Electric sense based perception for underwater robots

Stéphane Bazeille
Vincent Lebastard
Frédéric Boyer
Ecole des Mines de Nantes

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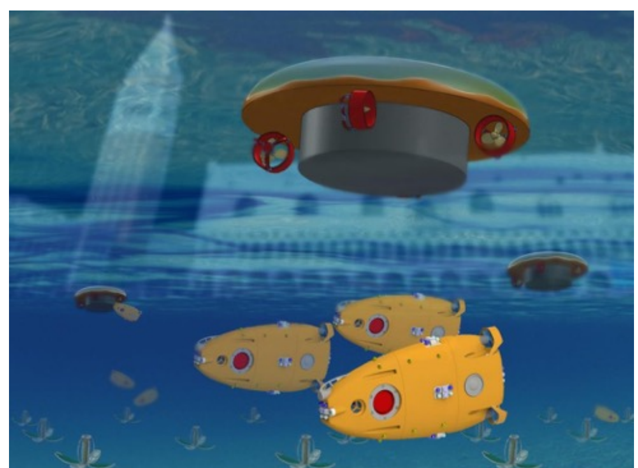
subCULTron

SUBCULTRON

SUBMARINE CULTURES PERFORM LONG-TERM ROBOTIC EXPLORATION OF UNCONVENTIONAL ENVIRONMENTAL NICHES

- EU FET project started in April 2015.
- Goal: Collective long-term monitoring of the Venice lagoon.
- Why Venice ? To understand changes due to humans activities to protect the lagoon.



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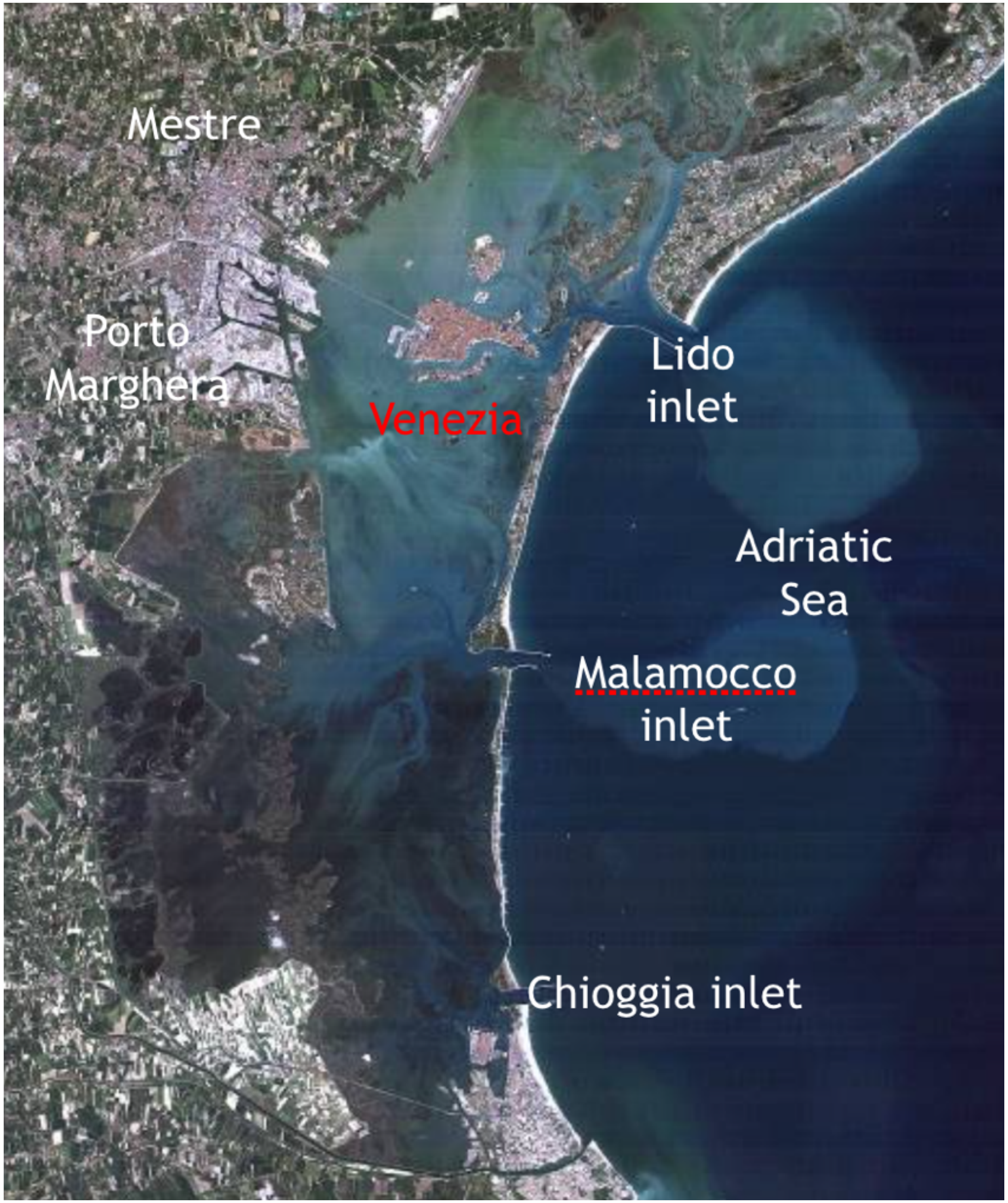


About Venice

Length: 51 km
Width: 12 km

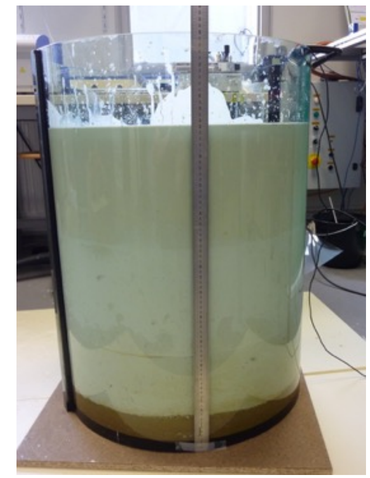
Shallow water embayment of 540 km^2
8% land above sea
92% water composed of: channels (12%) shallows, mud flats and salt marshes (80%)

Problems: confined, turbid, varying salinity, water current, various biological activities.

Why electric sense ?

- There is no sensor technology equipping underwater robots in confined spaces and turbid waters…

- Sonar fails due to multiple echoes…
- Vision fails due to turbidity…



- Some fish living in such an environment developed a new sense (**electric sense). Taking inspiration from nature we developed artificial electric sense for robots.**

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Main goal of subCULTron

- **Monitor a complex environment for underwater robots.**

- Idea: **Collect** l**ong-term data collection with a robot swarm:**

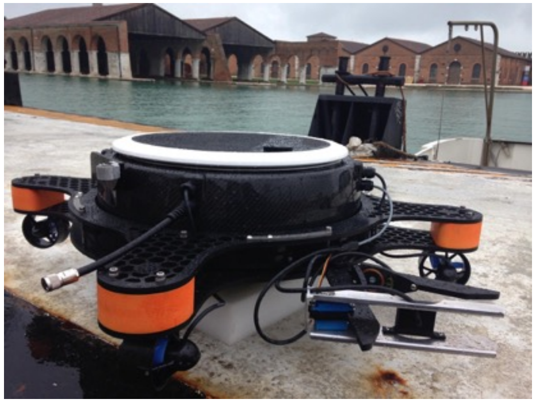
pH, temperature, salinity, conductivity, turbidity, pressure, water level, information about marine fauna and flora.

