Cooperative control, sailboats and underwater robots

Luc Jaulin, Saad Ibn, Vincent Drevelle, Olivier Ménage, Benoît Zerr, Benoît Clément, Thierry Terre, ...

OSM, IHSEV, ENSTA-Bretagne, LabSTICC, Brest, France

1 Reliable control

The robot satisfies a state equation

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

With the controller $\mathbf{u} = \mathbf{g}(\mathbf{x})$, the robot satisfies an equation of the form

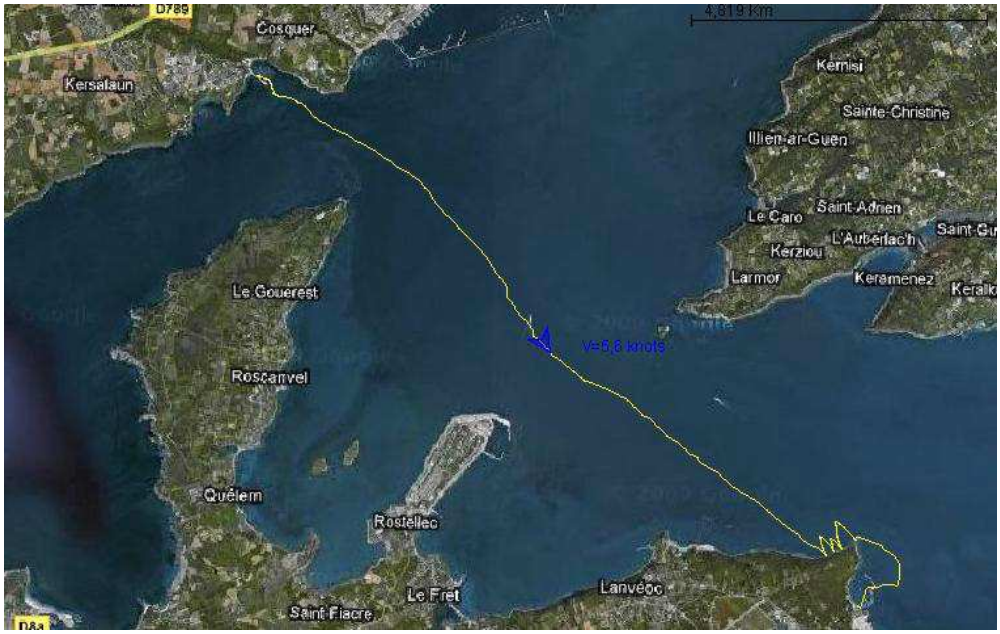
$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}).$$

With all uncertainties, the robot satisfies.

$$\dot{\mathbf{x}} \in \mathbf{F}(\mathbf{x})$$

which is *a differential inclusion*.

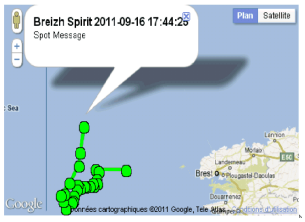

BREIZH
BREIZH
ENSIETA
ENSIETA
SPIRIT
SPIRIT

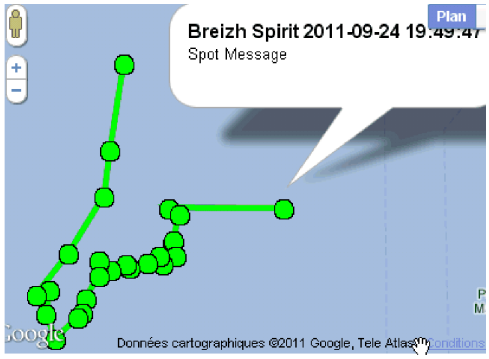

D789
Cosquer
Kersalaun
4,819 km
Kernisi
Sainte-Christine
Illien-ar-Guen
Le Caro
Saint-Adrien
L'Auberlach
Kerziou
Larmor
Keramenez
Le Gouerest
V=5,6 knots
Roscanvel
Quélern
Rostellec
Le Fret
Lanvéoc
Saint-Fiacre

France is the start line.

