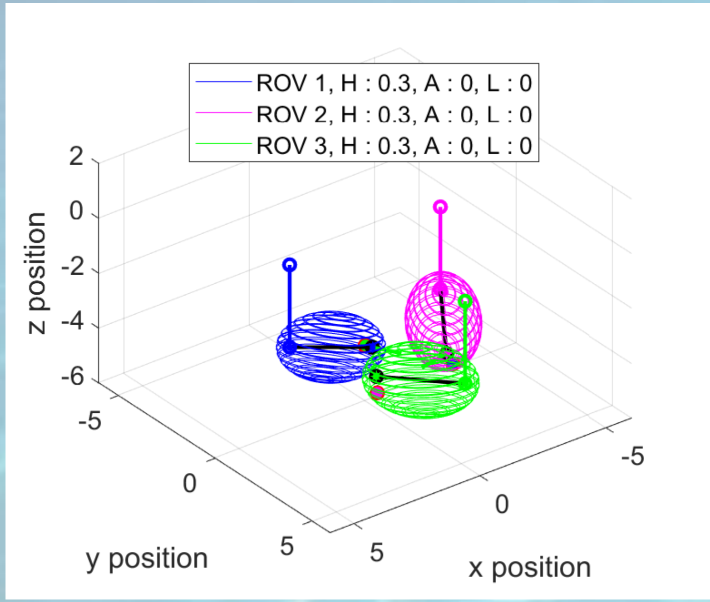
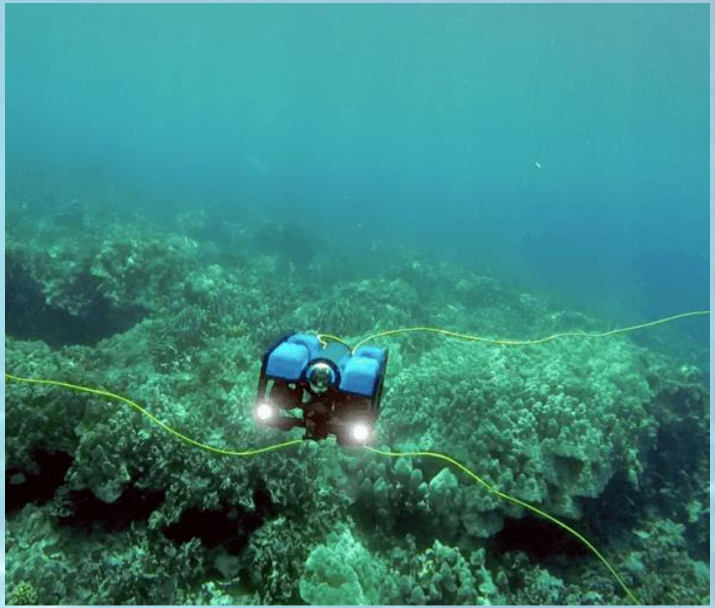
Ellipsoid tether model for collision avoidance in a fleet of ROVs



Christophe Viel

Robexday 2024



Summary

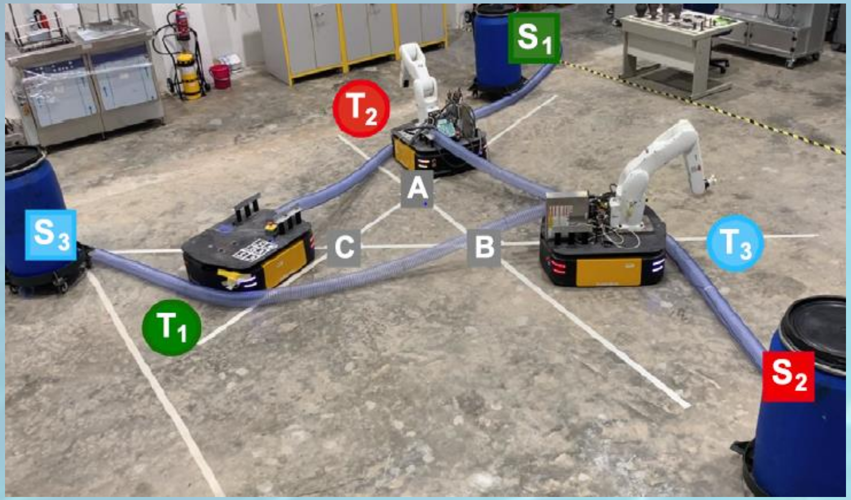
Introduction

1. Ellipsoid model
2. Obstacle model
3. Collision avoidance
4. ROV Personality
5. Simulation

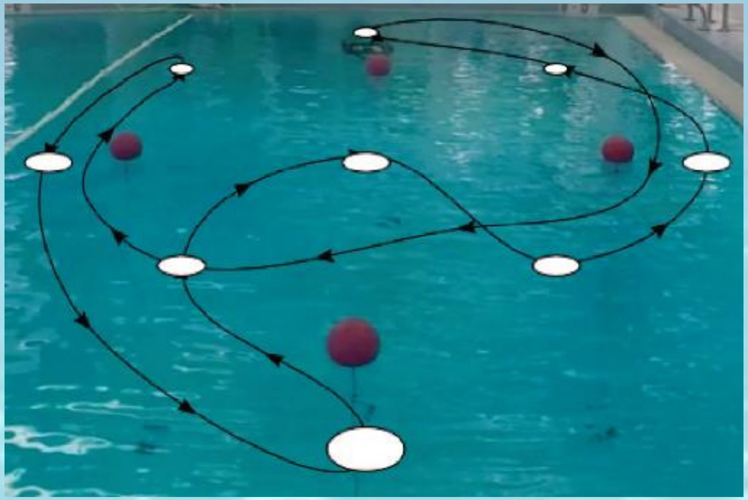
Conclusion

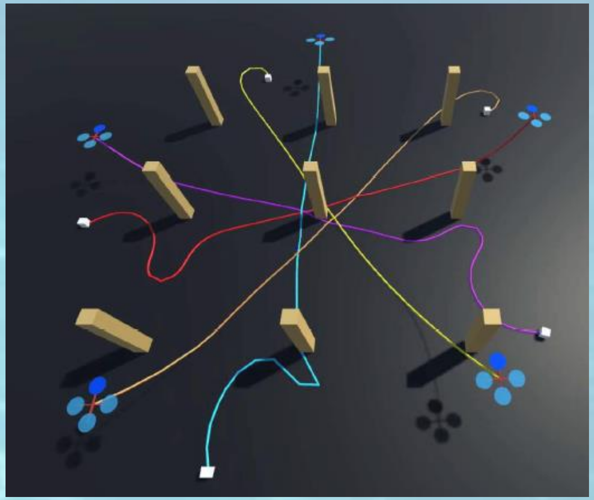
Introduction

Problematic: Despite recent progress in obstacle avoidance and trajectory planning for multiple robots, the problem of multiple tethered robots trying to reach their individual targets without entanglements remains a challenging problem



[1] Tether ground vehicle


[2] Tether underwater vehicle

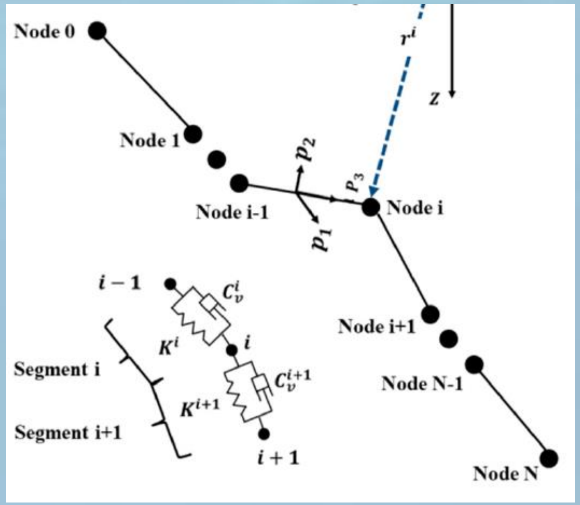

[3] Tether aerial vehicle

Introduction

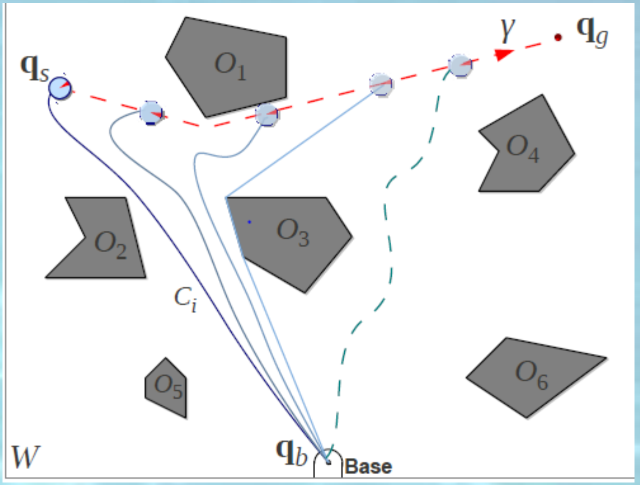
Problem of existing methods:

- Consider that plan environment OR that cable remain globally on the ground;
- Methods are heavy in calculation → many approaches are offline
- Consider taut cables forming straight lines between robots and bases OR require complex model of the tether;
- Consider the tether can come into contact with external obstacles.

