Journée thématique du GT8 Robotique et Neurosciences
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An electric sense for underwater robots

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Aim of Angels

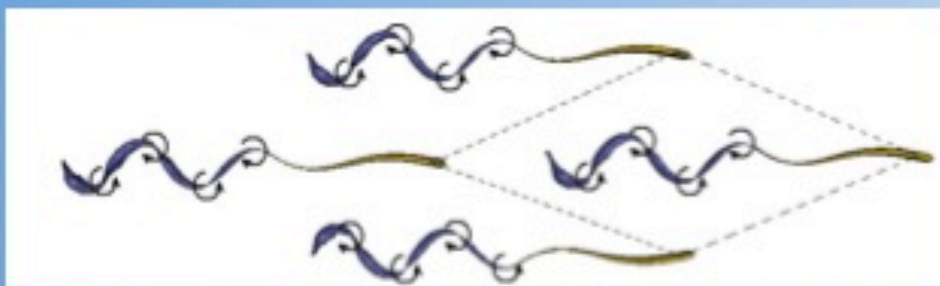
➢ To build a re-configurable anguilliform swimming robot…

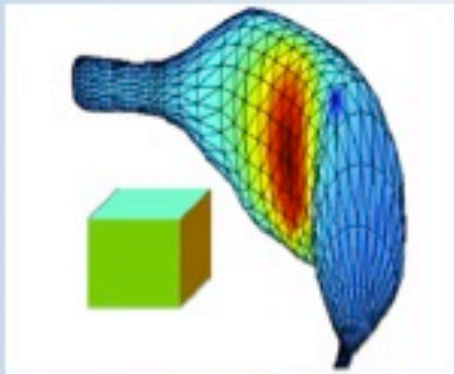
➢ Able to split into smaller robots (mechanical re-configurability).

Where each robot:

➢ can sense its environment (obstacles, objects and co-robots) and also communicate (co-robots) with a new bio-inspired sense for robotics: “the electric sense”.

➢ is able to shape the electric field around it by a kind of « electrical re-configurability ».

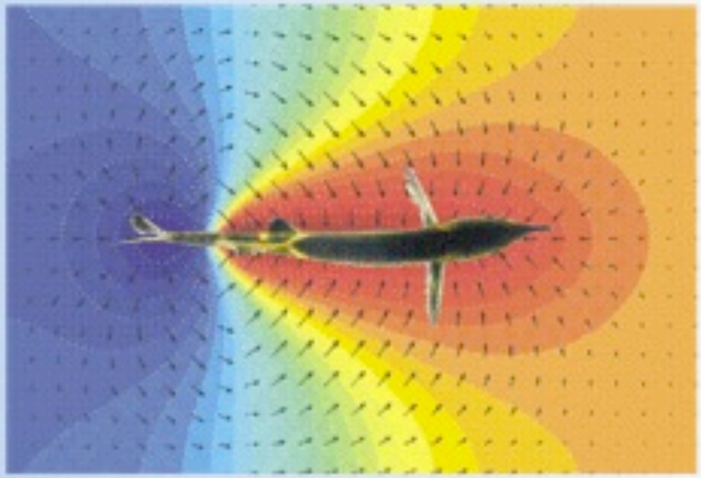


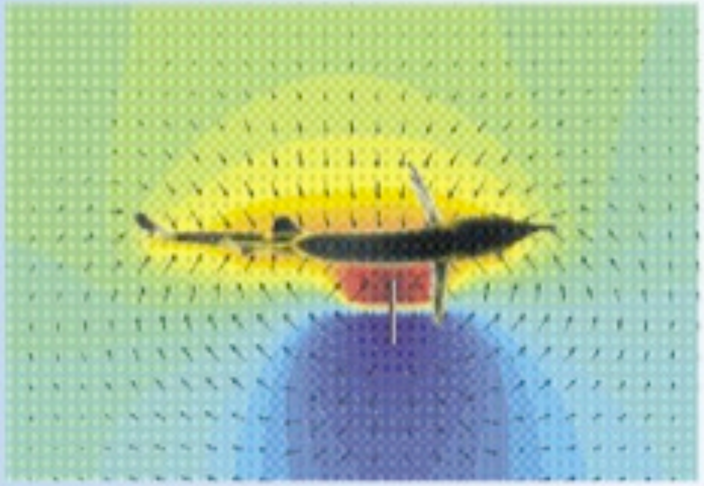


What is electric sense?

In order to perceive its environment, the fish polarizes two regions of its body…

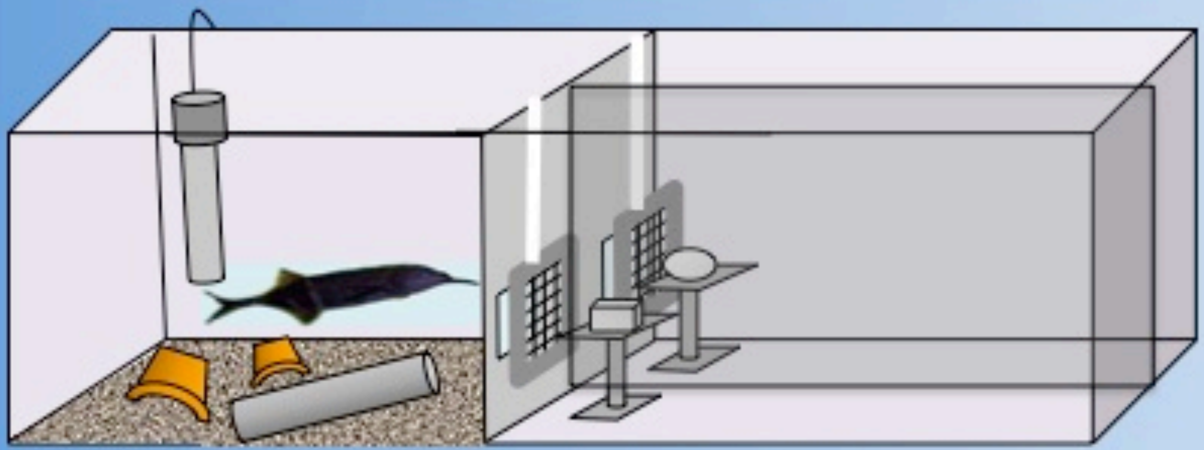
Gnathonemus petersii





By comparing the currents crossing the skin with and without objects, the fish perceives the objects (shape, locations, electric colors…)

Experiments in biology



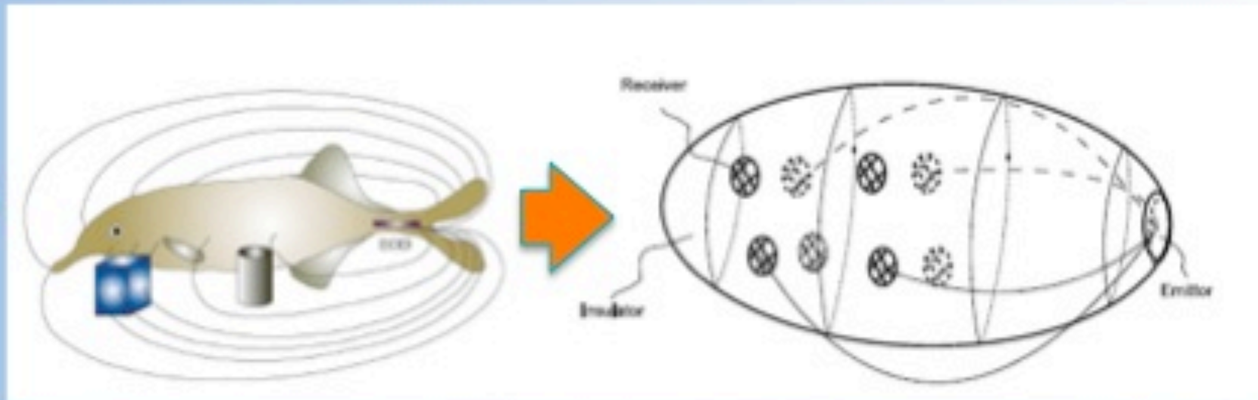
Experimental setup

Simple shaped objects

Ethological experiments
(from UBO)

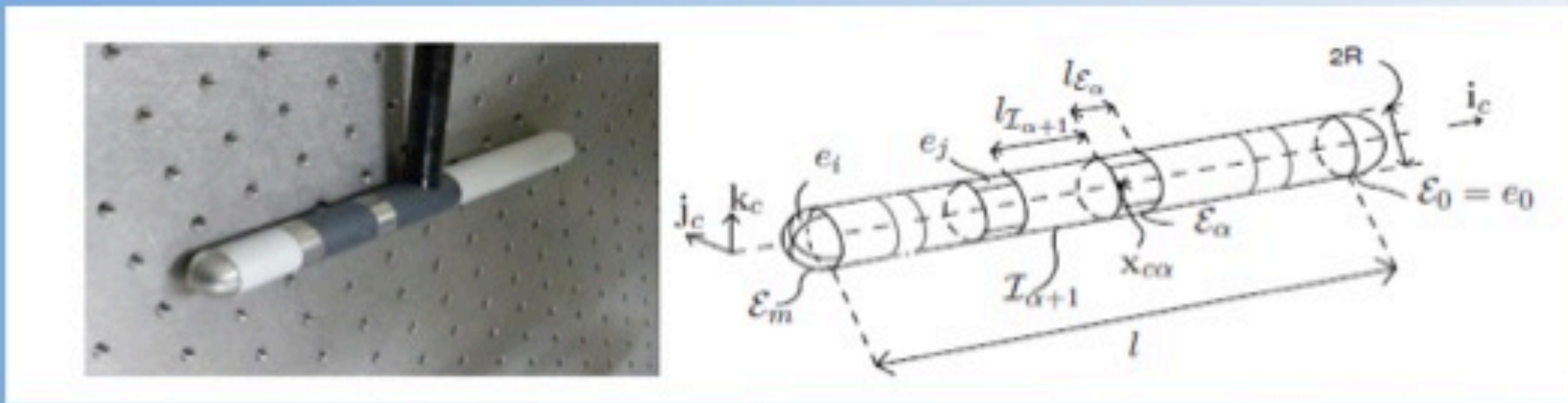
The electric sensor

Bio-inspired approach…



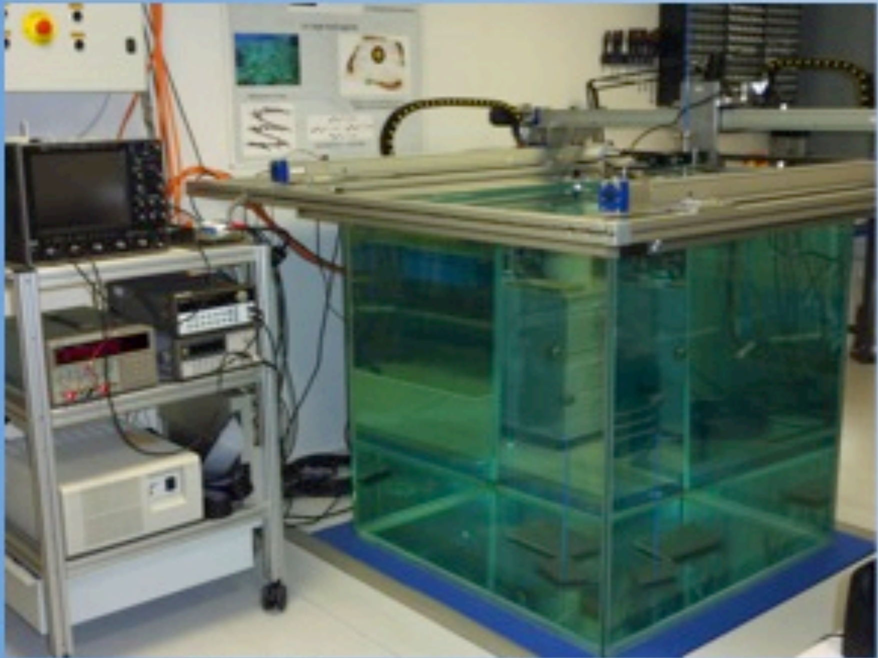
African dipolar fish
(UNIC)