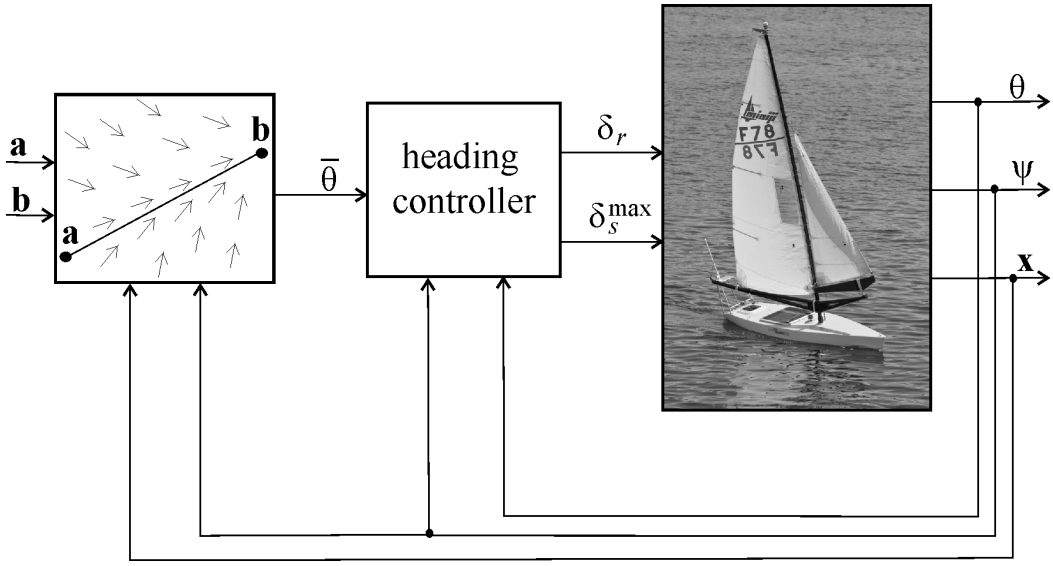
If you are not seeing any tracks on the map try reloading the page, sometimes they don't appear. Alternatively you can download the map for viewing in google earth.

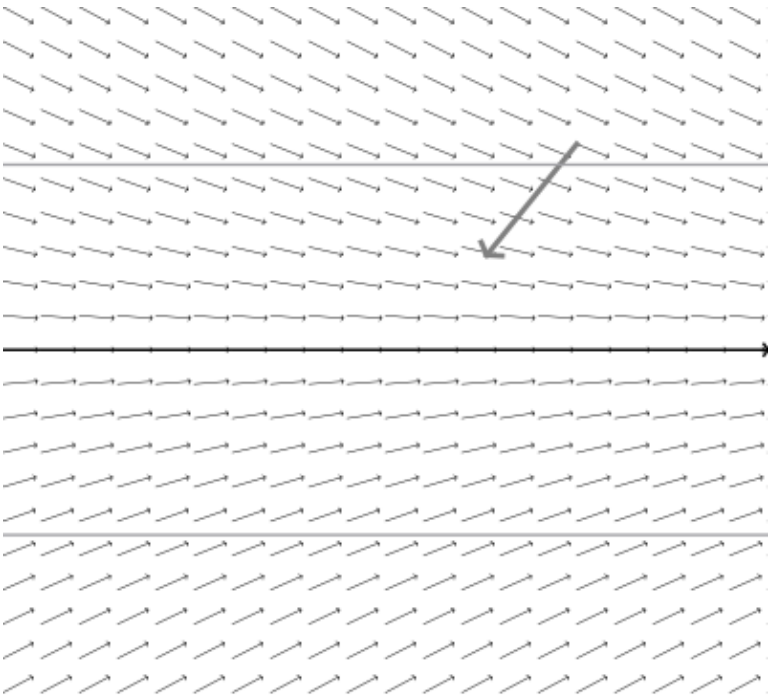
Boat	Team	Status	Latitude	Longitude	Time	Time Sailing
Breizh Spirit	ENSTA-Bretagne	Started: 2011-09-16 14:00:00	48.431	-6.0907	2011-09-24 19:49:47	197.8 hours





