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

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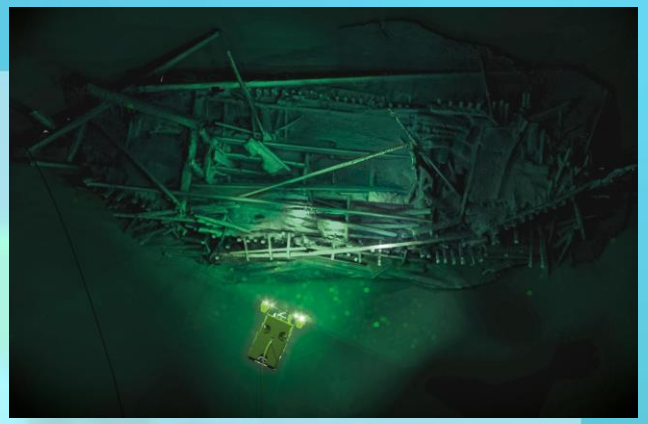
Context

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,
- …

The transmission of information in real-time or the supply of energy to the robot

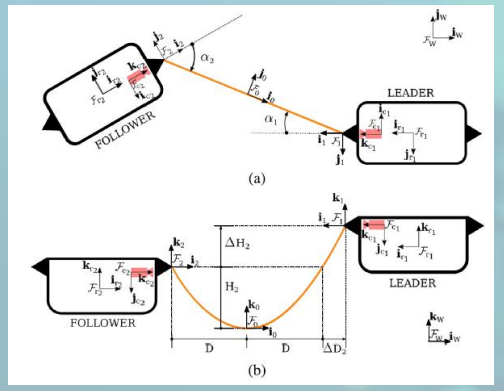
However, their umbilicals have as many advantages as disadvantages.



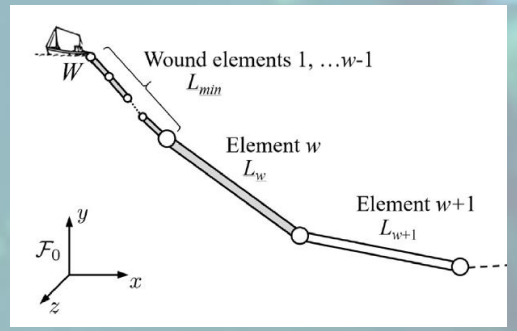
Umbilical model

Bibliography

Umbilical management strategy:

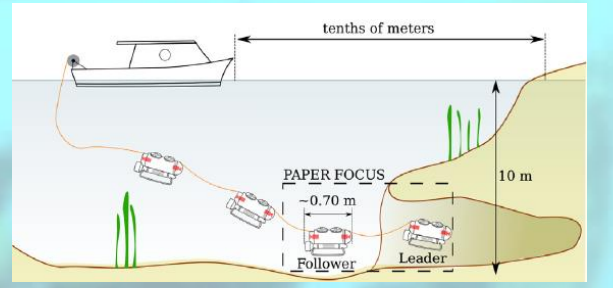


Straint line/Catenary curve

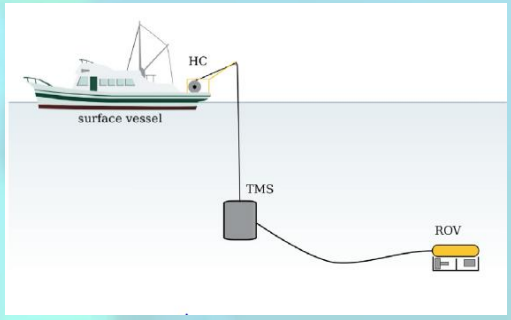


Finit-Element

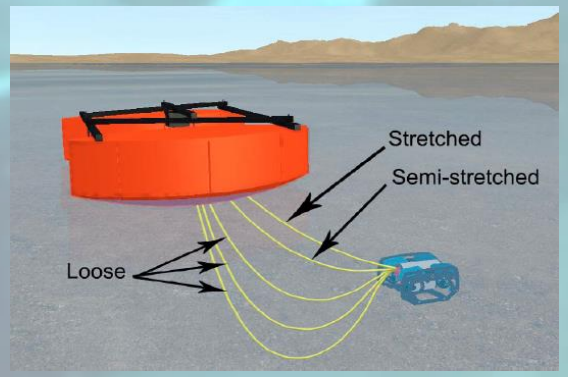
Umbilical management strategy:



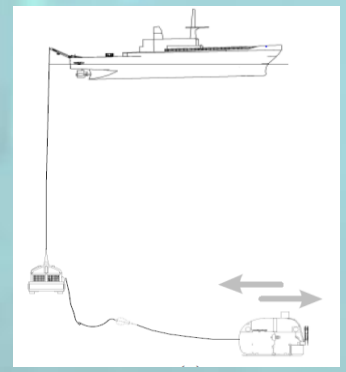
Chain of ROVs + feedback camera [Dune2020]



TMS and ROV



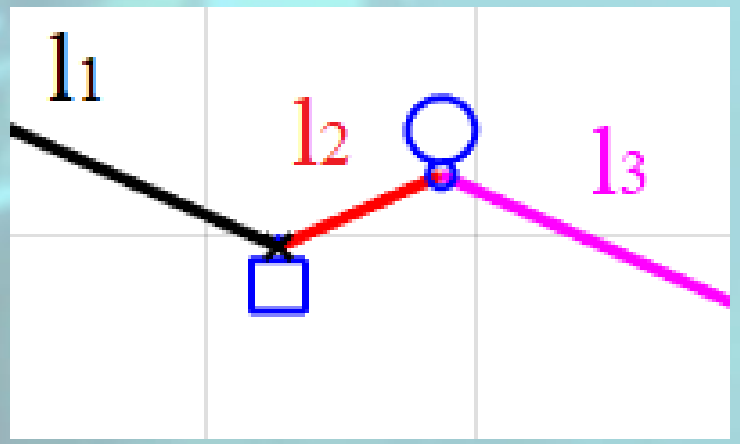
USV and ROV [Tortorici2019]



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

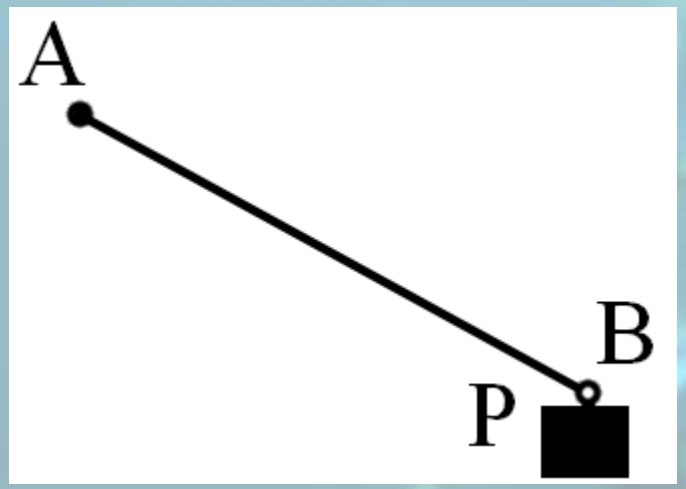


- **Use ballast and/or buoy**
  - ➢Fixed or sliding freely on the umbilical
  - ➢No motorized

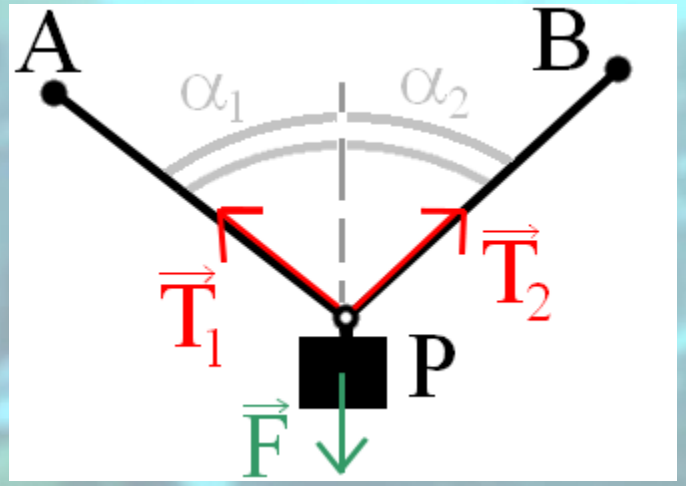
- **No TMS**
  - ➢ Self-management of the umbilical ballast and buoy.