The swarm composed of 3 different robots:

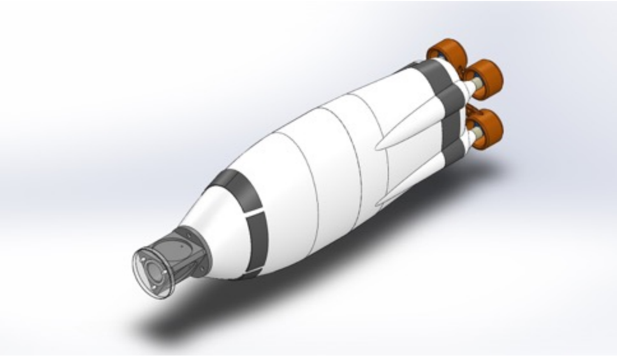
- **aPads: floating platforms** used as geolocalization satellites and recharge station for the swarm.
- **aMussels: robot sat on the seabed** used as landmarks for aFish as well as storage station.
- **aFish: AUV** used to explore the environment and collect data.

3 robotic species inspired by nature

5 aPADs
(water lily)

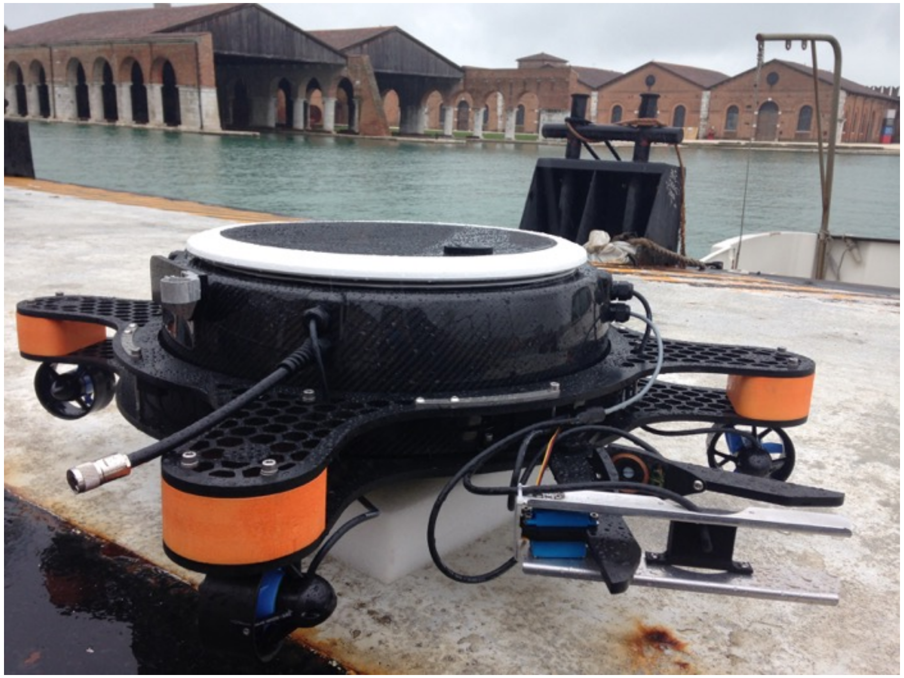


25 aFISH
(elephant fish)



120 aMUSSELs
(razor shell)

aPads



- Size : 70 cm x 70 cm, 30 kg
- Motors: 4 thrusters positioned in X configuration
- Long autonomy: big battery and solar panels
- Recharge base, plier for autonomous docking
- **Globally localized** (GPS) and communication with humans, coordination of the swarm.