Vaimos (IFREMER and ENSTA)


a
b
a
b
$\bar{\theta}$
heading
controller
δ_r
δ_s^{max}
θ
ψ
x



$$\theta^* = -\frac{2.\gamma_\infty}{\pi}.\mathrm{atan}\left(\frac{e}{r}\right)$$

Controller in: $\mathbf{m}, \theta, \psi, \mathbf{a}, \mathbf{b}$; out: $\delta_r, \delta_s^{\max}$; inout: q

$e = \det\left(\frac{\mathbf{b}-\mathbf{a}}{\|\mathbf{b}-\mathbf{a}\|}, \mathbf{m}-\mathbf{a}\right)$

if $|e| > \frac{r}{2}$ then $q = \text{sign}(e)$

$\varphi = \text{atan2}(\mathbf{b}-\mathbf{a})$

$\theta^* = \varphi - \frac{2.\gamma_\infty}{\pi}.\text{atan}\left(\frac{e}{r}\right)$

if $\cos(\psi - \theta^*) + \cos\zeta < 0$

  or ($|e| < r$ and $(\cos(\psi - \varphi) + \cos\zeta < 0)$)

  then $\bar{\theta} = \pi + \psi - q.\zeta.$

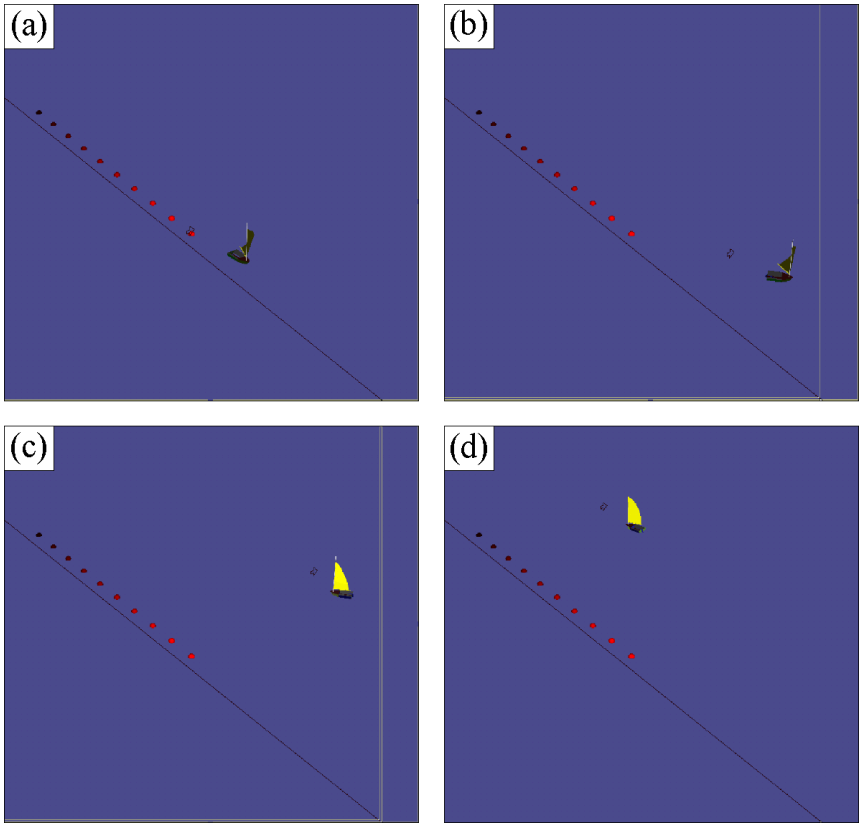
  else $\bar{\theta} = \theta^*$

end

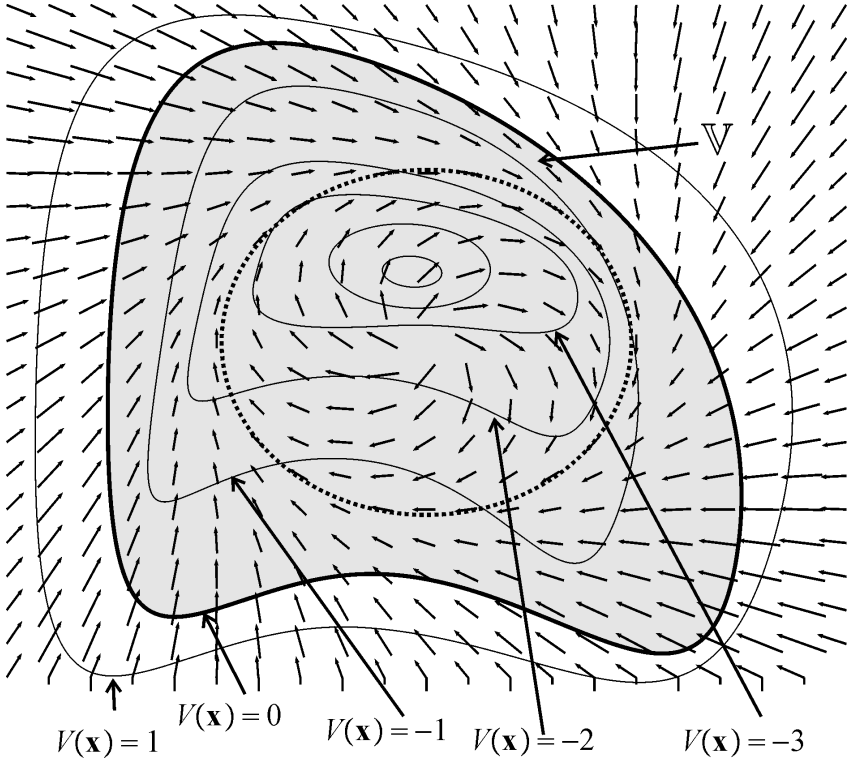
if $\cos\left(\theta - \bar{\theta}\right) \geq 0$ then $\delta_r = \delta_r^{\max}.\sin\left(\theta - \bar{\theta}\right)$

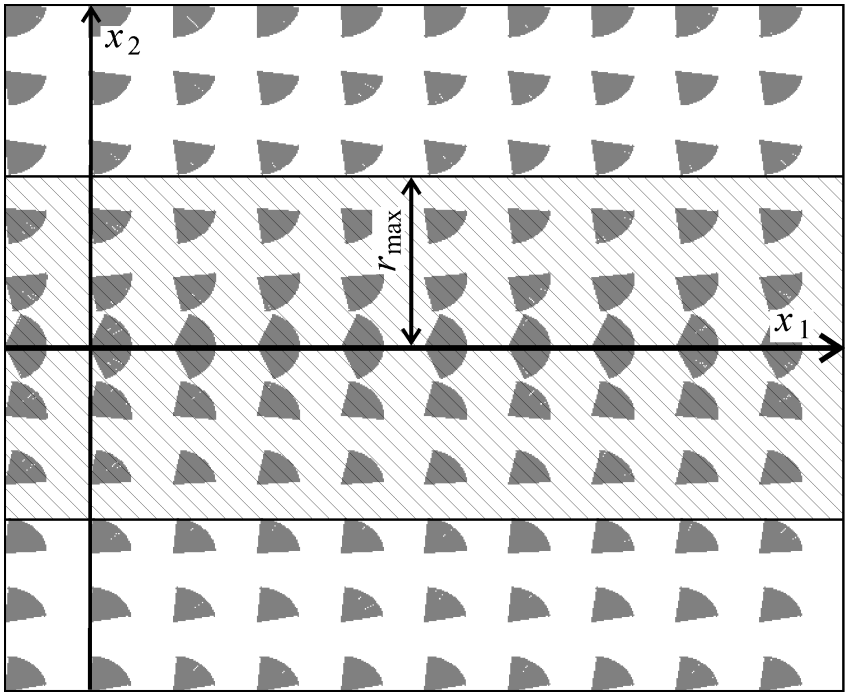
else $\delta_r = \delta_r^{\max}.\text{sign}\left(\sin\left(\theta - \bar{\theta}\right)\right)$