➤ Is there a simplier model of the tether and its interaction ?



Finit-element model



Example of homotopy approach (induce hight dimension graph)

Summary

Ellipsoid tether model

A tether can be characterized by the three parameters **L**, **O** and **R**, supposed known, with:

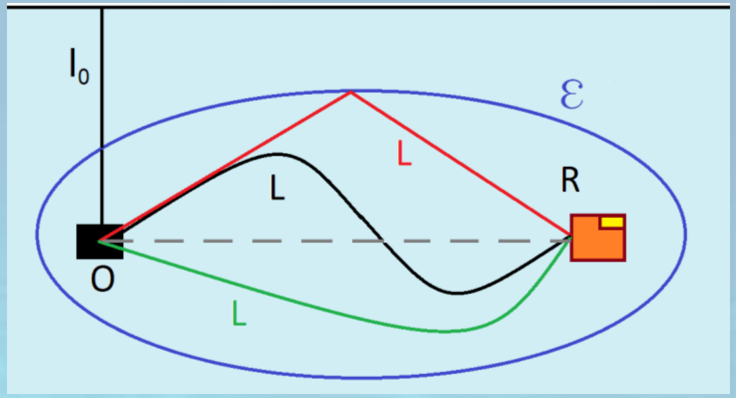
- R: ROV position
- O: Anchor/attachement position (supposed fixed)
- L: tether length

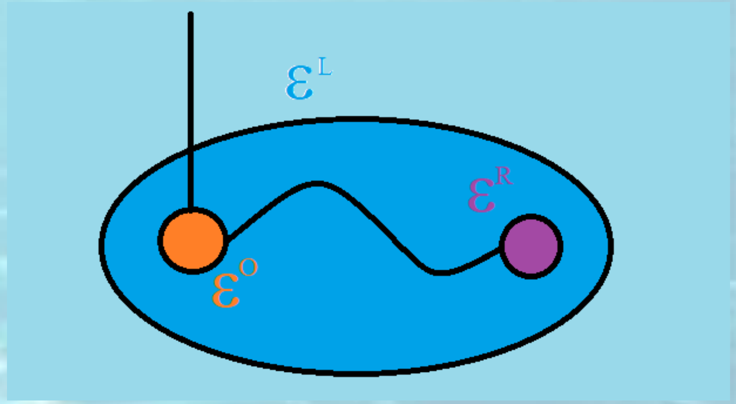
- The Anchor, ROV and tether can be contained in three ellipsoids ε^O, ε^R and ε^L.

- The semi-axis a_i, b_i and c_i of ε^L can be expressed as:

$$a_i = \frac{L_i}{2} \qquad c_i = b_i \qquad \theta_i = atan2\left(y_{R,i} - y_{O,i}, x_{R,i} - x_{O,i}\right)$$

$$b_i = \sqrt{\left(\frac{L_i}{2}\right)^2 - \left(\frac{d_i}{2}\right)^2} \qquad d_i = \|O_i R_i\| \qquad \psi_i = \begin{cases} asin\left(\frac{z_{R,i} - z_{O,i}}{d_i}\right) & if\ d_i > 0 \\ 0 & else \end{cases}$$





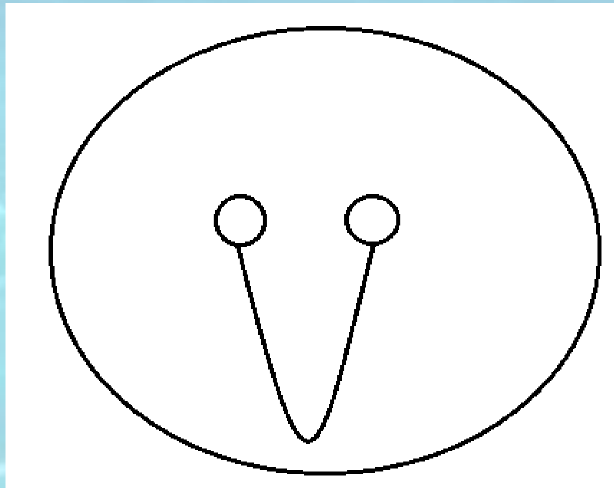
Ellipsoid tether model

- A model simple, but pessimistic:

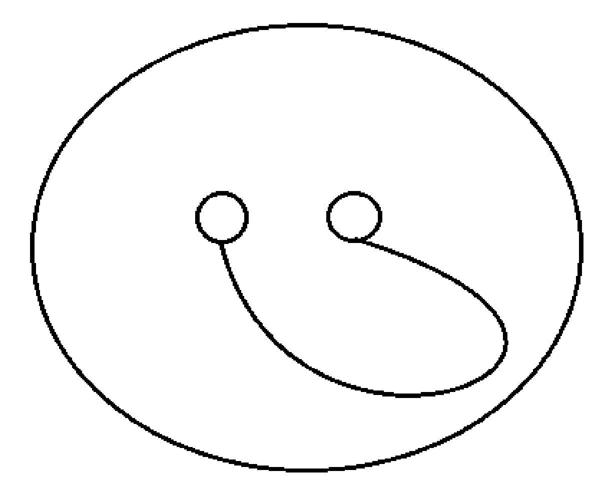
➢ The shape of the ellipsoid depends of the distance between the ROV and its anchor

➢ The management of tether's length is a method to reduce the pessimism

Example 1: O and R far away



Example 2: O and R close in static



Example 2: O and R close with dynamics

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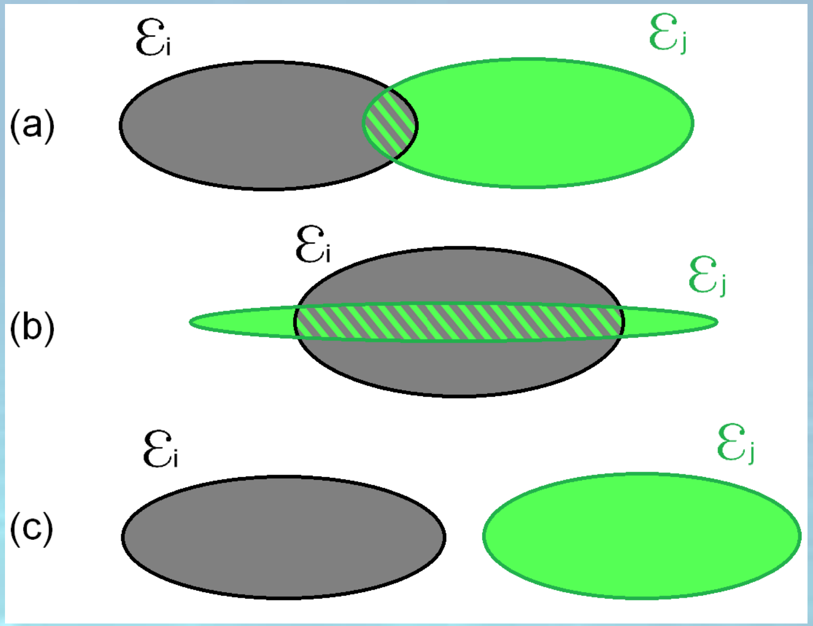
Intersection between ellipsoids

Theorem 1: ***[4]*** *Let's define two ellipsoids ε_i and ε_j with the associated two matrices $\boldsymbol{M_i}$ and $\boldsymbol{M_j}$. Let define the eigenvalues λ_{ij} of $\boldsymbol{M_{ij}} = \boldsymbol{M_i^{-1} M_j}$. It can be shown that:*

a) *If at least one of the eigenvalues have an imaginary part, then ε_i and ε_j intersect*

b) *If all eigenvalues are real positive, then ε_i and ε_j intersect and one ellipsoid crosses the other completely*

c) *Else, there is not intersection between ε_i and ε_j or the two are perfectly superposed*



[4] S. Alfano and M. L. Greer. Determining if two solid ellipsoids intersect. Journal of guidance, control, and dynamics, 26(1):106–110, 2003.