Physical principle: U imposed, I measured



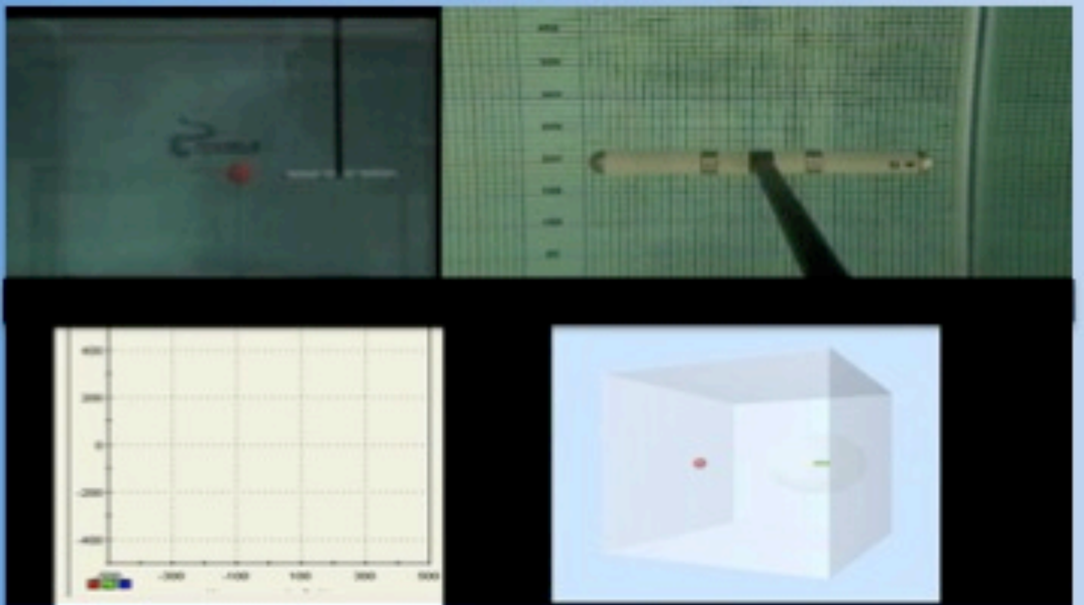
… based on this principle, we have built a set of slender probes… (ARMINES)

Electrolocation test bed



Electric sensor test-bed

Object electrolocation



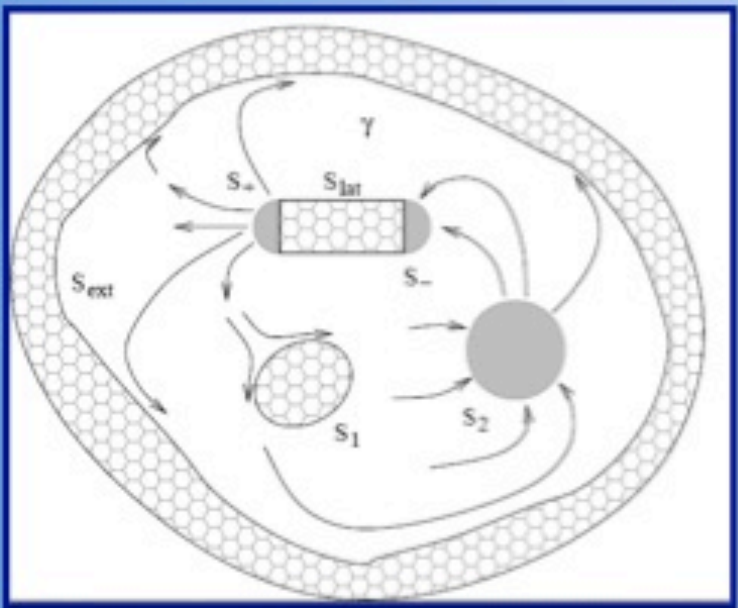
dSPACE rapid control prototyping device

ANGELS module (SSSA)
+ electric sensor (ARMINES)

What problem the fish solves?

Any electrolocation algorithm has to solve the inverse electric problem…

Originally, it appeared as the most difficult theoretical one that Angels addresses.



Basically, it can be stated as follows:

1°) First formulation:

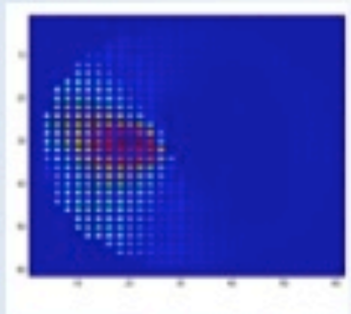
"Find γ such that in the scene :

$$\nabla.(\gamma\, \nabla \phi) = 0$$

For Bc imposed and measured on the sensor."

Inverse problem ⟷ Impedance –Tomography problem

EEG algorithms



From CVLab

What problem the fish solves?

Too costly to be used on-line… ⇨ Reduction of the parametric space

⇨ γ constant on sub-domains

$$\Delta\phi = 0 + \text{BC of sensor} + \text{B. crossing C}$$

Considering simple shaped objects ⇨ analytic solutions …

⇨ 2°) Second formulation:

“ Find p and γ such that the electric matrix equation:

$$U = R(p,\gamma)I$$

For any U and I respectively imposed and measured.”

⇨ Inverse problem ⇔ Finite dimensional non linear problem

⇨ Solvable with classical nonlinear control techniques…

We begun by adopting…

- For object recognition ⇨ a learning based approach
- For navigation ⇨ a Kalman filtering based approach…

… gave results but hard limitations arose:

- Requires an analytical model of the scene
- Due to the sensor range, it requires to change the state dimension …

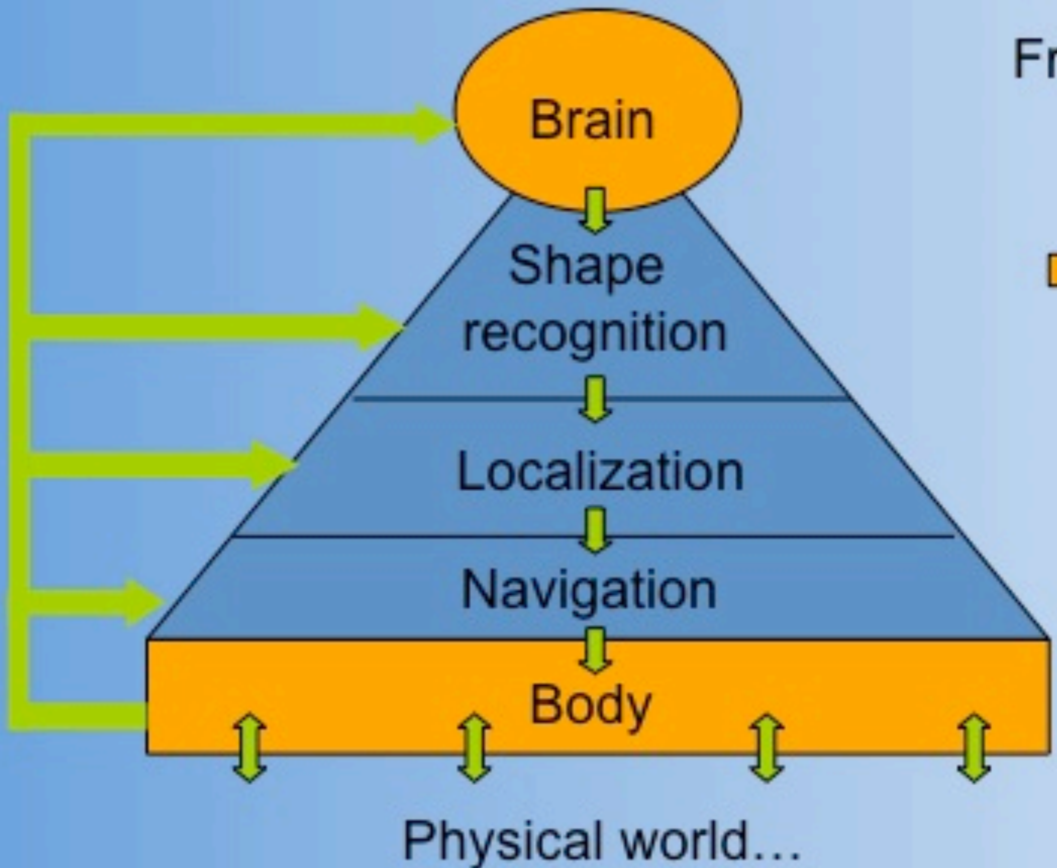
⇨ Limitations became a serious drawback due to the increasing complexity of the project (complex scenes, multi-agent…).

⇩

Solution: Use the concept of embodiement!

From classical to embodied approach

- Method: Reordering the modalities involved in the final scenarios into the following hierarchy
- Idea: Solve the max of pb posed by autonomy at the lowest levels, i.e. through fast local loops as close as possible to the body, ideally encoded by simple physical rules



From this basic idea…

→ Observer based approach involves 3 levels : very bad!

↓

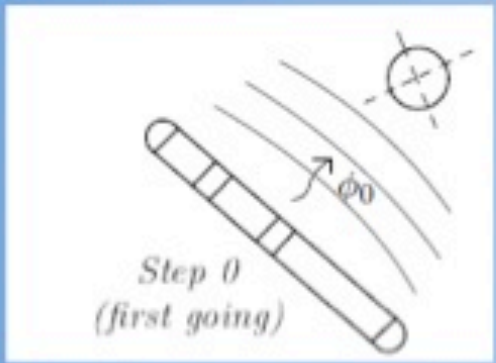
Use the concept of embodiement for navigation!

