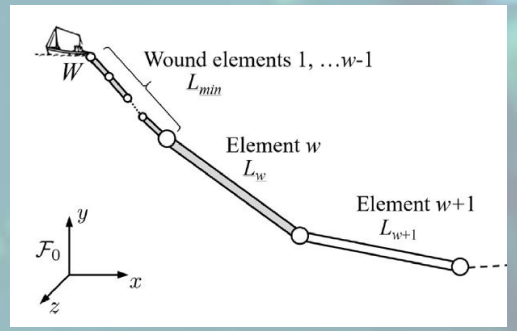


Bibliography

Umbilical management strategy:

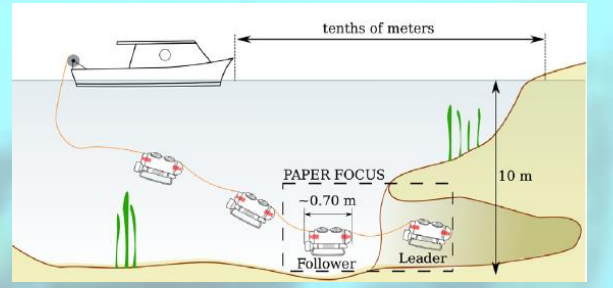


Straint line/Catenary curve

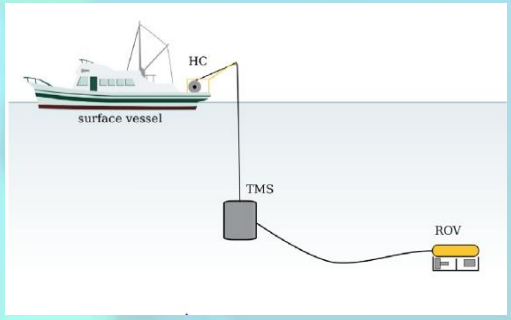


Finit-Element

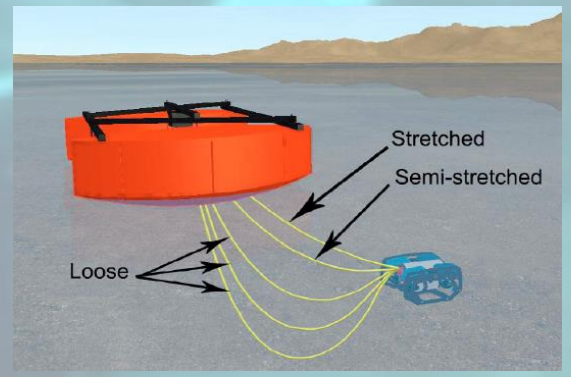
Umbilical management strategy:



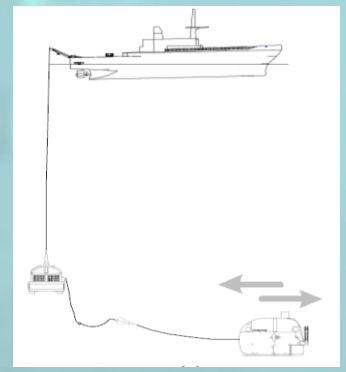
Chain of ROVs + feedback camera [Dune2020]



TMS and ROV



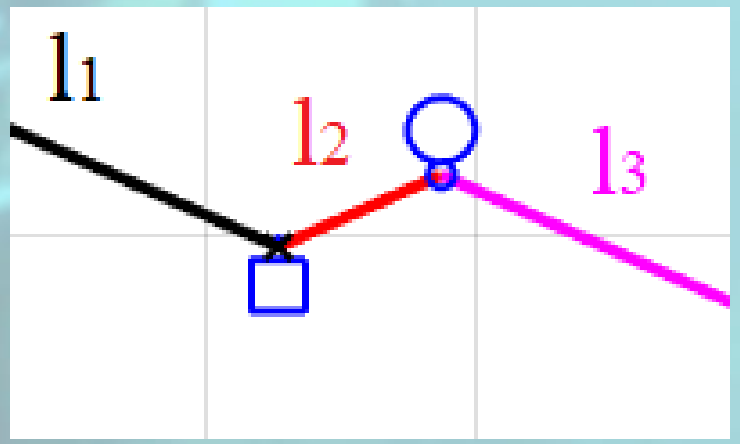
USV and ROV [Tortorici2019]



TMS, motor ballast/buoy, and ROV [Rigaud2015]

Main ideas

- **Umbilical shape is easier to estimate if the cable is taut**
  - ➢The cable must be taut in all cases to obtain a predictable model of the umbilical



- **Use ballast and/or buoy**
  - ➢Fixed or sliding freely on the umbilical
  - ➢No motorized

- **No TMS**
  - ➢ Self-management of the umbilical ballast and buoy.

Umbilical for surface exploration

Description:

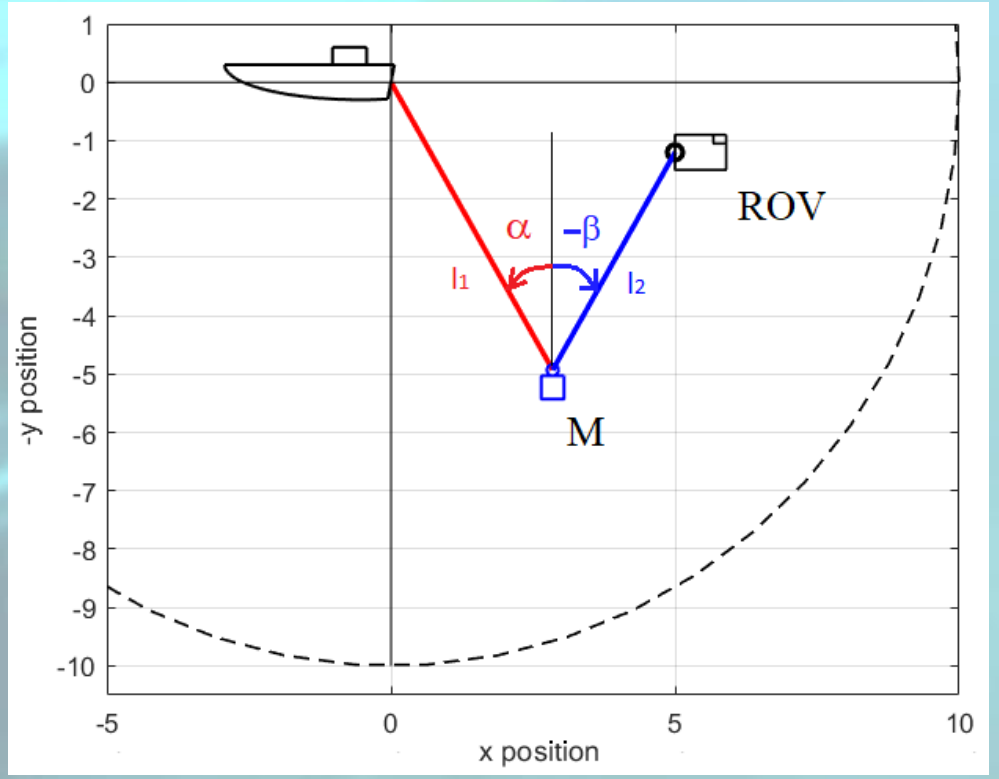
- Simple strategy of self-management of the umbilical to explore close to the surface,
- 1 sliding ballast.

Avantage:

- Ideal for surface exploration (inspection of boat hull, navigation under uniform ice floe, etc...).