Obstacle model

<u>1) Full obstacle</u>:

- An irregular shape object
- Considered as "untouchable"

➢ Contained inside an ellipsoid

<u>2) Tether obstacle</u>:

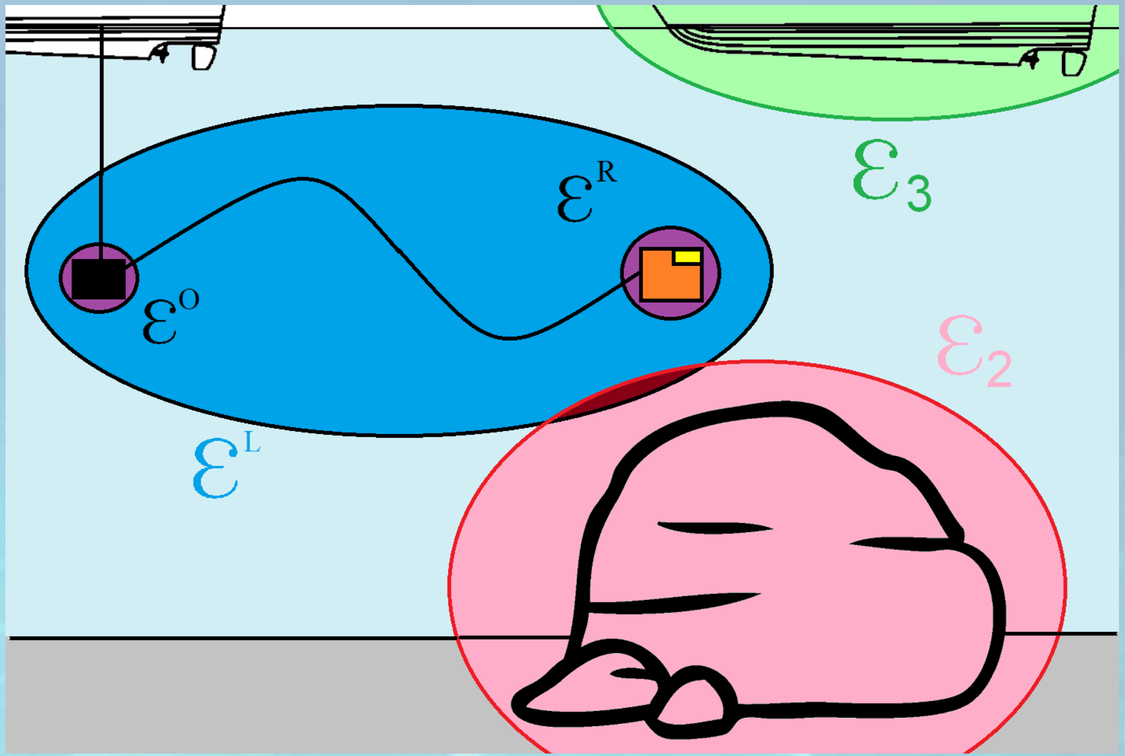
- Tether, cable or obstacle with more relaxed conditions on collision

➢ Contained inside an system of ellipsoids

<u>3) Plan obstacle:</u>

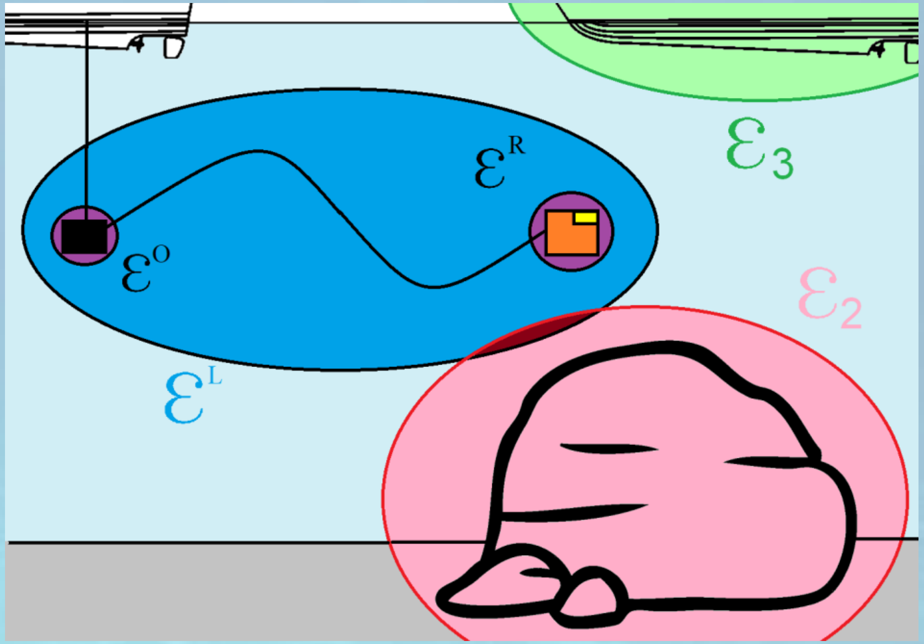
- A plane surface P, to model for example seabed, surface or wall

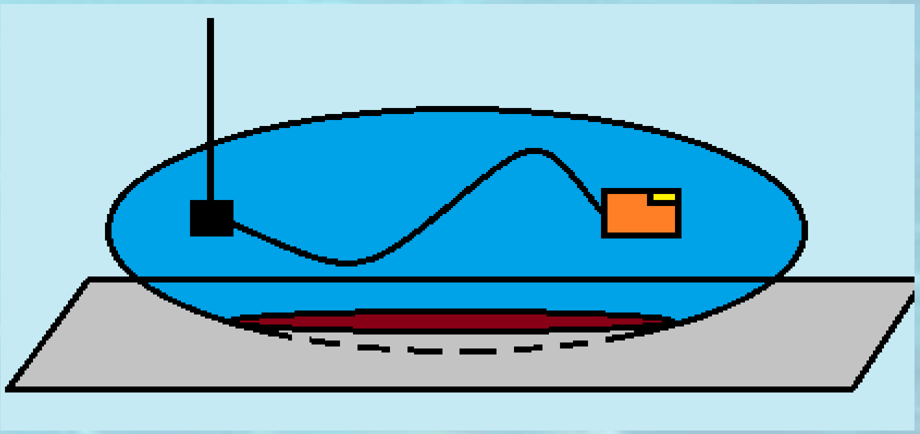
➢ Modelled by a plane tangent to the surface



Full obstacle et Plan obstacles

Theorem 2. *Consider two geometric volumes V_i and V_j which can be contained respectively inside ellipsoids $\mathcal{E}_i$ and $\mathcal{E}_j$, i.e. $V_i \subset \mathcal{E}_i$ and $V_j \subset \mathcal{E}_j$. If there is not intersection between $\mathcal{E}_i$ and $\mathcal{E}_j$, i.e. $\mathcal{E}_i \cap \mathcal{E}_j = \emptyset$, them there is not intersection (and so collision) possible between S_i and S_j, i.e $V_i \cap V_j = \emptyset$.*





Note these conditions must be respected for the three ellipsoids ε^O, ε^R and ε^L.

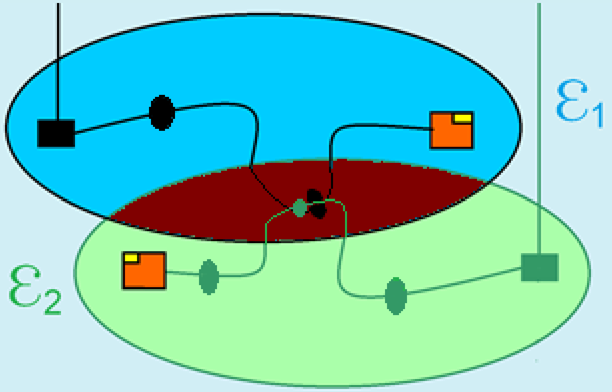
Tether obstacle

It can be observed that the risk of entanglement between the two cables appears only when:

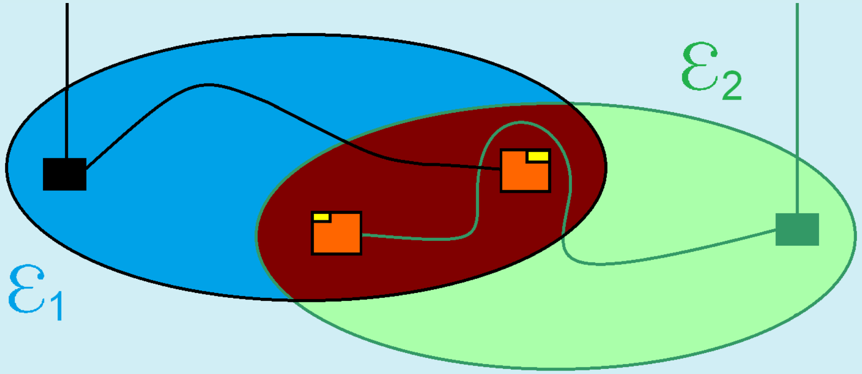
a) there is a risk of snagging when the tether i is in contact with
   1. objects attached to cable j (ballast, buoy, sensor, etc...);
   2. a tether naturally twisted.
   3. ROV or anchor

b) the end O or R passes inside a loop, risking of creation of a knot;

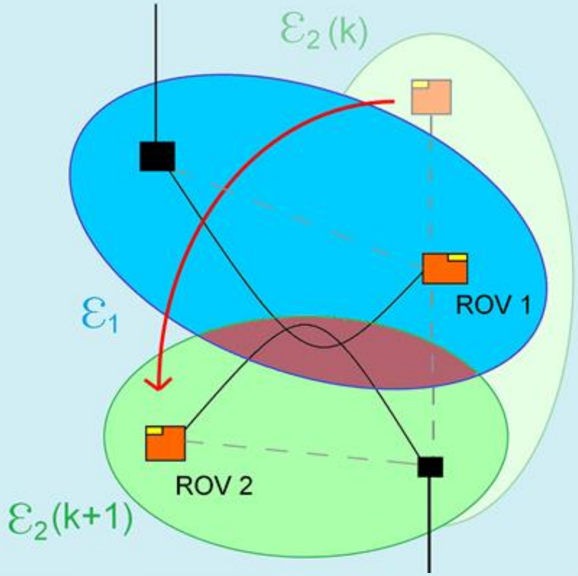
c) one cable tries to pass between the two ends of the other tether.