$\delta_s^{\max} = \frac{\pi}{2}.\left(\frac{\cos(\psi-\bar{\theta})+1}{2}\right)^q.$

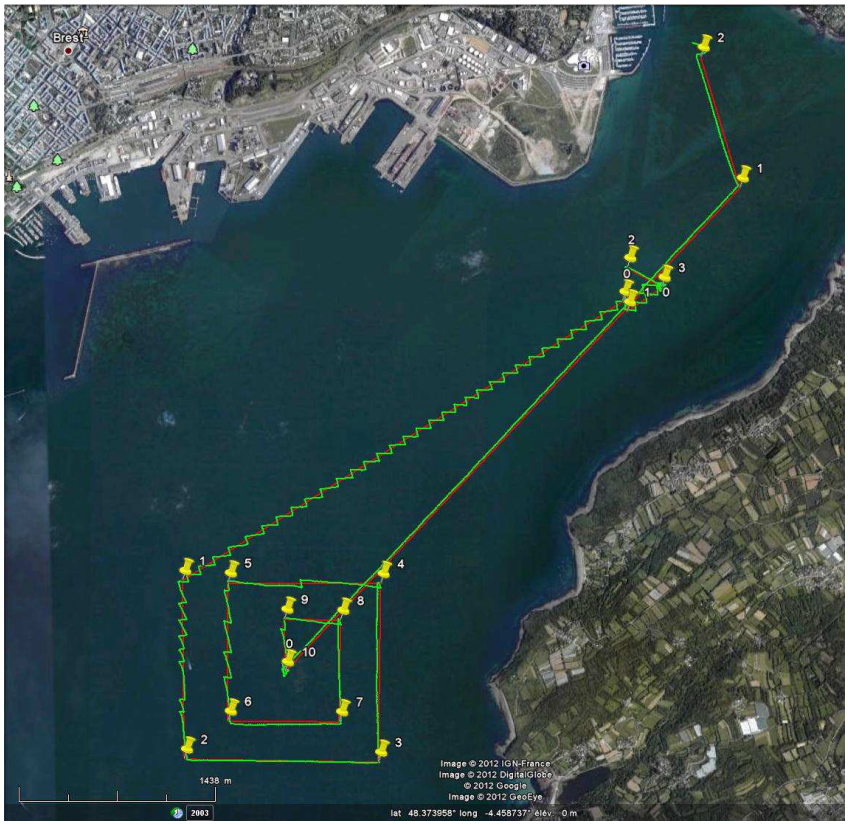


Validation by simulation


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


x_2
$r_{\max}$
x_1

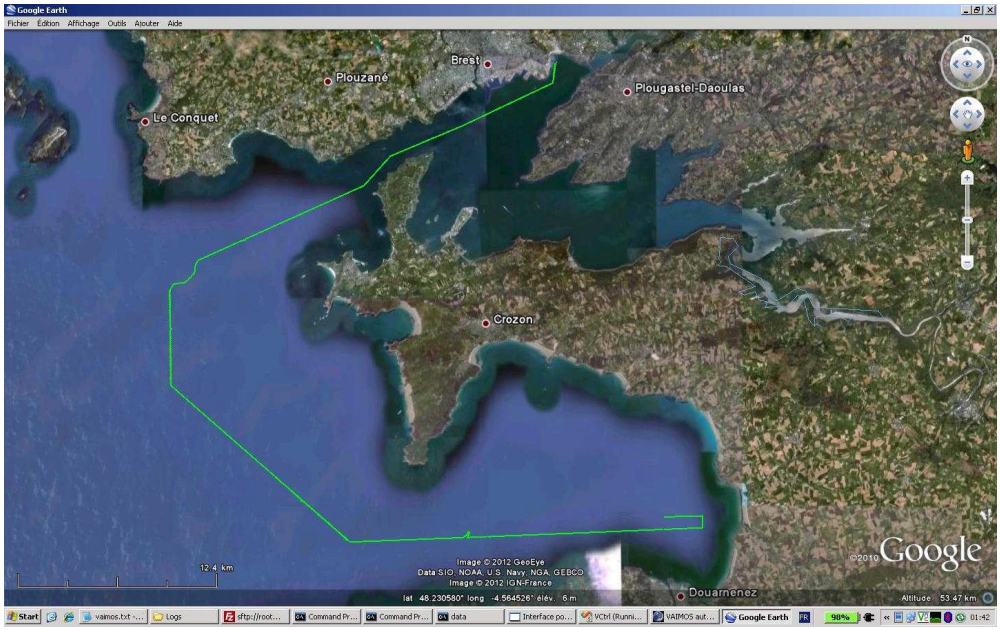
Brest


Brest
2
1
2
0
3
1
0
1
5
4
9
8
0
10
6
7
2
3
1438 m
2003
Image © 2012 IGN-France
Image © 2012 DigitalGlobe
© 2012 Google
Image © 2012 GeoEye
lat 48.373958° long -4.458737° élev 0 m

Brest-Douarnenez. January 17, 2012, 8am


Brest
PRO
BR DSB 505
YAMAHA


F78