Properties of a sliding element

<u>Three geometrically possible configurations</u>:

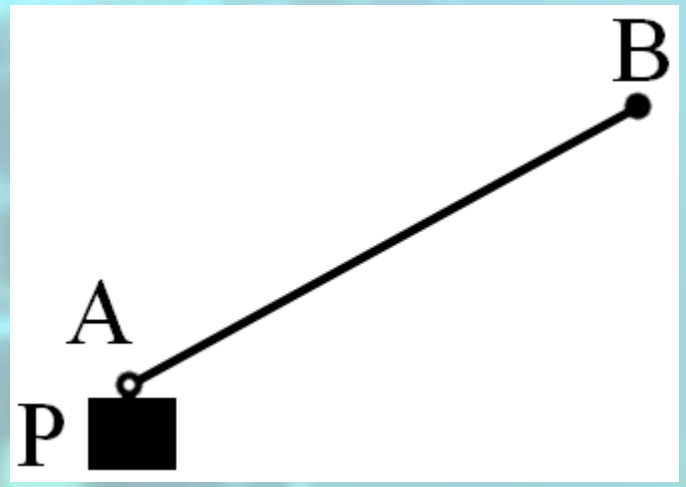


1. Contact with the extremity B



2. Moving freely on the cable.

$$\|\vec{T}_1\| = \|\vec{T}_2\|$$



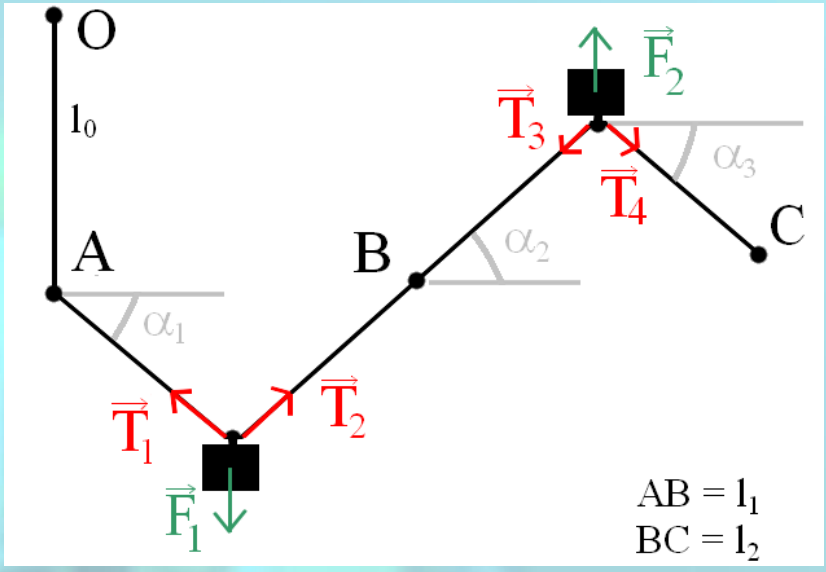
3. Contact with the extremity A

In practice and depending of A and B positions and $\vec{F}$ orientation, some configurations are impossible.

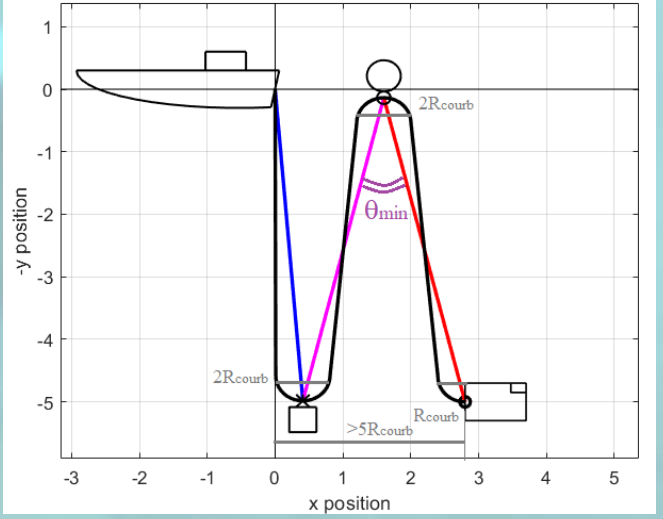
Geometrical model

A simple model is obtained by assimilating :

- the cable to straight lines,
- the rigidity by minimum angle.



$$\begin{cases} x = l_{11}\cos(\alpha_1) + (l_{12}+l_{21})\cos(\alpha_2) + l_{22}\cos(\alpha_3) \\ y = l_0 + l_{11}\sin(\alpha_1) + (l_{12}+l_{21})\sin(\alpha_2) + l_{22}\sin(\alpha_3) \\ l_1 = l_{11} + l_{12} \\ l_2 = l_{21} + l_{22} \end{cases}$$



Umbilical self-management strategy

Umbilical with single element

Description:

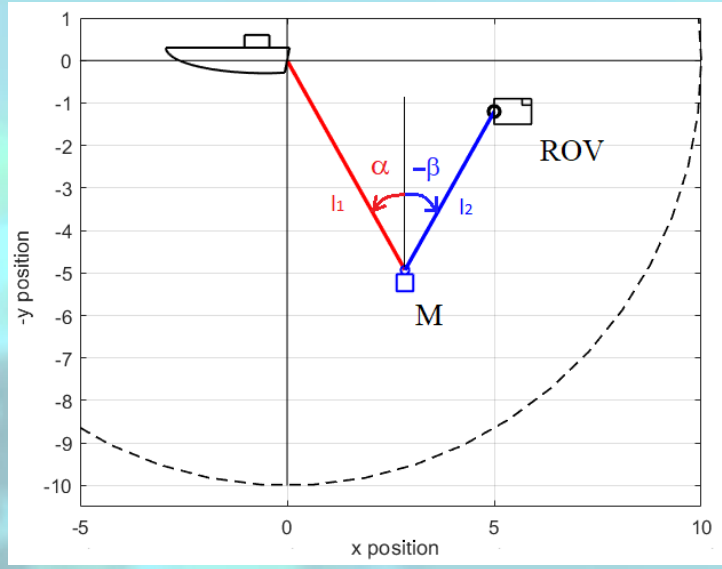
- Simple strategy of self-management of the umbilical to explore close to the surface/seabed,
- 1 sliding ballast/buoy.

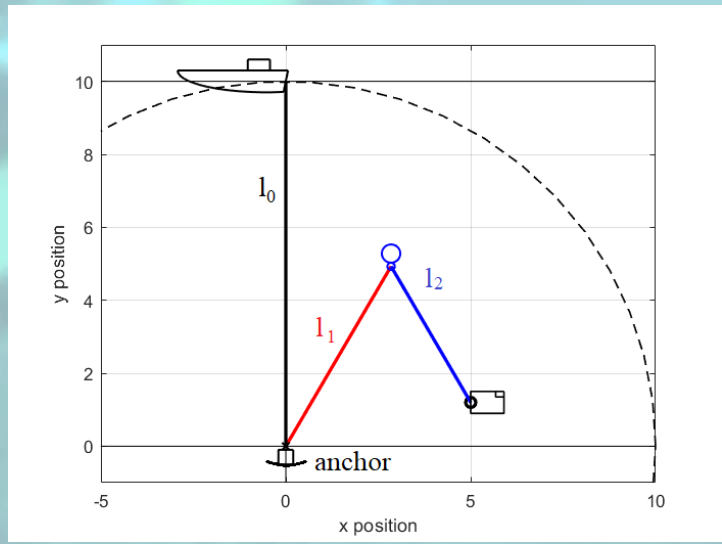
Advantage:

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

Disadvantage:

- Ballast: Unsuitable for seabed exploration,
- Buoy: Unsuitable for surface exploration,





Umbilical for sea exploration

Description:

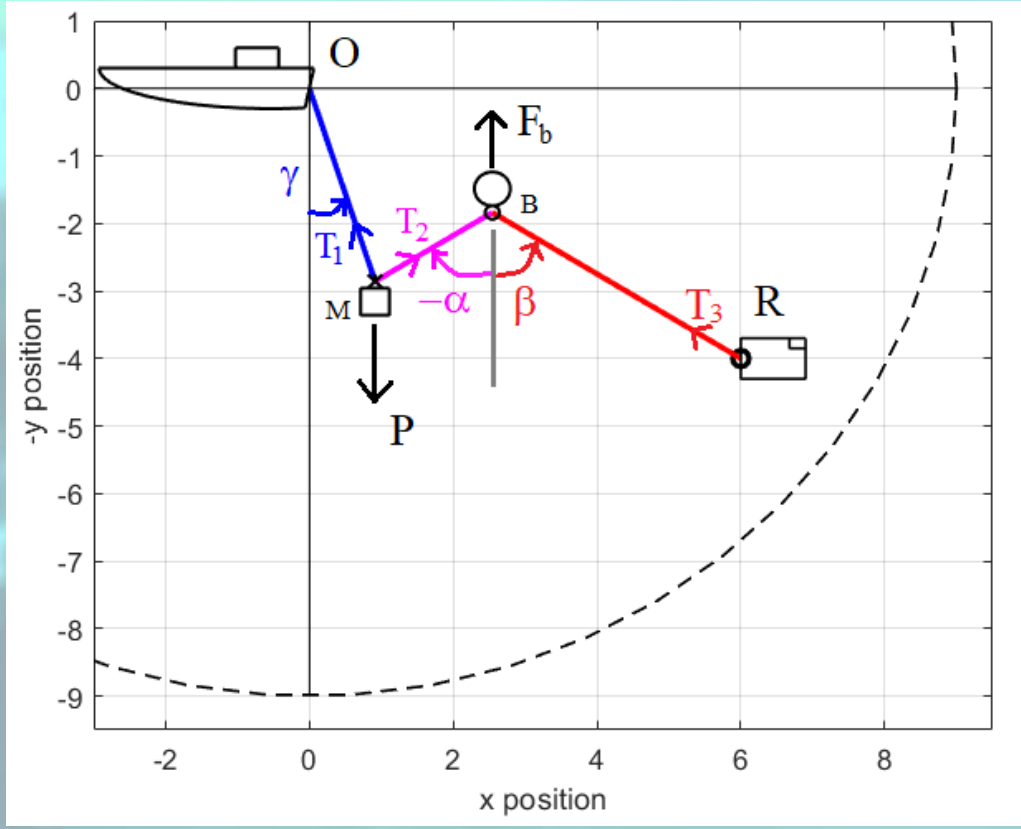
- Simple strategy of self-management of the umbilical to explore the sea and the seafloor,
- 1 ballast and 1 buoy,
- Fixed ballast, sliding buoy,
- Constaint P > F_b

Avantage:

Perfect for sea and seafloor exploration with flew obstacles,

Disavantage:

Exploration of surface limited.