Intersection ε_i^L and ε_j^L



Intersection ε_j^L with ε_i^O or ε_i^R

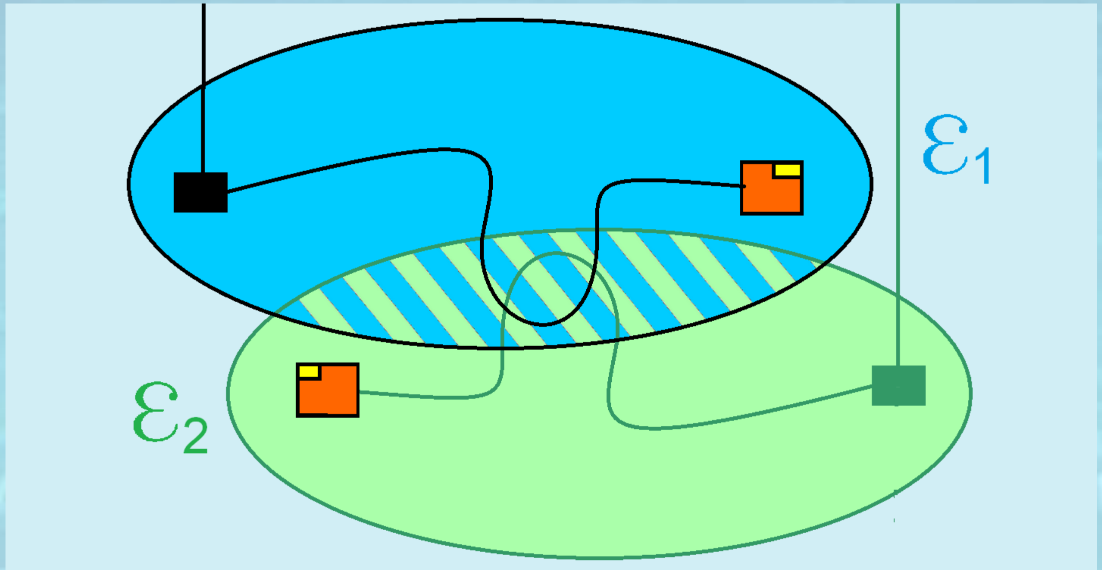


"Crossing collision"

Tether obstacle

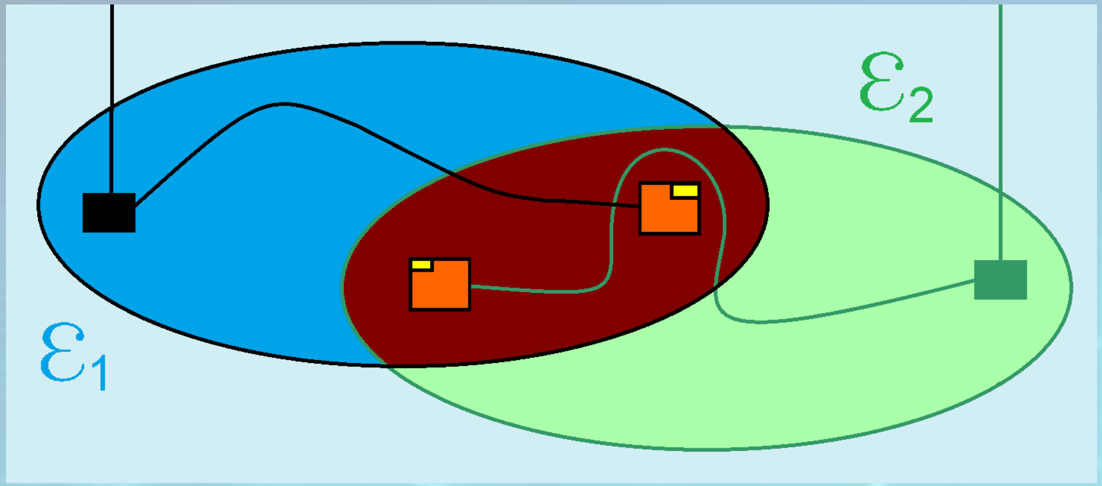
If no objects are attached to cable j (ballast, buoy, sensor, etc...) and cable is not twisted

→ $\varepsilon_i^L \cap \varepsilon_j^L$ is not considered as collision



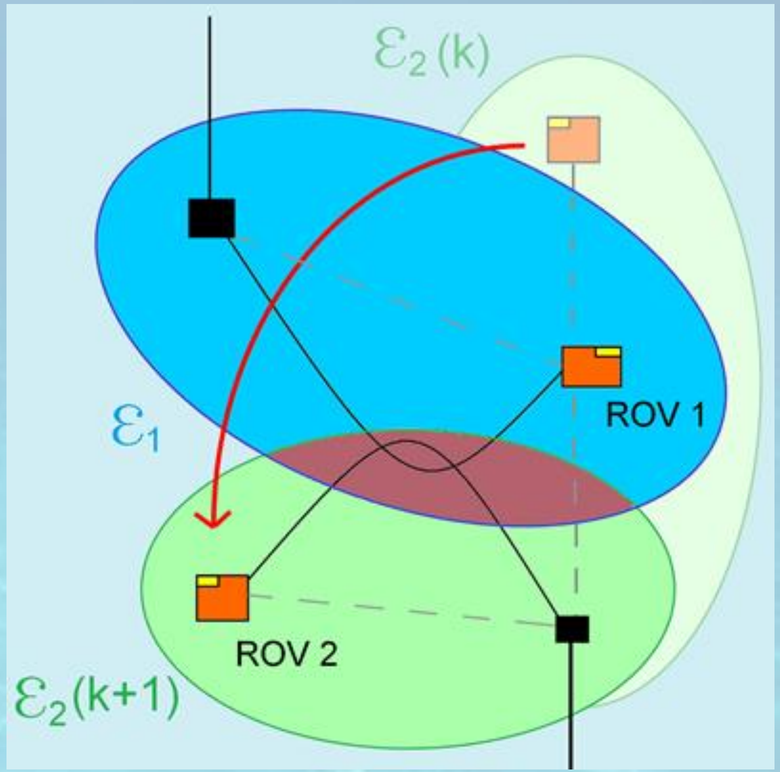
Tether obstacle

Two type of collision considered:



Intersection ε_j^L with ε_i^O or ε_i^R:

“Intrusion collision”

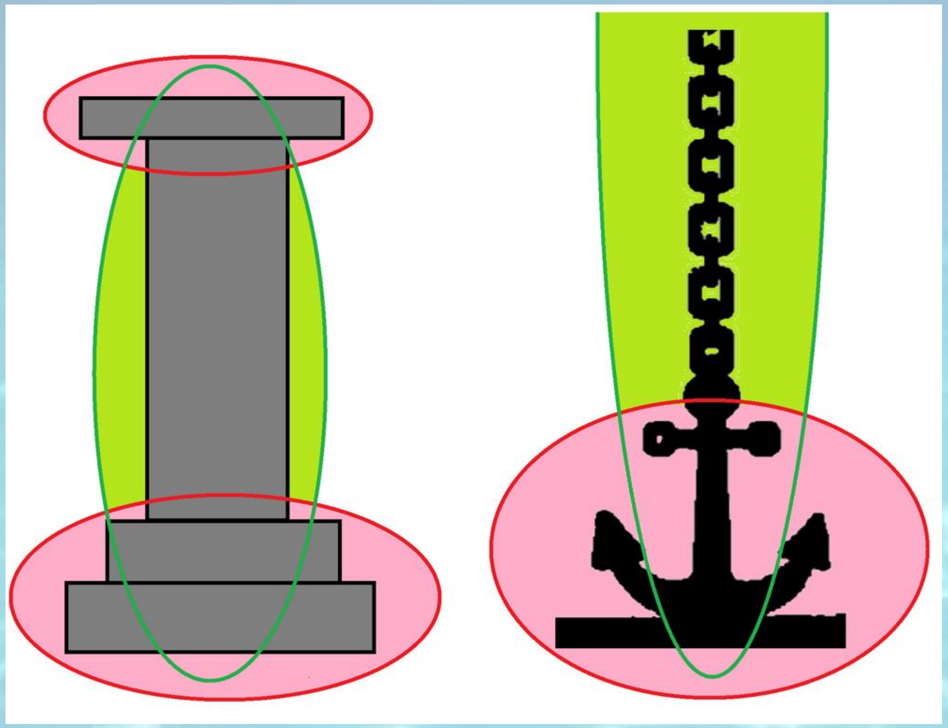


“Crossing collision”