Rigid modules navigation

1°) Deeper understanding of models based on:

– Method of reflections: Interactions sensor-object $= \sum$ successive reflections

$$I = I^{(0)} + I^{(1)} + I^{(2)}$$, where:



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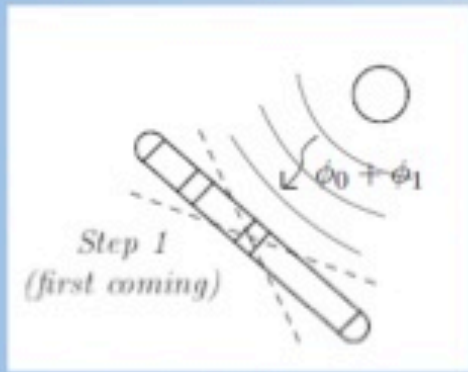

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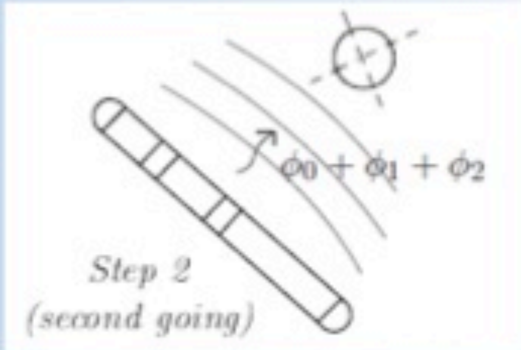


+...

$I^{(0)} =$ currents with no object

$I^{(1)} =$ currents reflected by the object with no sensor

$I^{(2)} =$ currents generated by the electric response of the sensor to the first reflection

– Exploitation of symmetries of the sensor:

$$I = I_{ax} \oplus I_{lat}$$, with: $I_{lat} \sim \Phi_{lat}(\vec{E}_{(1)})$

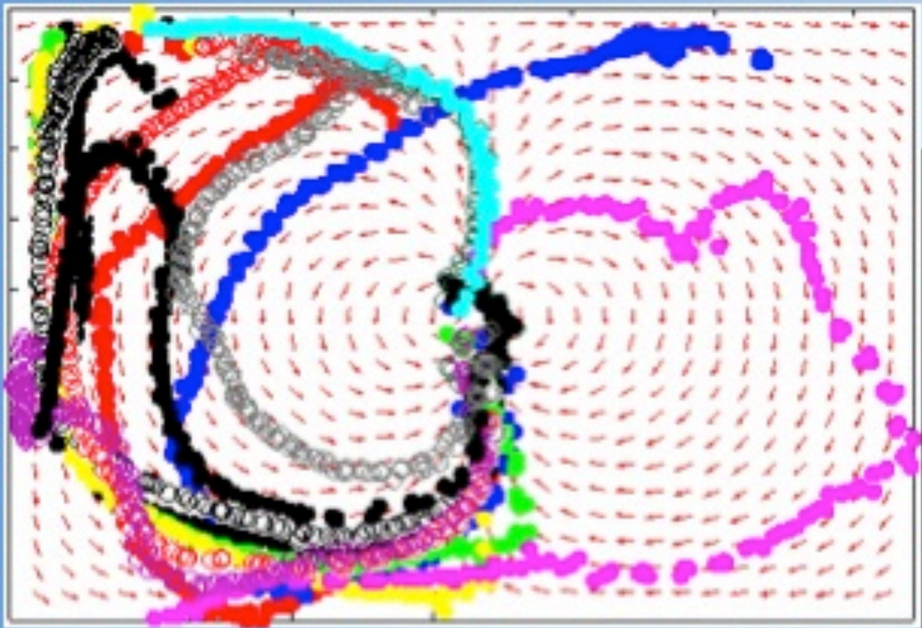
I_{ax} ↓ Axial currents

I_{lat} ↓ Lateral currents

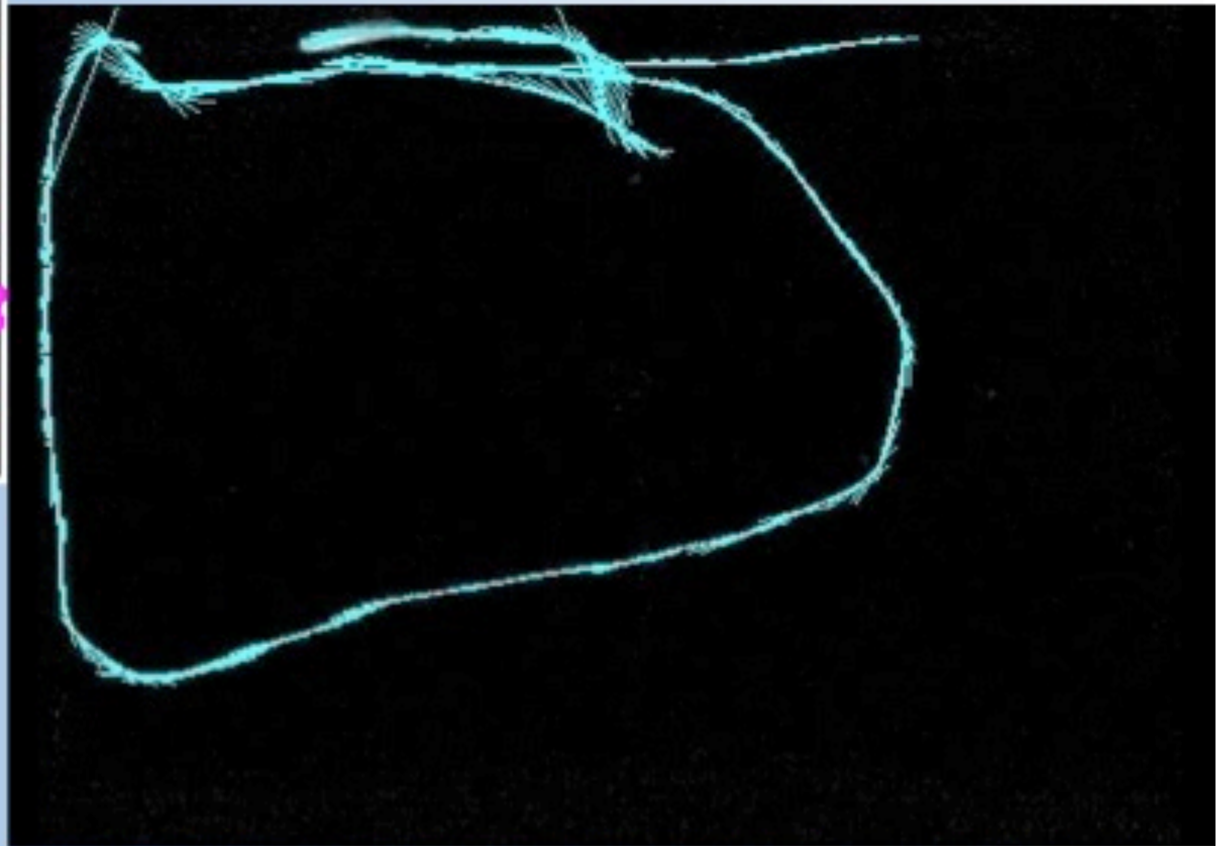
I_{ax} tells us if object is conductive or insulating, I_{lat}: if it is on left or right

Rigid modules navigation

2°) Coming back to the nature…



From IIBCE



The idea consists in implementing this navigation strategy on the rigid modules…

Embodied navigation

➡ In order to achieve this navigation strategy…

- Remove the basal component $I^{(0)}$ from measurements
- Apply the control law:

$$V = cte, \quad \omega = k\, I_{lat} \;\Rightarrow\; I_{lat} \sim \Phi_{lat}(\vec{E}_{(1)}) \;\Rightarrow$$

{ The sensor aligns on the current lines.

➡ With simple $k = k(I_{ax})$, one can encode relevant navigation behaviors, as :

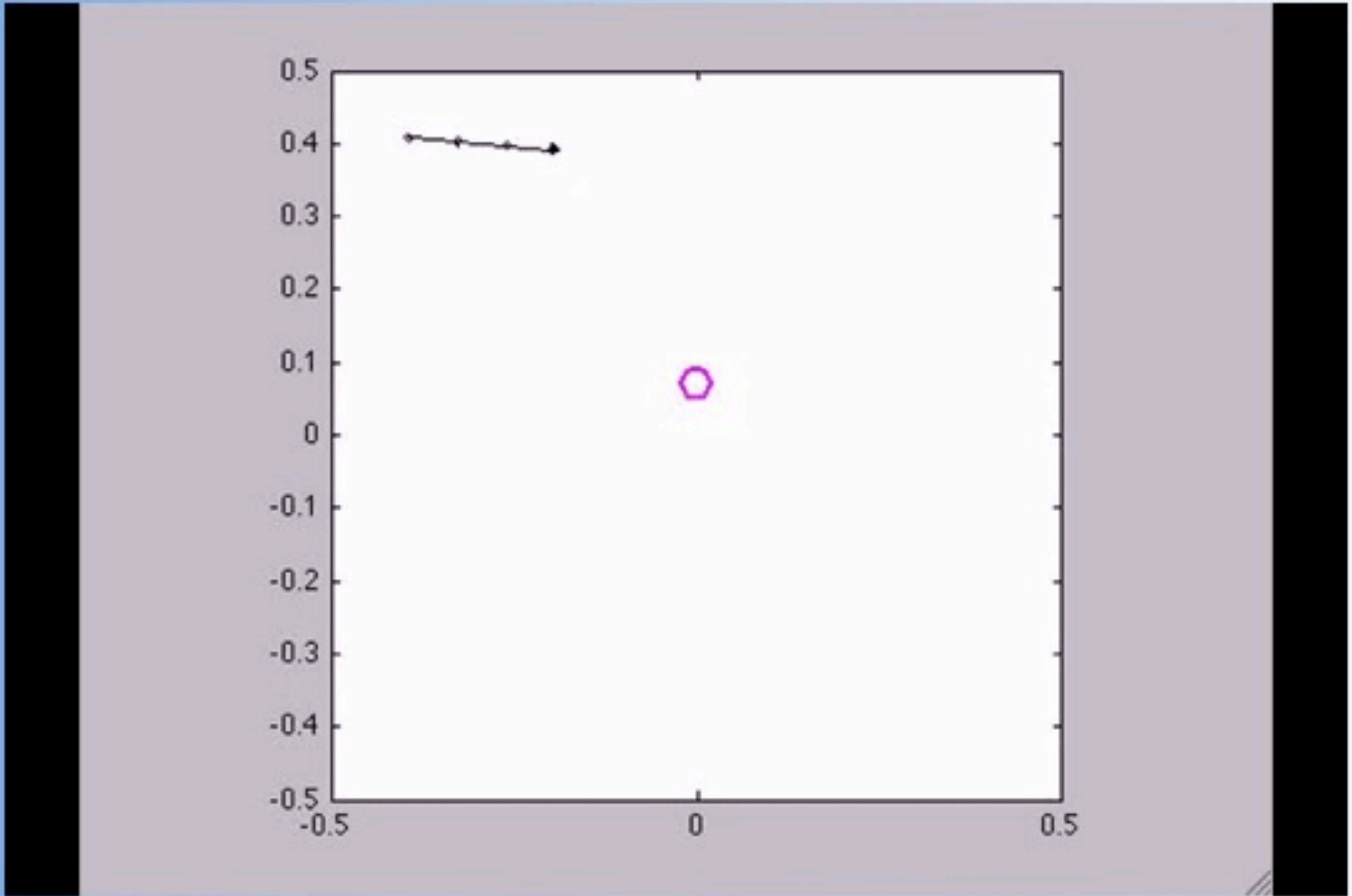
- Seeking conducting objects
- Avoiding insulating obstacles