Disavantage:

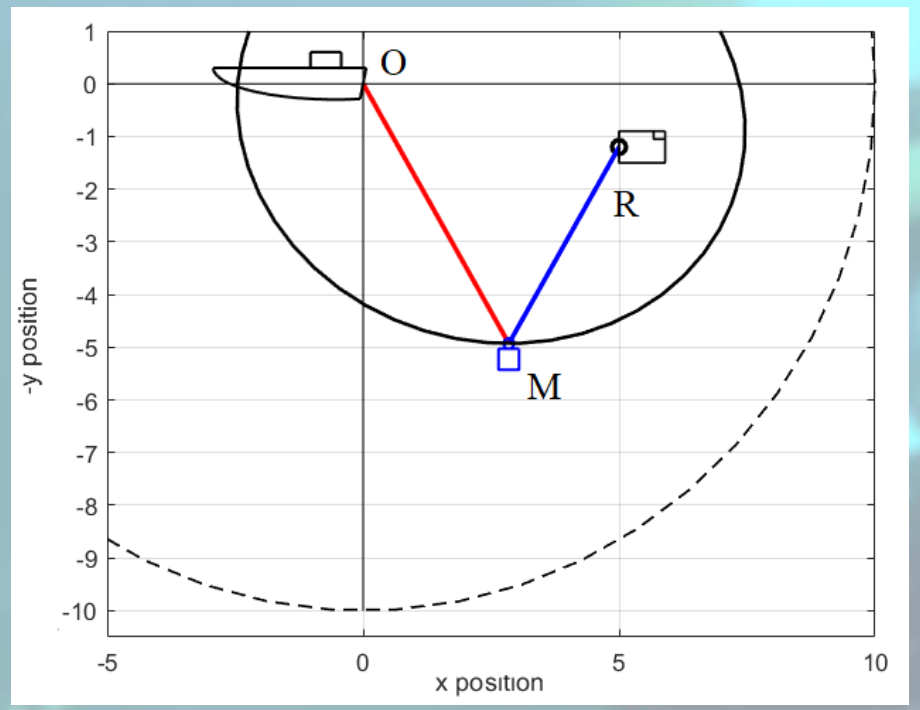
- Unsuitable for seabed exploration



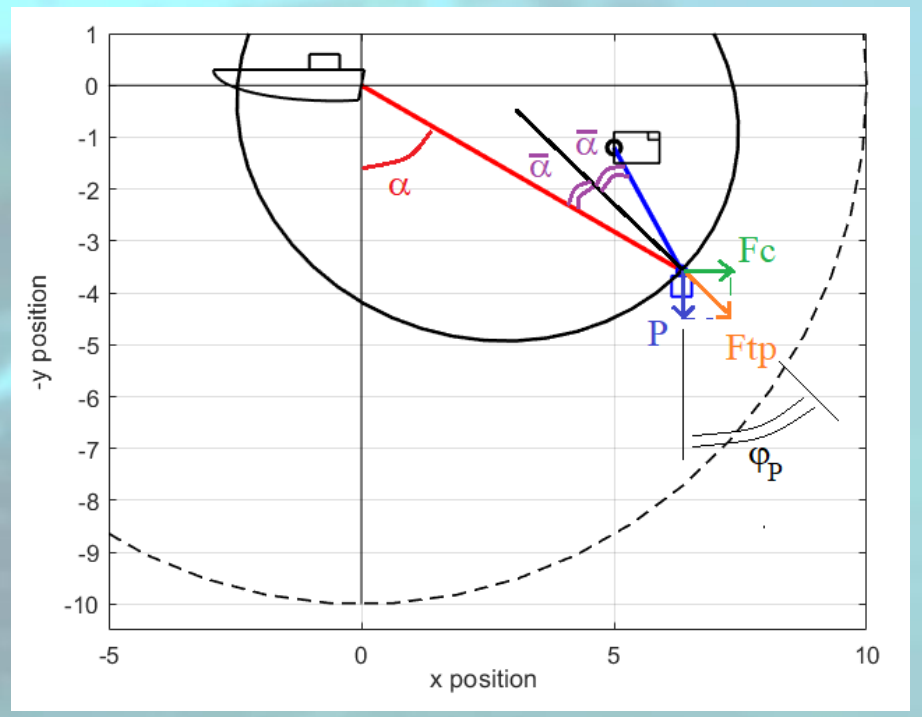
Parameters of the umbilical. $L=l_1+l_2$ is the umbilical length.

Umbilical for surface exploration

Sliding ballast stay on an ellipse:



Without current



With current

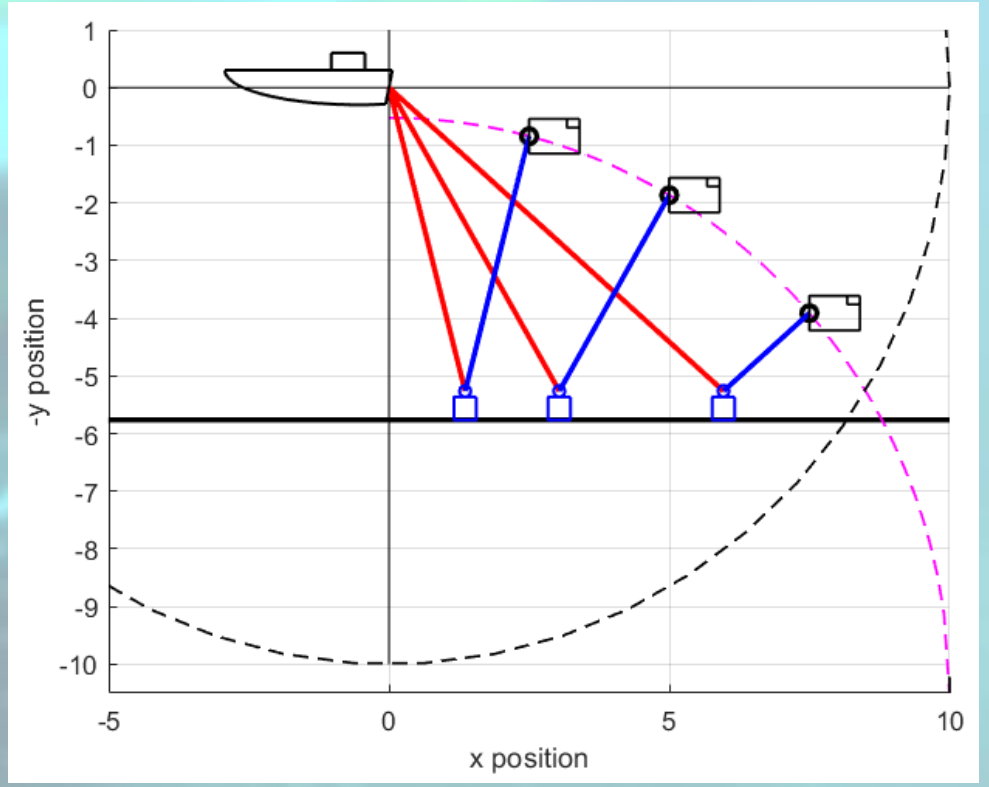
Umbilical for surface exploration

Minimum seafloor depth:

To keep umbilical taut, the ballast must remain suspended

- Minimum seafloor depth required,
- Maximal ROV's dive limited according to the position x.

$$y_{\text{lim}}(x) = 2\left(y_{\text{floor}} - h_M\right) - L\sqrt{1 - \left(\frac{x}{L}\right)^2}$$



Magenta line: maximum dept of the ROV without the ballast touches the sea floor (dept y_{floor})

Umbilical for sea exploration

Description:

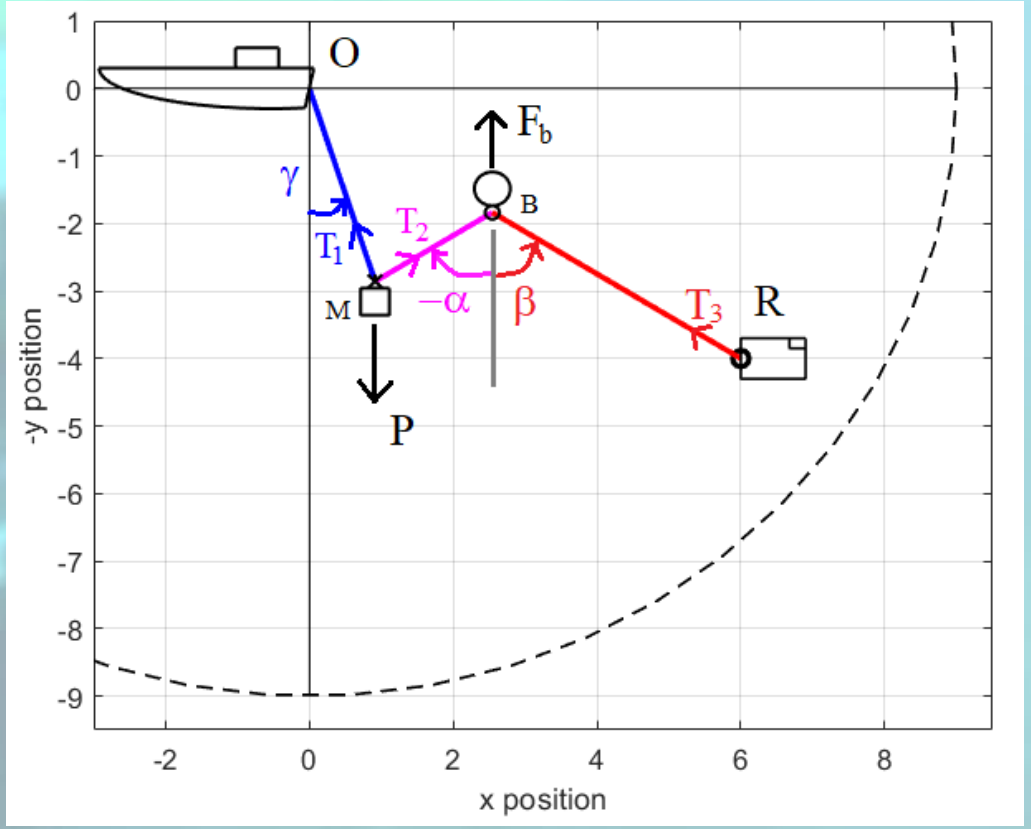
- Simple strategy of self-management of the umbilical to explore the sea and the seafloor,
- 1 ballast and 1 buoy,
- Fixed ballast, sliding buoy,
- Constaint P > Fb

Avantage:

Perfect for sea and seafloor exploration with flew obstacles,

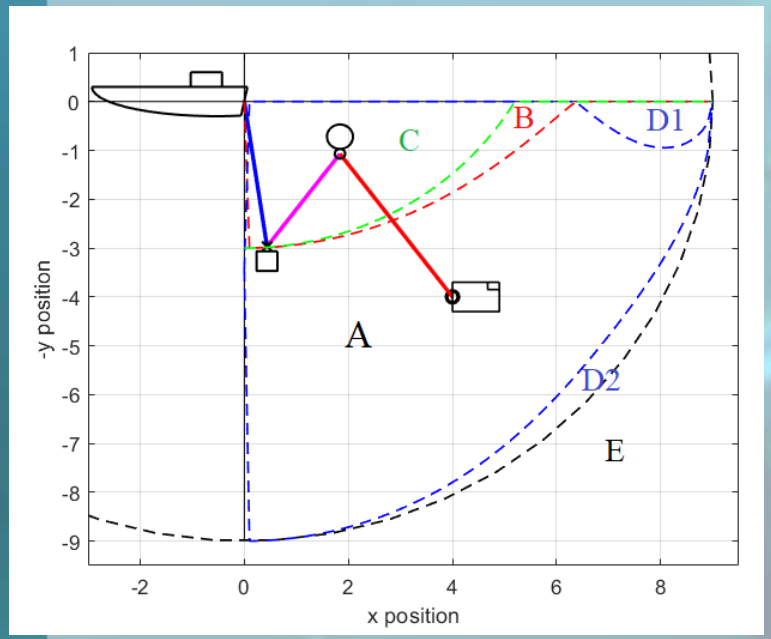
Disavantage:

Exploration of surface limited.

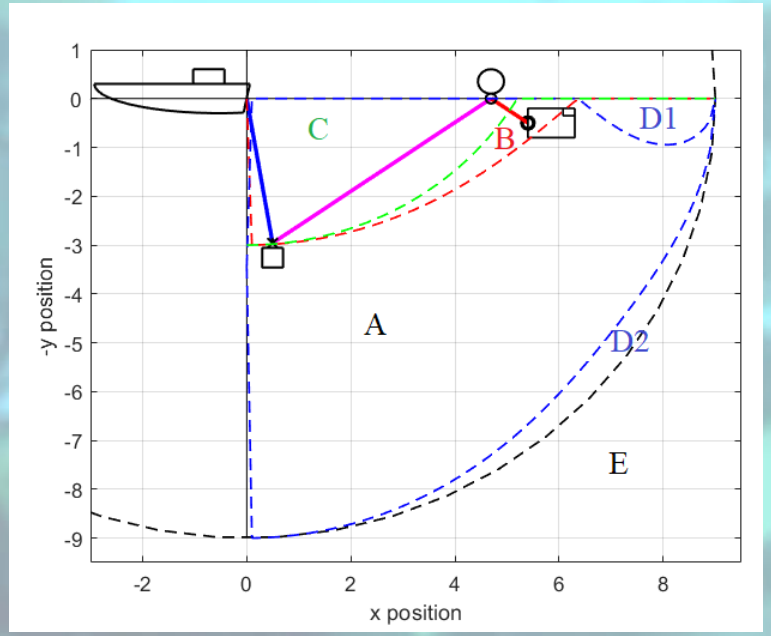


Umbilical for sea exploration

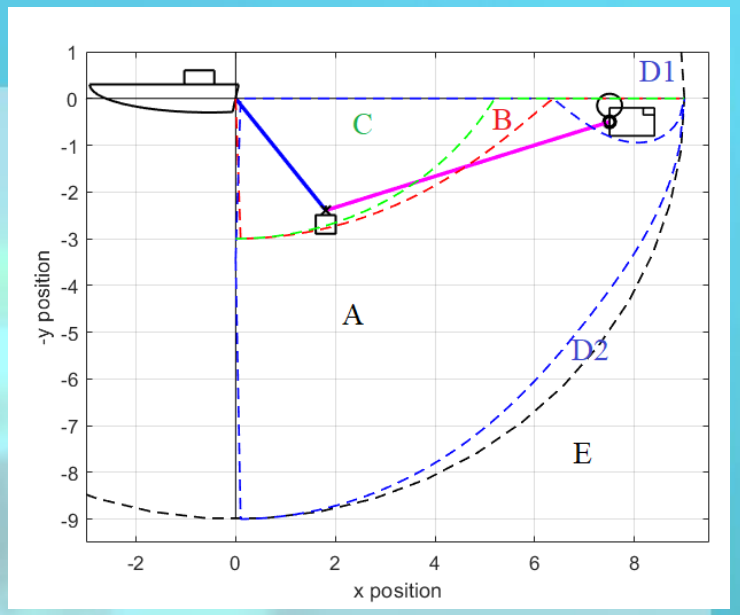
The differents areas:



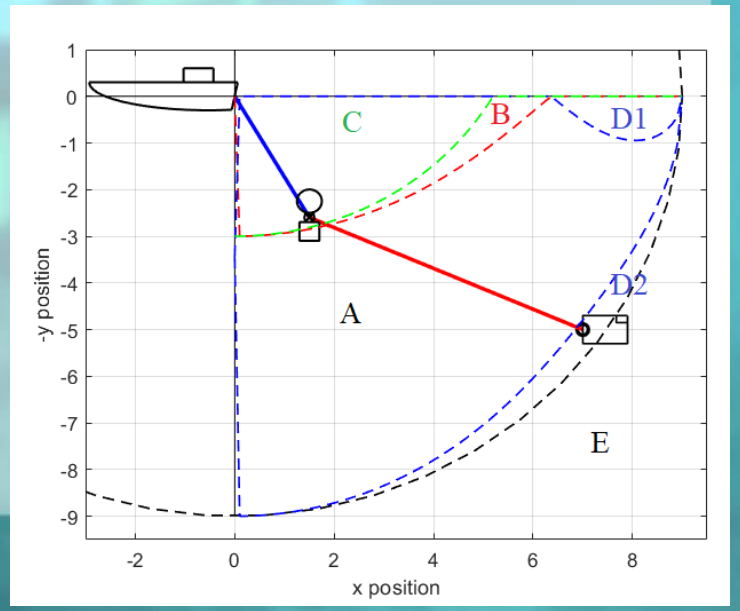
Area A :
Standard configuration



Area B :
Buoy on the surface



Area D1 and D2 :
Buoy on contact with ROV/ballast



Umbilical for sea exploration

Areas parametrization

$$y_{area\,B}(x) = \max\left(\left[-l_1\cos(\gamma_A(x)) + \frac{L}{\sqrt{1+\Lambda^2\tan(\gamma_A(x))^2}}, 0\right]\right)$$

$$y_{area\,C}(x) = \begin{cases} \sqrt{l_1^2 - x^2} - L & \text{if} \quad \left(x < \sqrt{l_1^2 - L^2}\right) \,\&\, (l_1 > L), \\ \sqrt{L^2 - x^2} - l_1 & \text{if} \quad \left(x < \sqrt{L^2 - l_1^2}\right) \,\&\, (L > l_1), \\ 0 & \text{else.} \end{cases}$$

$$y_{area\,D1}(x) = \max\left(\left[l_1\cos(\gamma_A(x)) - \frac{L}{\sqrt{1+\Lambda^2\tan(\gamma_A(x))^2}}, 0\right]\right)$$

$$y_{area\,D2}(x) = \max\left(\left[l_1\cos(\gamma_A(x)) + \frac{L}{\sqrt{1+\Lambda^2\tan(\gamma_A(x))^2}}, 0\right]\right)$$

$$y_{area\,E}(x) = \sqrt{l^2 - x^2}$$

with

l : umbilical length

l_1: cable ballast-boat

L: l-l_1

F: strength applied by ballast

Fb: strength applied by buoy

$$\Lambda = 2\frac{P}{F_b} - 1$$

Theorem 1. *The solution of (41) with the parameters of our study is*

$$X = \min_{i\in[1,2,3,4]}(|X_i|)$$

where

$$X_1 = \frac{\sqrt{U - \frac{2}{3}A} - \sqrt{\Delta_{Y1}}}{2}, \quad X_2 = \frac{\sqrt{U - \frac{2}{3}A} + \sqrt{\Delta_{Y1}}}{2},$$
$$X_3 = \frac{-\sqrt{U - \frac{2}{3}A} - \sqrt{\Delta_{Y2}}}{2}, \quad X_4 = \frac{-\sqrt{U - \frac{2}{3}A} + \sqrt{\Delta_{Y2}}}{2}.$$

for $\Delta_{Y1} = -\left(U + \frac{4}{3}A + \frac{2B}{\sqrt{U - \frac{2}{3}A}}\right)$ *and* $\Delta_{Y2} = -\left(U + \frac{4}{3}A - \frac{2B}{\sqrt{U - \frac{2}{3}A}}\right)$ *with*

$$A = -\frac{x^2}{2l_1^2} - \frac{(L^2\Lambda^2 - l_1^2)}{l_1^2(\Lambda^2 - 1)}$$

$$B = -\frac{l_1^2 + L^2\Lambda^2}{l_1^3(\Lambda^2 - 1)}x$$

$$C = \frac{x^4}{16l_1^4} + \frac{x^2(l_1^2 - L^2\Lambda^2)}{4l_1^4(\Lambda^2 - 1)}$$

$$U = \begin{cases} \left(-\frac{q}{2} + \sqrt{\frac{q^2}{4} + \frac{p^3}{27}}\right) + \left(-\frac{q}{2} - \sqrt{\frac{q^2}{4} + \frac{p^3}{27}}\right) & \text{if } \Delta_U > 0, \\ 2\cos\left(\frac{1}{3}acos\left(-\frac{q}{2\sqrt{-\frac{p^3}{27}}}\right)\right)\sqrt{-\frac{p}{3}} & \text{if } \Delta_U < 0, \\ = -\sqrt{-\frac{p}{3}} & \text{if } \Delta_U = 0 \end{cases}$$

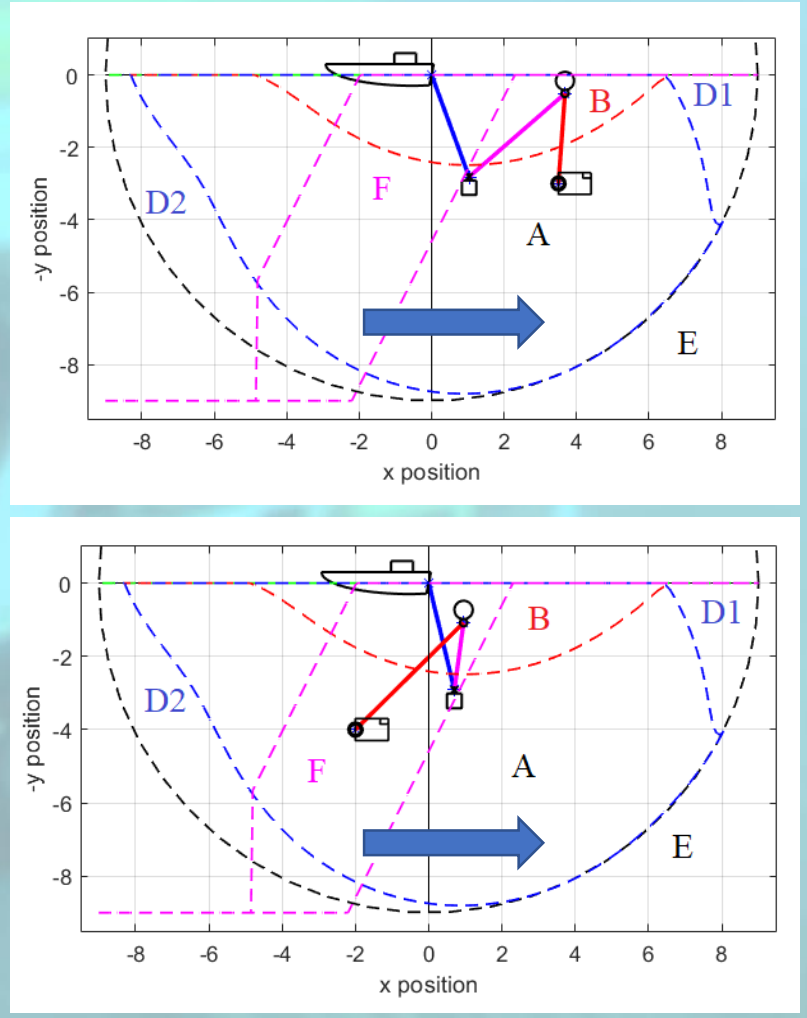
with $p = -4C - \frac{A^2}{3}$ *and* $q = \frac{2A^3}{27} + (4AC - B^2) + \frac{-4CA}{3}$.