Tether obstacle

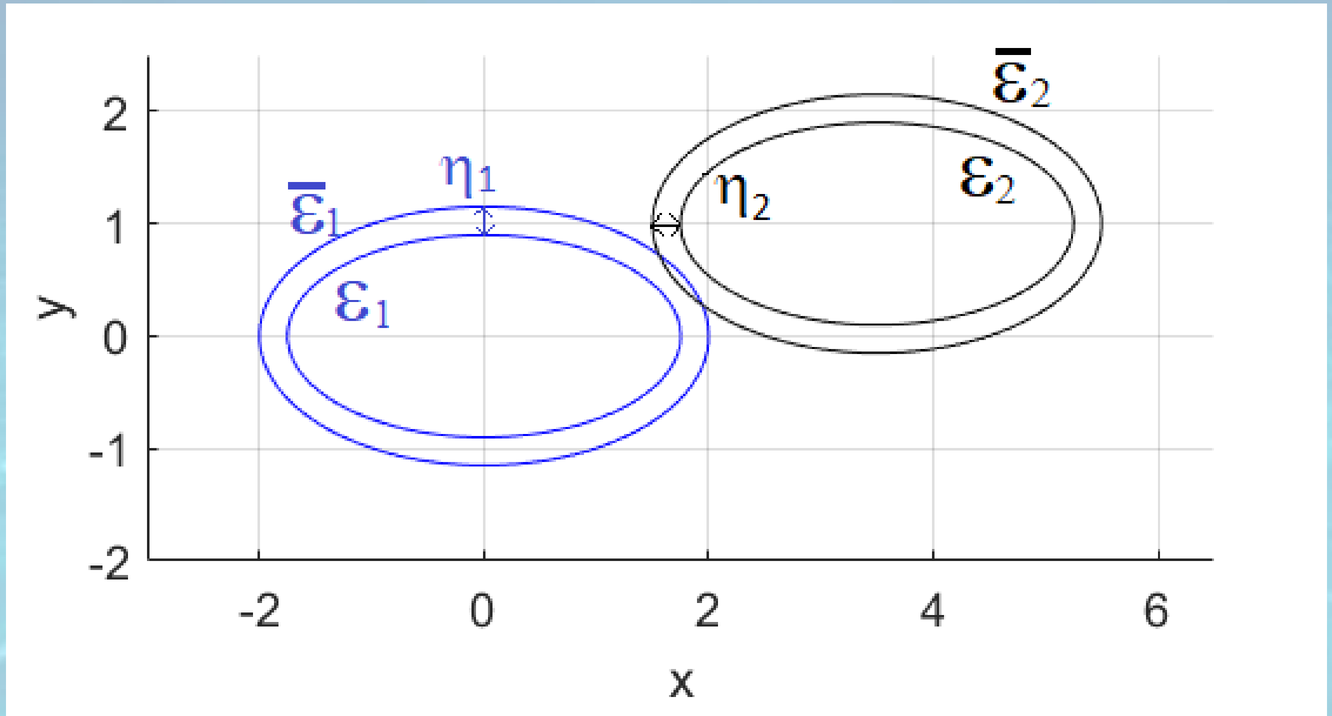
Remark:

Some obstacles can be assimilated to a tether obstacle:



Prediction collision: ellipsoid layer

To prevent collision, the ellipsoids are enveloped in a larger one, called a “layer”:



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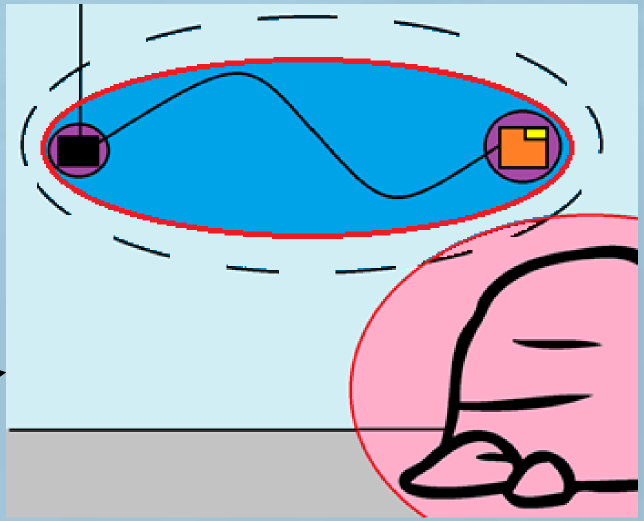
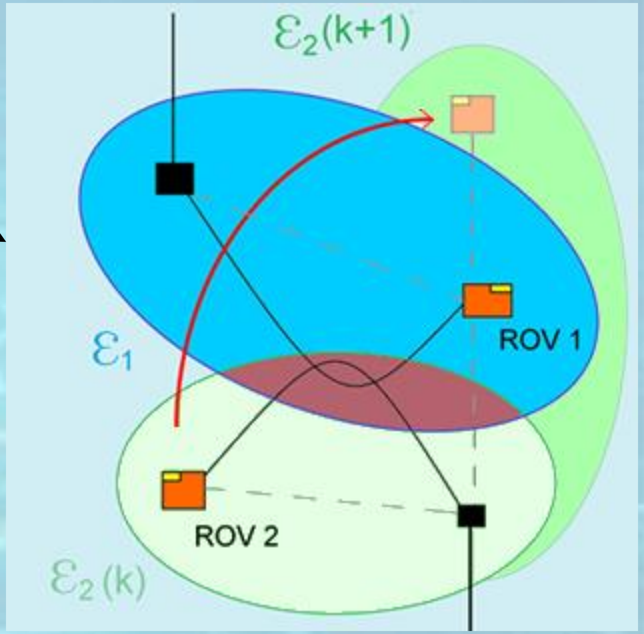
Collisions avoidance

Several methods to avoid collision:

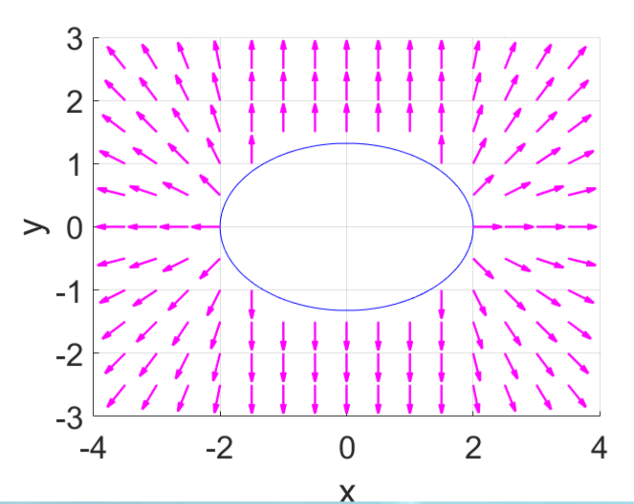
1. Reduce the tether length
2. Anti-crossing collision strategy
3. Repelling strategy
4. Bypass strategy





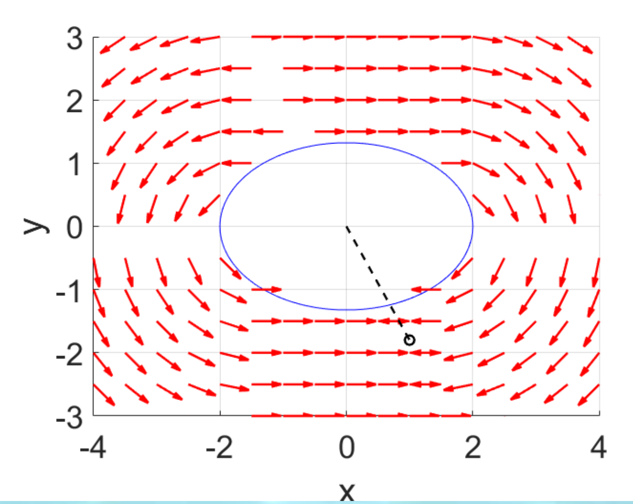
Repelling strategy

Repelling strategy to move the ROV away from the obstacle, Combination of three poential field:



Repulsive potential field

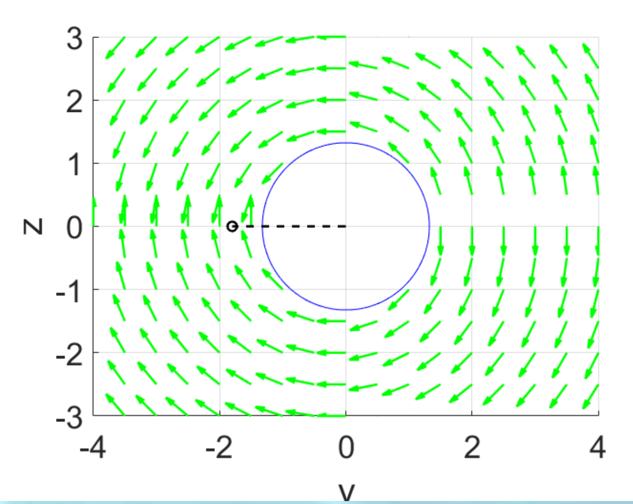
+



Rotary potential field

around main axis

+

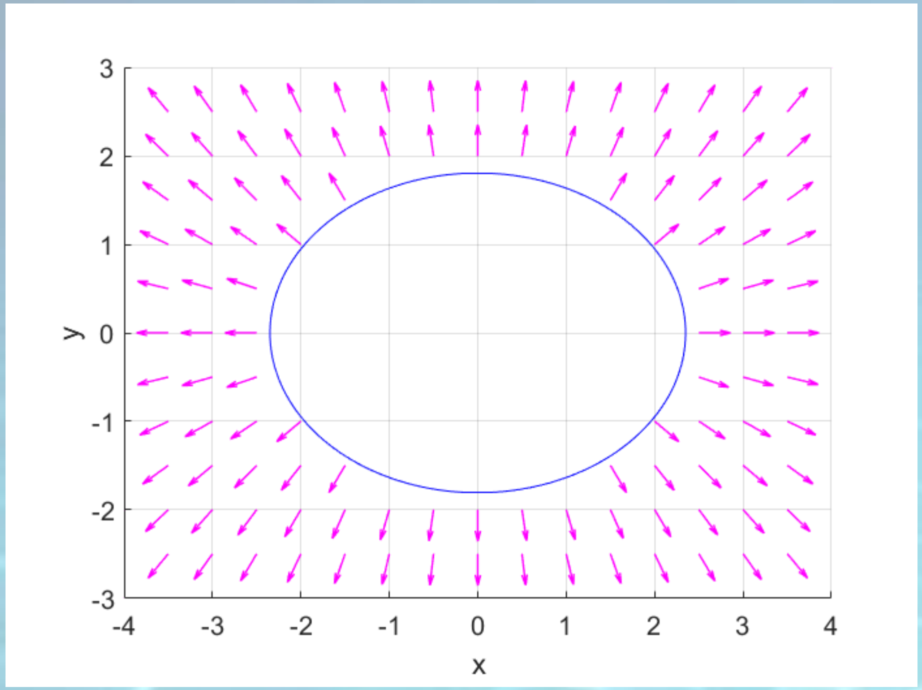


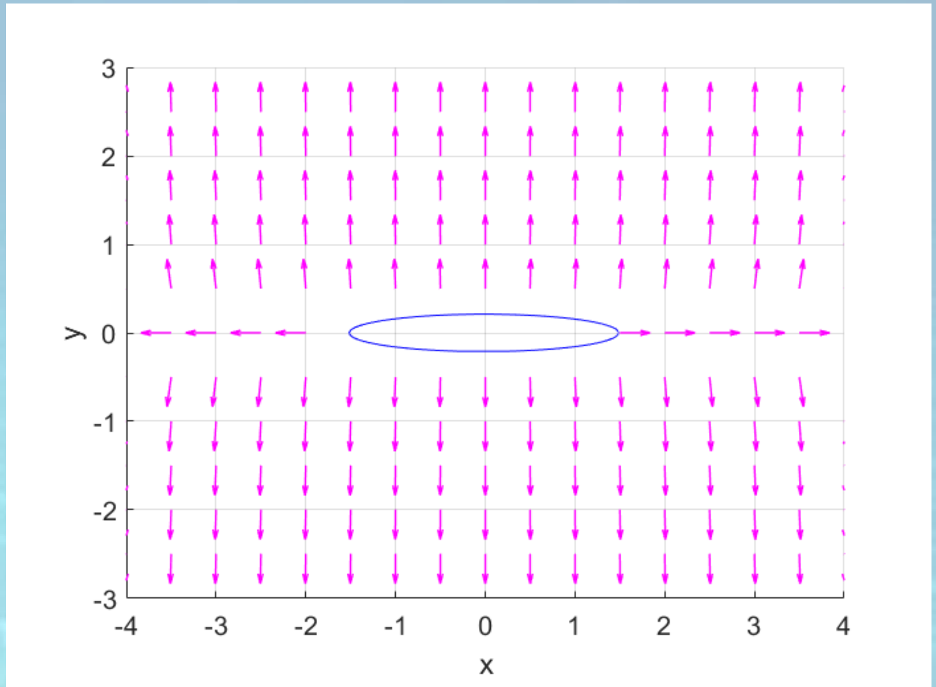
Rotary potential field

around second axis

Repelling strategy

Potential field using the Jacobian of the ellipsoid:



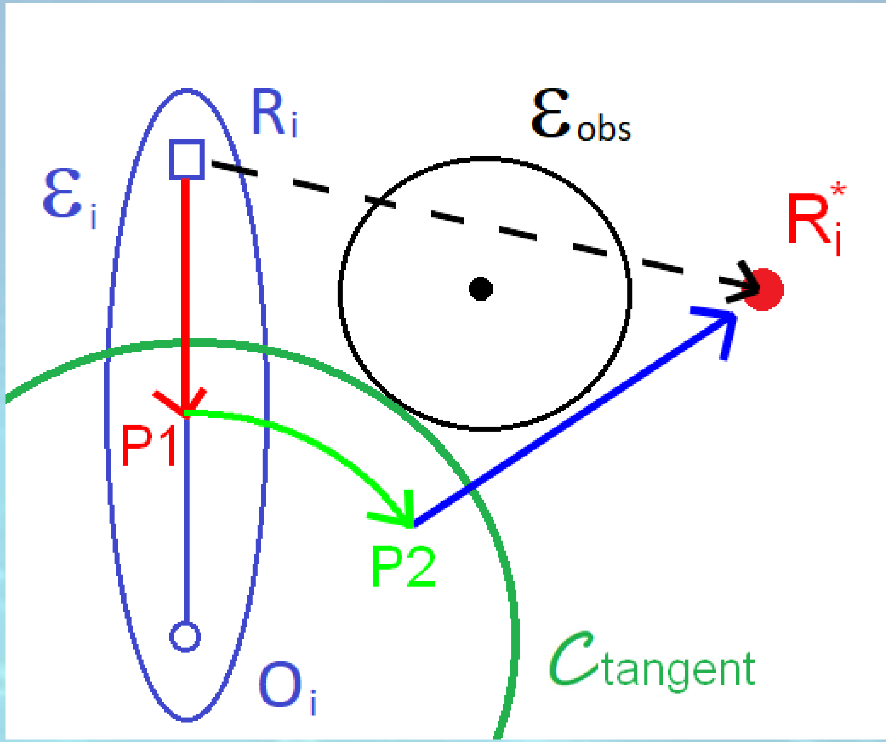


→ Problem when the obstacle ellipsoid is flat

Bypass strategy

The bypass strategy is divided in three steps :

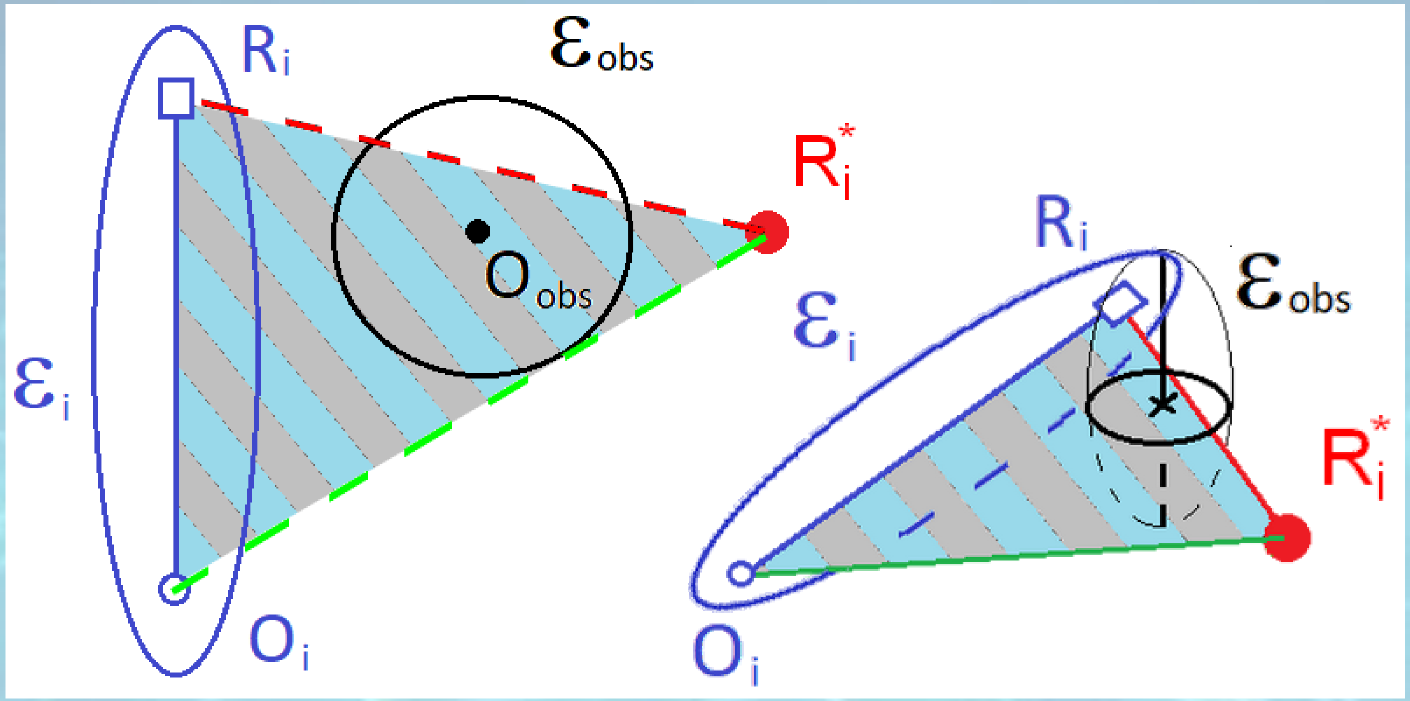
1. Folding the system inside a folding circle area tangent to the obstacle
2. Go around the obstacle staying inside tangent circle
3. Go towards the target once the obstacle has been bypasse