⇔ { Method of potentials where Potentials are not virtual but real

Simulations

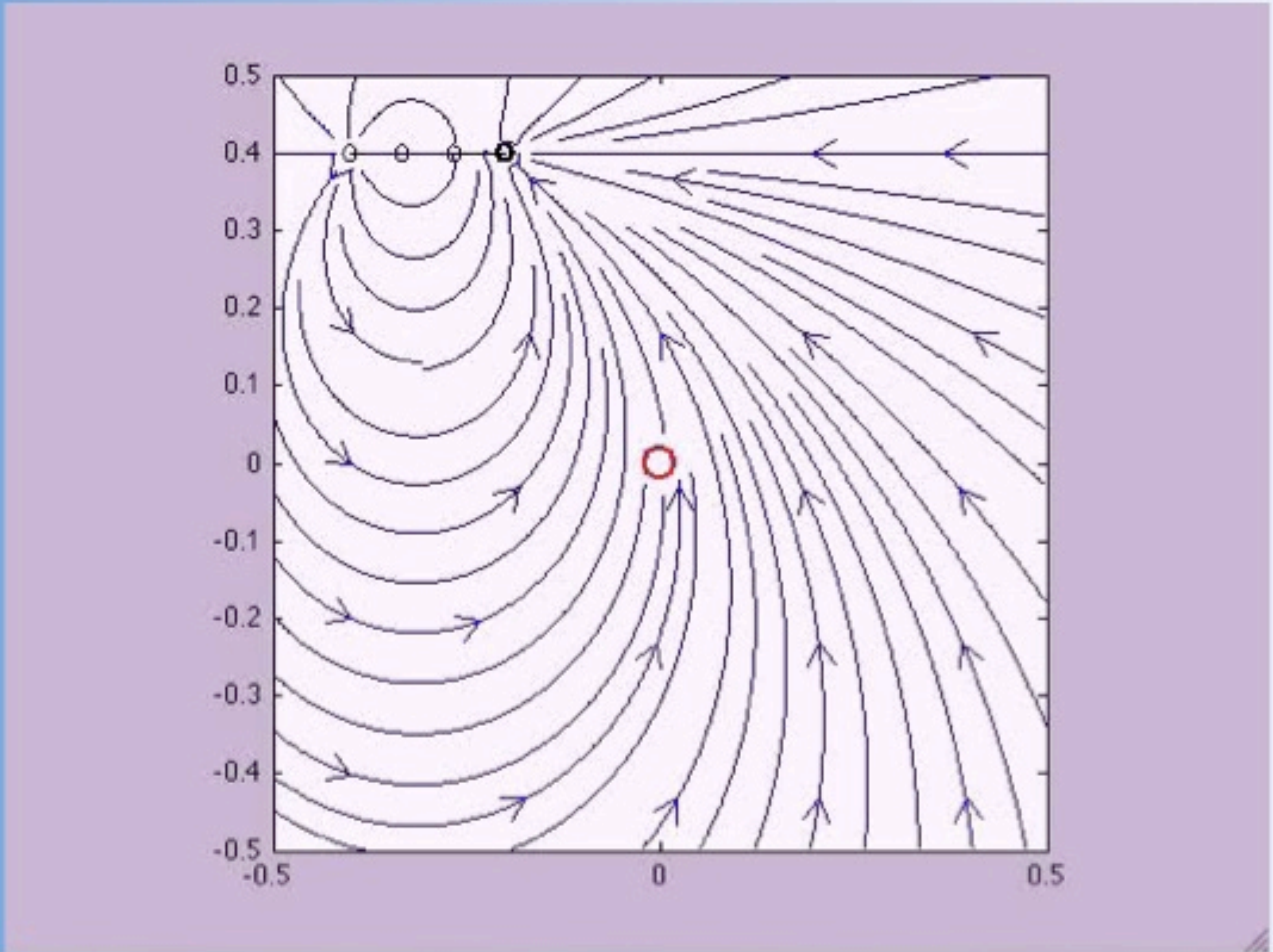
Behaviour = joining conductors and avoiding insulators

