

Big sensors: collecting measurements with robots

Journée Big Sensor 28 janvier 2015

ENSTA Bretagne, LabSTICC, OSM.

What is a **big** sensor?

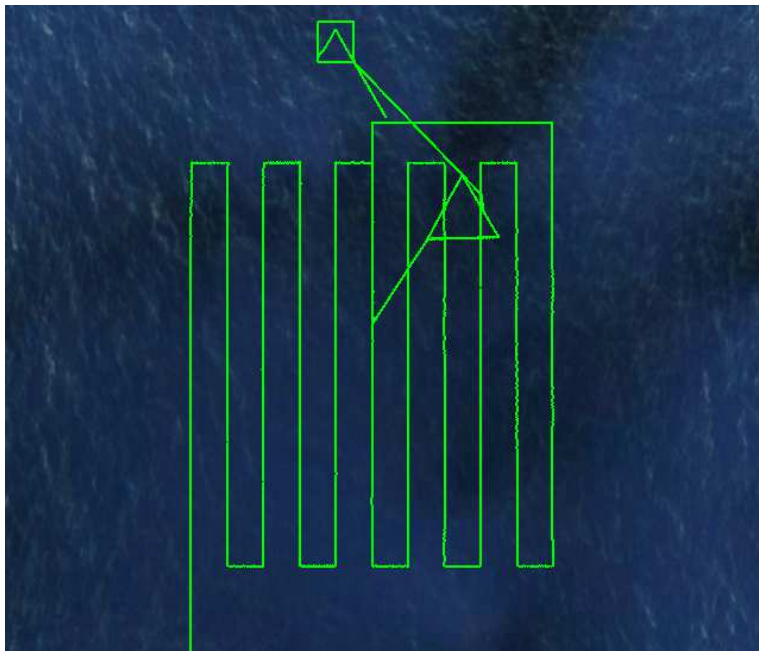
It is a sensor (which is big).

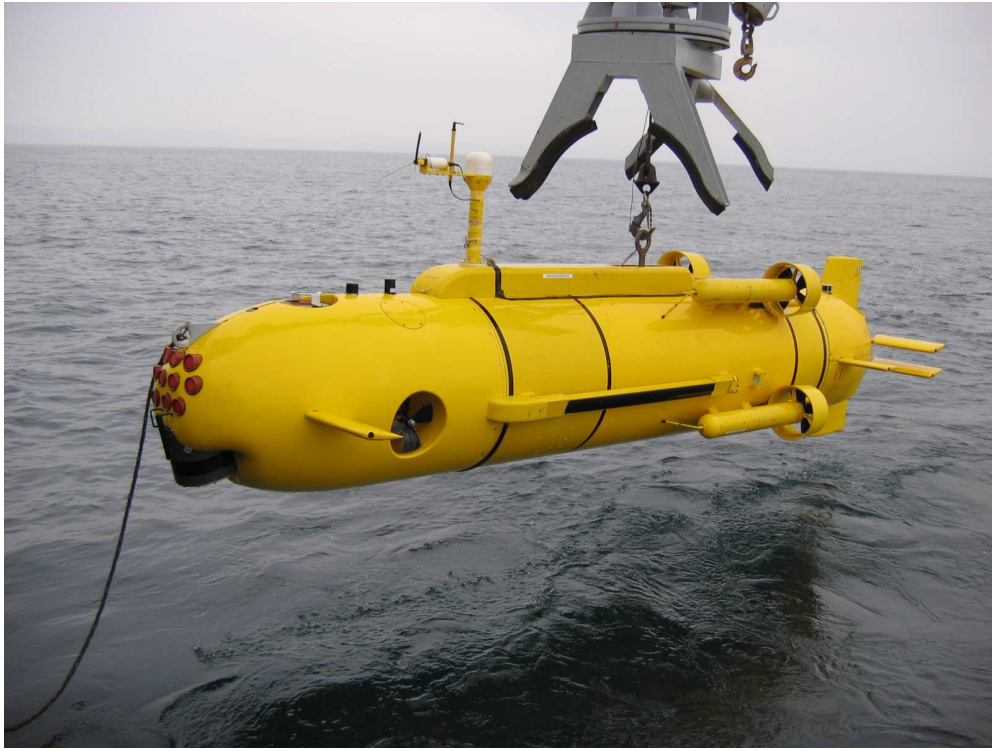
Inside the sensor, robots move, compute, communicate, decide.