aMussels

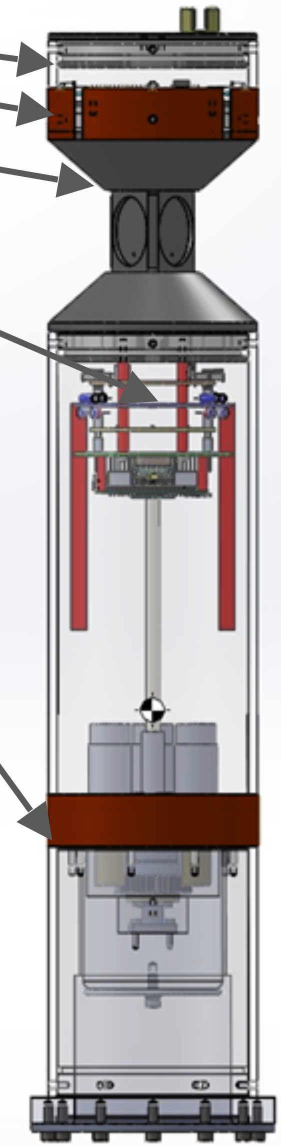
Sensor chamber

Receivers e-sense

Docking unit

Electronics sandwich and batteries

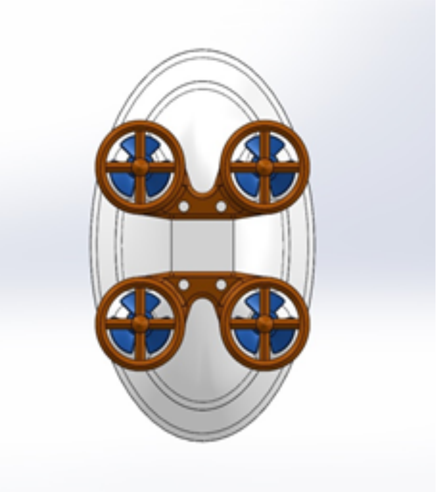
Emitter e-sense

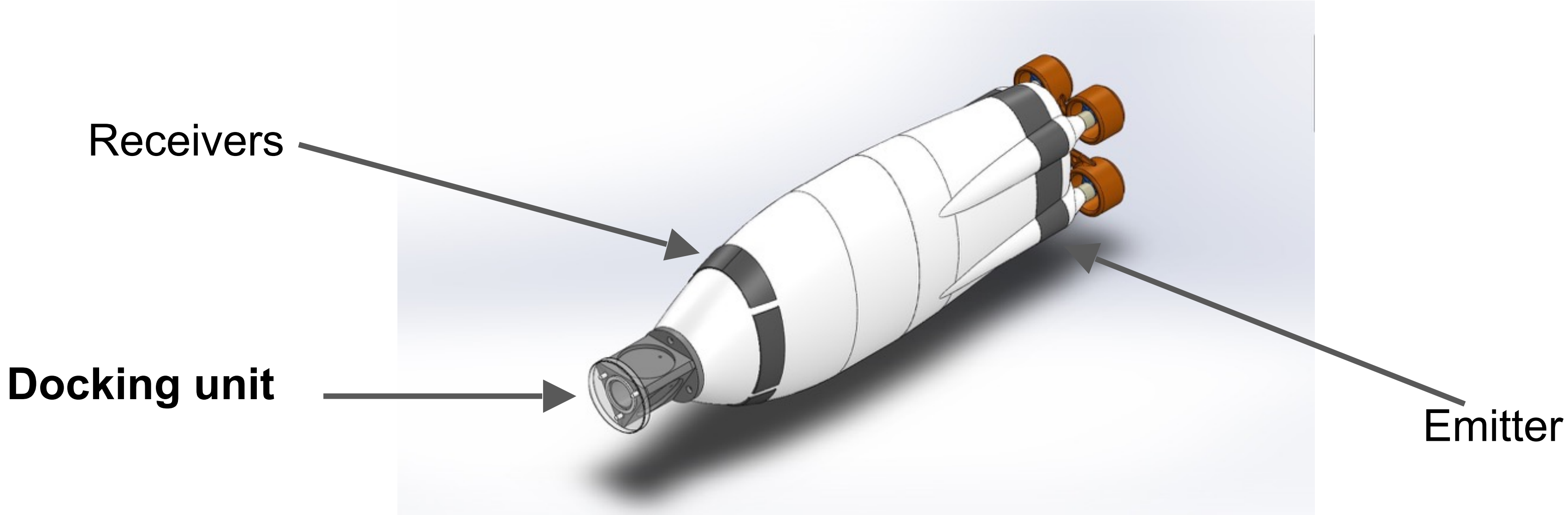


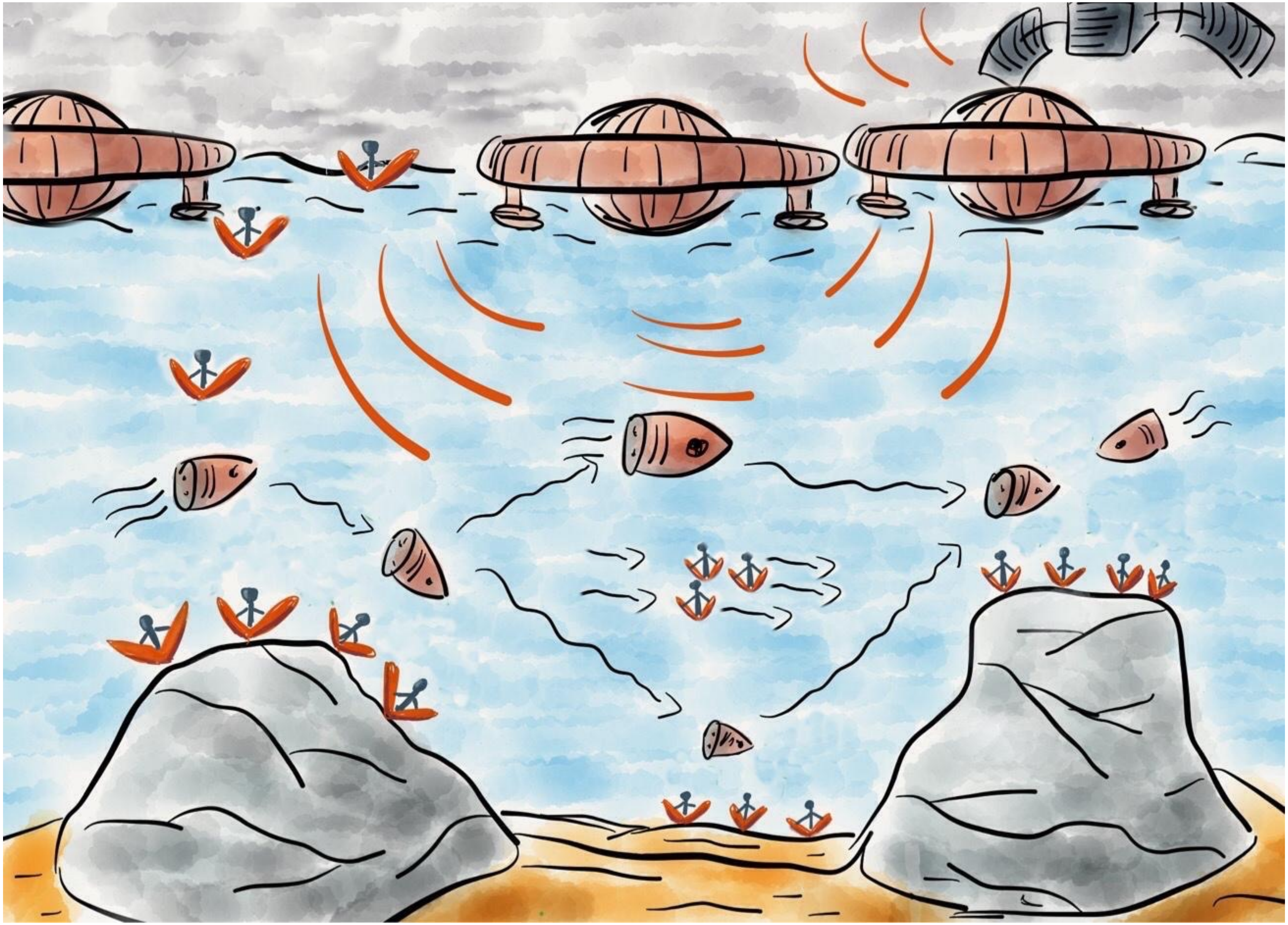
- Size 630 x 120mm
- Max depth: 15 m
- Motor: **active buoyancy**
- Autonomy: 1 month
- Energy harvesting: microbial fuel cells,
- Sensors: **Acoustics and electric sense**

aFish (still not produced)

- Size: 350 x 140 x 100 mm
- Motors: 4 thrusters in rear part
- Max depth 15 m
- Max current 1 m/s
- Autonomy (4-5 hours)
- Sensors: **Acoustics and electric sense**

