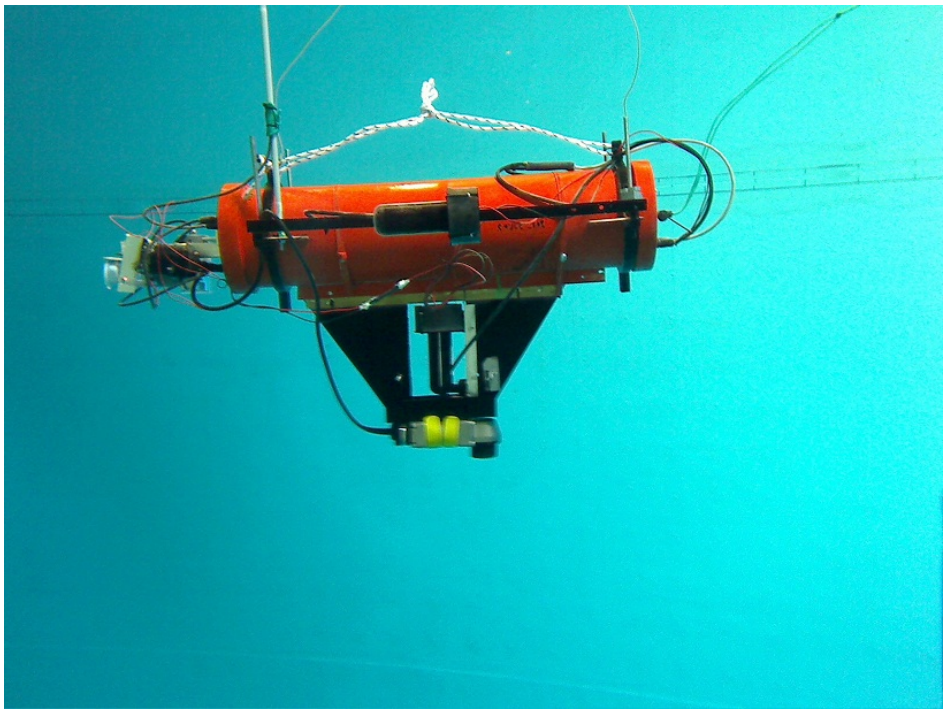
Ocean robotics

Luc Jaulin, Lab-STICC, ENSTA-Bretagne
Plymouth, 2017 August 9-11

What is a robot ?

A robot is a mechanical system equipped with actuators, sensors and a brain.[1]



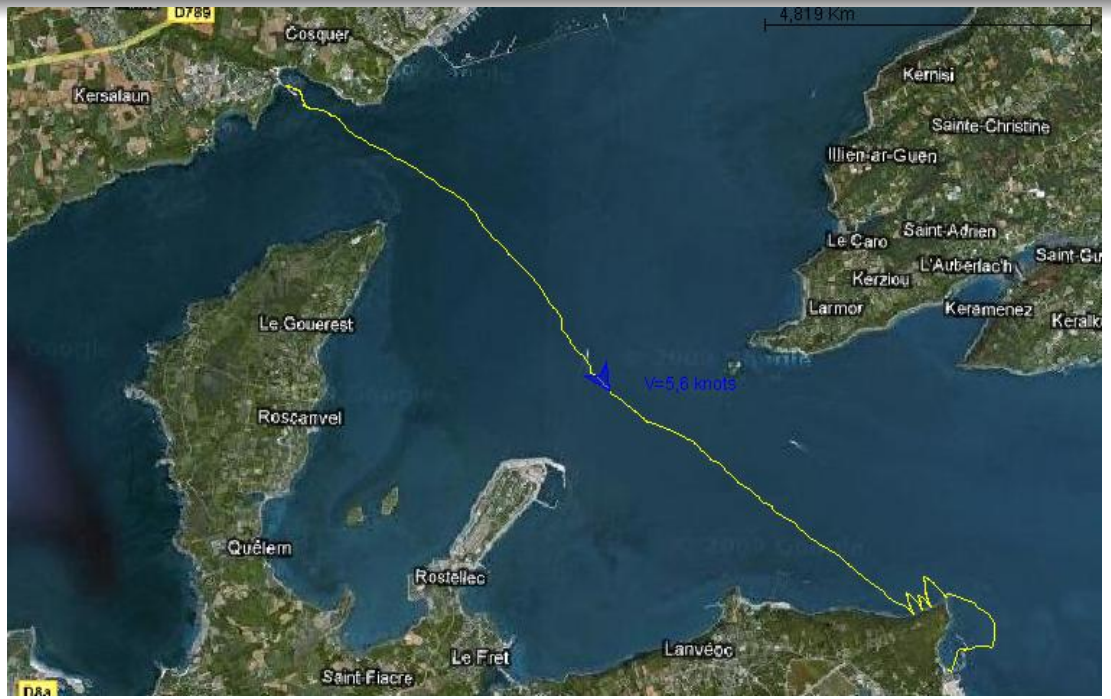
Saucisse (ENSTA Bretagne). First at SAUCE'2016

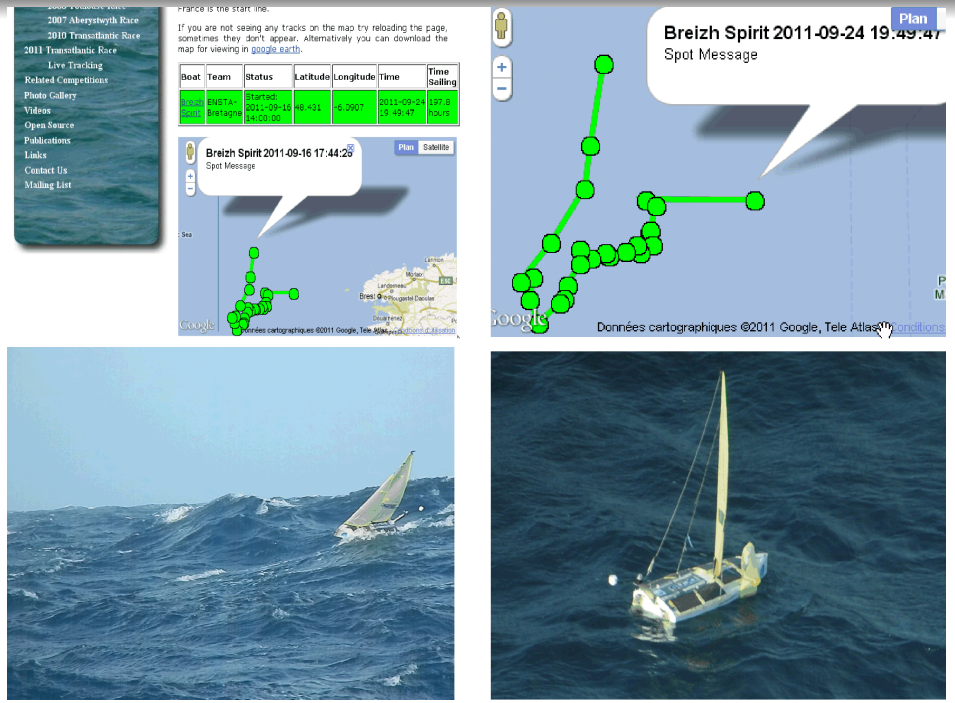
Gouelack (ENSTA Bretagne)

Concombre: Premier catégorie lourde HYDROcontest 2016

Saiboat robots


BREIZH
ENSIETA
SPIRIT
ENSIETA


D789
Cosquer
4,819 Km
Kersalaun
Kernisi
Sainte-Christine
Illien-ar-Guen
Le Caro
Saint-Adrien
L'Auberlac'h
Kerziou
Larmor
Keramenez
Le Gouerest
V=5,6 knots
Rosçanvel
Quélern
Rostellec
Le Fret
Lanvéoc
Saint-Fiacre