Umbilical for sea exploration

Strategy with current:

- Forbiden area to keep ballast behind the buoy, and so avoid crossing in the umbilical
- System can not be solved analyticly
  - ➢ numerical solution required
- Areas become asymetric and must be recalculated.

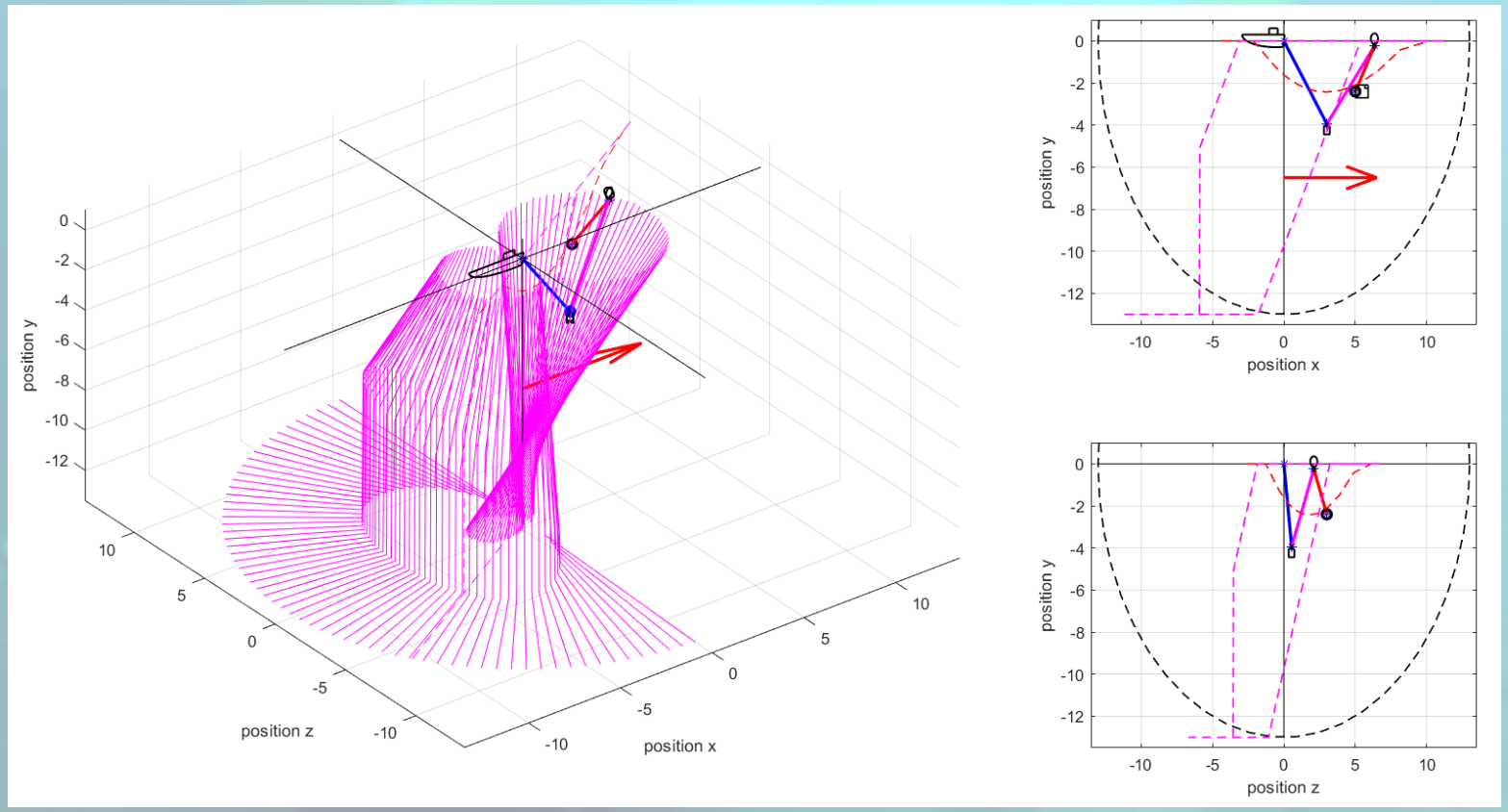
However, previous areas B ans C can become « suffisant conditions »



Umbilical in present of horizontal current. Blue arrow: current orientation. Red line: forbidden area.

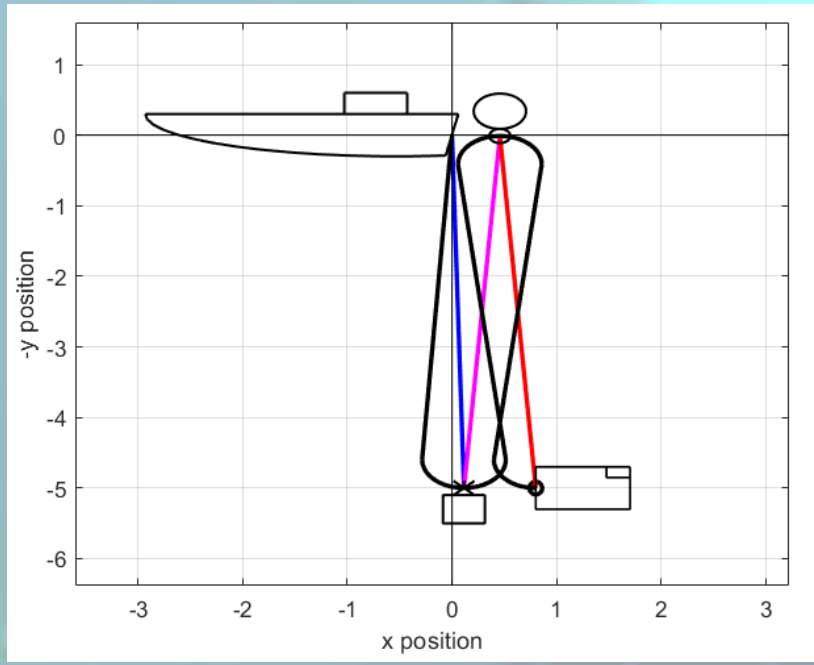
Umbilical for sea exploration

3D case:

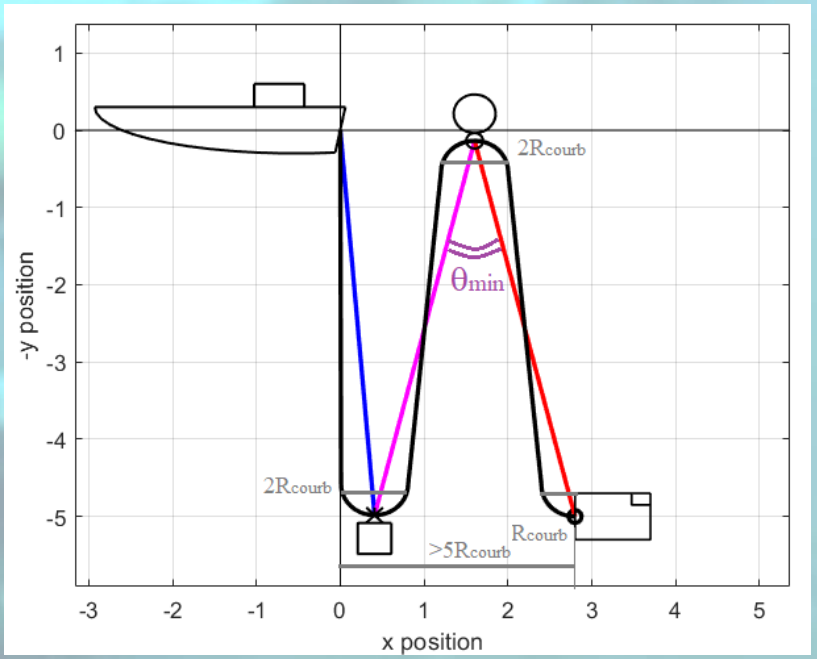


Umbilical for sea exploration

Rigidity of the umbilical

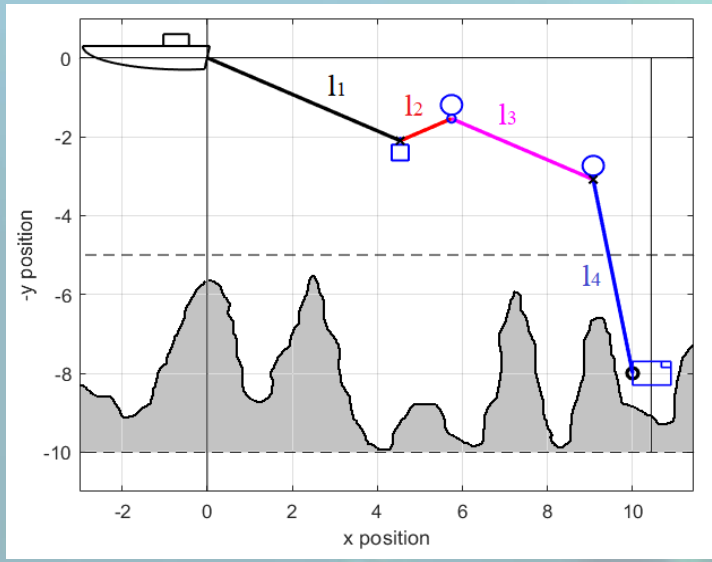


Collision due to umbilical rigidity

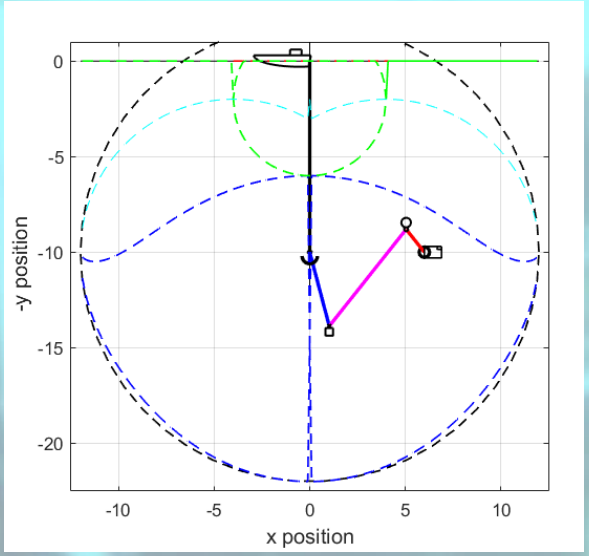


Absence of collision

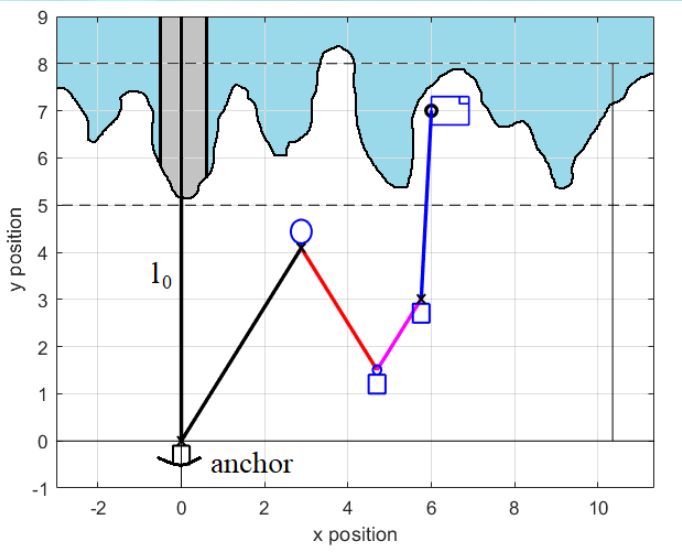
Others methods



Accidented seafloor



Translation of the model using an anchor



Reversed model

Experimentation

Conditions:

- Tests have been performed in pool and sea with shallow water

Parameters:

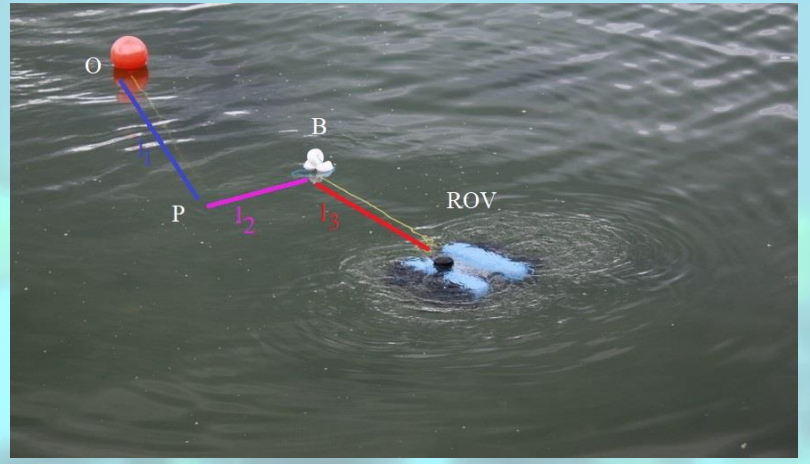
Ballast: 0,255 Kg

Buoy: 1.323N (lift 0,135 Kg)

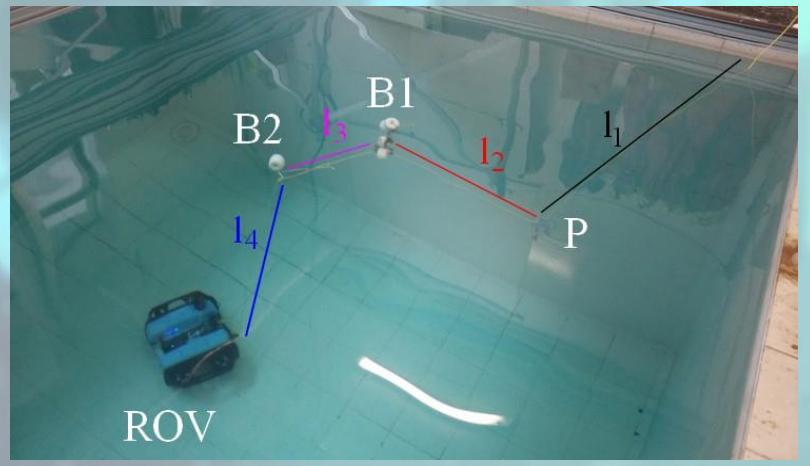
Total cable length: 6m

Pool size: 3m x 4m for 3m depth

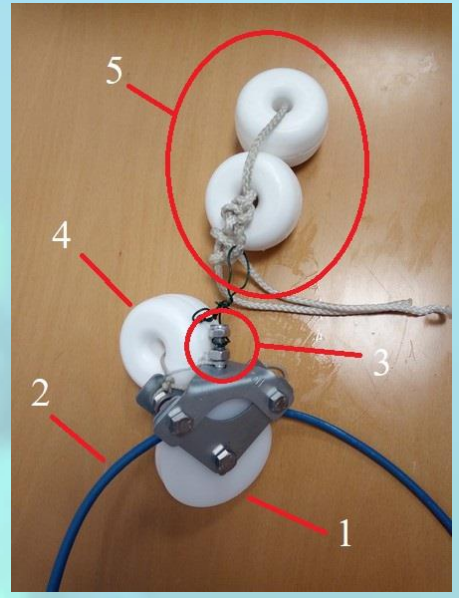
Results submitted to Ocean Engineering and on HAL



Umbilical for Sea Exploration



Umbilical for accidented seafloor



Pulley to obtain a sliding buoy.