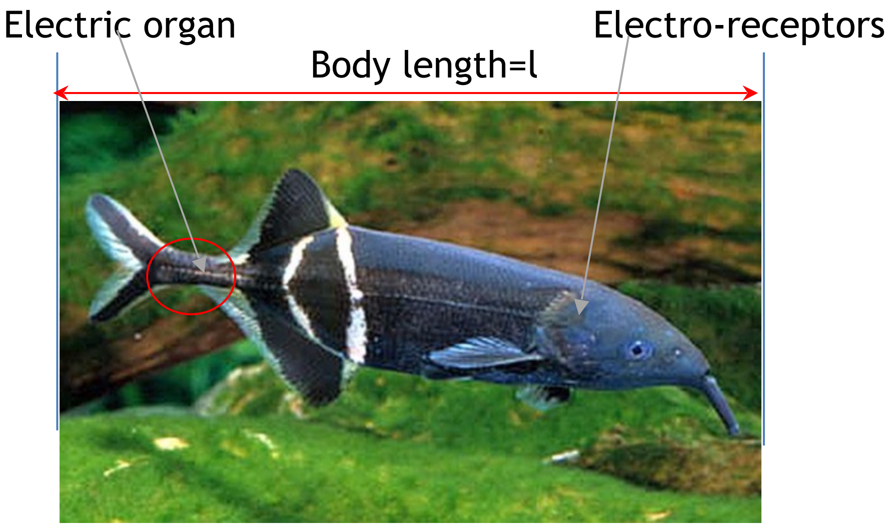




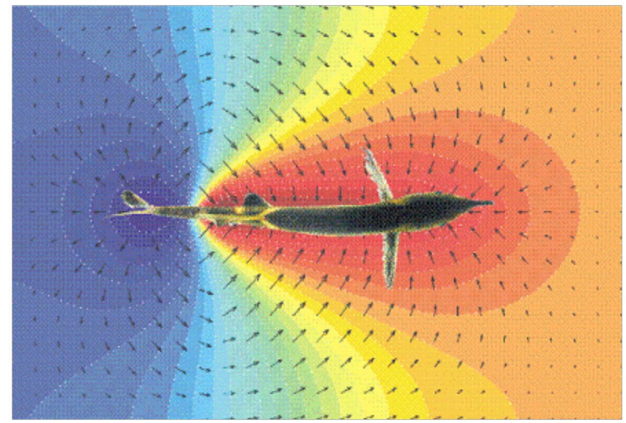


Electric sense in nature

To perceive their environment, e-fish polarize an electric organ / body.



Elephant fish:
Gnathonemus petersii



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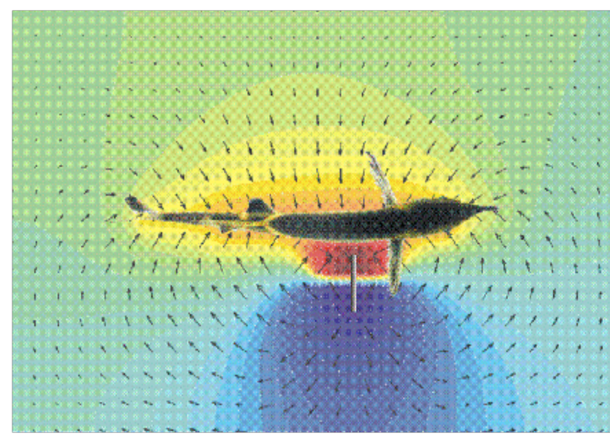


B

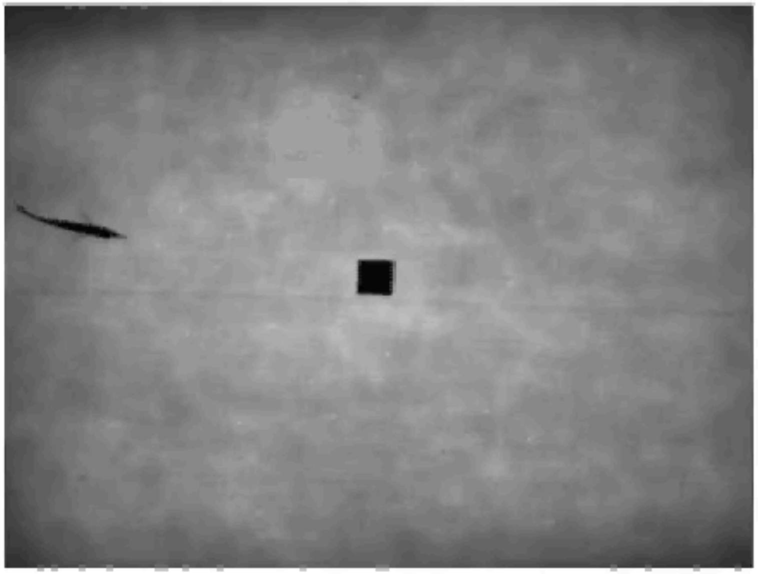
By comparing the currents crossing the skin with and without object, the fish perceives the environment

- 2 modalities: active and passive if it is not emitting
- Short range sense: passive (3l) active (1l)

Use of electric sense

In nature:

- Used by fish to recognize and communicate with their congeners and hunt their preys (passive electric sense),
- To navigate in cluttered environment by detecting obstacles and recognize shape, size, electric color (active).

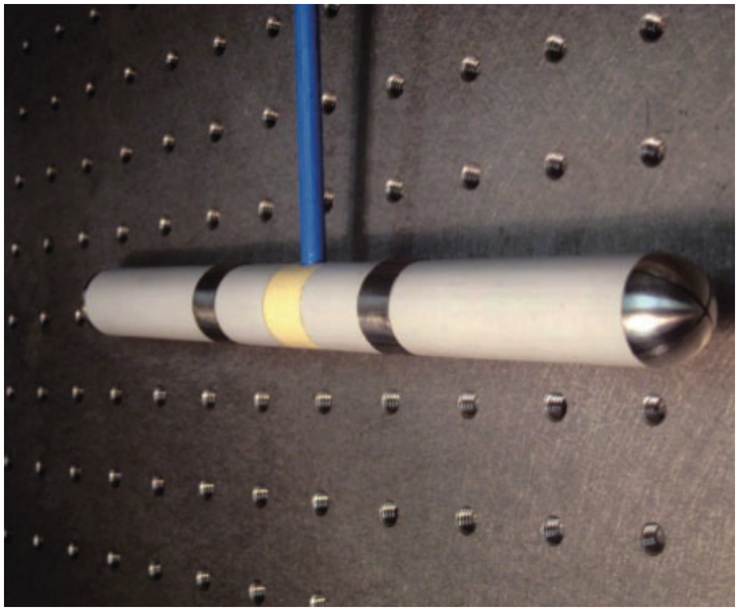


On AUV this omnidirectional short range sense can be used for

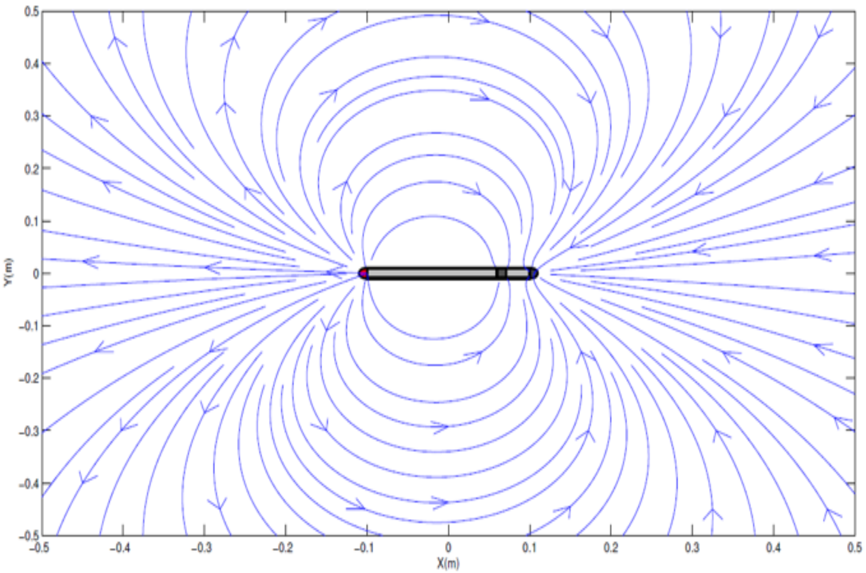
- for reactive navigation (active),
- object localization and recognition, SLAM (active),
- communication between robots (active/passive),
- autonomous docking (passive),