2007 Aberystwyth Race
2010 Transatlantic Race
2011 Transatlantic Race
Live Tracking
Related Competitions
Photo Gallery
Videos
Open Source
Publications
Links
Contact Us
Mailing List
France is the start line.
If you are not seeing any tracks on the map try reloading the page, sometimes they don't appear. Alternatively you can download the map for viewing in google earth.
Boat
Team
Status
Latitude
Longitude
Time
Time Sailing
ENSTA-Bretagne
Started: 2011-09-16 14:00:00
48.431
-6.0907
2011-09-24 19:49:47
197.8 hours
Breizh Spirit 2011-09-16 17:44:25
Spot Message
Plan
Satellite
Breizh Spirit 2011-09-24 19:49:47
Spot Message
Plan
Données cartographiques ©2011 Google, Tele Atlas

Second at WRSC'2016

Vaimos at the WRSC (ENSTA Bretagne-IFREMER)
with F. Le Bars, O. Ménage, P. Rousseau

Vaimos (IFREMER and ENSTA) in Angers

youtu.be/tmfkKNM76Qg

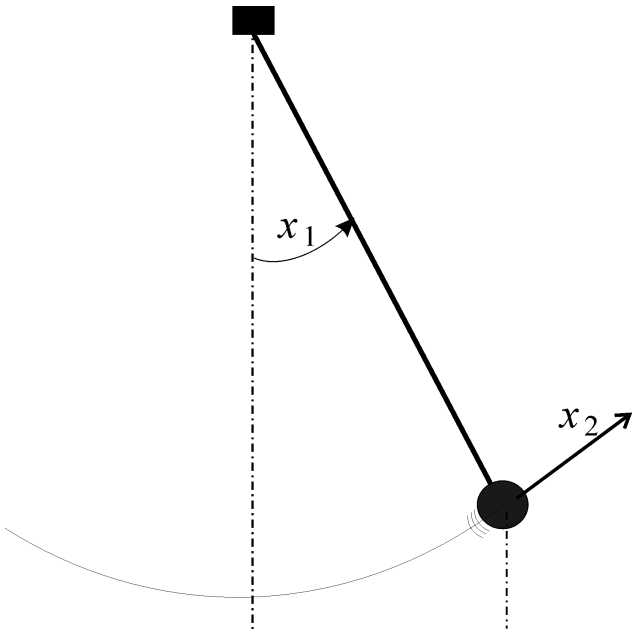
A robot is a dynamical system

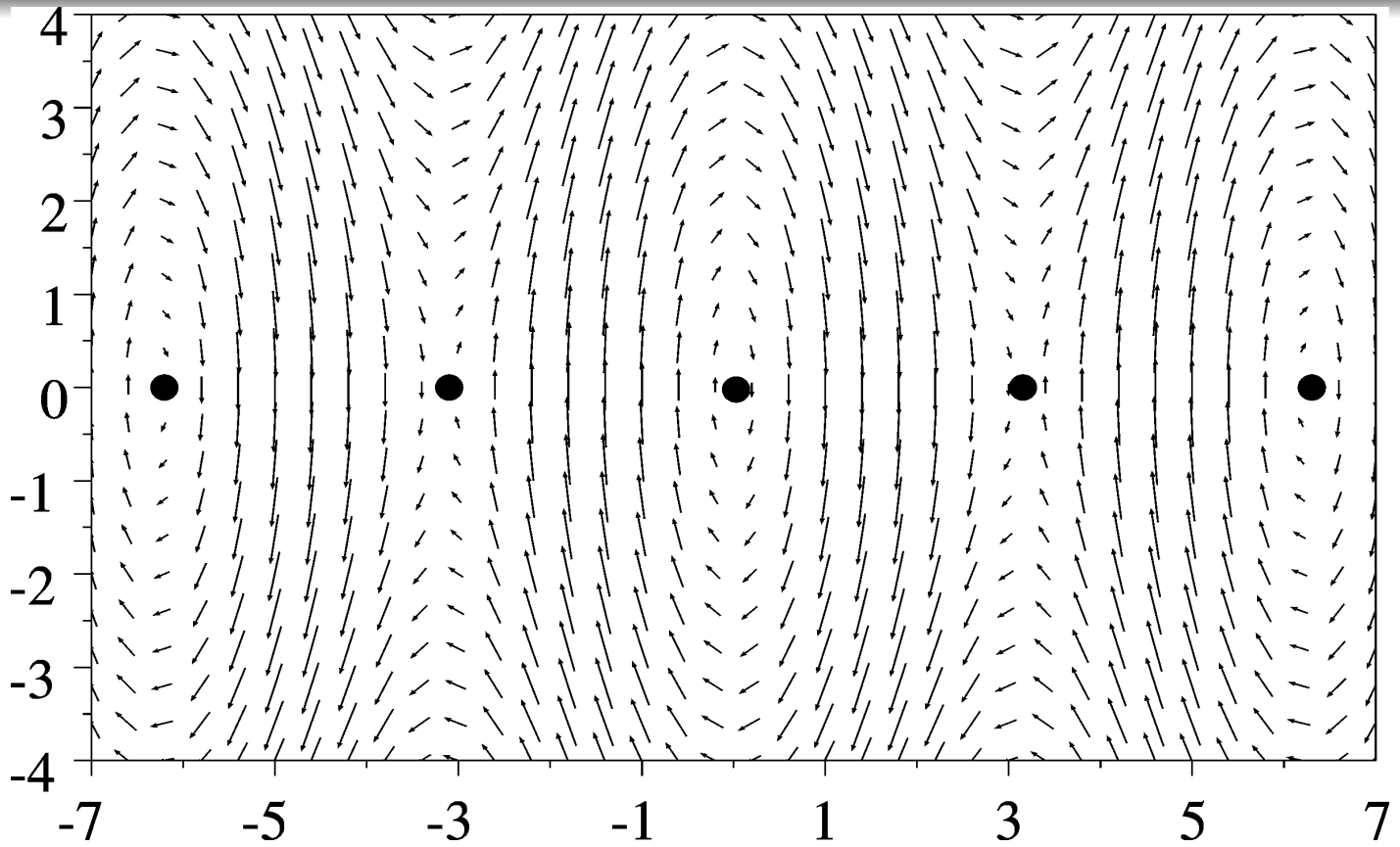
A dynamical system can be written as [Newton 1690]

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}).$$

Example: The pendulum

$$\begin{cases} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= -\sin x_1 . \end{cases}$$

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-1
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5
7

A robot is a vehicle

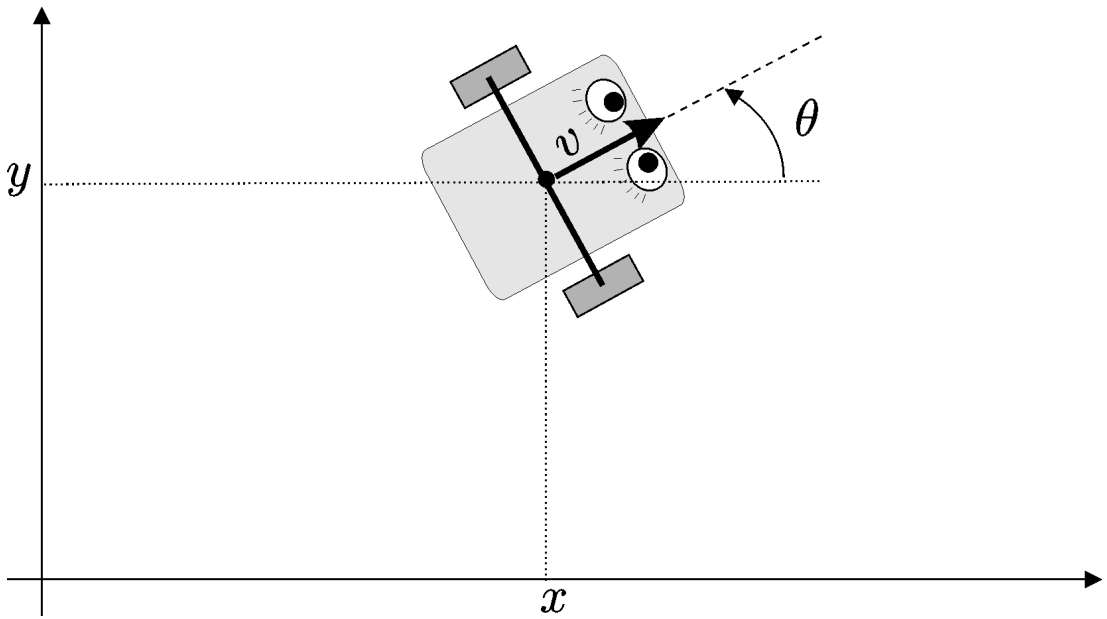
A **vehicle** is a controlled mechanical system