Google Earth
Fichier Edition Affichage Outils Ajouter Aide
Brest
Plouzané
Plougastel-Daoulas
Le Conquet
Crozon
Douarnenez
12.4 km
Image © 2012 GeoEye
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2012 IGN-France
lat 48.230580° long -4.564526° élév 6 m
©2010 Google
Altitude 53.47 km
Start
Google Earth
98%
01:42

Montrer la mise à l'eau

Middle of Atlantic ocean

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

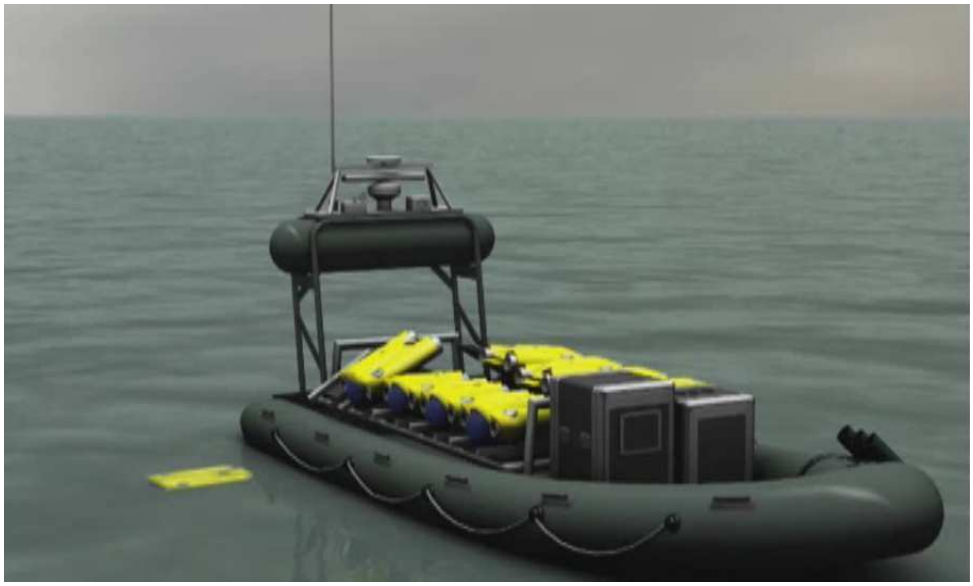
Consequence.

It is possible for a sailboat robot to navigate inside a corridor.