Joining a conductive object



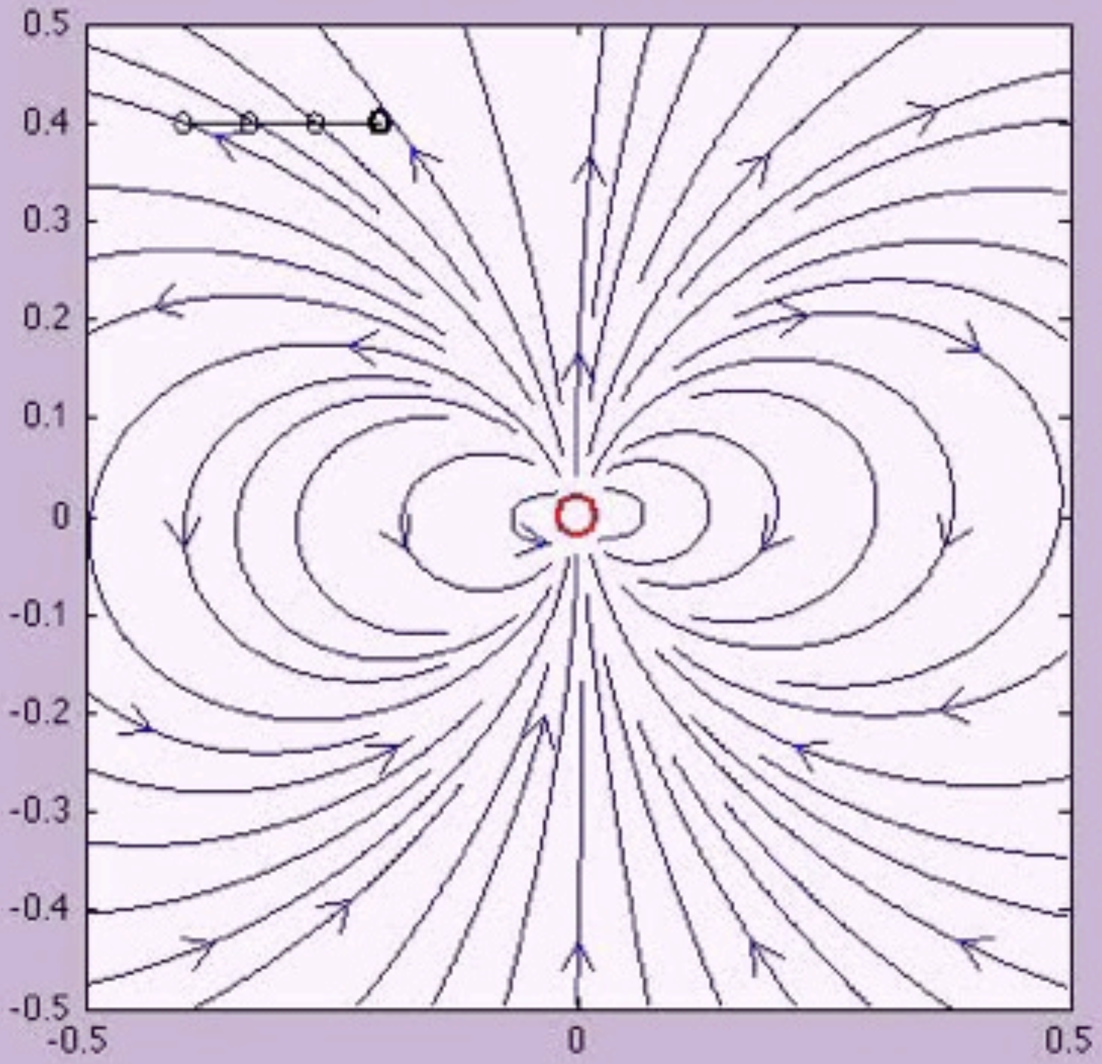
One conductive object

Joining a conductive object



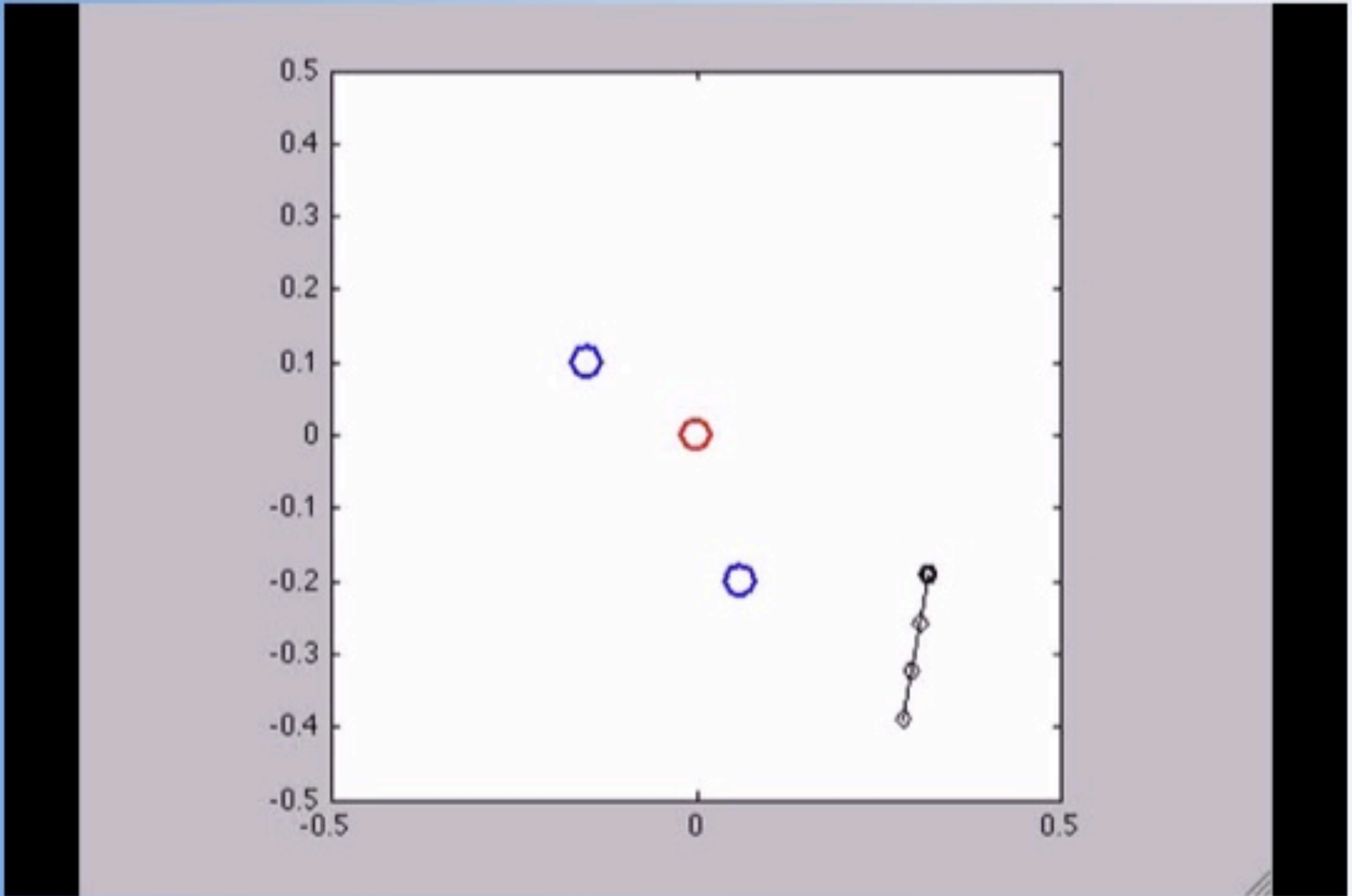
Portrait of the total electric field

Joining a conductive object



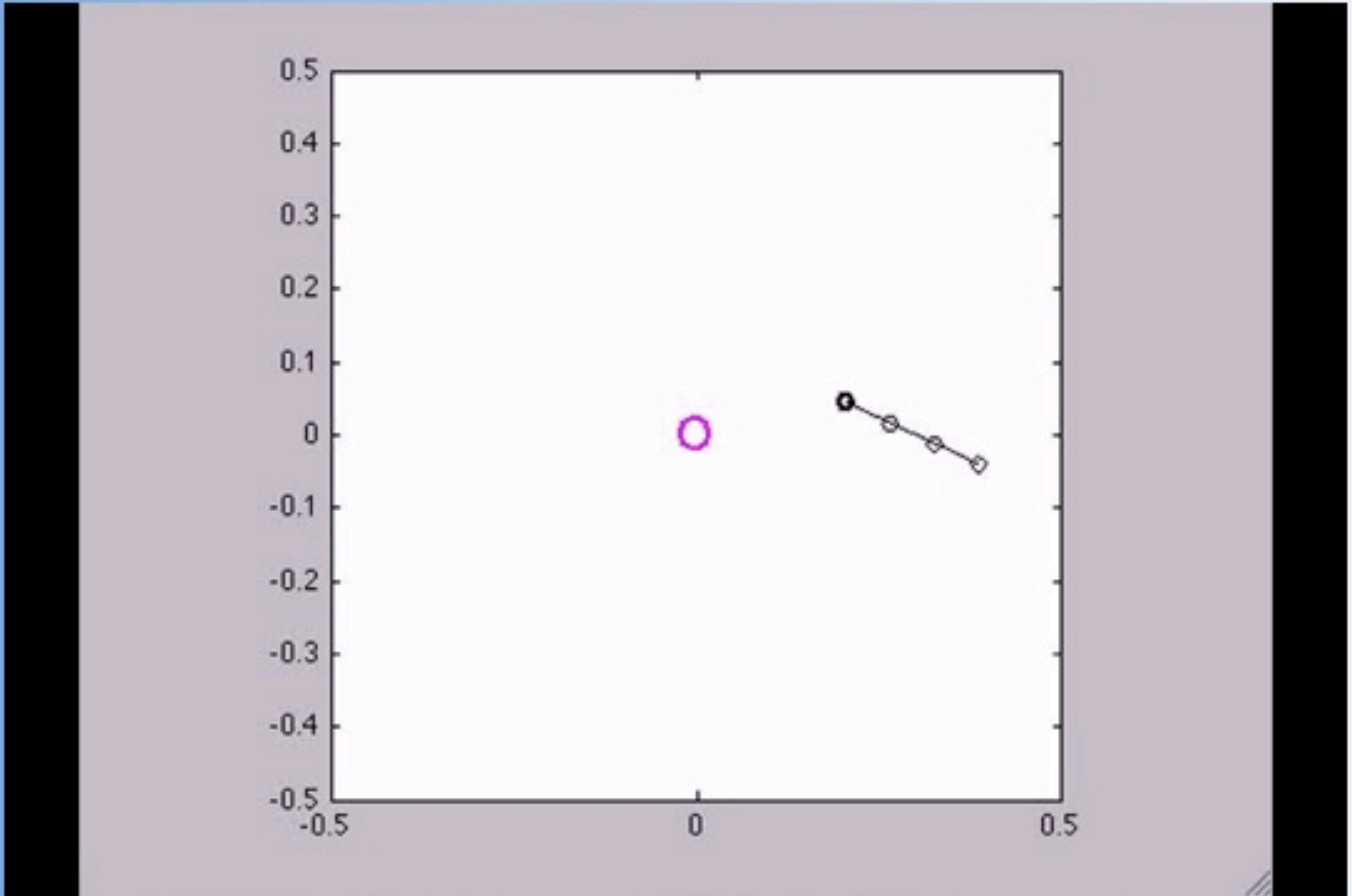
Portrait of the perturbative component of the field