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}, \mathbf{u}).$$

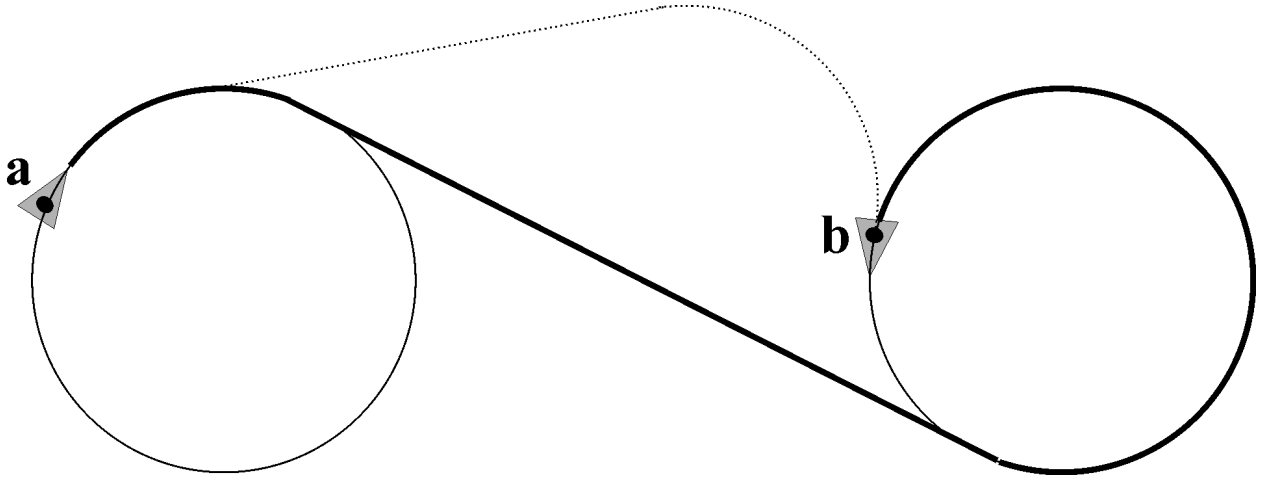
Example. Dubin's car (1957).

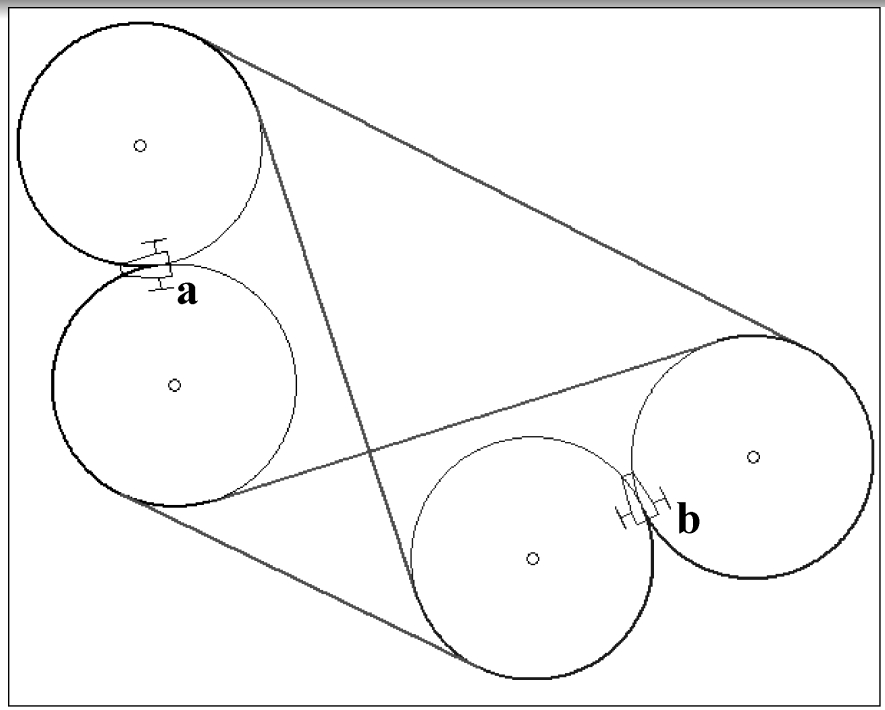
$$\begin{cases} \dot{x} &= \cos\theta \\ \dot{y} &= \sin\theta \\ \dot{\theta} &= u \end{cases}$$

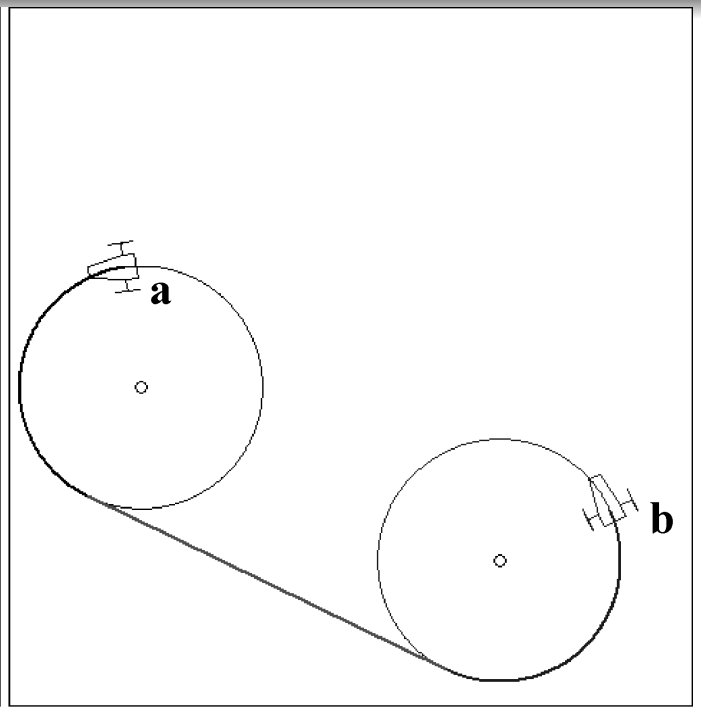
with $u \in [-1, 1]$.