A big sensor returns a high level information (an image, a map, ...).



VAIMOS (Ifremer-ENSTA Bretagne)

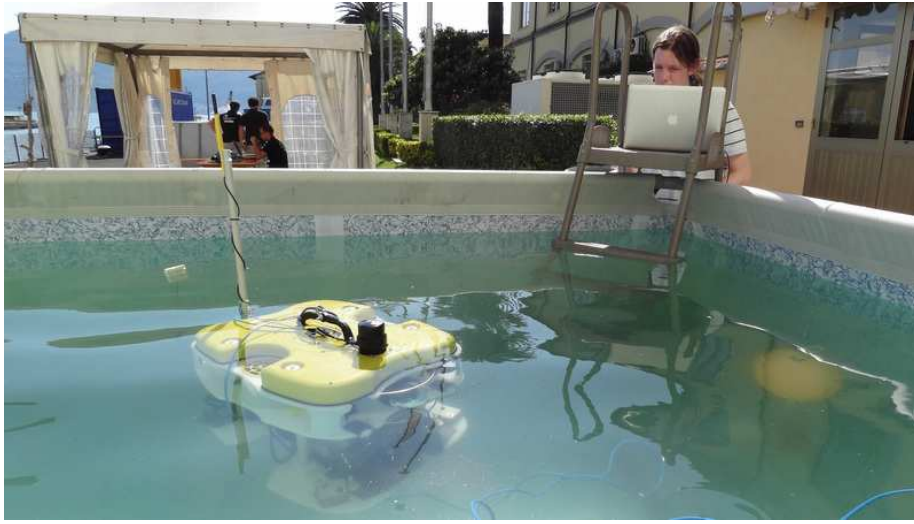


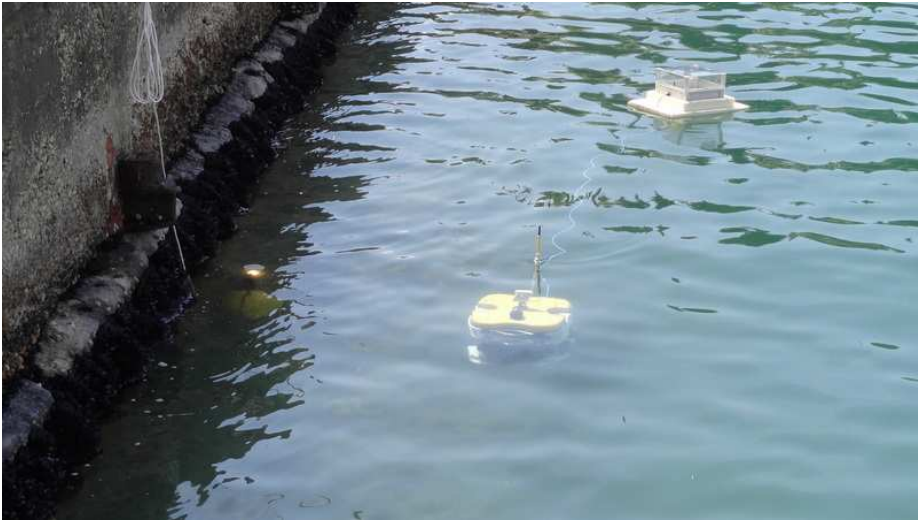


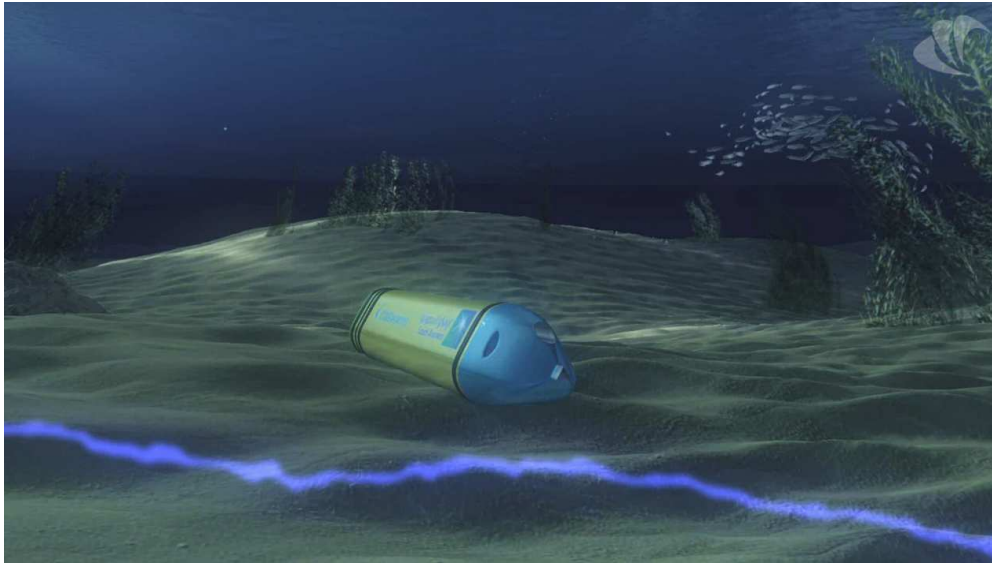
Redermor, DGA-TN

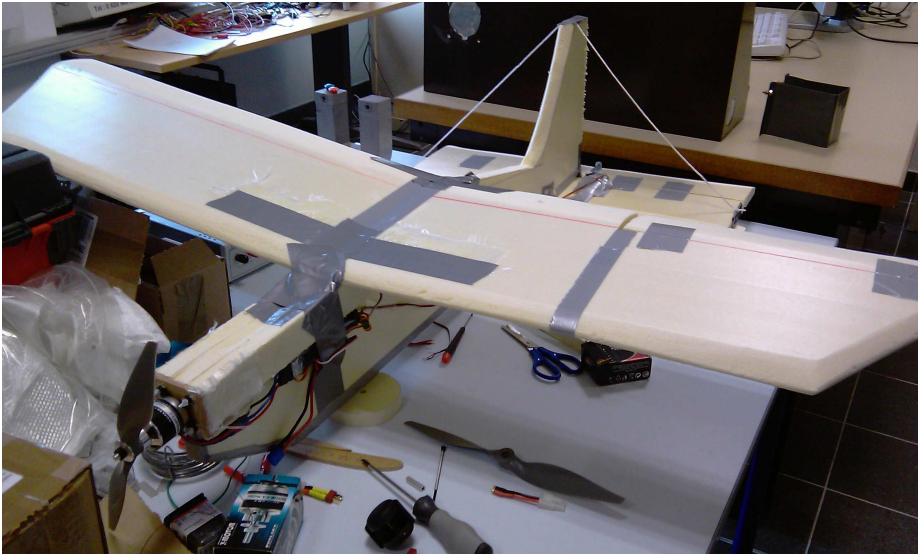














Some questions to discuss

- 1) In 2014, in the ocean, robots are only used as big sensors?
- 2) What are the main differences between ocean robotics and land-space-air robotics?
- 3) What is the future of ocean robotics (10 years, 20 years, 50 years)?

1 Calcul par intervalles

Problème. Soit $f : \mathbb{R}^n \rightarrow \mathbb{R}$. Montrer que

$$\forall \mathbf{x} \in \mathbb{R}^n, f(\mathbf{x}) \geq 0.$$

Arithmétique des intervalles

$$\begin{aligned}[-1, 3] + [2, 5] &= [1, 8], \\[-1, 3] \cdot [2, 5] &= [-5, 15], \\ \text{abs}([-7, 1]) &= [0, 7]\end{aligned}$$

L'extension intervalle de

$$f(x_1, x_2) = x_1 \cdot x_2 - (x_1 + x_2) \cdot \cos x_2 \\ + \sin x_1 \cdot \sin x_2 + 2$$

est

$$[f]([x_1], [x_2]) = [x_1] \cdot [x_2] - ([x_1] + [x_2]) \cdot \cos [x_2] \\ + \sin [x_1] \cdot \sin [x_2] + 2.$$