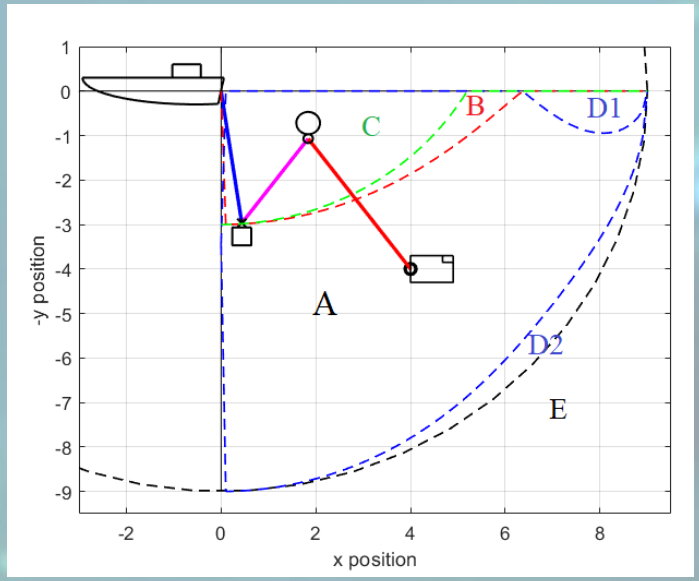


Umbilical for sea exploration

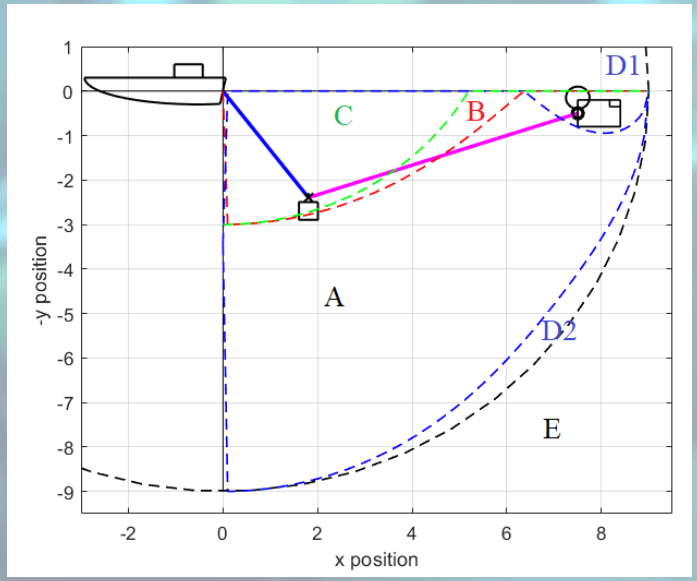
The different configuration areas:

6 areas can be defined, each with

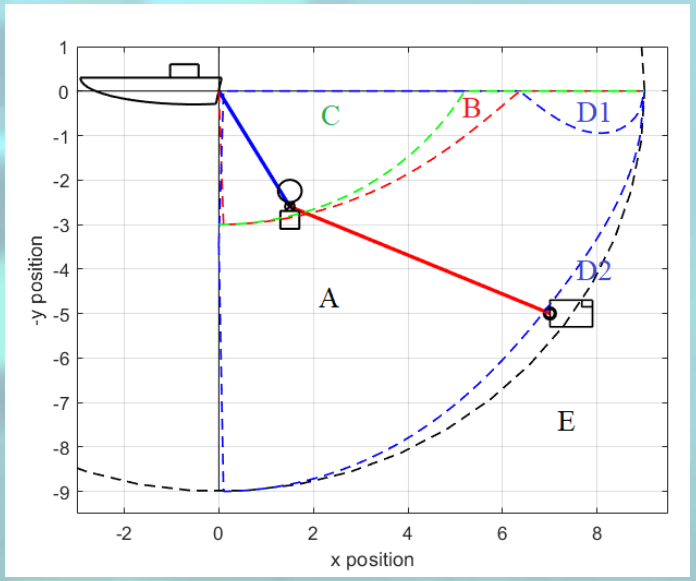
- a specific mathematical model,
- a boundary that can be estimated.



Area A: Standard configuration



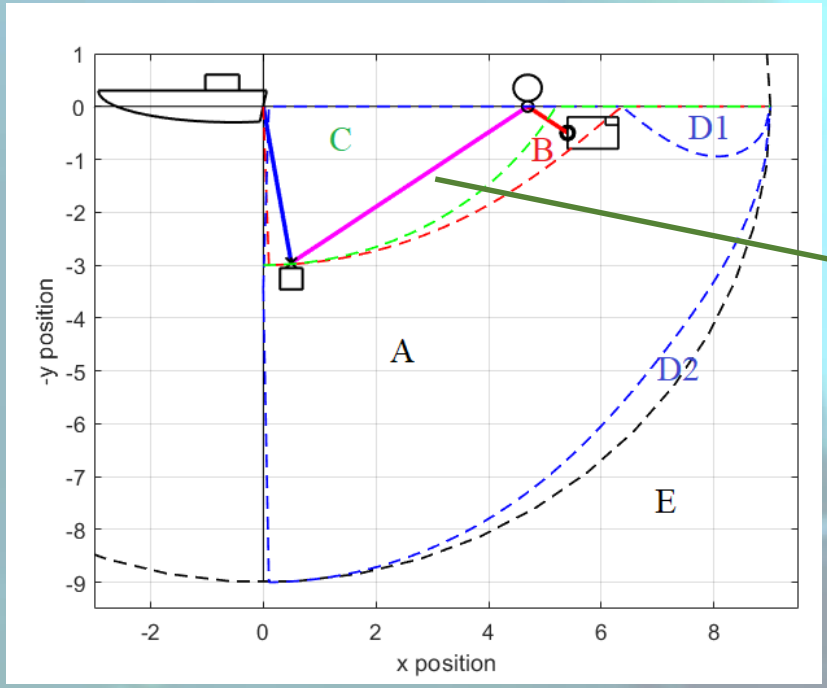
Area D1: Buoy on contact with ROV



Area D2: Buoy on contact with ballast

Umbilical for sea exploration

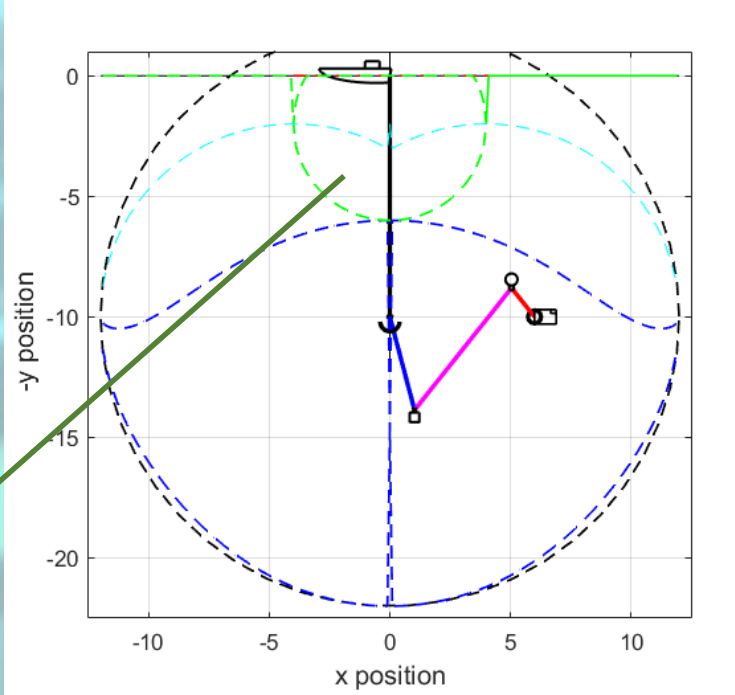
The differents configuration areas:



Area B : Buoy in contact with the surface

Area C: cable with the sliding element slacked

Area C: cable with the fixed element slackened



Case where the ROV is far from the surface

Umbilical equipped with two sliding elements and a stop

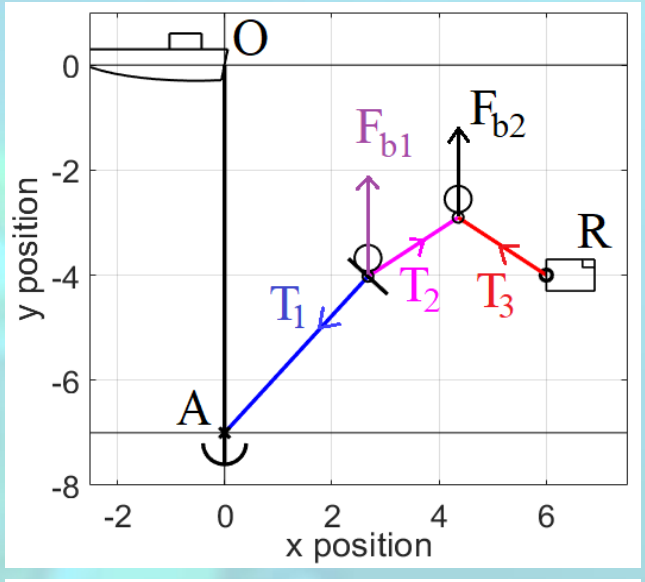
Description:

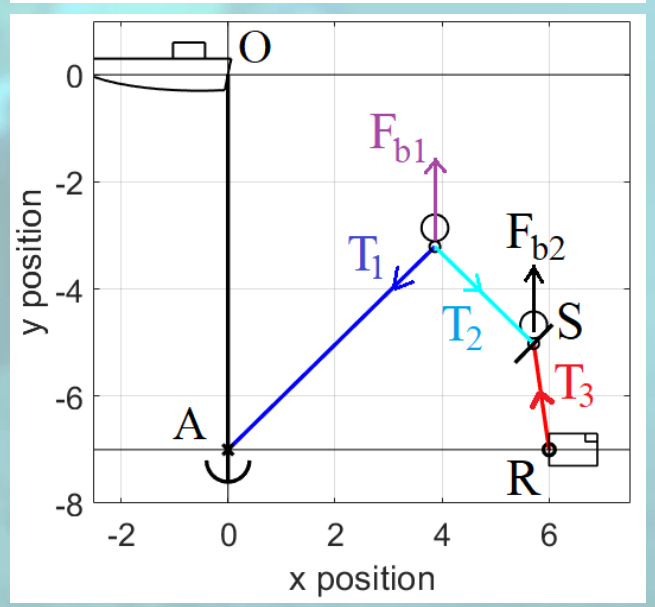
- Simple strategy of self-management of the umbilical to explore the seabed,
- 2 sliding buoys (Fb1 and Fb2),
- 1 stop (S),
- 1 anchor (A),

Advantage:

- Perfect for sea and seafloor exploration
- **a model of the umbilical simple to compute in real-time**

Disadvantage: Unsuitable for surface exploration





Configuration areas

Depending on the ROV's position, the buoys can

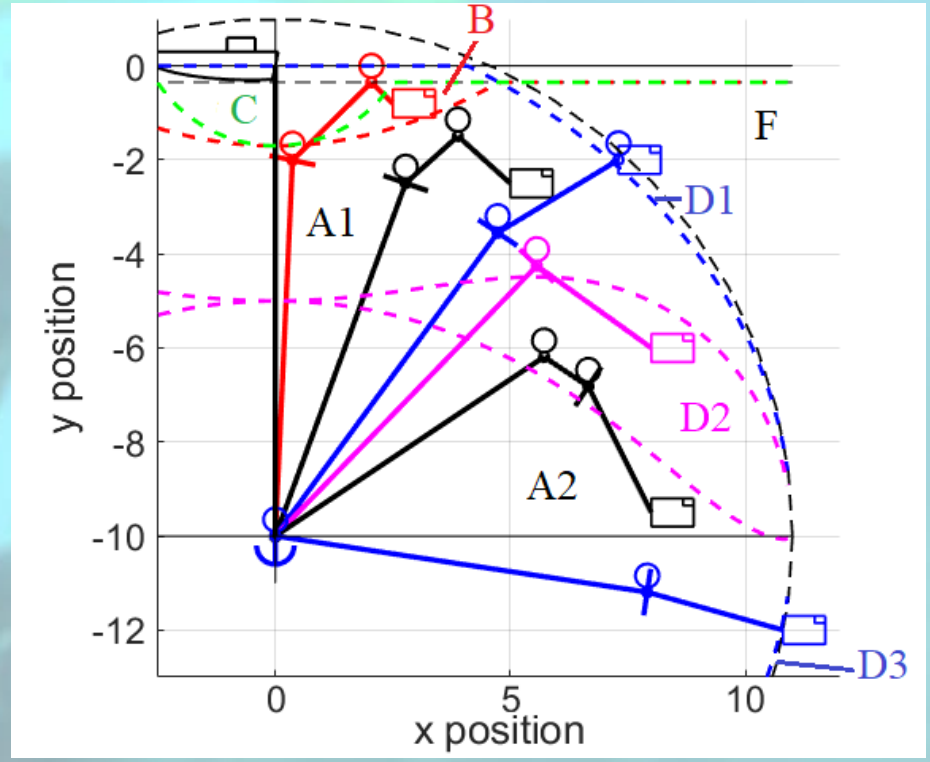
- Move freely on the cable

or be in contact with

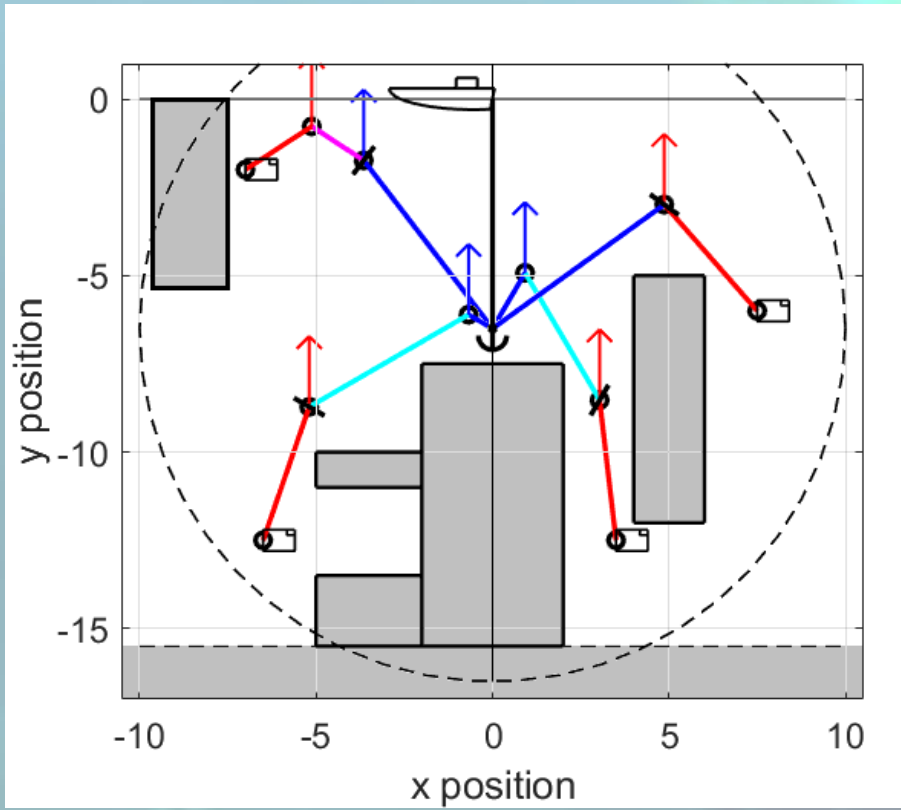
- the anchor A,
- the stop S,
- the ROV.

8 areas can be defined, each with

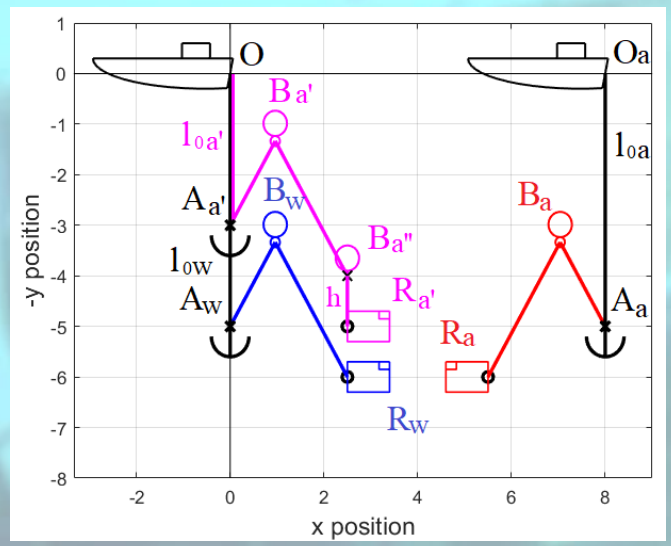
- a specific mathematical model,
- a boundary that can be estimated.