Dubin's paths




a
b


a
b

A robot is an intelligent vehicle

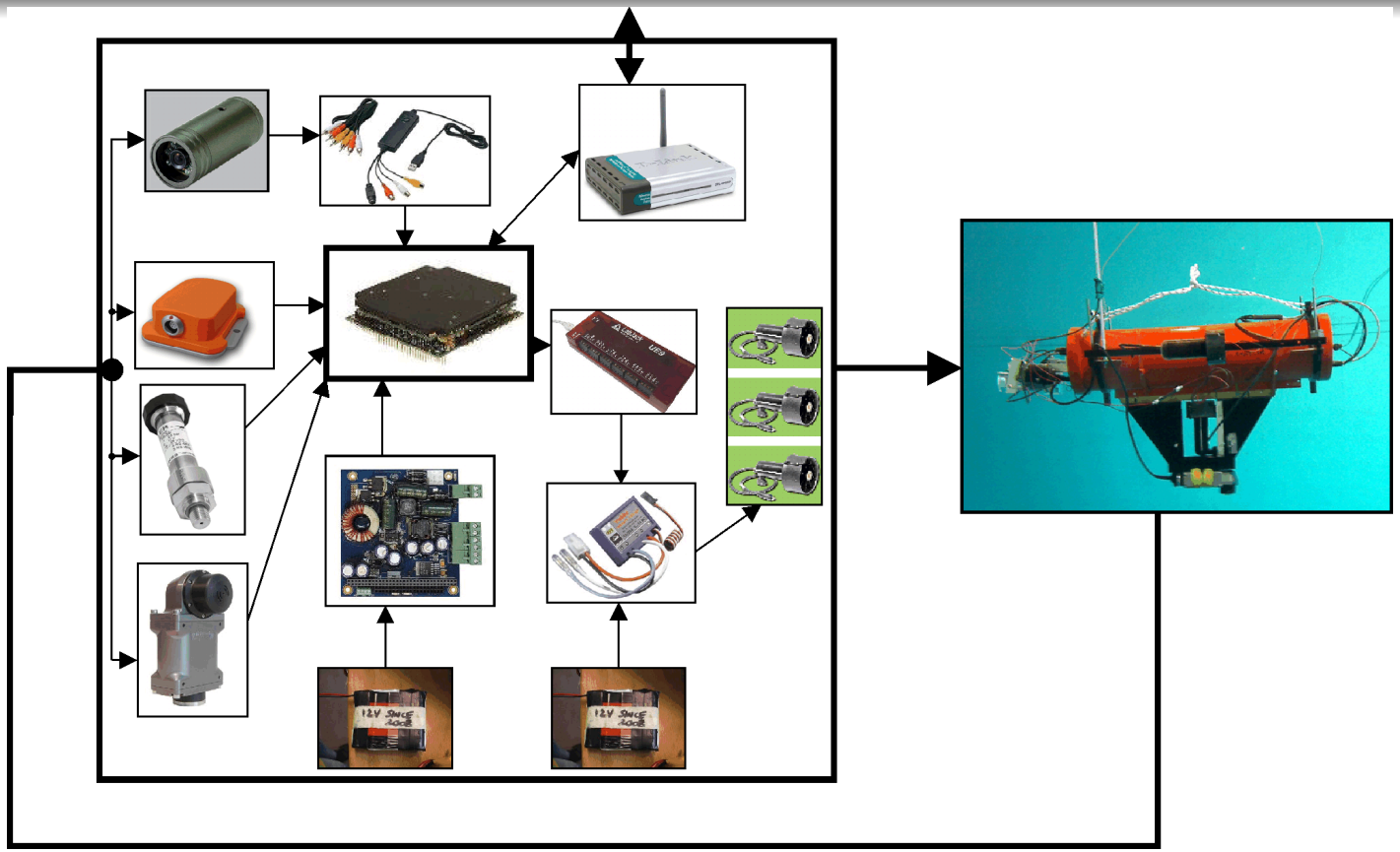
A robot is a vehicle with actuators, sensors, and a brain

$$\begin{aligned} \dot{\mathbf{x}} &= \mathbf{f}(\mathbf{x},\mathbf{u}) && \text{(evolution)} \\ \mathbf{y} &= \mathbf{g}(\mathbf{x}) && \text{(observation)} \\ \mathbf{u} &= \mathbf{h}(\mathbf{y},\mathbf{w}). && \text{(control)} \end{aligned}$$

We have

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x},\mathbf{h}(\mathbf{g}(\mathbf{x}),\mathbf{w})) = \psi(\mathbf{x},\mathbf{w})$$

and thus a robot is a dynamical system.



Why do we need robots ?

Brest-Douarnenez. January 17, 2012, 8am

Vaimos (IFREMER and ENSTA): from Brest to Douarnenez

youtu.be/XxQ_KWI1q74

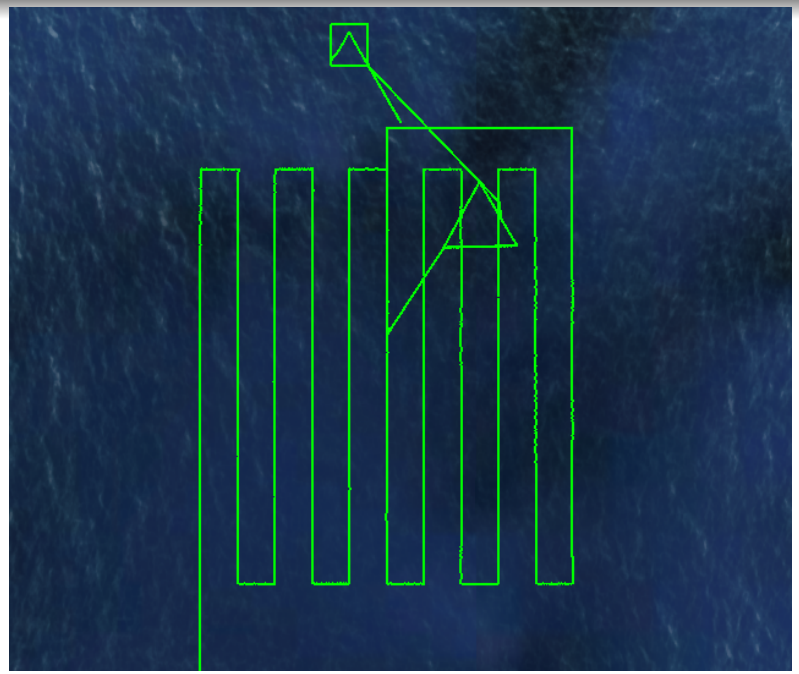
Brest-Douarnenez. January 17, 2012


F78


Google Earth
Fichier Édition Affichage Outils Ajouter Aide
Brest
Plouzané
Plougastel-Daoulas
Le Conquet
Crozon
Douarnenez
Image © 2012 GeoEye
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 IGN-France
©2010 Google
Altitude 53.47 km

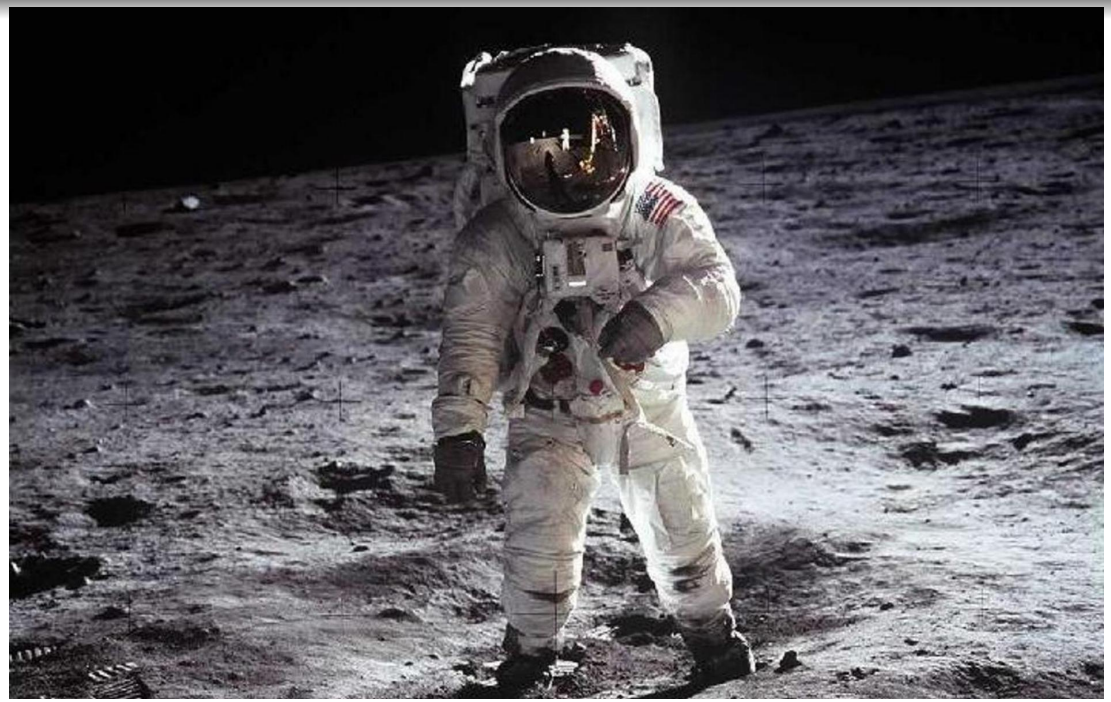
Middle of Atlantic ocean

youtu.be/pb_KhcYZI_A



350 km made by Vaimos in 53h, September 6-9, 2012.