Use of electric sense for robotics

We developed the following sensor technology:



Angels' technology



$$\delta I_{ax2} = (I_{r2} + I_{l2}) - (I_{r2}^{(0)} + I_{l2}^{(0)})$$

$$I_{lat2} = I_{r2} - I_{r2}$$

Insulating shell with electrodes obeying a left /right symmetry
Principle of emission: U imposed by a wave generator
Principle of reception : I is measured (only amplitude), ILAT, IAX.

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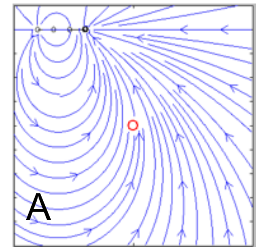
Experiments on 4 use cases

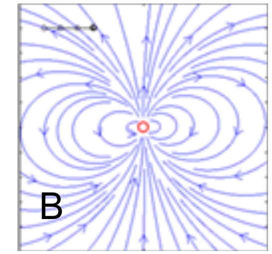
- Experiment with 1 active aFish.
  - Reflex behavior « track/avoid any object ».
- Experiment with 1 active aFish.
  - Memory based behavior « follow the boundaries of an object ».
- Experiment with 1 passive aFish.
  - Autonomous docking on an emitter.
- Experiment with 1 active aFish.
  - Localization and recognition of an object.

Reflex behaviours based on electric sense

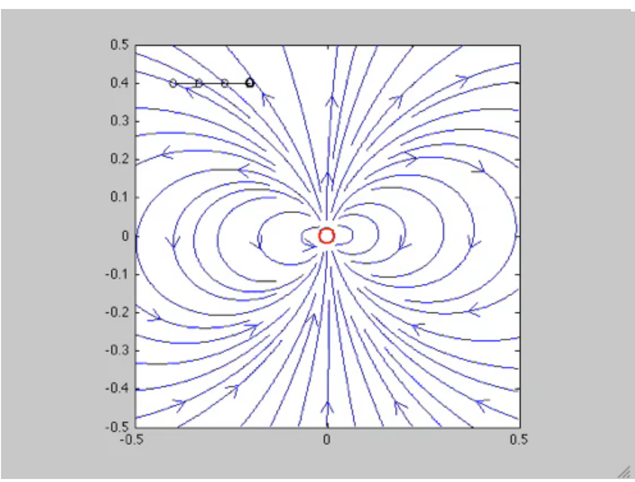
Simple behaviors for aFish

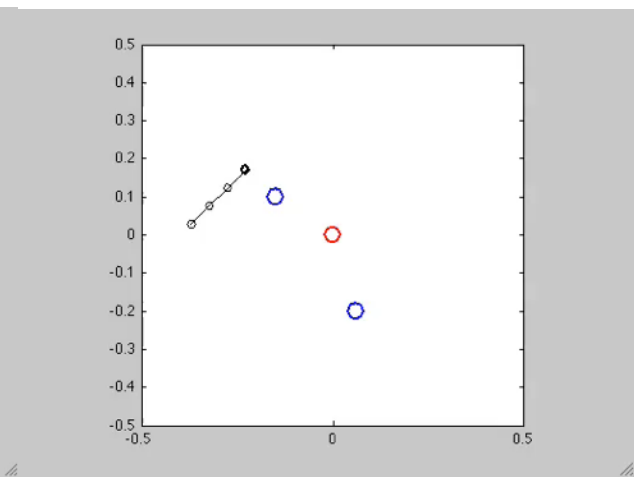
- The robot emits a field in its surrounding (A)
- The field is reflected by an object (B)

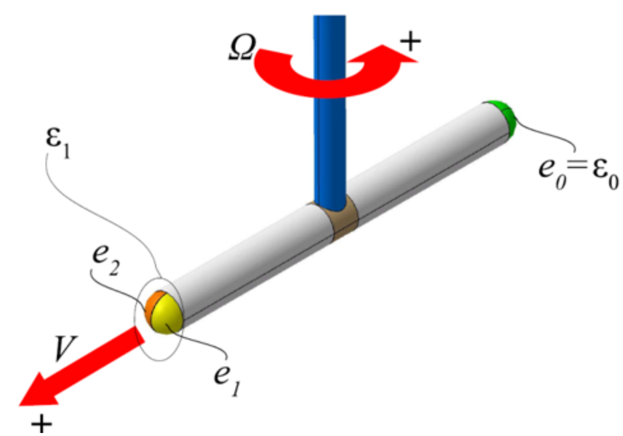




- Then, the robot reacts to the reflected field according to simple control laws



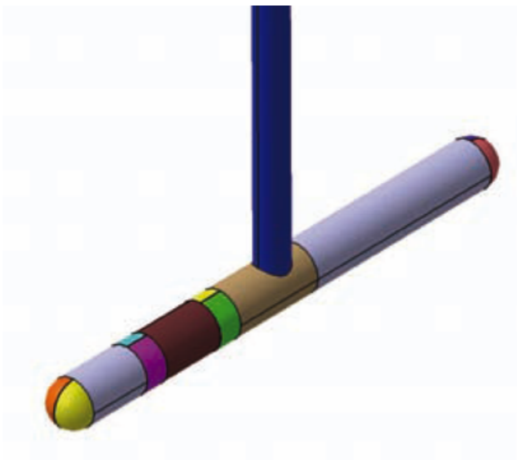




A: Attracted by a conductive object
B: Attracted by a conductive object and repulsed by insulating ones…
<u>All behaviors can be reversed.</u>