2 Calcul ensembliste

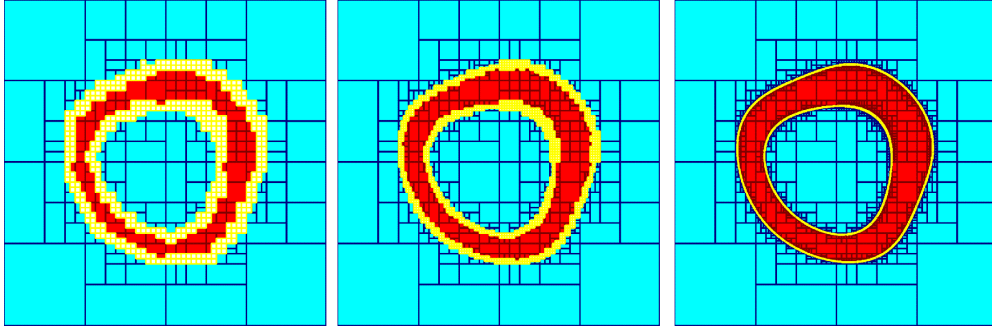
Les sous-ensembles $\mathbb{X} \subset \mathbb{R}^n$ peuvent être encadrés par des sous pavages :

$$\mathbb{X}^- \subset \mathbb{X} \subset \mathbb{X}^+.$$

grâce au calcul par intervalles.

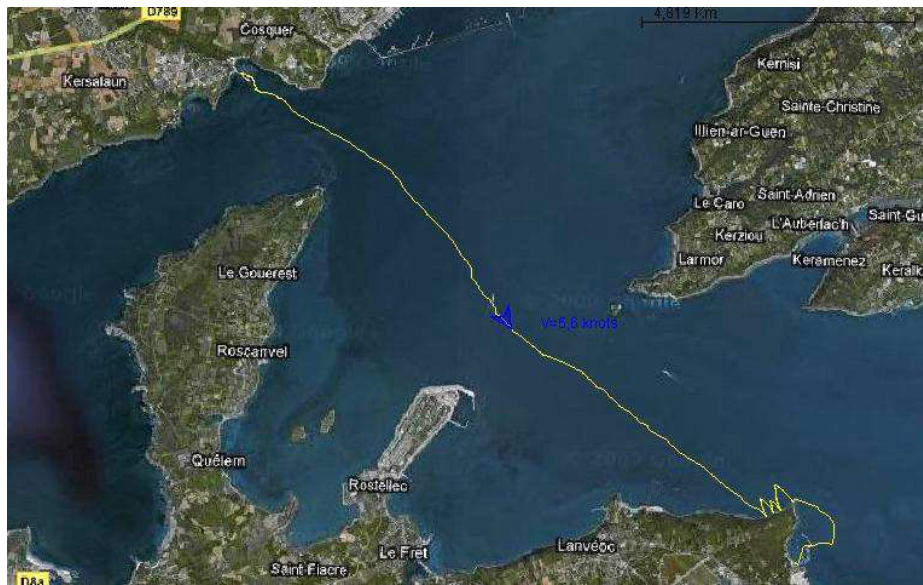
Exemple.

$$\mathbb{X} = \{(x_1, x_2) \mid x_1^2 + x_2^2 + \sin(x_1 + x_2) \in [4, 9]\}.$$



3 Sur la mer







ERWAN 1 (Ecole Navale)



3.1 Vaimos

Collaboration ENSTA/IFREMER



Vaimos à la WRSC (ENSTA-IFREMER-Ecole Navale).