Ocean satellites ?

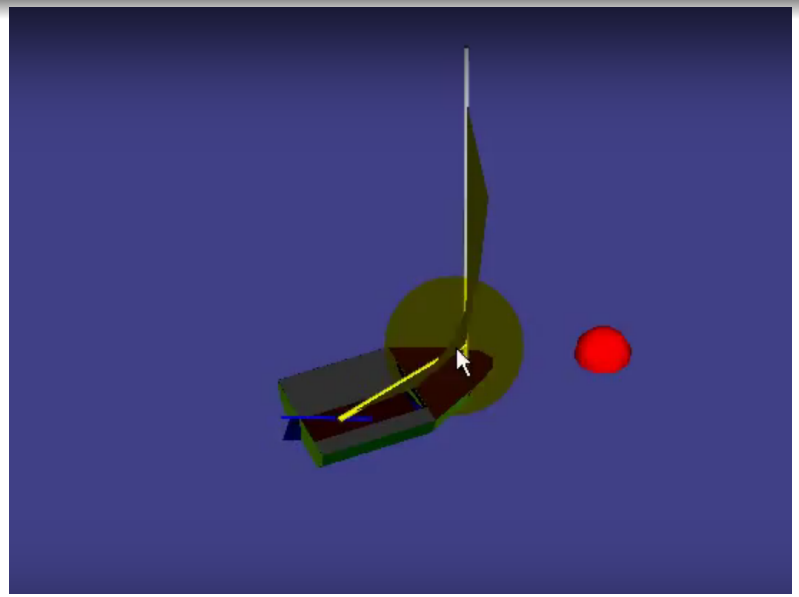


Robots are needed for dirty, dangerous and dull jobs

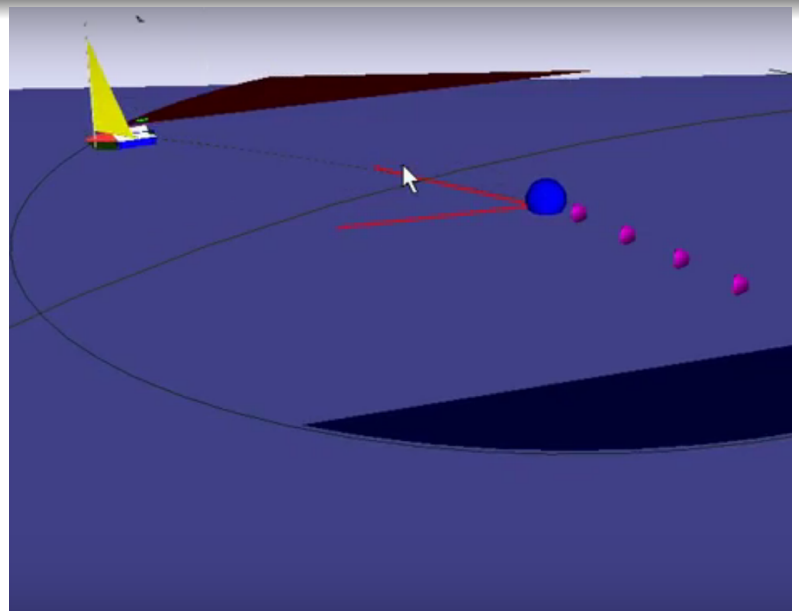
Curiosity

About 3,600 satellites in orbit (1,000 are operational).
In the ocean, we have gliders, drifting buoys.
In the ocean, a robot could be autonomous in energy, and could survive for years (persistent autonomy).

Validation by simulation



youtu.be/TOY1ZF1fYSA



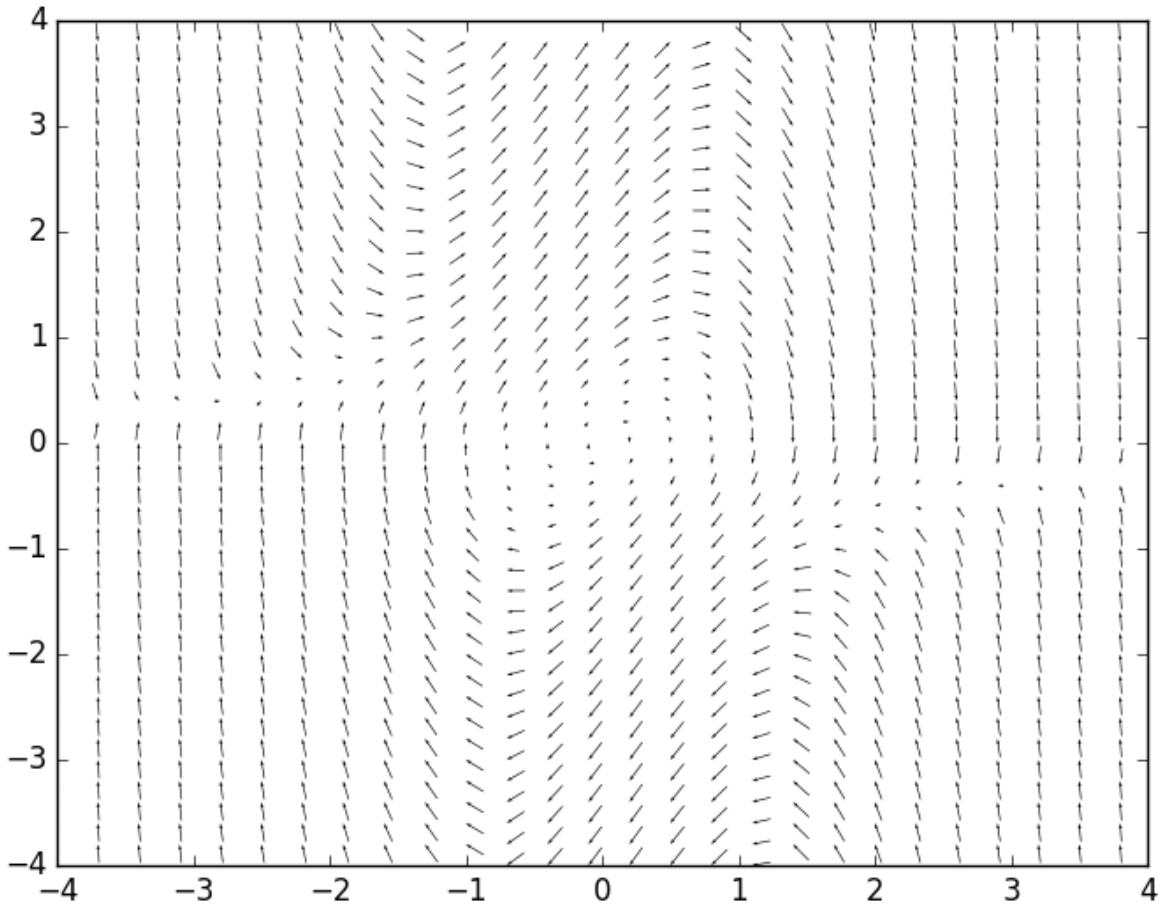
youtu.be/GT0Mcc0ZliQ

Theoretical Validation

A robot $\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x})$.