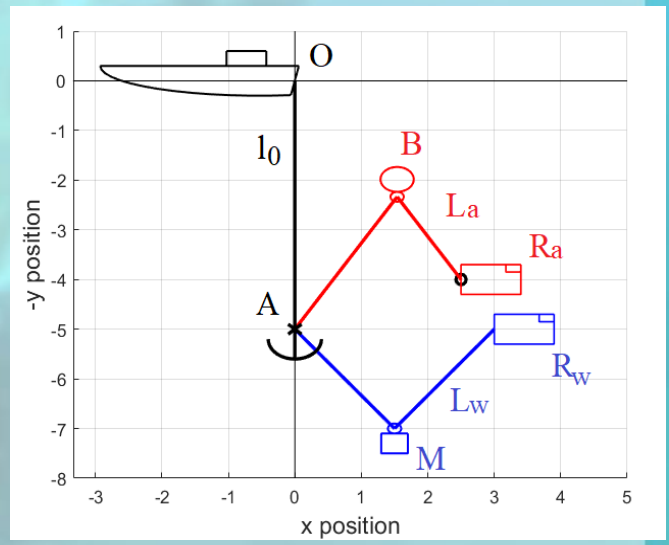


Advantage of the method



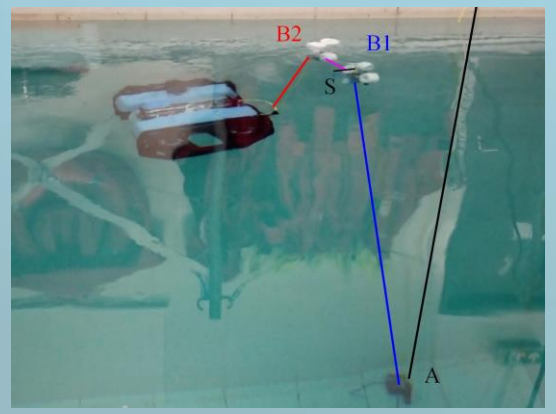
Exploration in the presence of obstacle

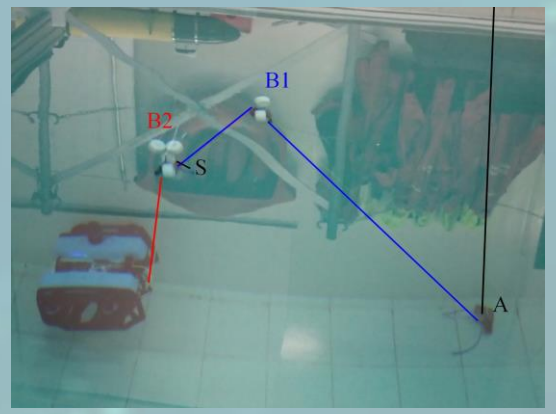




Configuration with two ROVs

Experimentation with two sliding buoys

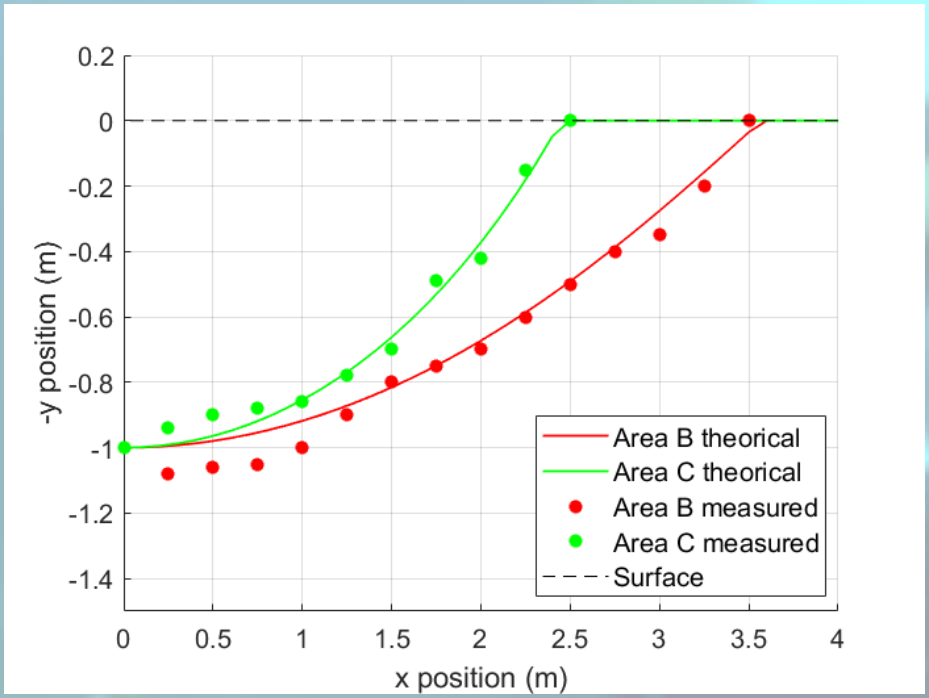




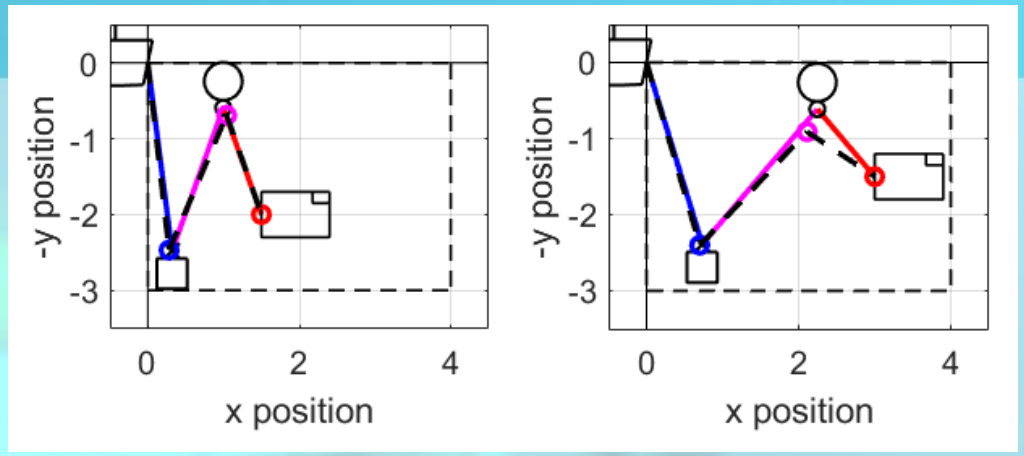
Materials used for experimental tests in pool

Experimentation

Results:

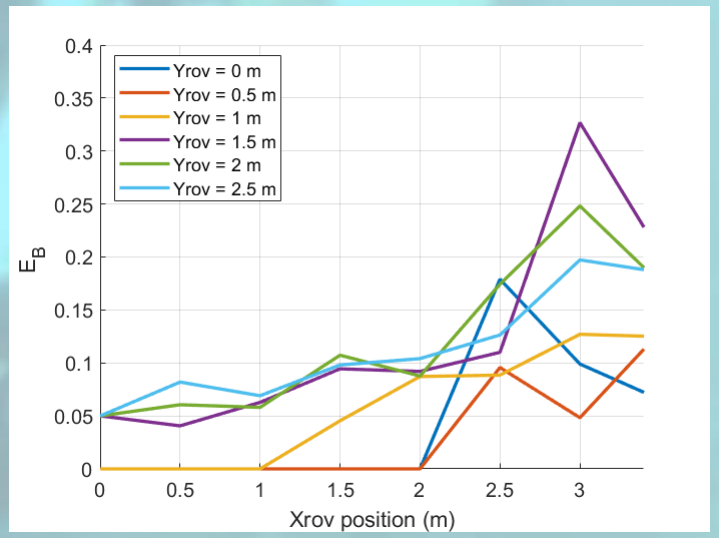


Difference between theoretical and measured areas A and B



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).