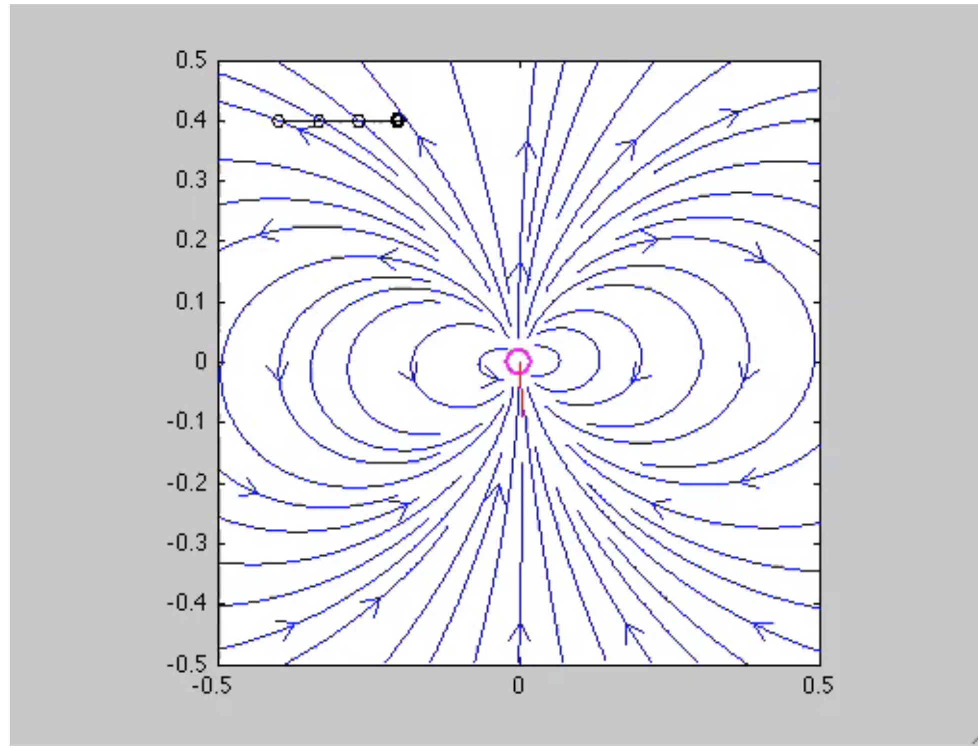
Memory based behaviours

With more electrodes, we can build complex behaviors



Only robot requirements:

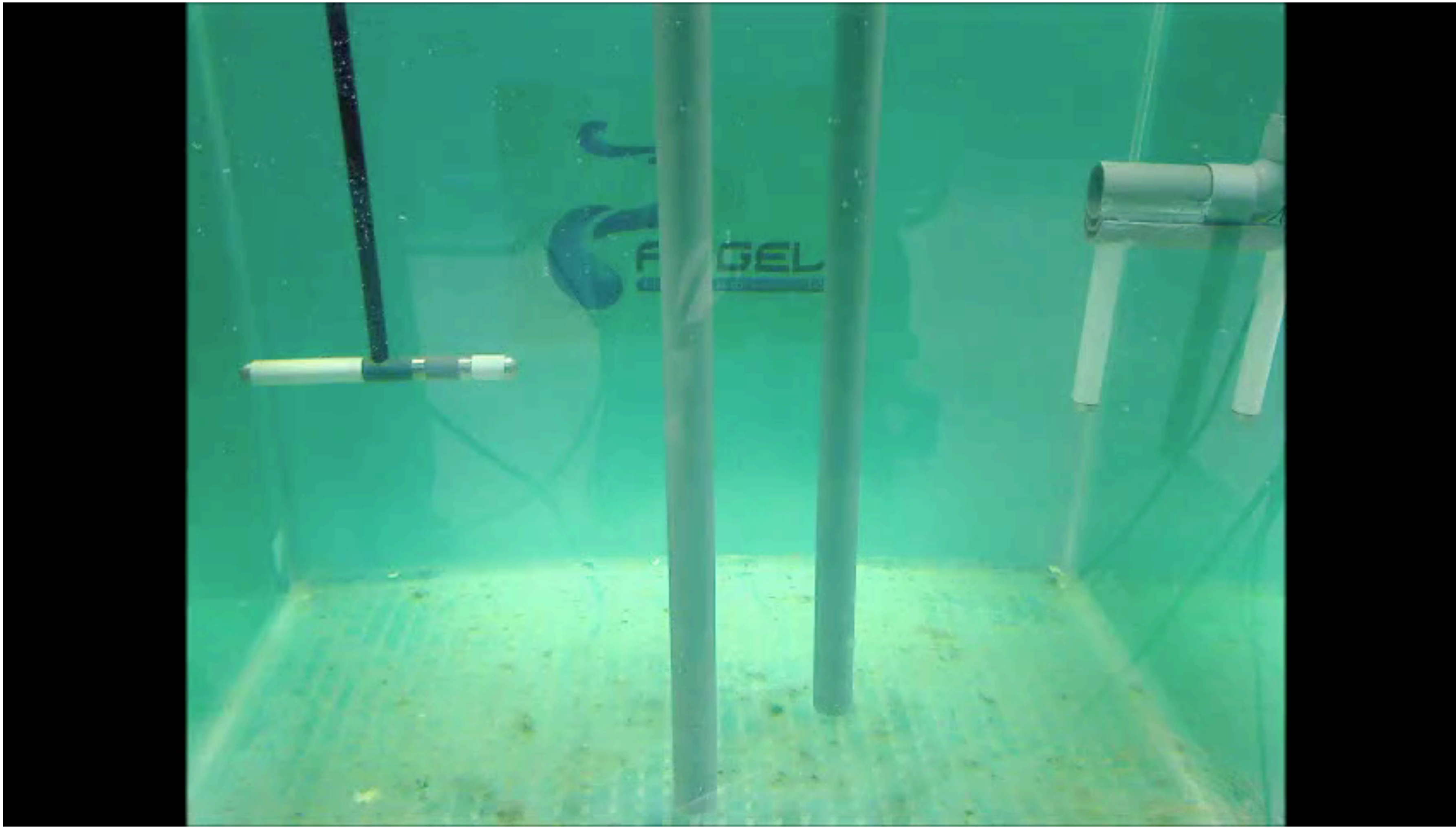
- The left/right symmetry
- Compressed shape (flat).