La dynamique d'un robot est décrite par une équation d'état

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

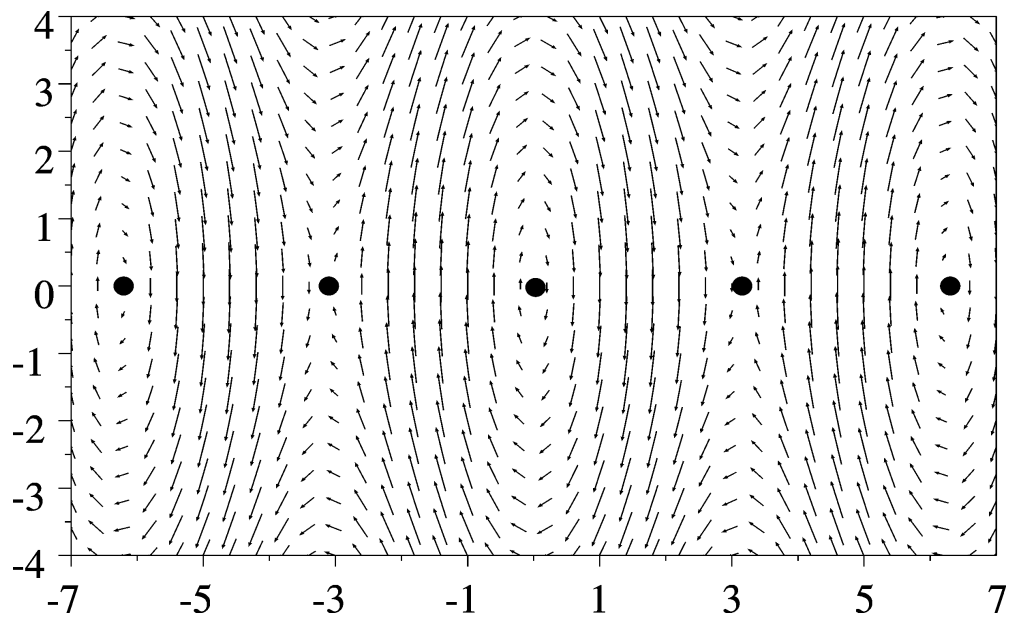
$$\left\{ \begin{array}{lcl} \dot{x} & = & v \cos \theta + p_1 a \cos \psi \\ \dot{y} & = & v \sin \theta + p_1 a \sin \psi \\ \dot{\theta} & = & \omega \\ \dot{v} & = & \frac{f_s \sin \delta_s - f_r \sin u_1 - p_2 v^2}{p_9} \\ \dot{\omega} & = & \frac{f_s (p_6 - p_7 \cos \delta_s) - p_8 f_r \cos u_1 - p_3 \omega}{p_{10}} \\ f_s & = & p_4 a \sin (\theta - \psi + \delta_s) \\ f_r & = & p_5 v \sin u_1 \\ \sigma & = & \cos (\theta - \psi) + \cos (u_2) \\ \delta_s & = & \left\{ \begin{array}{ll} \pi - \theta + \psi & \text{si } \sigma \leq 0 \\ \text{sign} (\sin (\theta - \psi)) . u_2 & \text{sinon.} \end{array} \right. \end{array} \right.$$

Après insertion d'un régulateur $\mathbf{u} = \mathbf{g}(\mathbf{x})$, le système

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

devient un robot

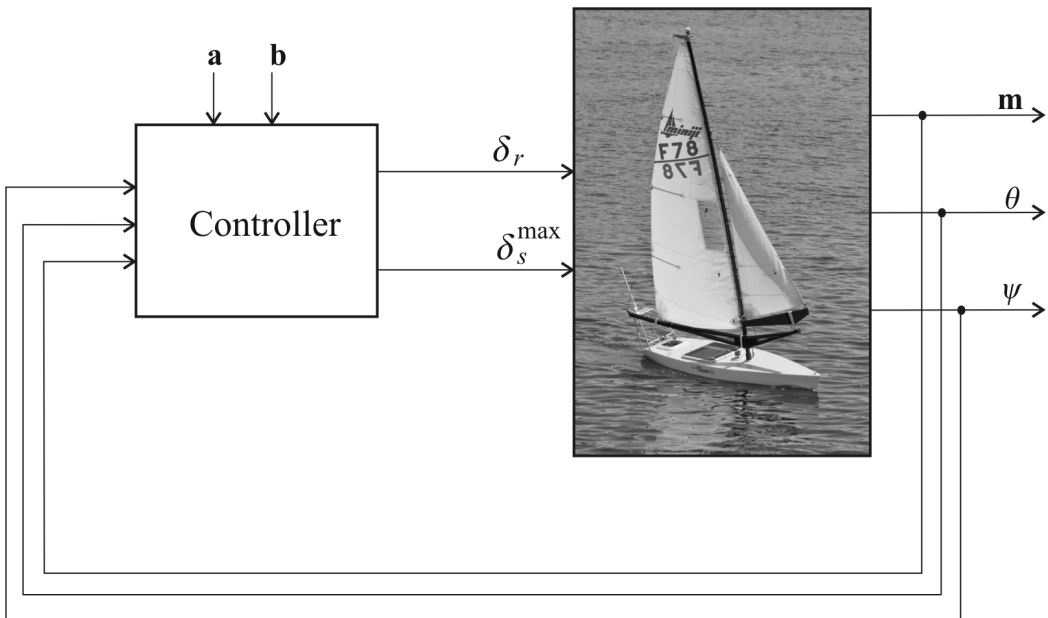
$$\dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}).$$