1: pulley.

2: umbilical.

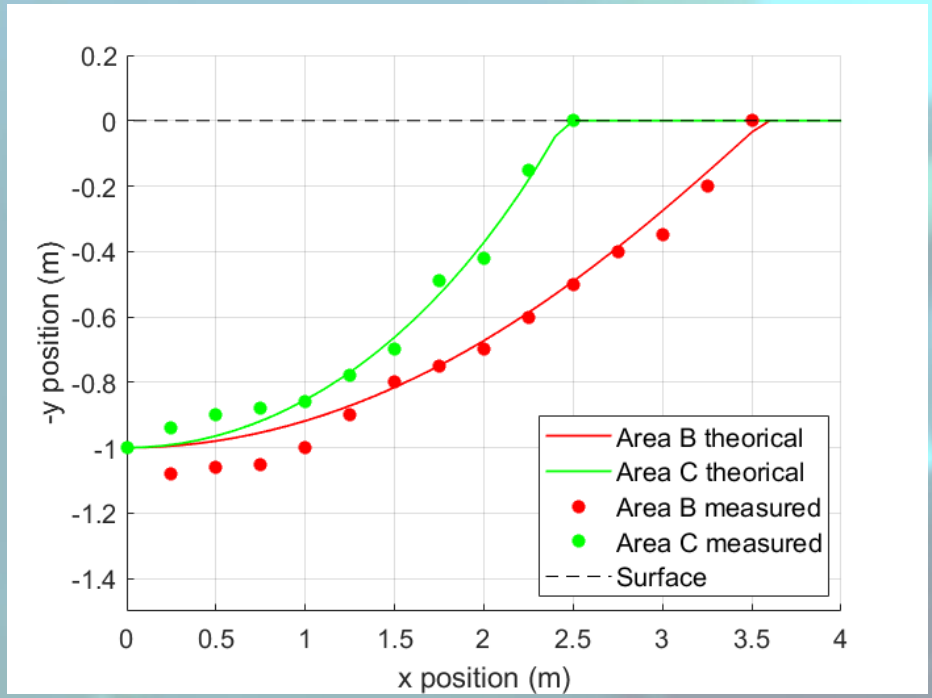
3: ball joint to reduce twist effort between the buoy and the pulley.

4: additional buoy and ballast to give a neutral buoyancy to the pulley assembly (without considering the buoys in 5).

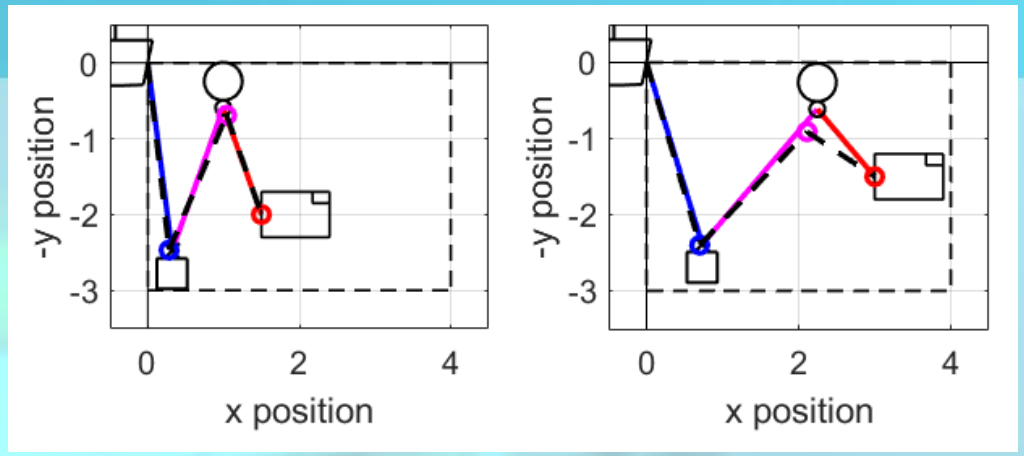
5: buoys Fb for the self-management strategy

Experimentation

Results:

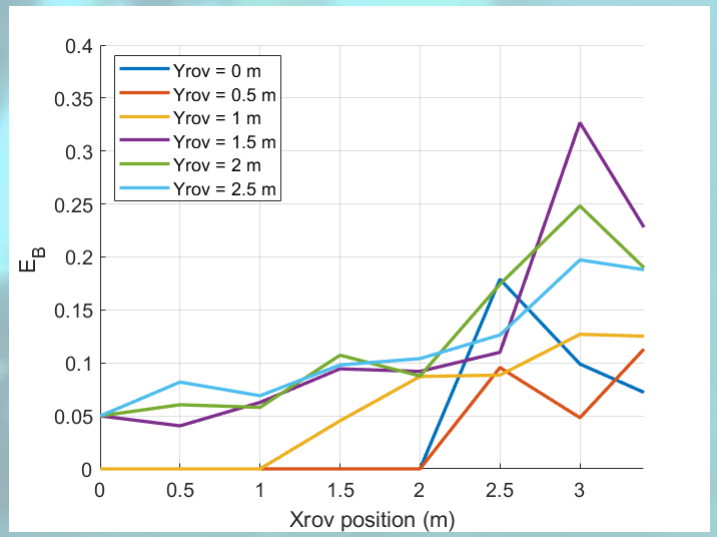


Difference between theoretical and measured areas A and B



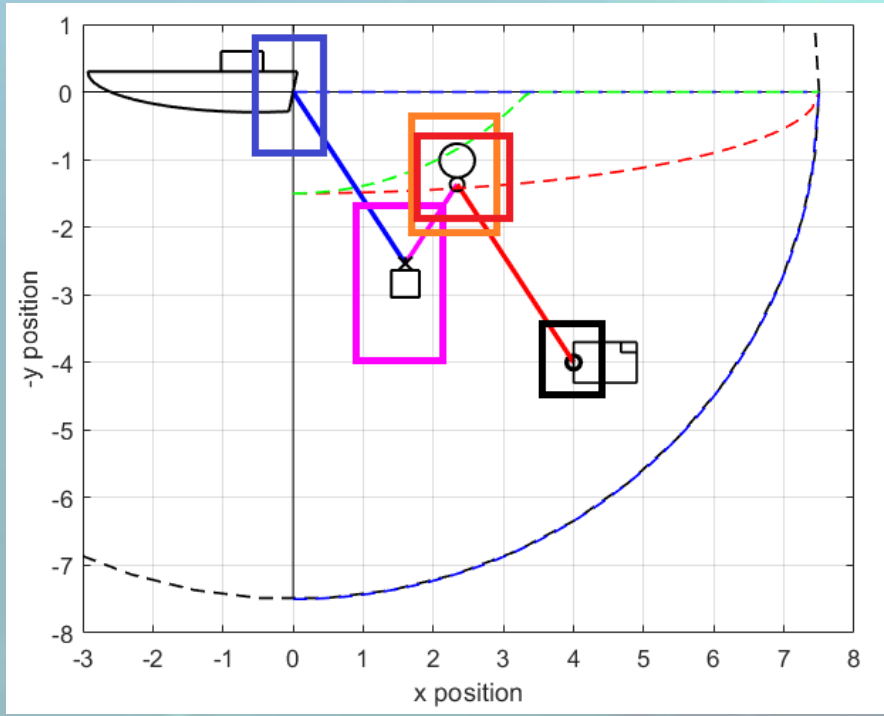
Left: minimum error between theoretical and measured position.