Example: The Van der Pol system

$$\begin{cases} \dot{x}_1 &= x_2 \\ \dot{x}_2 &= \left(1 - x_1^2\right) \cdot x_2 - x_1 \end{cases}$$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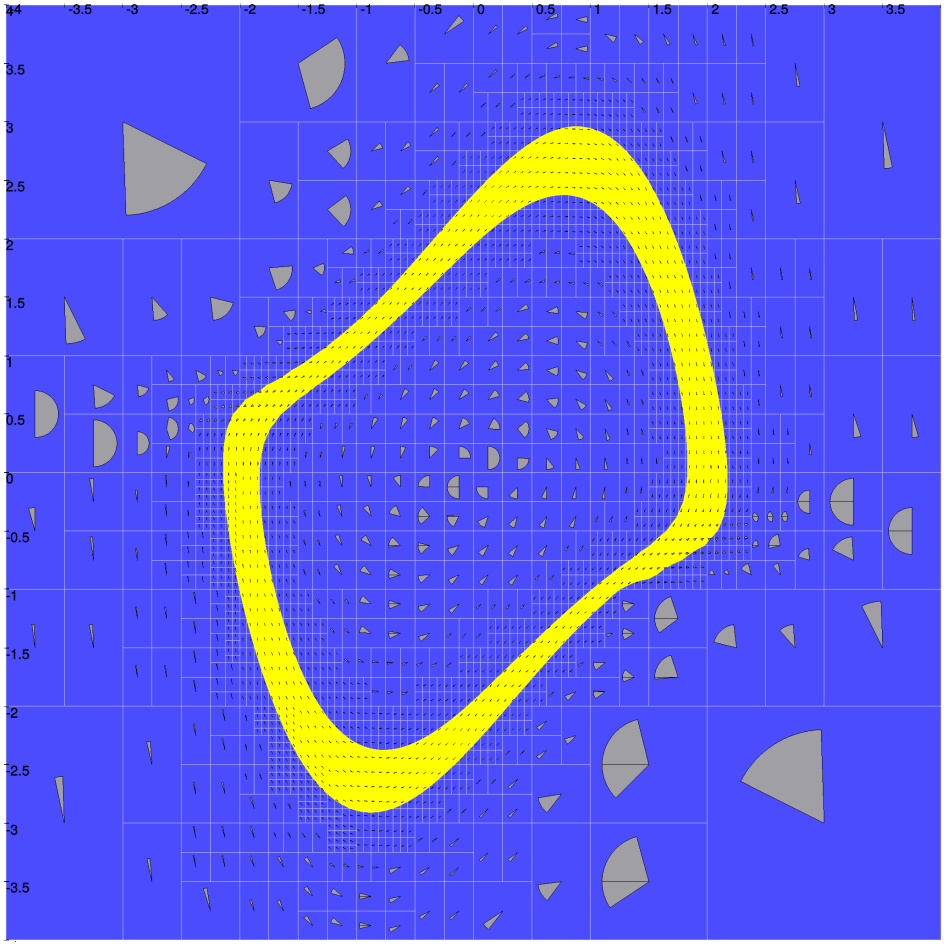
Invariants sets can be computed [4]



When the wind is known, the sailboat with the heading controller is described by

$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}).$$

The system

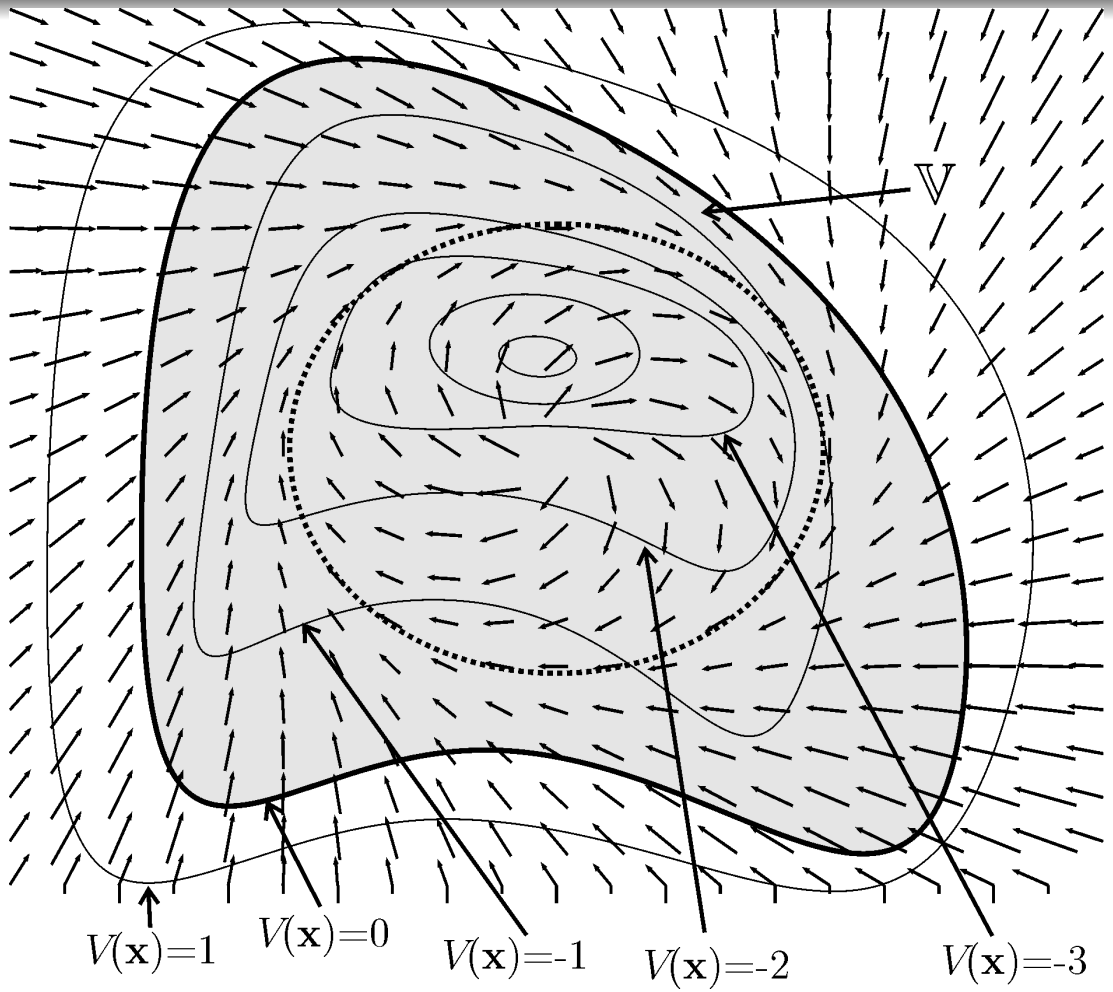
$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x})$$

is Lyapunov-stable (1892) is there exists $V(\mathbf{x}) \geq 0$ such that

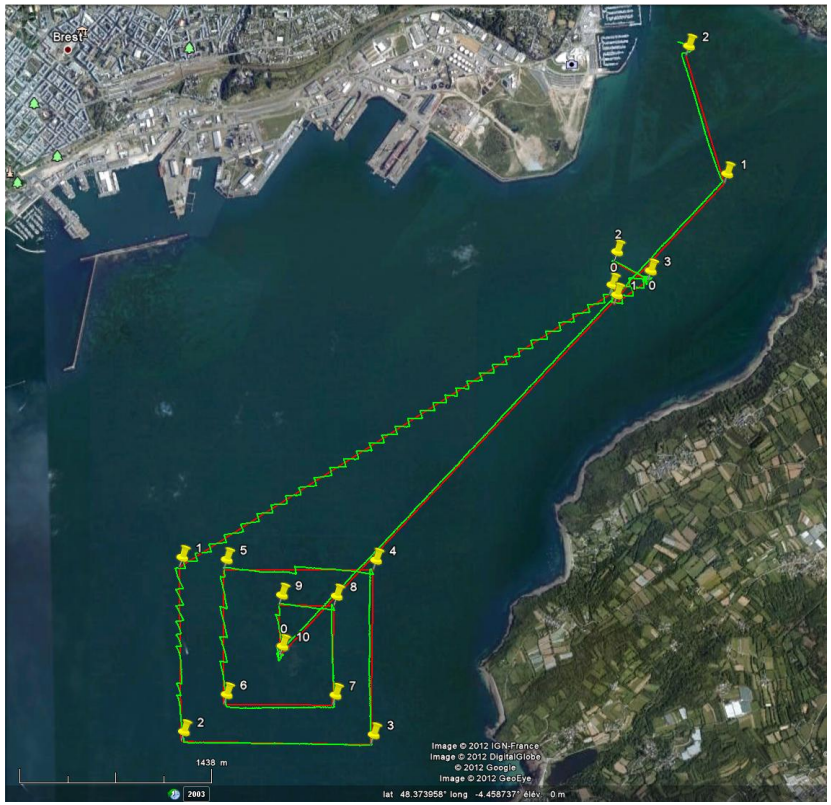
$$\begin{aligned} \dot{V}(\mathbf{x}) &< 0 \text{ if } \mathbf{x} \neq \mathbf{0}, \\ V(\mathbf{x}) &= 0 \text{ iff } \mathbf{x} = \mathbf{0}. \end{aligned}$$