Navigation in complex scenes



Two insulating obstacles and one conductive object

Tracking a moving object

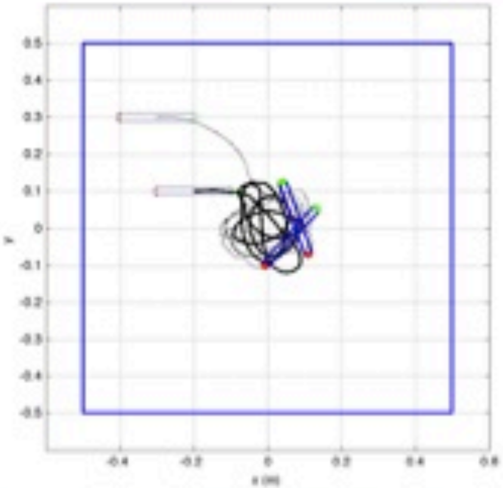


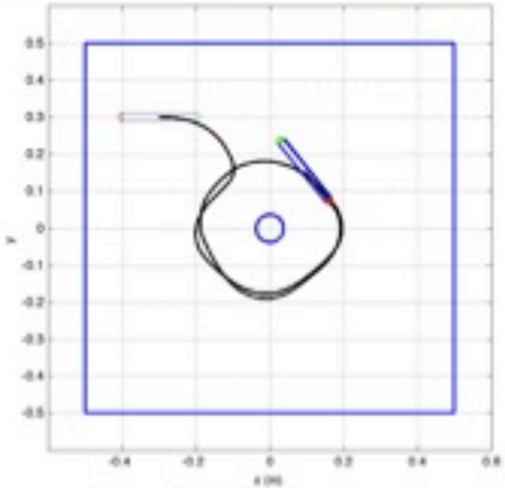
Sensor motion

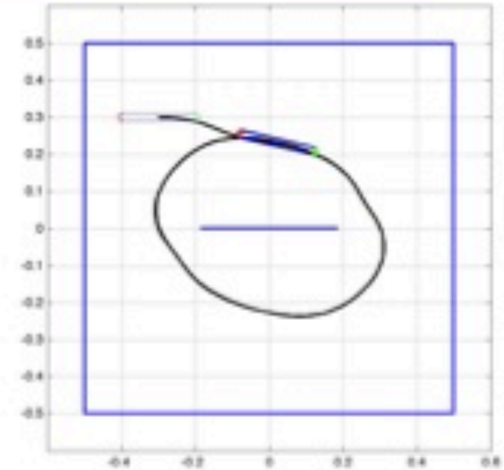
Experiments

Behaviour = seeking conductors and avoiding insultors

Avoiding insulators



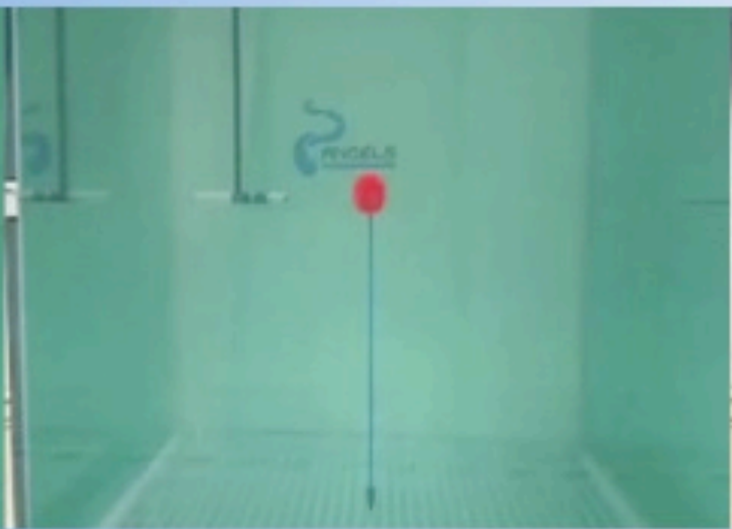


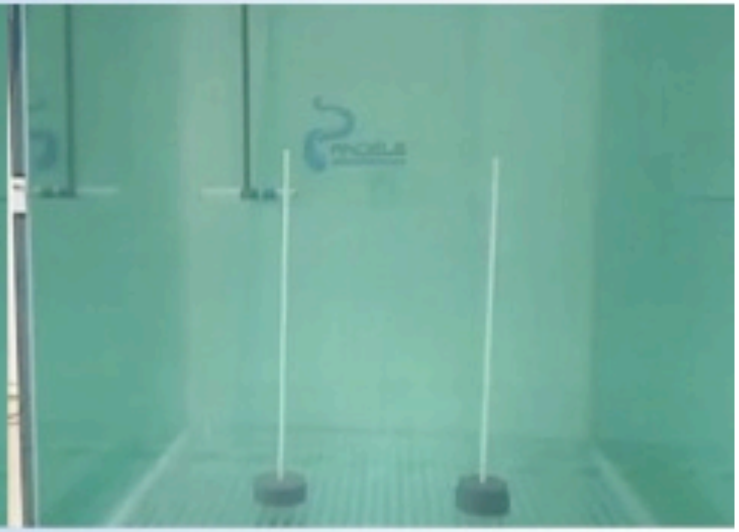


Tank with no object

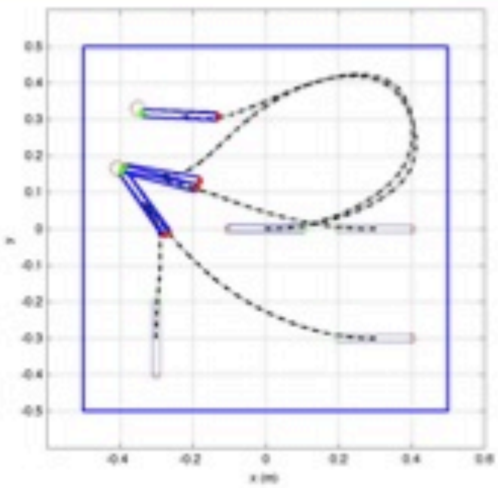
Tank + insul. sphere

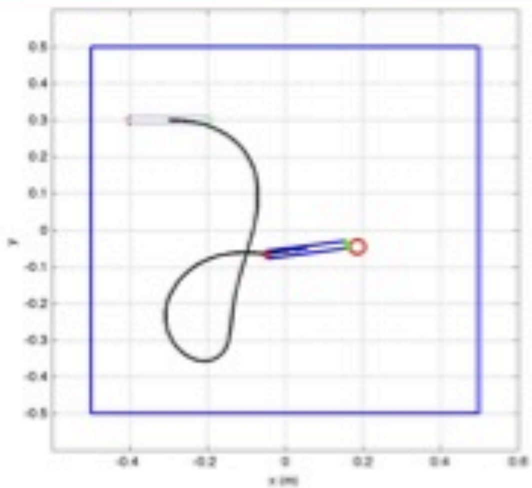
Tank with an insul. wall

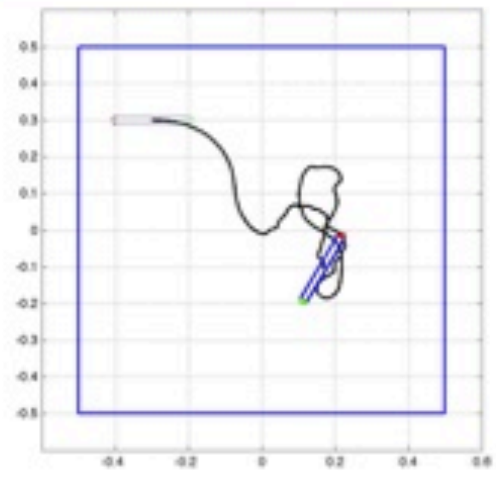




Joining conductive objects



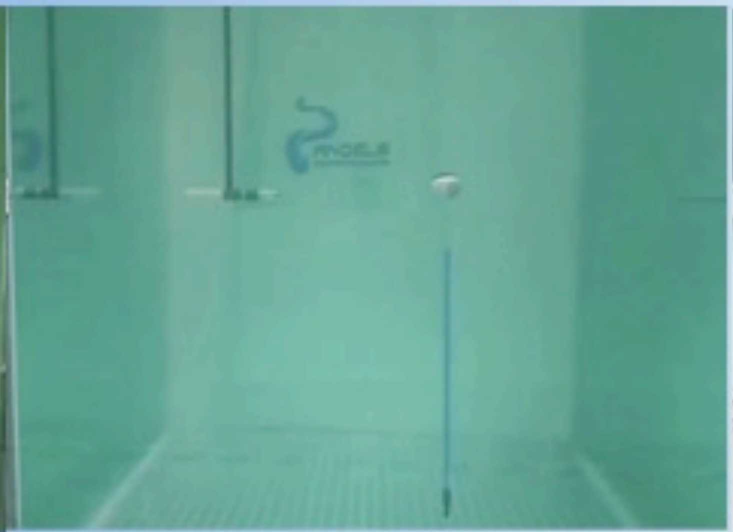




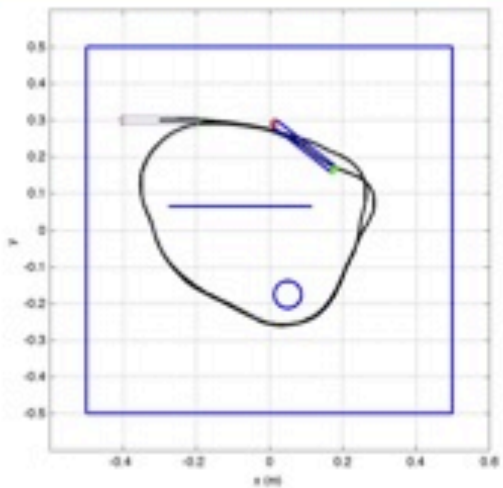
Tank with an active dipole

Tank with a fixed conductor

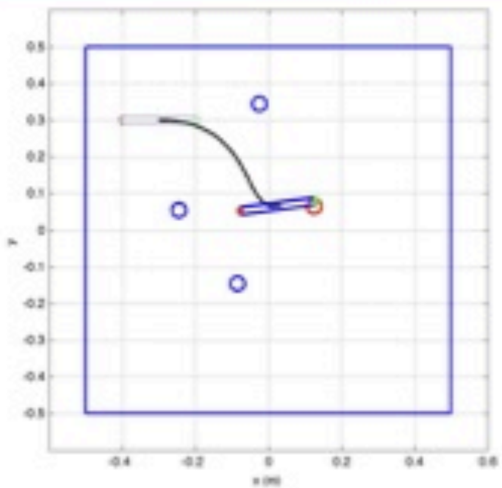
Tank with a mobile conduct.



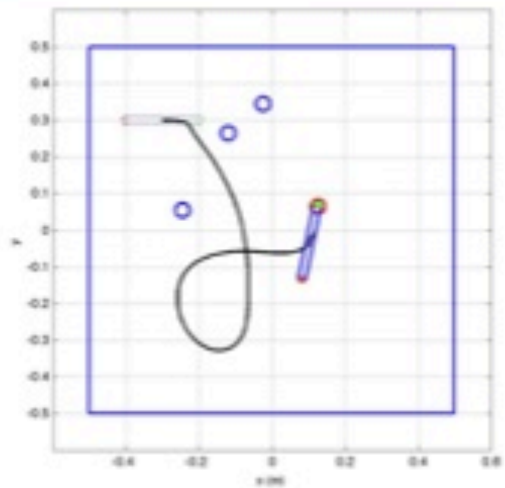
Navigation in complex scenes



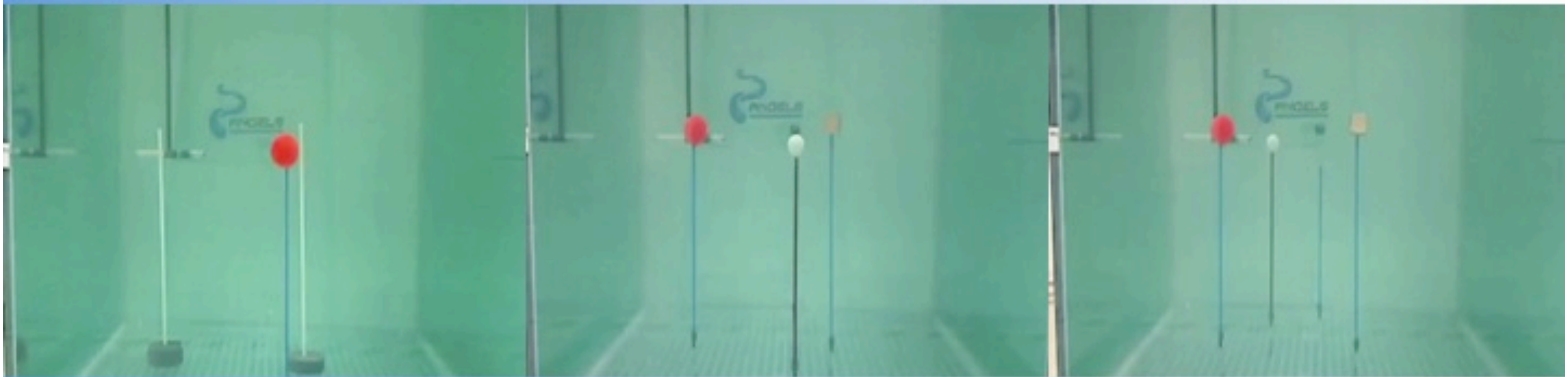
Tank with 2 insulators



Tank + 3 insulators + 1 conduct.



Tank + 3 insulators + 1 conduct.



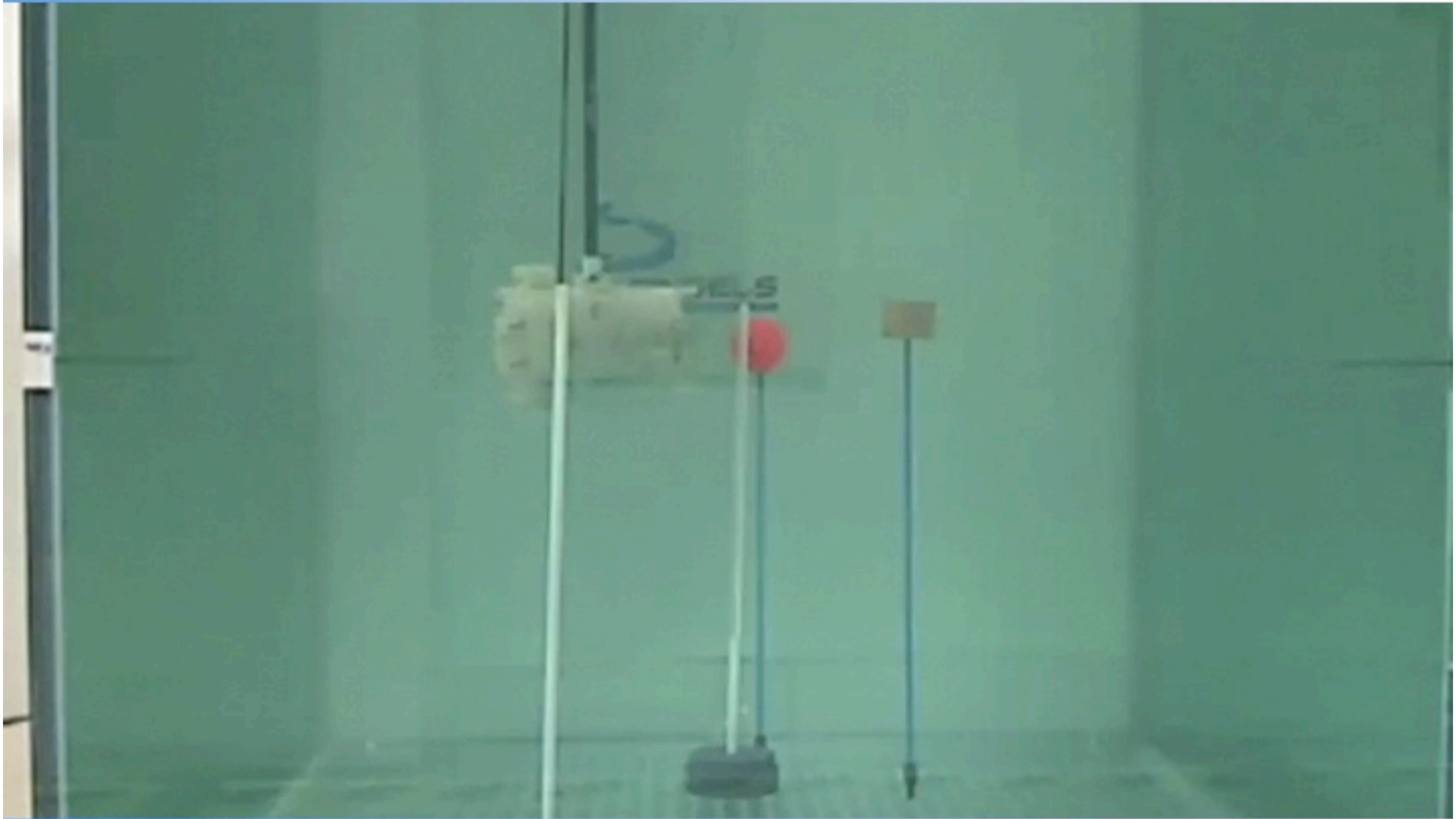
Conclusion

Conclusion and work in progress

- New solution to the pb of underwater navigation…
  - requires no model
  - replaces locomotion by manipulation…
  - the electric field is an extension of the body of the robot
  - exploits the haptic modality of electric sense
  - ~~Virtual~~ “Real" potential field approach for underwater navigation...