Right: error between theoretical and measured position.

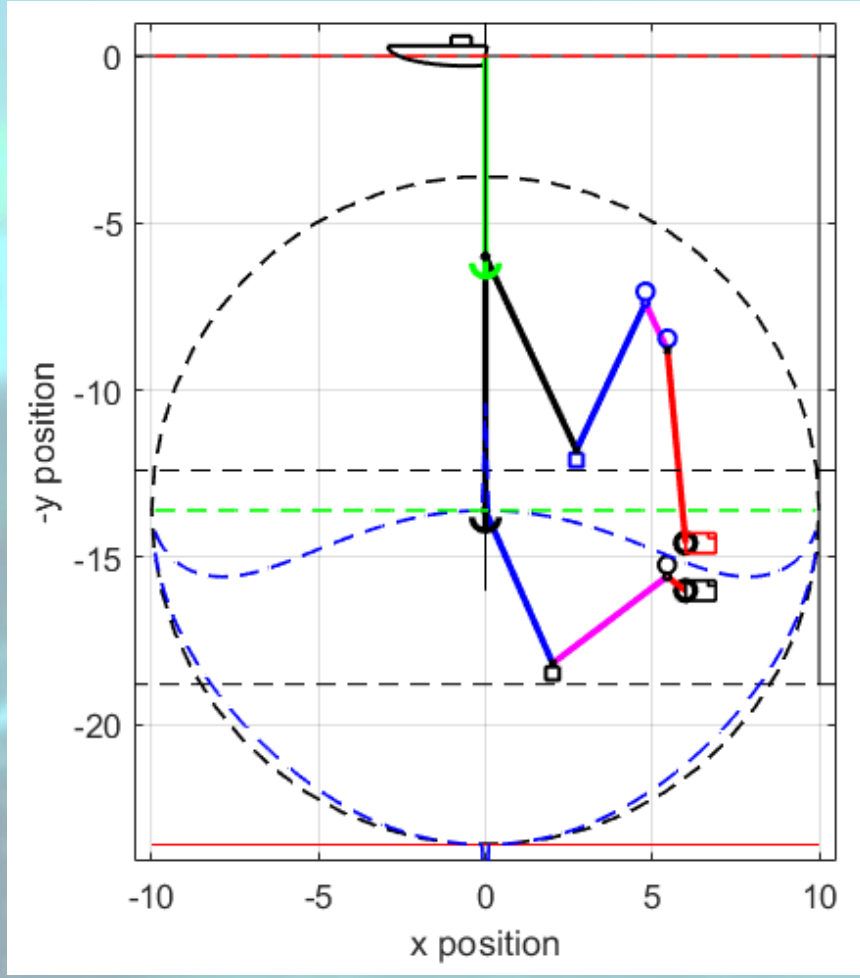


Error between theoretical and measured position.
(Xrov, Yrov): coordinate of the ROV in the plan (X,Y).

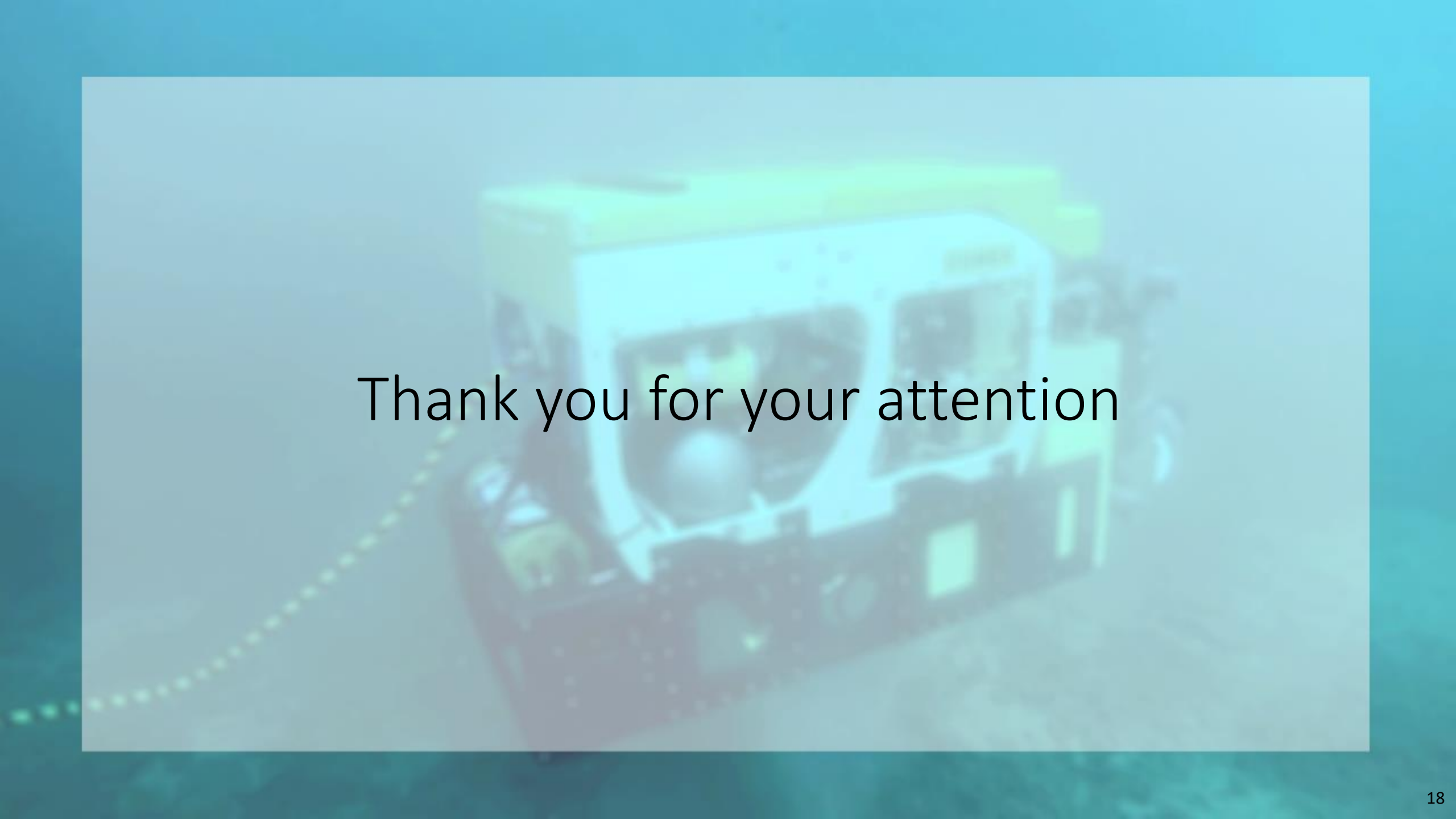
Future works



Interval analysis



Collaboration of two ROVs



Thank you for your attention