Umbilical general model

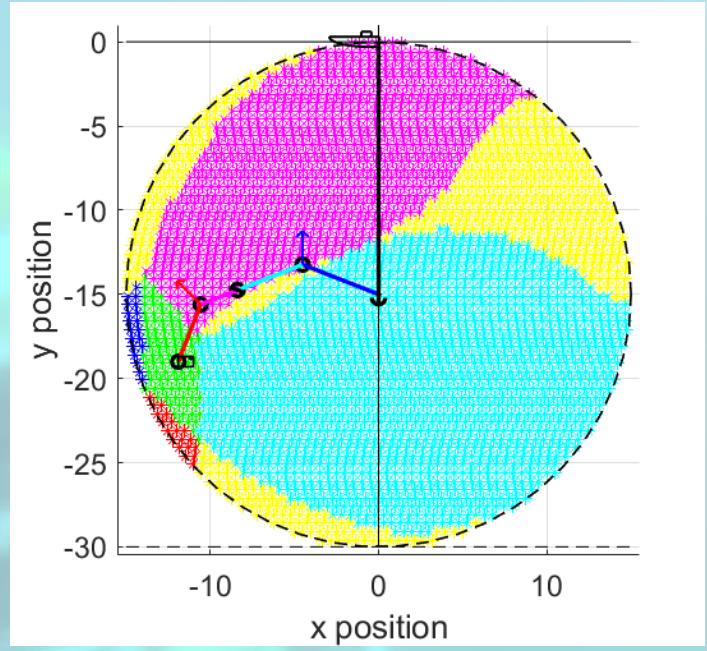
General model

Vertical forces only, without horizontal current:

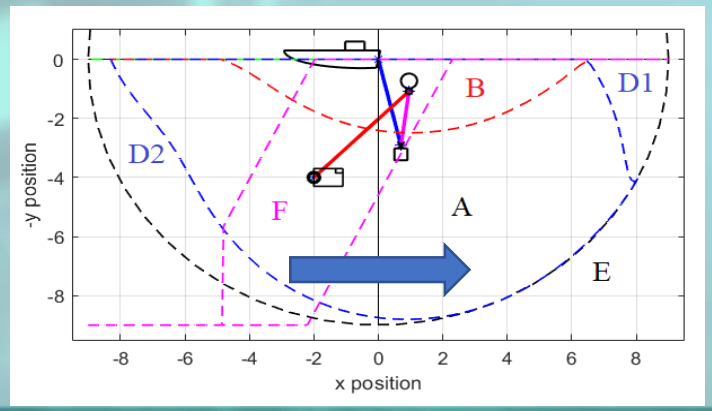
- Area's boundaries are easy to define,
- Nonlinear model but which can be solved analytically.

General model:

- Area's boundaries cannot be defined analytically,
- Nonlinear model must be solved numerically.
  - ➢ All solution must be evaluated simultaneously
  - ➢ A criterion is defined to chose the correct configuration.

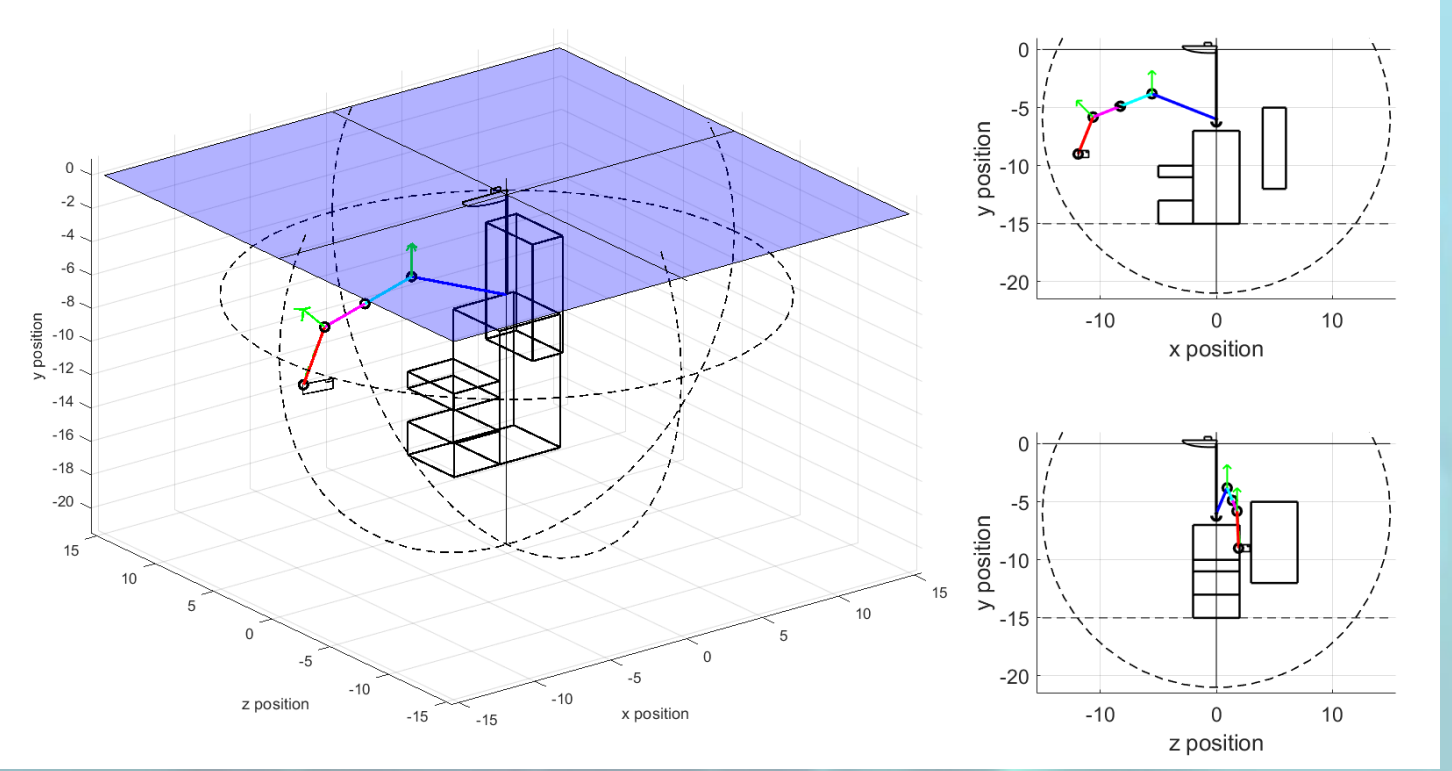


Example 1: areas for a configuration with horizontal current.



Example 2: Umbilical in present of horizontal current. Blue arrow: current orientation.

General model: 3D case



$$\begin{cases} x = l_{11}\cos(\psi_1)\cos(\alpha_1) + (l_{12}+l_{21})\cos(\psi_2)\cos(\alpha_2) + l_{22}\cos(\psi_3)\cos(\alpha_3) \\ y = l_0 + l_{11}\cos(\psi_1)\sin(\alpha_1) + (l_{12}+l_{21})\cos(\psi_2)\sin(\alpha_2) + l_{22}\cos(\psi_3)\sin(\alpha_3) \\ z = l_{11}\sin(\psi_1) + (l_{12}+l_{21})\sin(\psi_2) + l_{22}\sin(\psi_3) \end{cases} \quad (1)$$

with $0 \leq l_{11} \leq l_1$, $0 \leq l_{12} \leq l_1$, $0 \leq l_{21} \leq l_2$, $0 \leq l_{22} \leq l_2$ et $\psi_1 \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$,$\psi_2 \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$,$\psi_3 \in \left[-\frac{\pi}{2}, \frac{\pi}{2}\right]$.

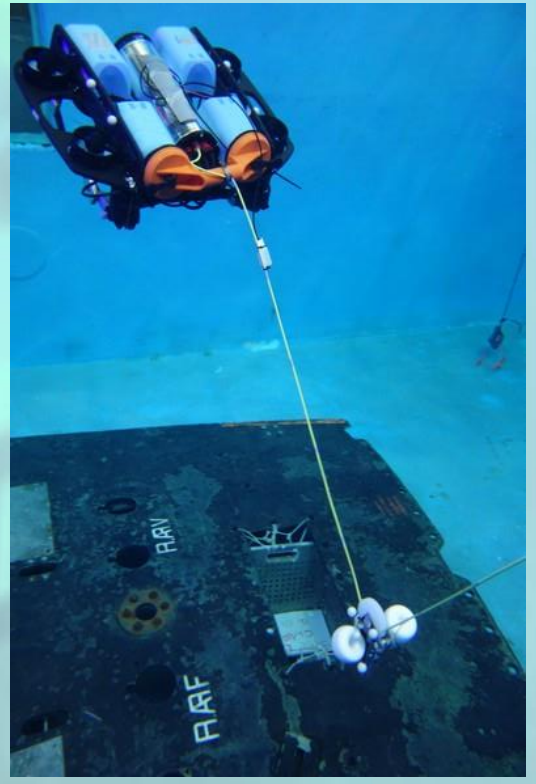
Localization system using umbilical

Localization system using umbilical

By measuring only the angles at the ends of the cable and the depth of the ROV, we propose a method:

- to estimate the ROV position without USBL, UWSN or sonar,
- that can be added easily to existing ROVs with a practical setup without motorization nor TMS

$$\begin{cases} x = l_{11}\cos(\alpha_1) + (l_{12}+l_{21})\cos(\alpha_2) + l_{22}\cos(\alpha_3) \\ y = l_0 + l_{11}\sin(\alpha_1) + (l_{12}+l_{21})\sin(\alpha_2) + l_{22}\sin(\alpha_3) \\ l_1 = l_{11} + l_{12} \\ l_2 = l_{21} + l_{22} \end{cases}$$