- Work in progress:
  - Extension of the approach to other behaviors (orbiting around objects, following walls, etc…)
  - Extension to multi-agent in progress
  - Electric reconfiguration…
  - Implementation on the Angels platform…

With the Angels module…



Questions…?

The Angels team in Nantes:

Researcher

Pr. Pol-Bernard Gossiaux
Dr. Christine Chevallereau
Dr. Noel Servagent
Dr. Alexis Girin
Dr. Stéphane Bouvier

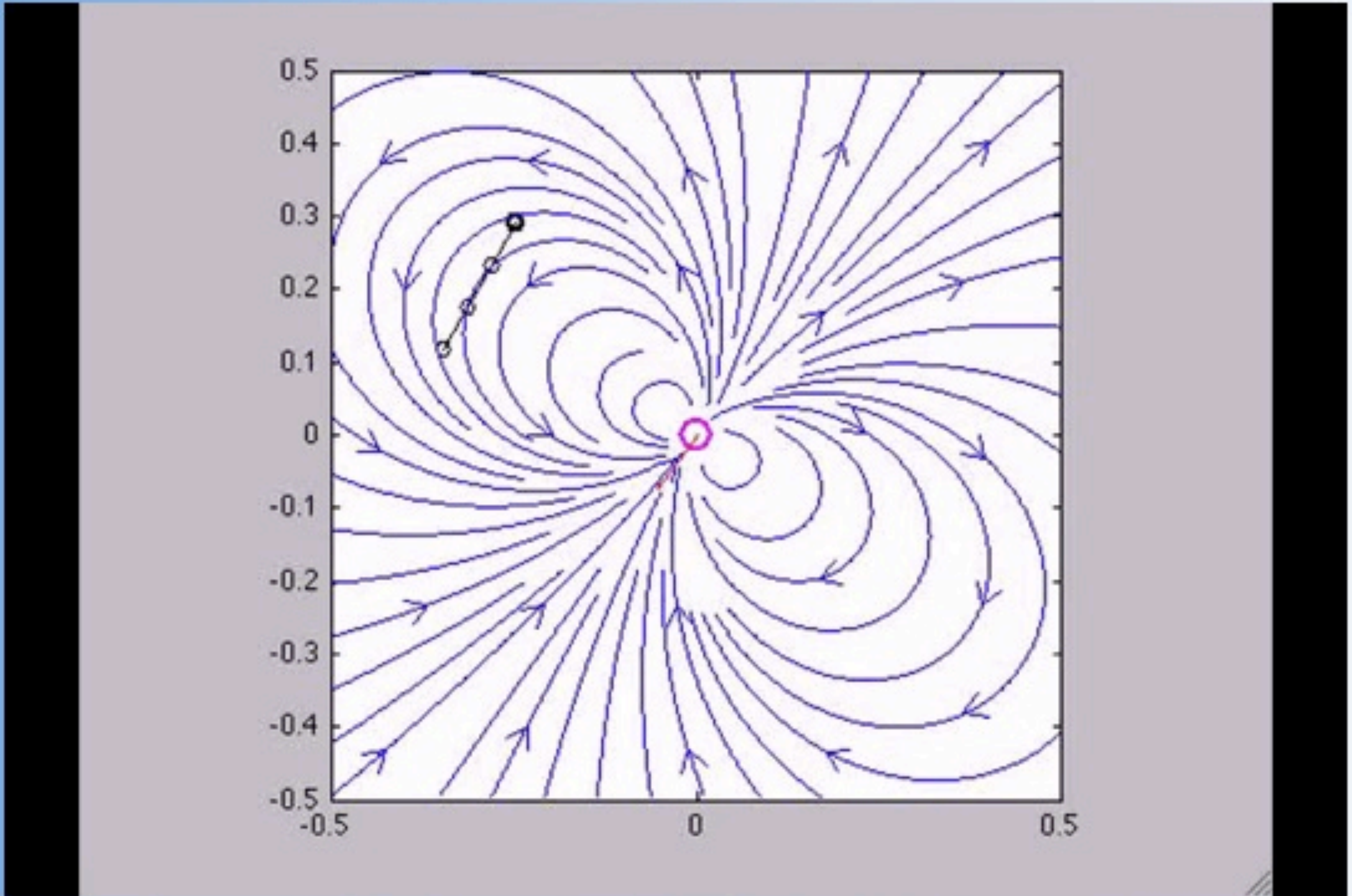
PhD Students

Brahim Jawad
Réda Benachenhou

Technicien

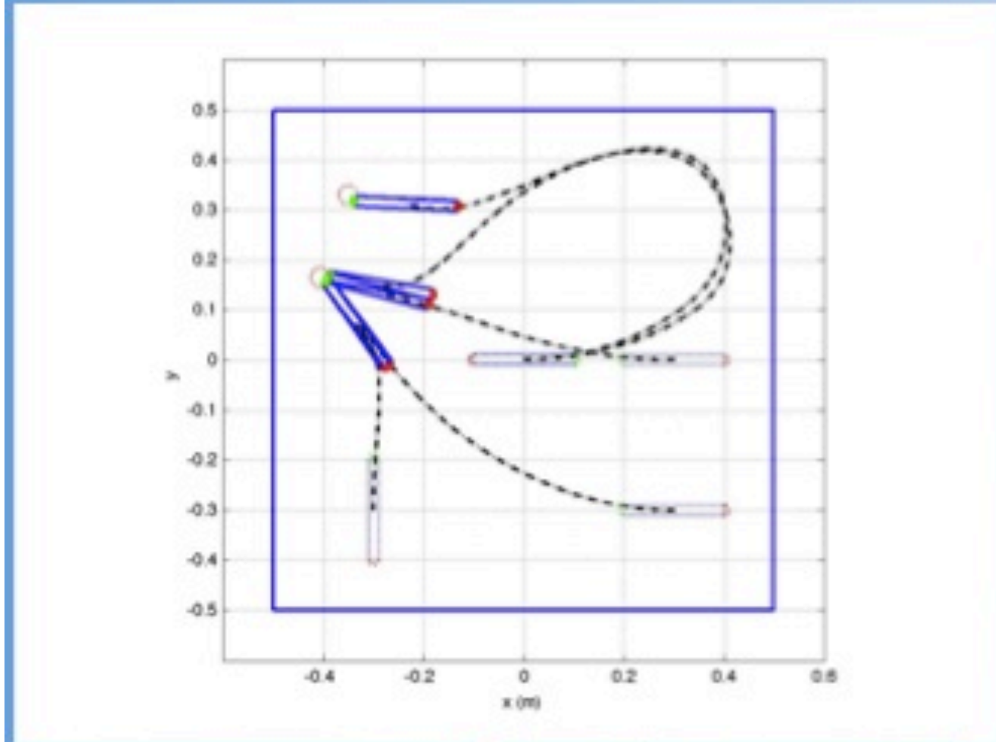
Francesco Gomez

Embodied navigation



Orbiting around an object

Embodied navigation



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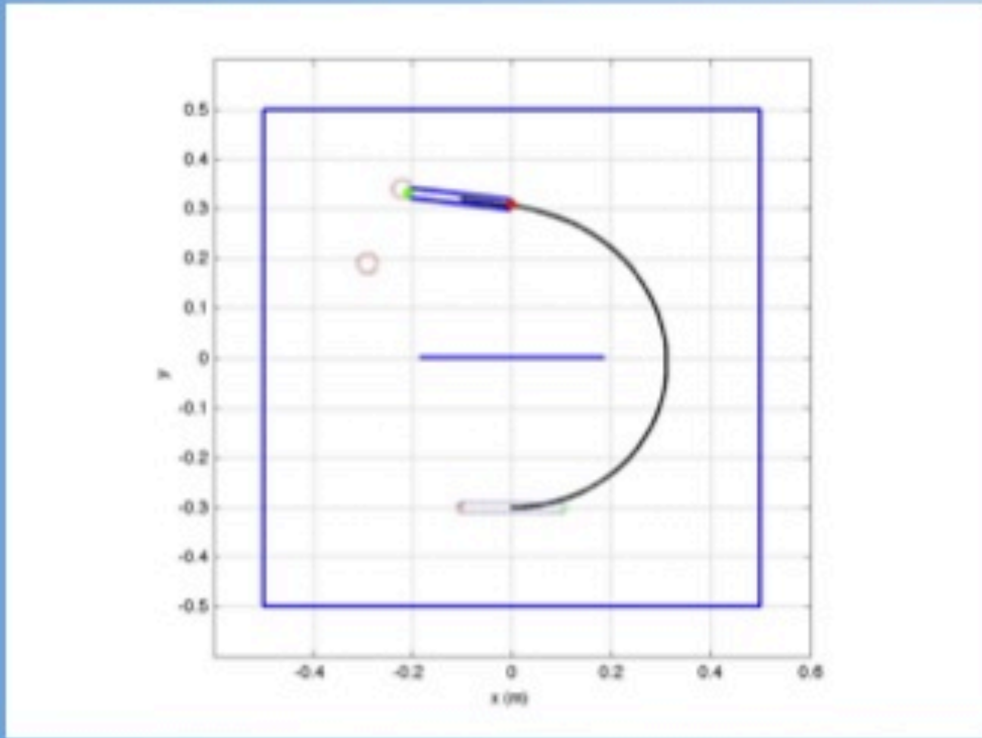