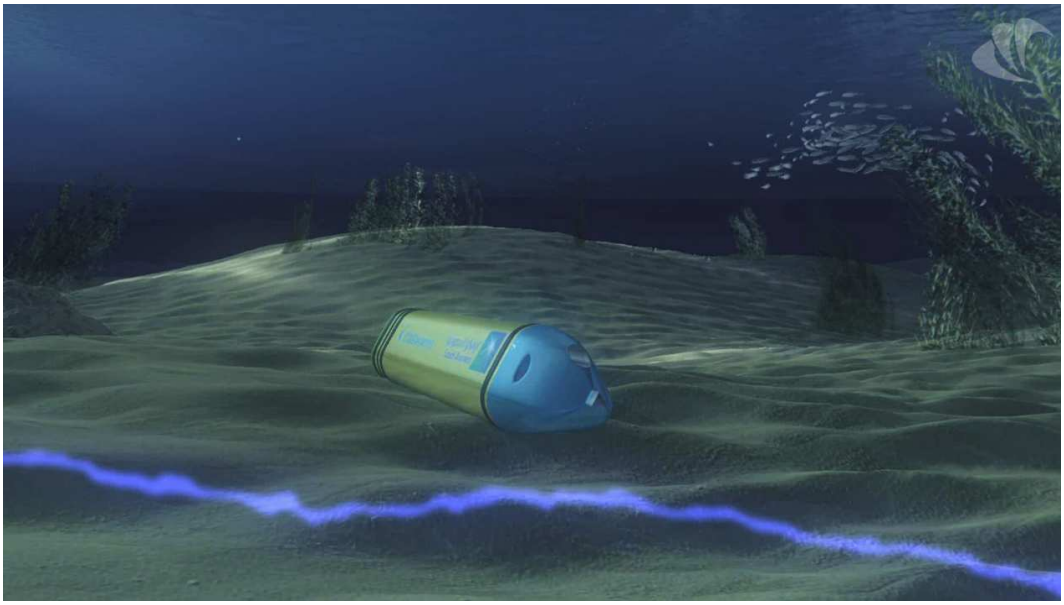
Essential, to create circulation rules when robot swarms are considered.

Essential to determine who has to pay in case of accident.