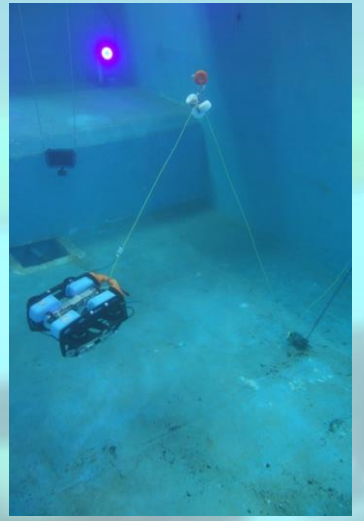
IMUs to measure angles at the extremity of the umbilical

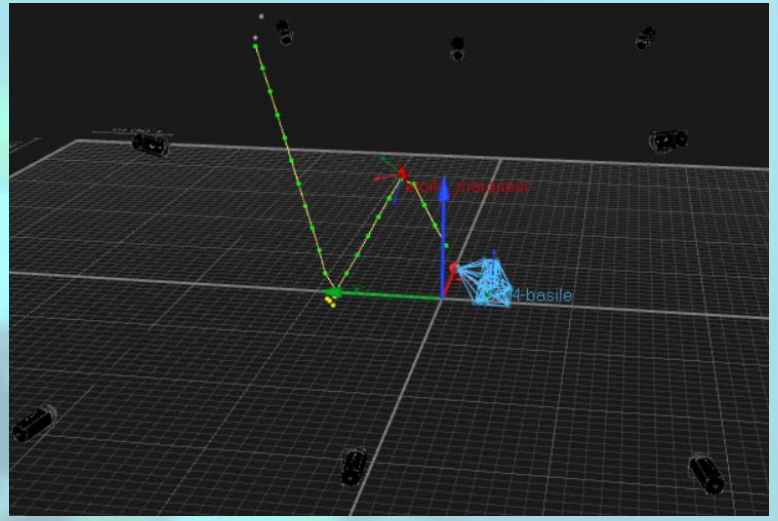
Work in collaboration with The COSMER, University of Toulon

Localization system

Measured were performed in the pool of the Cephismer, Base Navale of Toulon, France.

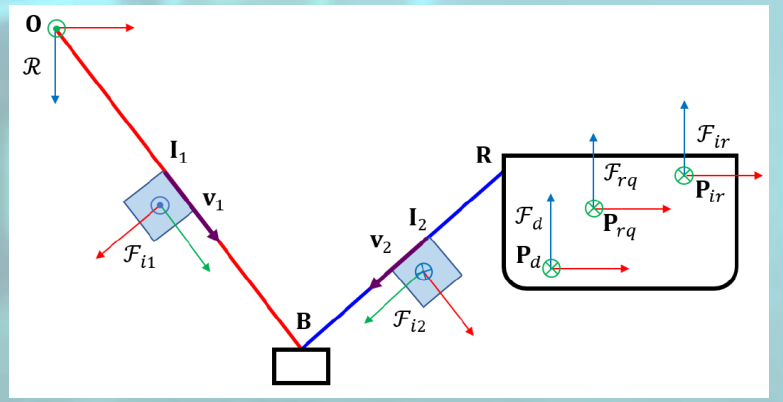
- The position of the ROV and umbilical shape were measured using Qualisys system
- Angles at umbilical extremities were measured using
  1. Qualisys system
  2. IMUs
- Estimation of the position were performed off-line.





Umbilical shape measured using Qualisys system

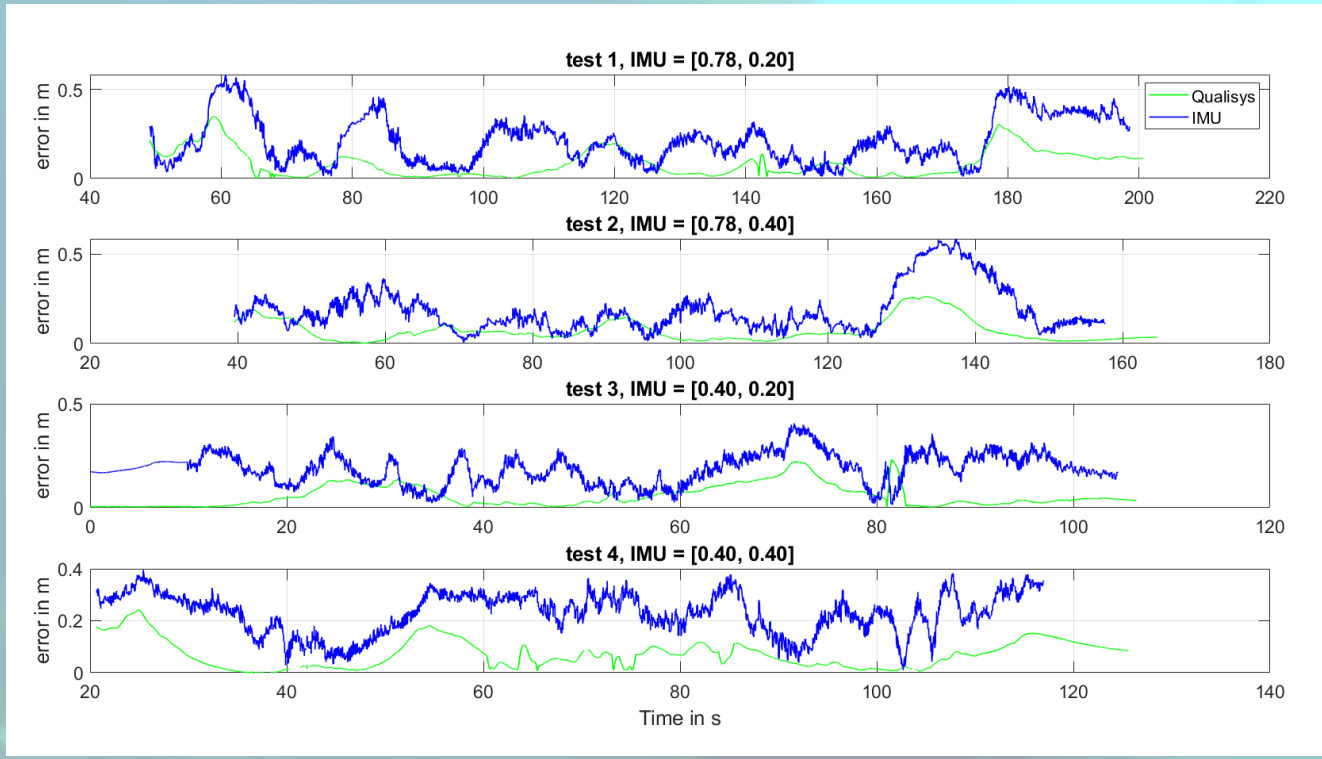
Polley to obtain a sliding ballast



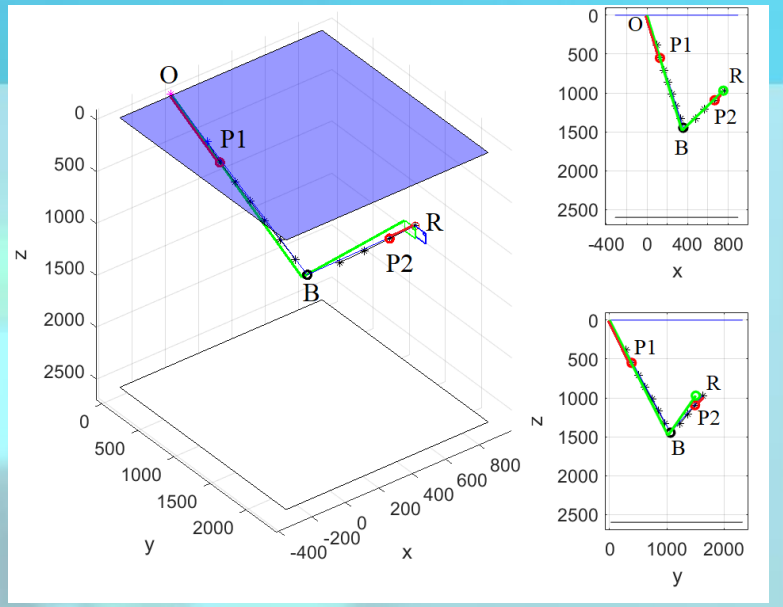
IMUs to measure angles at the extremities of the umbilical