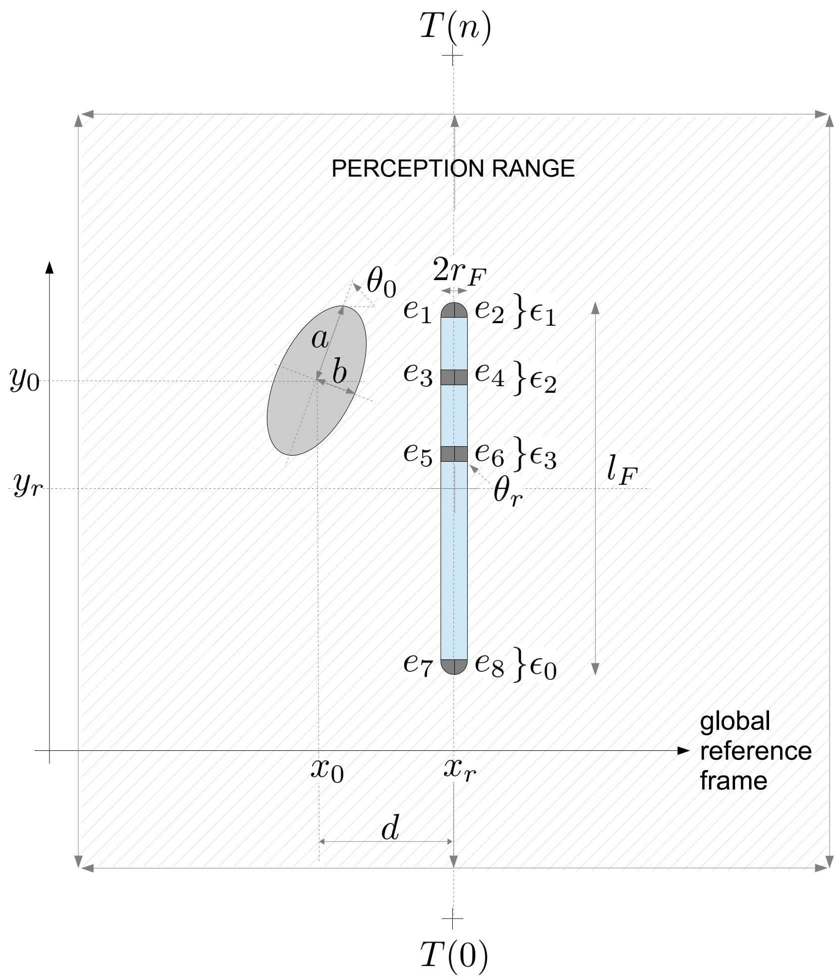
Revolve around objects

All these behaviors can be performed without any model of the environment.

Autonomous docking



Ellipse localization and recognition

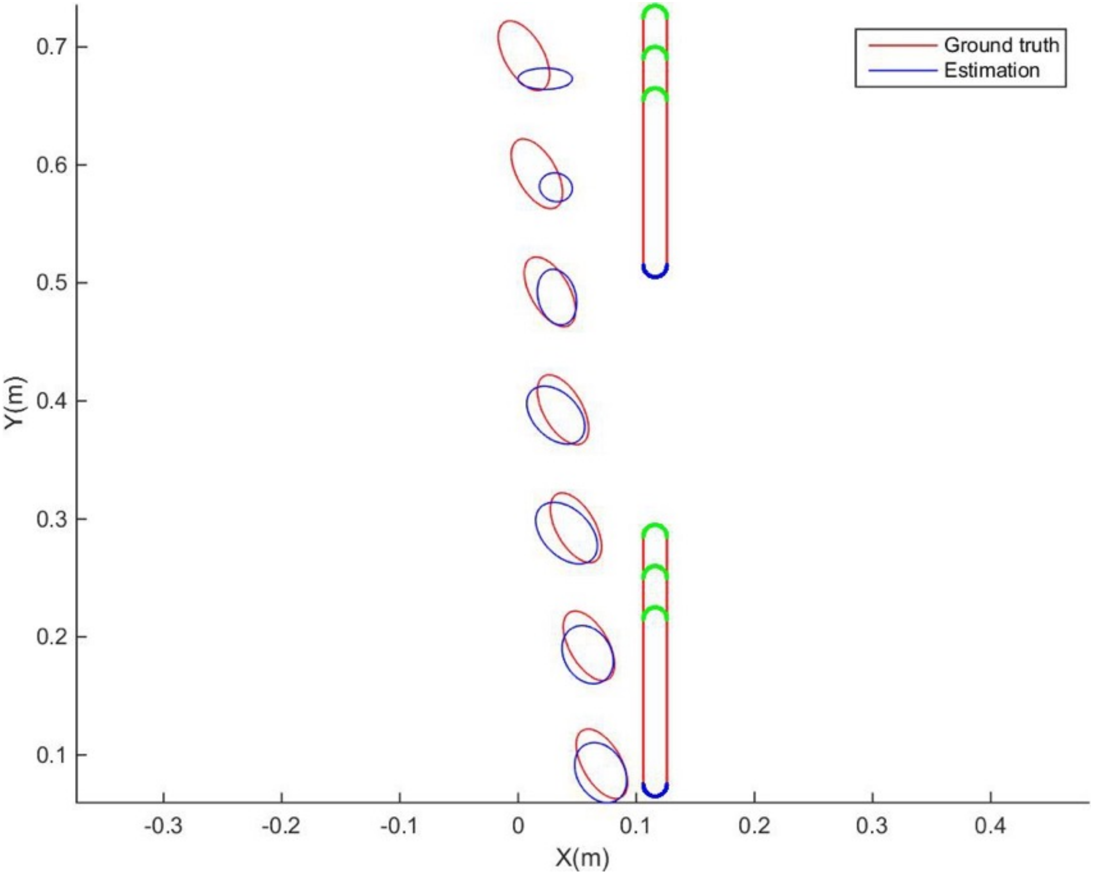


Estimate the 6 parameters of the ellipse (x, y, a, b, theta, color).

- Prior knowledge:
  - conductivity,
  - robot localization in a global frame of reference

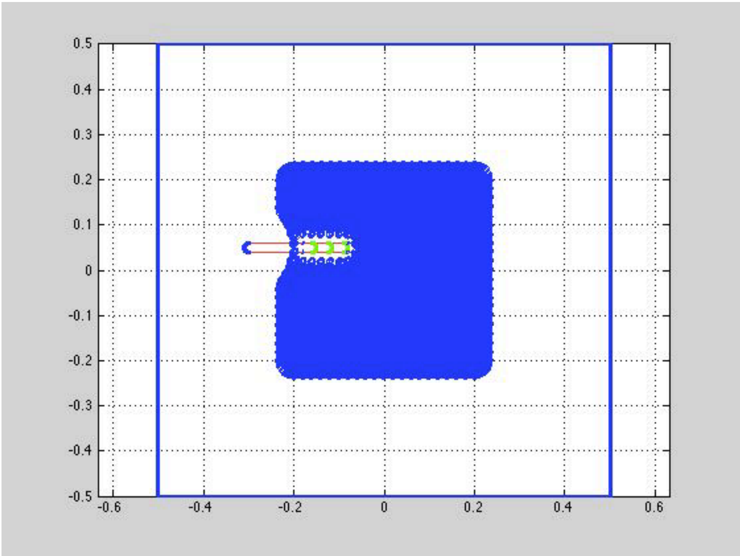
- **Brute force method** based on an analytical model able to estimate the 6 received currents giving a scene [Boyer2012].
- For each object tested a fitting score is sumed up along the trajectory.