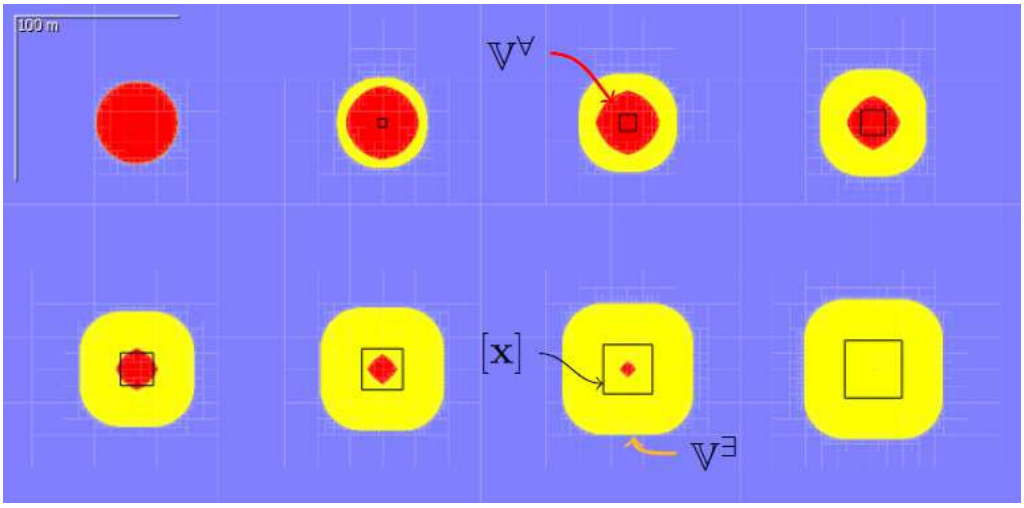
2 Reliable exploration with squads

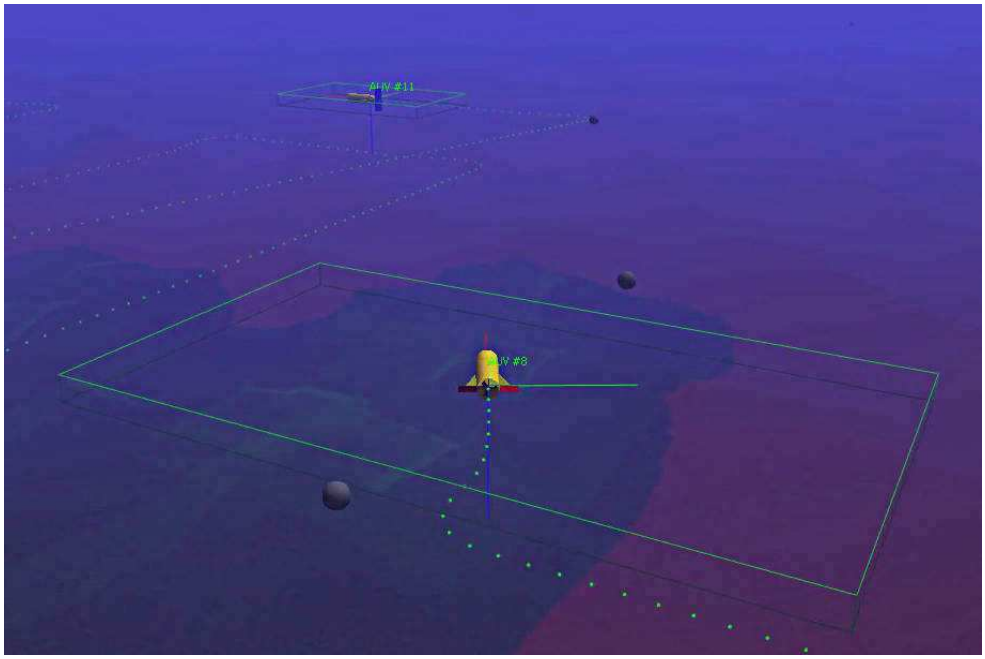


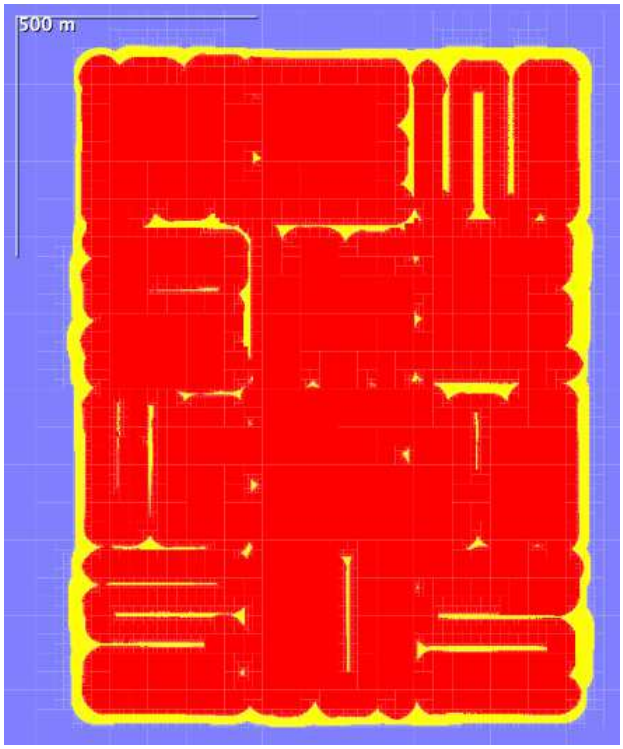
With Thales



Spicerack, with CGG


100 m
$\mathbb{V}^{\forall}$
[x]
$\mathbb{V}^{\exists}$


AUV #11
AUV #8


500 m