Definition. Consider a differentiable function $V(\mathbf{x}) : \mathbb{R}^n \to \mathbb{R}$. The system is V-stable [3] if

$$\left(V(\mathbf{x}) \geq 0 \;\Rightarrow\; \dot{V}(\mathbf{x}) < 0 \right).$$


$\mathbb{V}$
$V(\mathbf{x})$=1
$V(\mathbf{x})$=0
$V(\mathbf{x})$=-1
$V(\mathbf{x})$=-2
$V(\mathbf{x})$=-3

Validation with experiments


Brest
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1438 m
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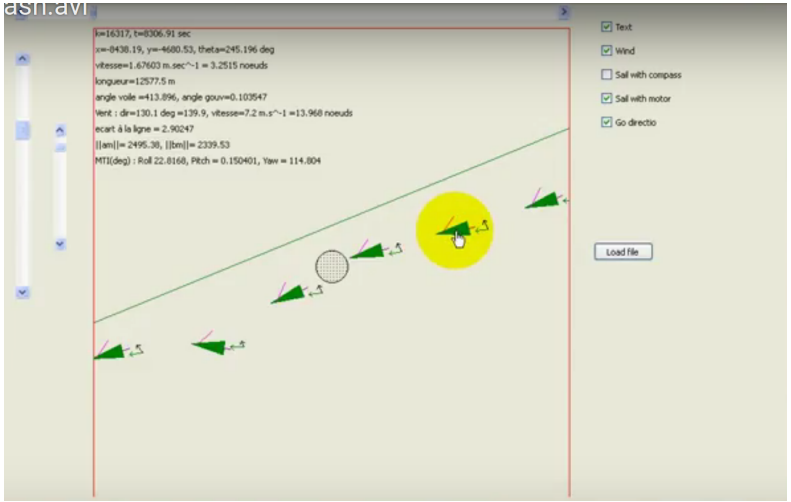
Image © 2012 IGN-France
Image © 2012 DigitalGlobe
© 2012 Google
Image © 2012 GeoEye

Use a dash to check inconsistencies



youtu.be/pHteidmZpnY

Try to make the system fail

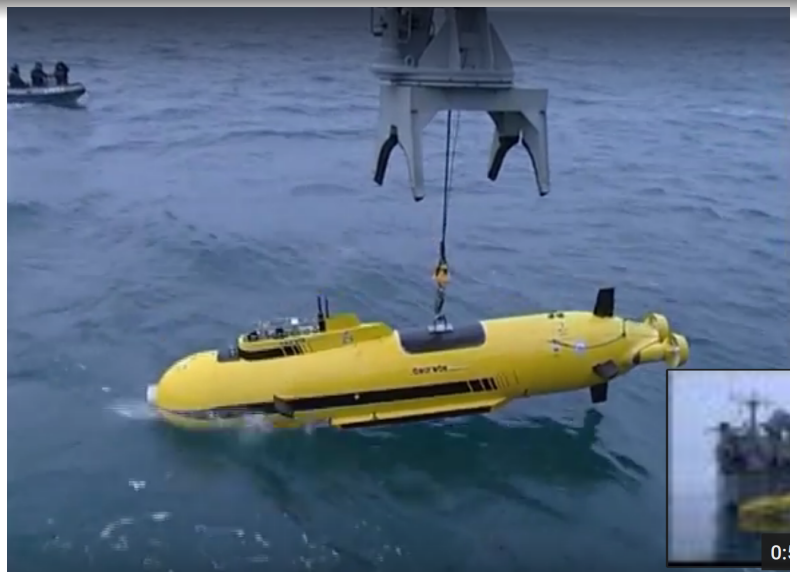
Forum DGA, Palaiseau

youtu.be/mPGUnsDX9aU

Groups

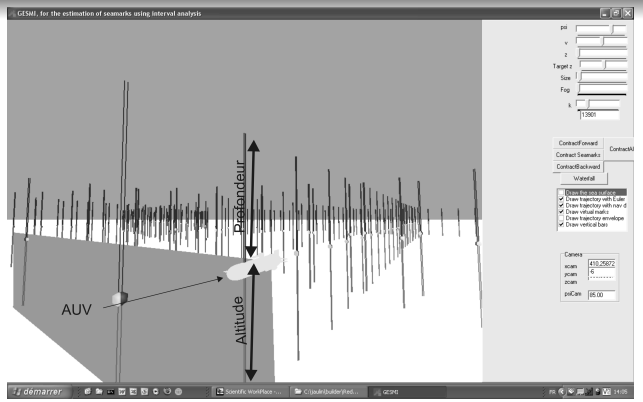
youtu.be/gwxfMg5oRSA

Mine hunting



Redermor (GESMA, Brest)