Localization and size estimation for a conductive ellipse 33 x 16mm



Will be improved with an optimized trajectory…

	E_x (mm)	E_y (mm)	E_θ (rad)	E_{shape} (%)
50mm	1	7,5	0	18,4
60mm	1	7.5	0	20.7
70mm	7,9	4.5	0.26	10,8
80mm	6	4.5	0.26	12.3
90mm	6	4,5	0.26	23,8
100mm	16	11.5	0.78	52.5
110mm	17.9	19,5	1.04	33.3



Example for a spherical object.
Resolution x, y:0.002 [-0.2;0.2]
Resolution r:0.002 [0.002;0.03]

Project subCULTron

UNI GRAZ
artificial life lab

Coordinator and Bio-inspired controllers

THE BIOROBOTICS INSTITUTE
Scuola Superiore Sant'Anna

Hardware development

FER
UNIVERSITY OF ZAGREB
FACULTY OF ELECTRICAL ENGINEERING AND COMPUTING

Firmware and algorithms

CORILA

Experiments

ARMINES

Electric Sense

ULB
UNIVERSITÉ LIBRE DE BRUXELLES

Culture and Society

Cybertronica Research
beyond technology

Electronics development

Bibliography

F. Boyer, P. Gossiaux, B. Jawad, V. Lebastard, and M. Porez. Model for a sensor bio-inspired from electric fish. *IEEE transactions on robotics*, 28(2):492–505, April 2012.

N. Servagent, B. Jawad, S. Bouvier, F. Boyer, A. Girin, F. Gomez, V. Lebastard, and P.-B. Gossiaux. Electrolocation sensors in conducting water bio-inspired by electric fish. *IEEE Sensor Journal*, 13(5):1865–1882, 2013.

F. Boyer, V. Lebastard, C. Chevallereau, and N. Servagent. Underwater reflex navigation in confined environment based on electric sense. *IEEE Transactions on Robotics*, 29(4): 945–956, 2013.

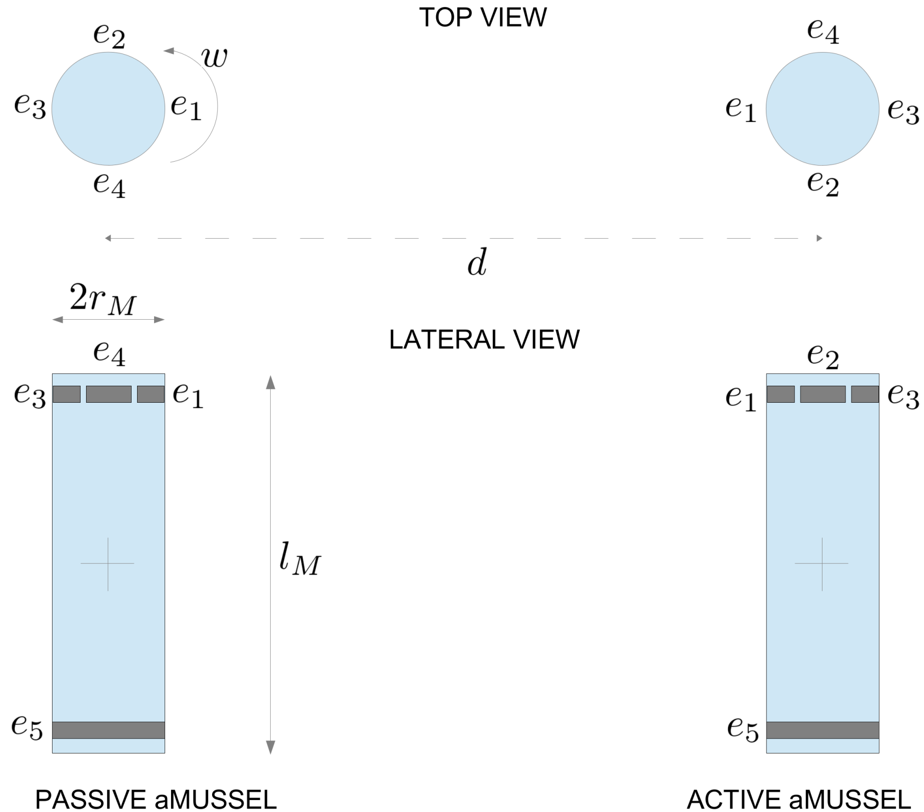
F. Boyer, V. Lebastard, C.Chevallereau, S. Mintchev, and C. Stefanini. Underwater navigation based on passive electric sense: New perspectives for underwater docking. *The International Journal of Robotics Research*, page 0278364915572071, 2015.

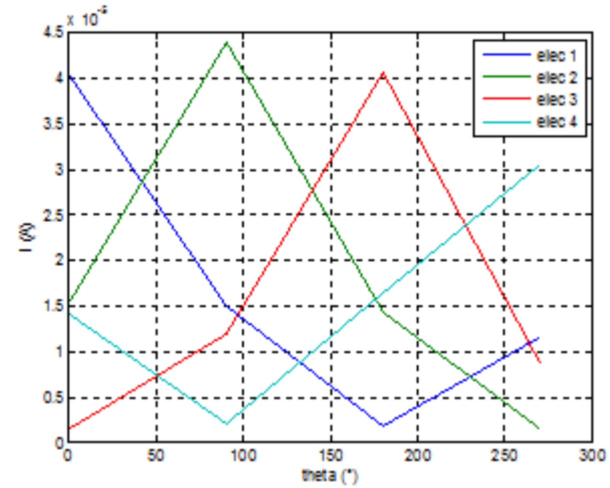
S. Lanneau, V. Lebastard, and F. Boyer. Object shape recognition using electric sense and ellipsoid's polarization tensor. *In Proceedings of the IEEE International Conference on Robotics and Automation (ICRA)*, pages 4692–4699, 2016.

V. Lebastard, F. Boyer, and S. Lanneau. Reactive underwater object inspection based on artificial electric sense. *Bioinspiration and Biomimetics*, 11(4):045003, 2016.

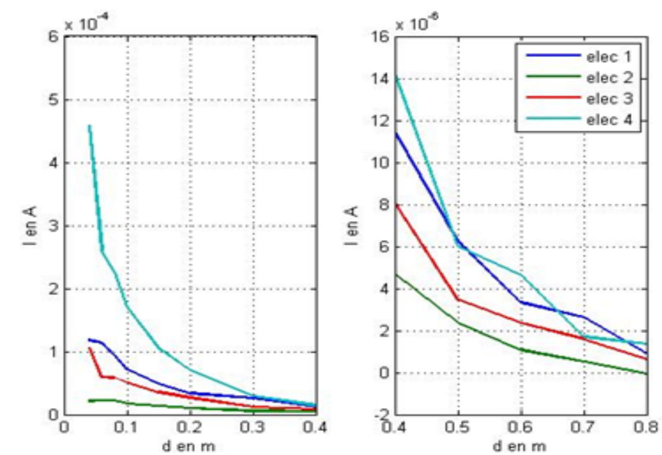
aMussel experiment subCULtron

From a passive aMussel estimate the direction and the distance of an emitter





Plot: 4 measured currents vs angle (directional detection)



Plot: 4 measured currents vs distance (omnidirectional range detection)

aMussel experiment subCULTron (salt water 1S/m)