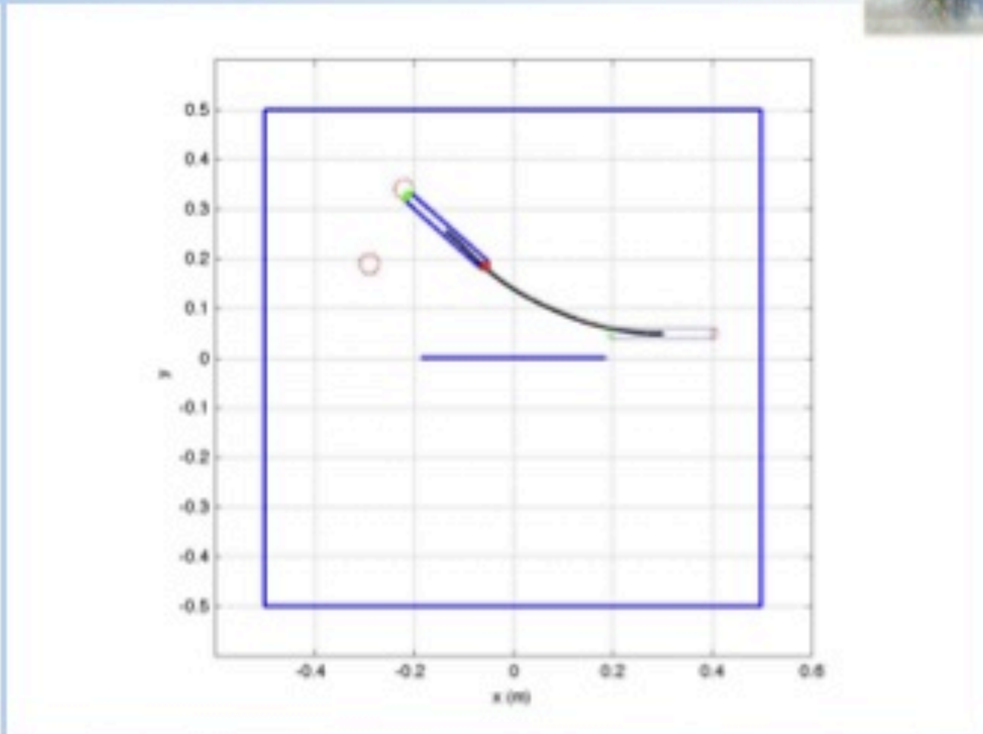

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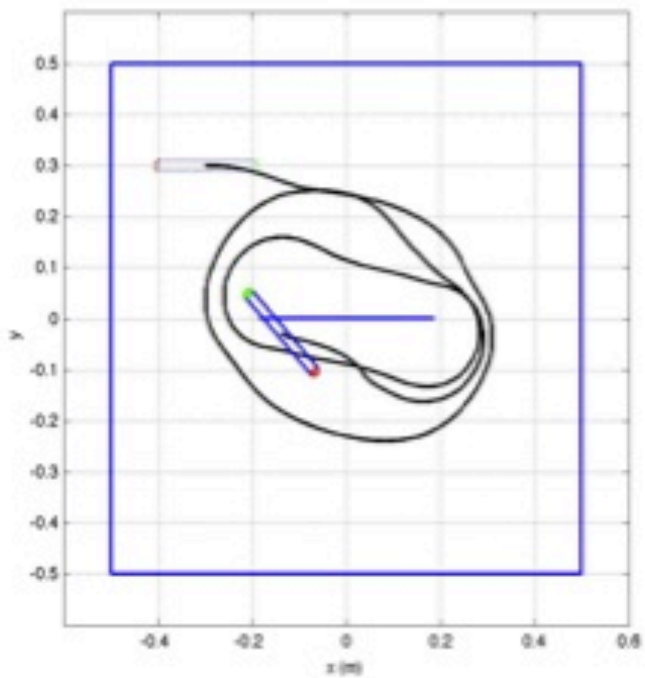
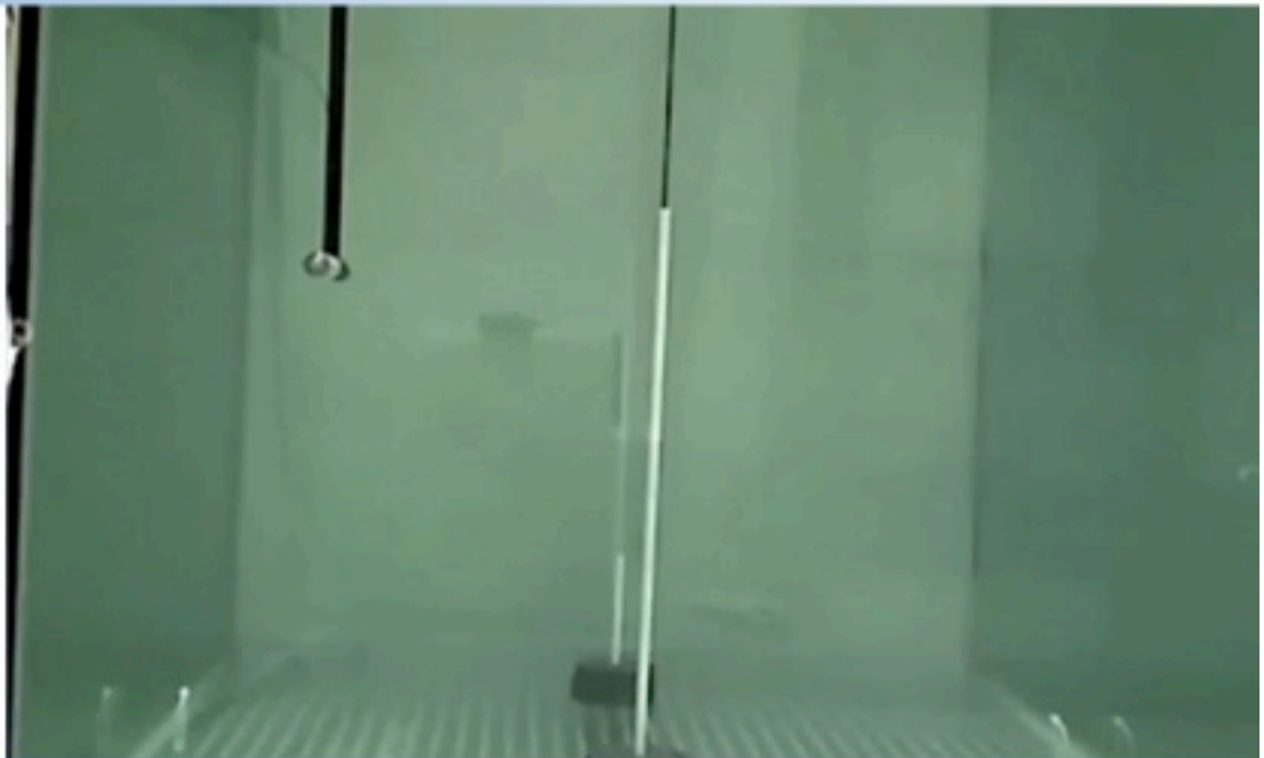
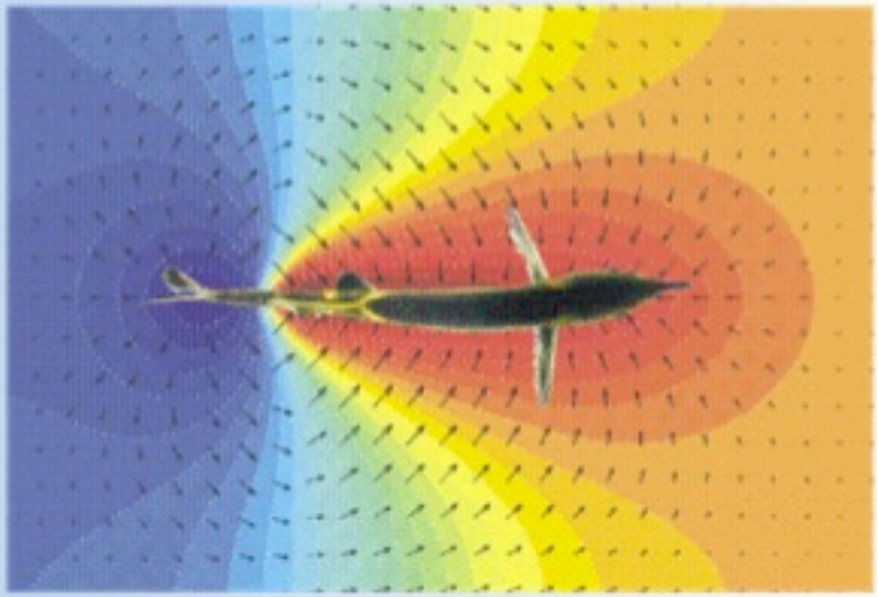
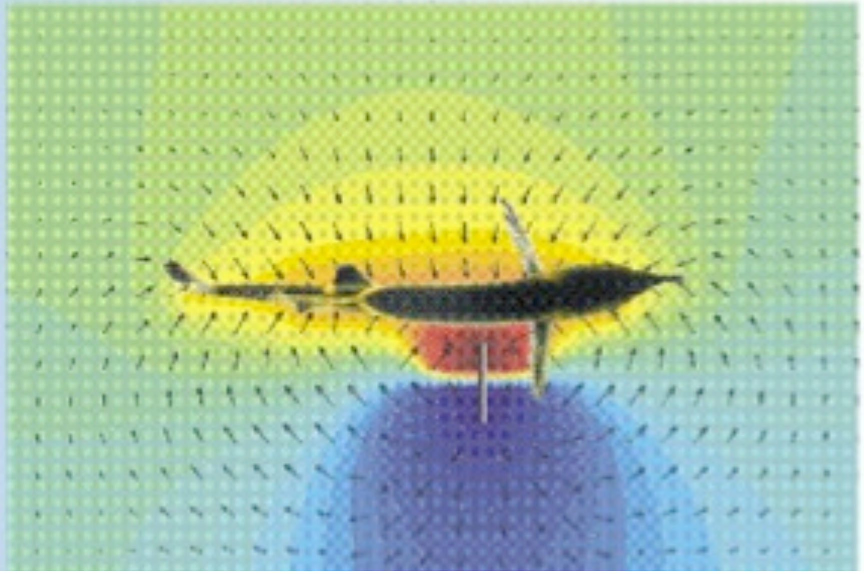




Advantages of electric sense…

- Works in murky and confined environments
- Omni-directional
- No blind spots
- Can be used for communication AND electrolocation
- Provides information about the material of an object…
- 3-D perception (in depth)





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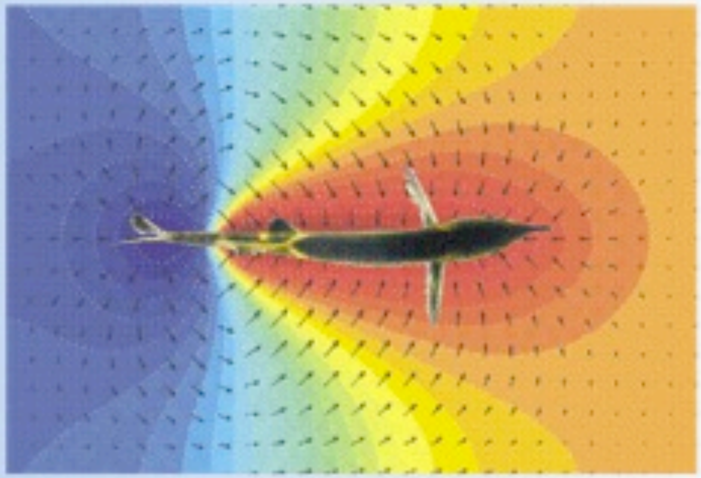

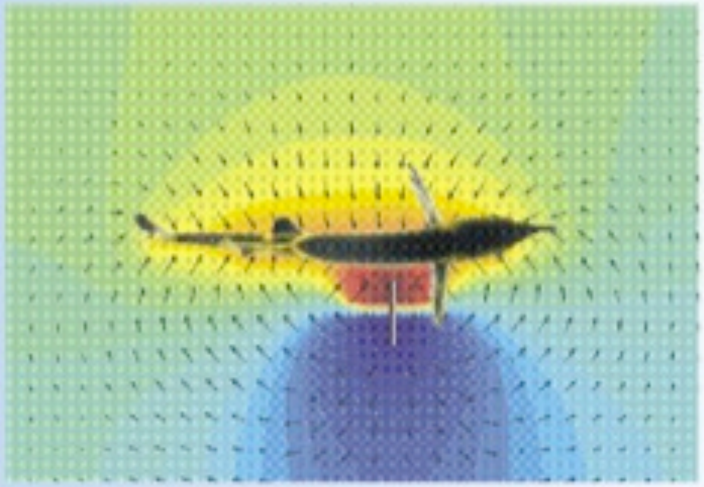

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