Note: the repelling strategy and tether length management are used in parallel

Bypass strategy

<u>Detection of obstacle on the way:</u>



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ROVs personality

If all the cars want to go straight ahead but respect the rule “right of way” rule, the situation will remain eternally blocked. The same if all cars decide to ignore the rule (crash).

But if just one “aggressive” car forces its way through while the others stay “passive”, the situation will be unblocked.

→ **Having different behavior can help to solve conflict.**

ROVs personality

- **Hazardousness (H)**: the more dangerous the ROV/obstacle i, the more ROVs try to keep their distance from it → Larger layer
- **Aggressiveness (A)**: if an ROV i is more aggressive that an ROV/obstacle j **AND** at least as hazardous → no bypass strategy
- **Laziness (L)**: if an ROV i is lazier that an other ROV/obstacle j **AND** at least as aggressive, it will slow down during the collision avoidance

ROVs personality

It can be observed that:

1. Fixed obstacles will have an infinit agressivity and laziness : **A= ∞, L=∞**
2. A large hazardousness H can be given to items with
   - high velocity
   - truly hazardous or fragile
   - A priority ROV
3. Laziness can be used for ROV/vehicle which have difficulty maneuvering.

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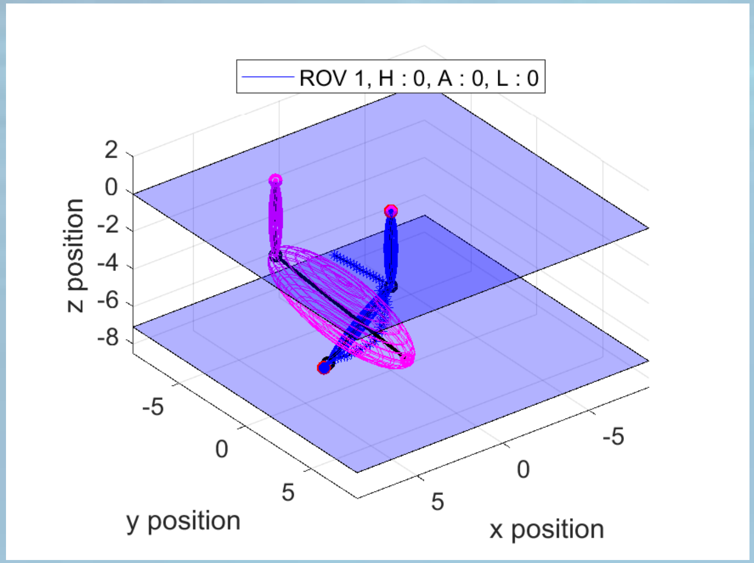
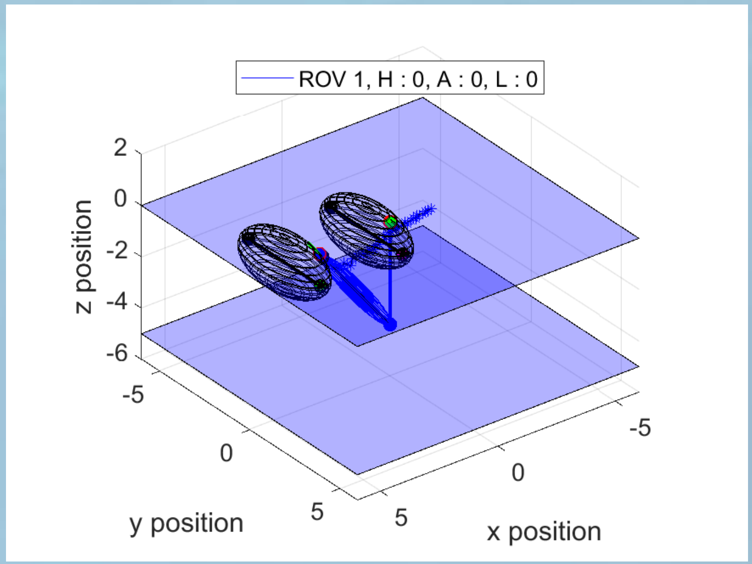
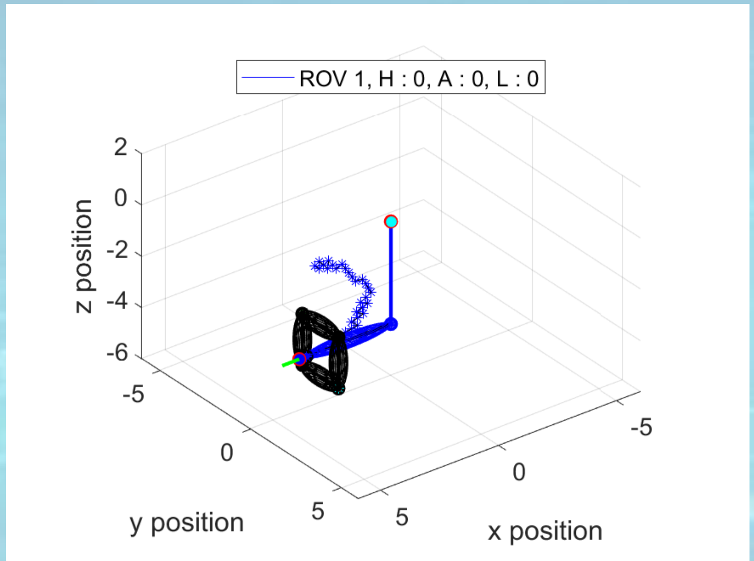
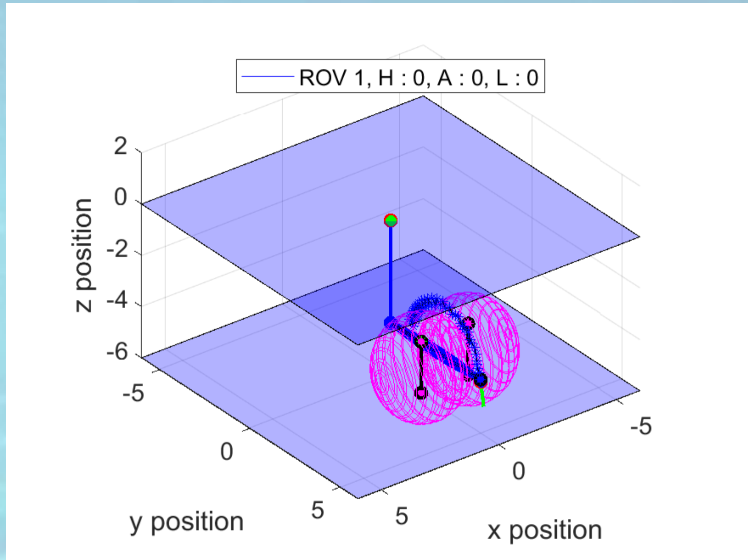
Simulations

<u>Test with 1 ROV</u>:





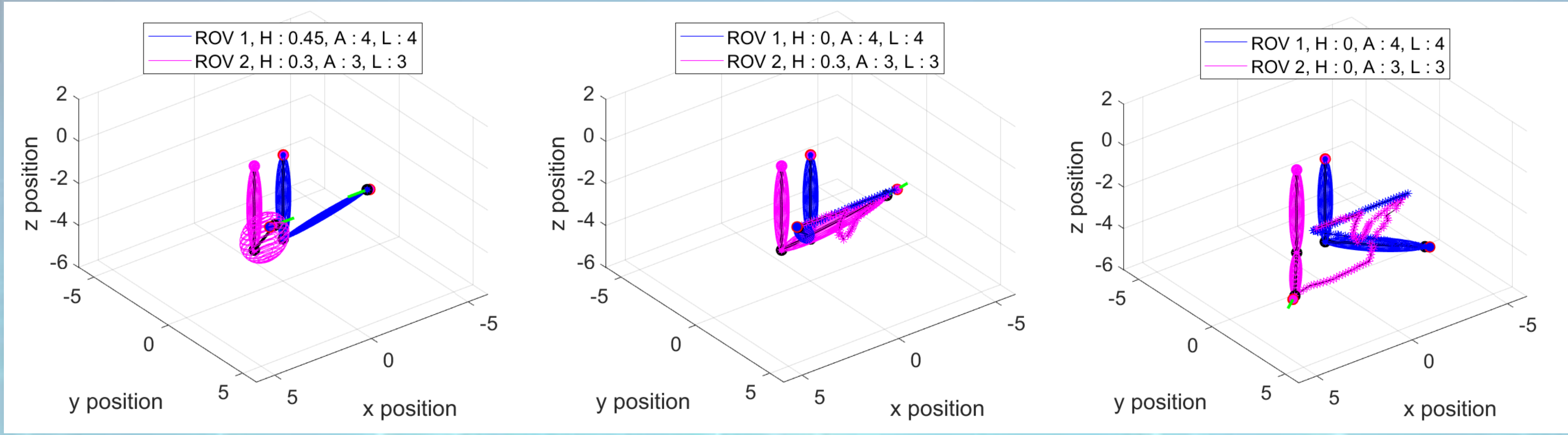




Link: https://youtu.be/l8kwkpFDTKY

Simulations

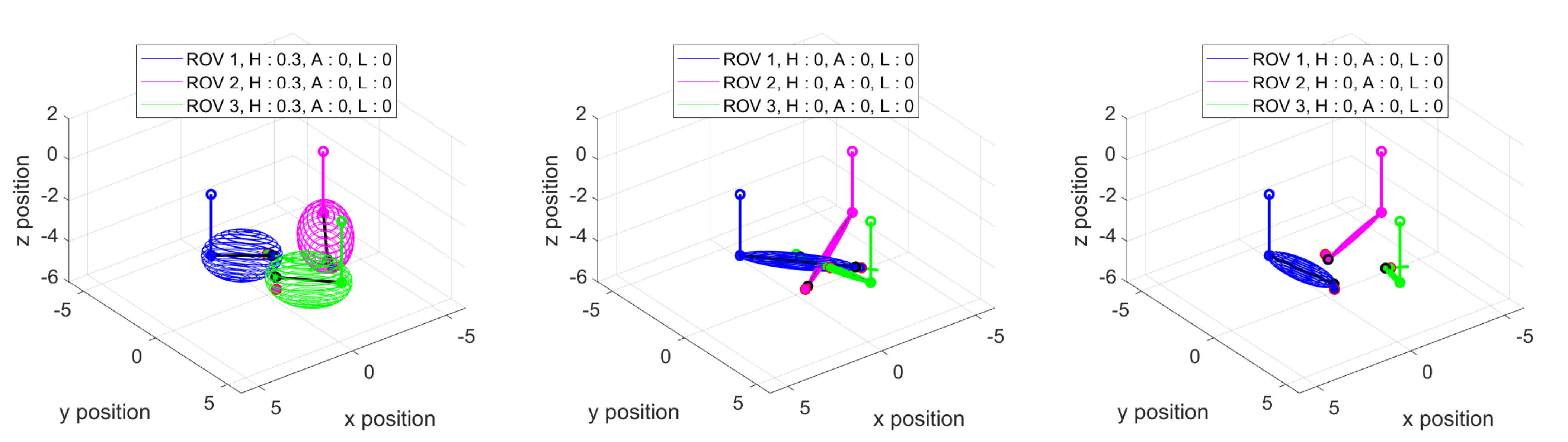
<u>Two ROVs</u>: the influence of personalities



Link: https://youtu.be/MVhnOfxujIY

Simulations

Three ROVs:



Link: https://youtu.be/No91xVVsZv4

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Conclusion

We propose:

- A simple 3D-model of an un-stretched ROV tether based on ellipsoid
- A collision avoidance method between the different tethers in a fleet of ROVs and the external obstacles
- The introduction of ROV personality to smooth the collision avoidance between ROVs and solve some local minima.

Bibliography

[1] "Planning coordinated motions for tethered planar mobile robots", Xu Zhang, Quang-Cuong Pham, Robotics and Autonomous Systems, 2019.

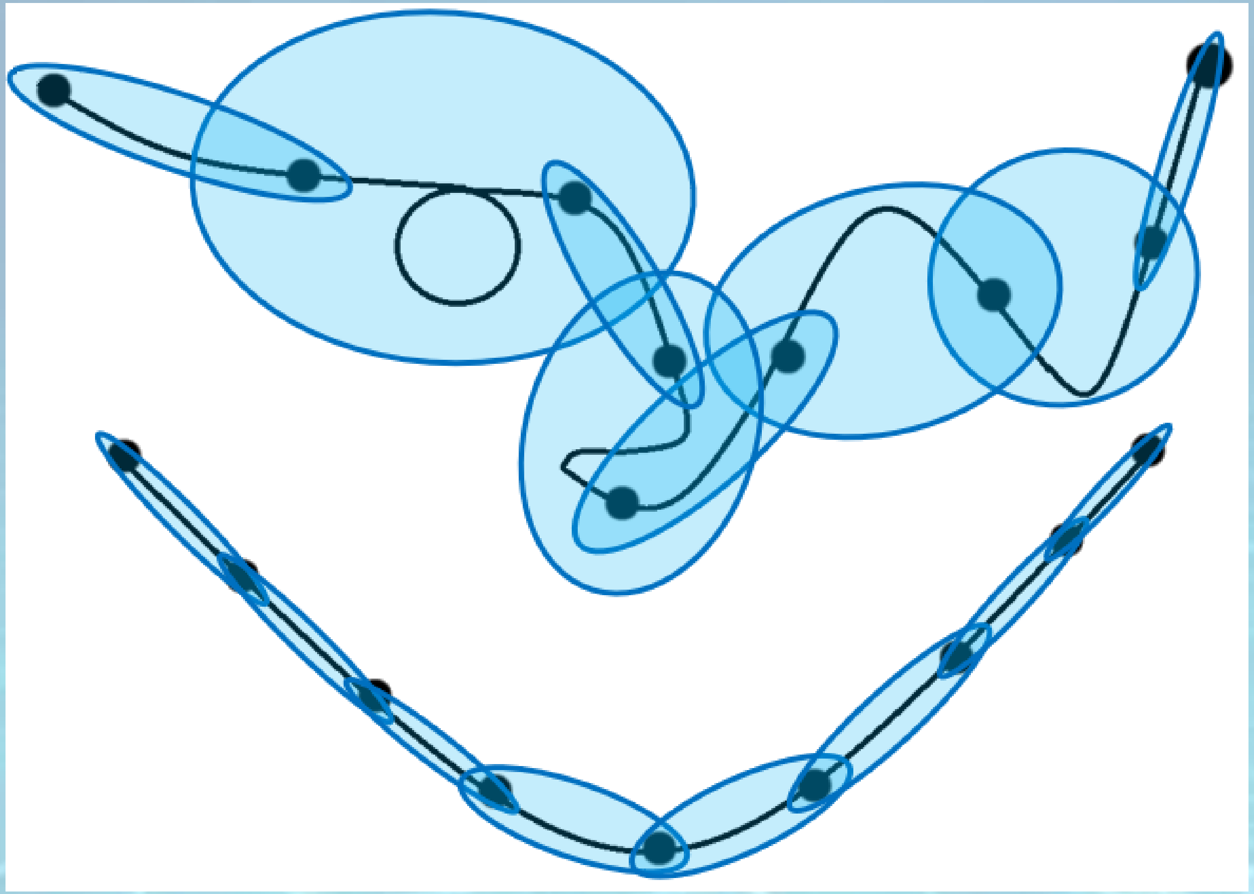
[2] "Planning and Executing Optimal Non-Entangling Paths for Tethered Underwater Vehicles", Seth McCammon and Geoffrey A. Hollinger, ICRA, 2017.

[3] "NEPTUNE: Nonentangling Trajectory Planning for Multiple Tethered Unmanned Vehicles", Muqing Cao , Kun Cao , Shenghai Yuan , Thien-Minh Nguyen, and Lihua Xie, IEEE Transactions on Robotics, 2023.

[4] S. Alfano and M. L. Greer. Determining if two solid ellipsoids intersect. Journal of guidance, control, and dynamics, 26(1):106–110, 2003.

Ellipsoid tether model

- Remark:



In this study, we considere only the position of O and R are known