Localization system

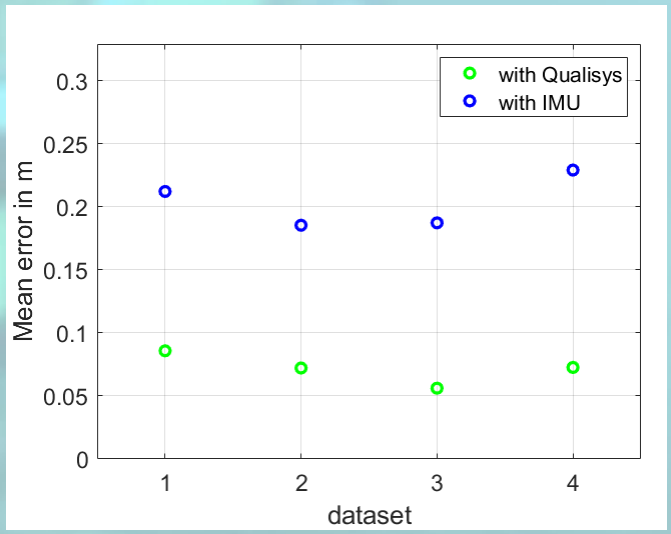
Angles measured using Qualisys system and IMUs



Error of position



Data measured by Qualisys



Mean error of the dataset

Conclusion

Conclusion

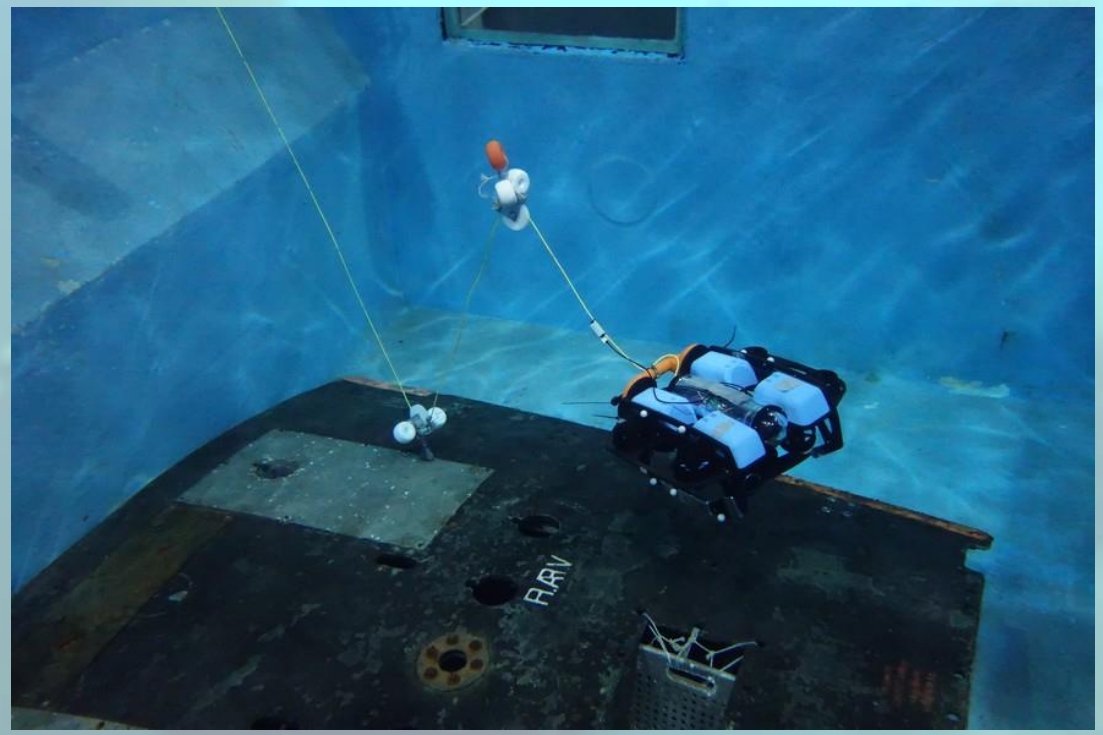
We propose a self-management of the umbilical

- Passive without motorization nor TMS,
- Avoiding entanglement,
- Providing a model of the umbilical simple to compute in real time,
- Allowing to estimate the position of the ROV.

Perspective

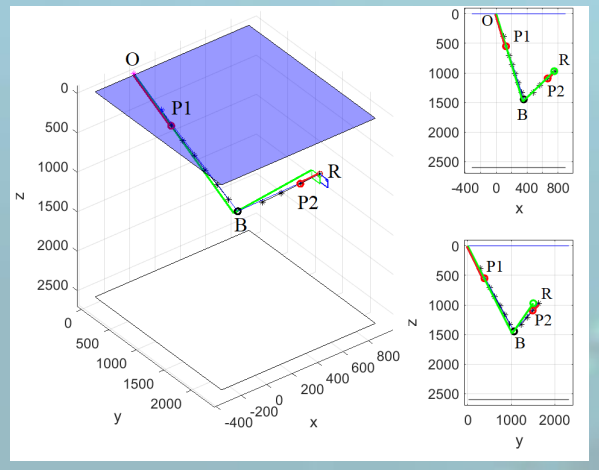
- Finish the general model for all orientation of the forces,
- Improve the method of estimation of the position.

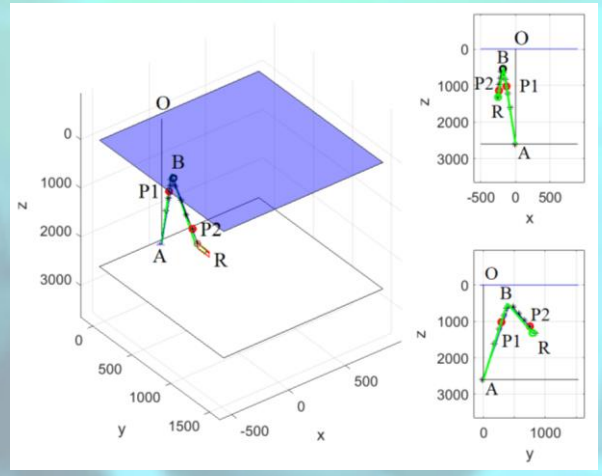
Thank you for your attention

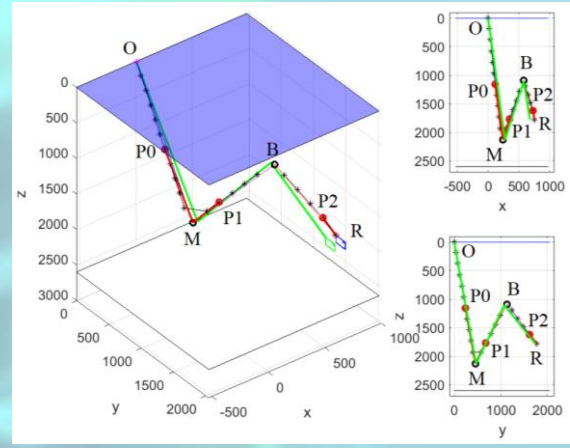


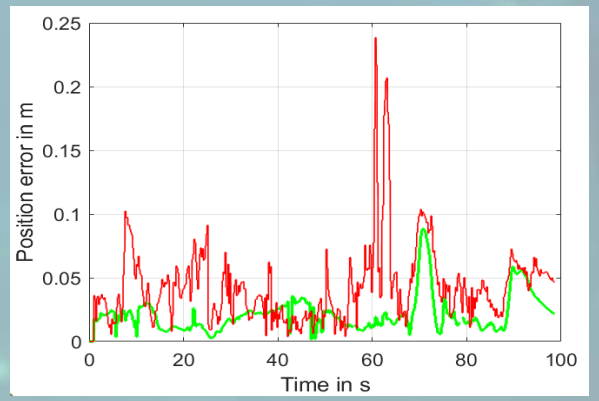
Localization system

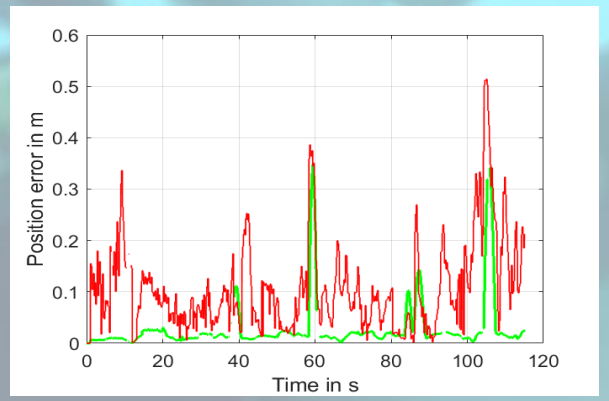
Angles measured using Qualisys system

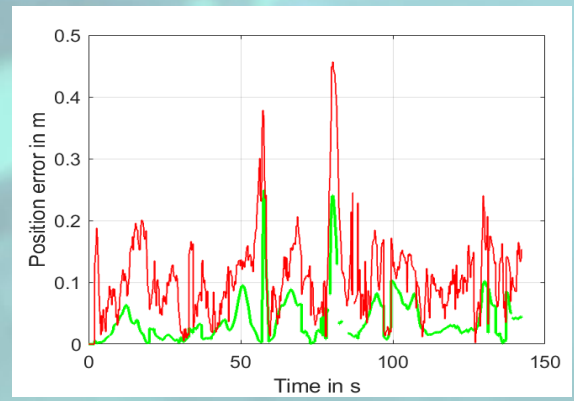












Green lines: estimation made with ideal measurement. Red lines: estimation made with non-ideal measurement.