https://youtu.be/X0IqZxb-tFs

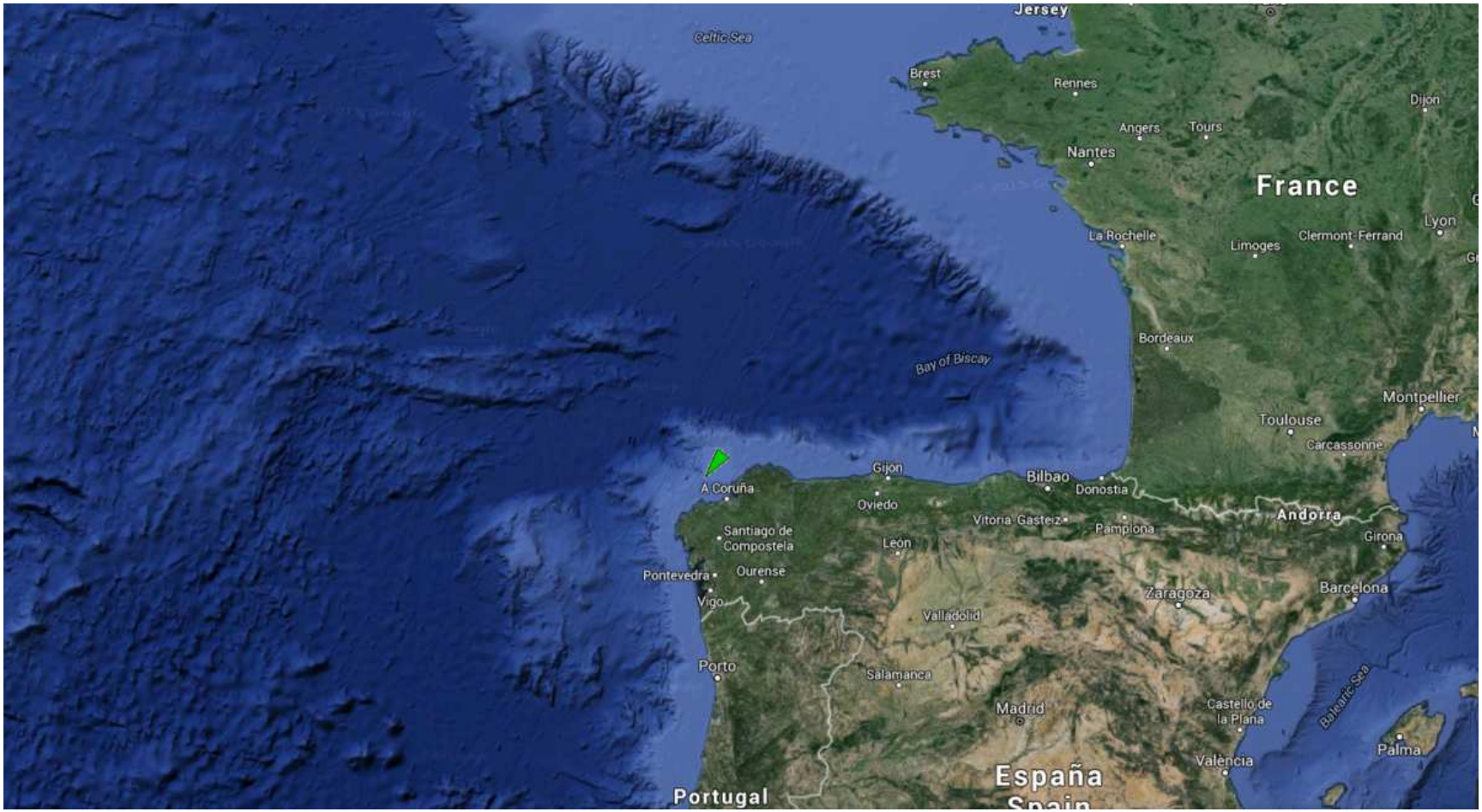


youtu.be/lzJtAfAT7h4

Secure a zone

INFO OBS. Un sous-marin nucléaire russe repéré dans le Golfe de Gascogne

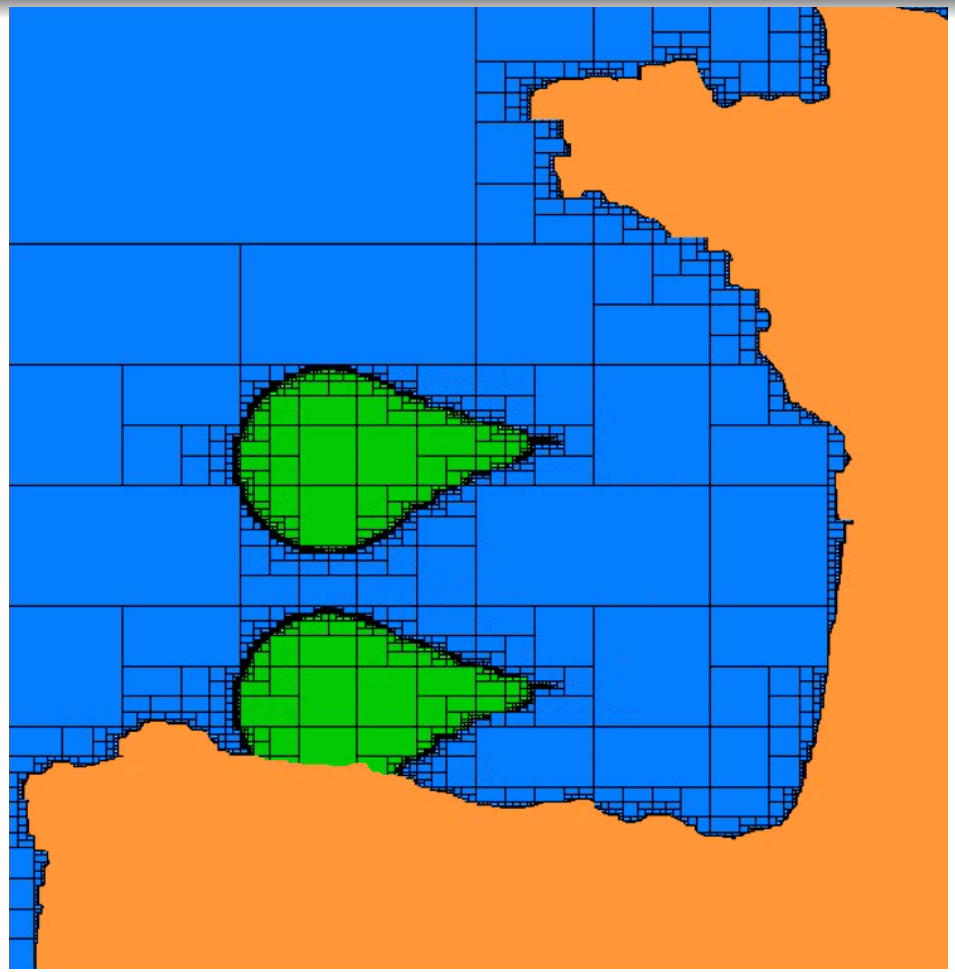
Le navire a été repéré en janvier. Ce serait la première fois depuis la fin de la Guerre Froide qu'un tel sous-marin, doté de missiles nucléaires, se serait aventuré dans cette zone au large des côtes françaises.



Bay of Biscay 220 000 km^2

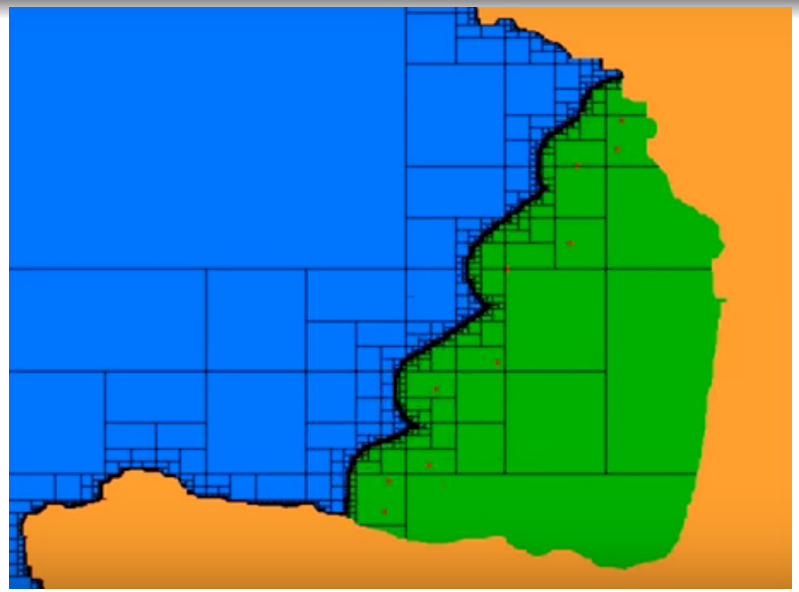
An intruder

- Several robots $\mathscr{R}_1, \ldots, \mathscr{R}_n$ at positions $\mathbf{a}_1, \ldots, \mathbf{a}_n$ are moving in the ocean.
- If the intruder is in the visibility zone of one robot, it is detected.



Blue:

$$\mathbb{X}(t) = \mathbb{G} \cap (\mathbb{X}(t - dt) + dt \cdot \mathbb{F}(\mathbb{X}(t - dt))) \cap \bigcap_i g^{-1}_{\mathbf{a}_i(t)}([d_i(t), \infty]).$$



youtu.be/rNcDW6npLfE

MOOCs and books

A MOOC made from the book Mobile Robotics [2]

Experiments


Argo


D36 918
HONDA
HONDA


ENSTA
caribe

Club and challenges

youtu.be/DFg3K09cMwU


L. Jaulin.
Automation for Robotics.
ISTE editions, 2015.


L. Jaulin.
Mobile Robotics.
ISTE editions, 2015.


L. Jaulin and F. Le Bars.
An Interval Approach for Stability Analysis; Application to Sailboat Robotics.
IEEE Transaction on Robotics, 27(5), 2012.


T. Le Mézo, L. Jaulin, and B. Zerr.
An interval approach to compute invariant sets.
IEEE Transaction on Automatic Control, 2017.