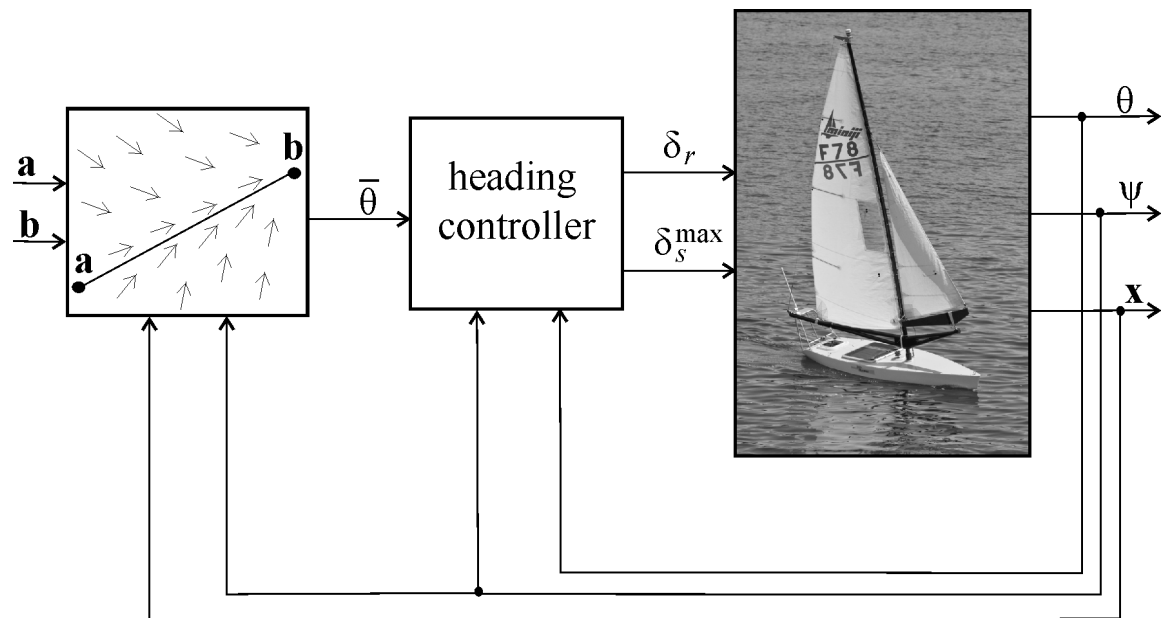


Avec toutes les incertitudes, le robot satisfait une *inclusion différentielle*

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

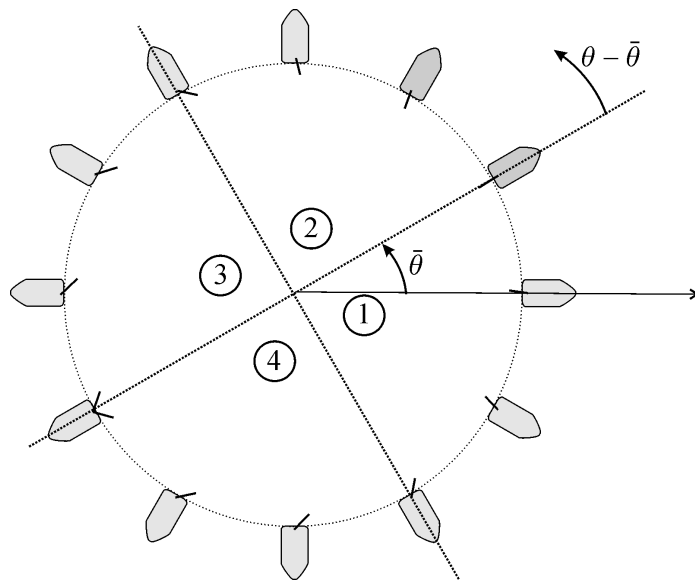
3.2 Suivi de ligne



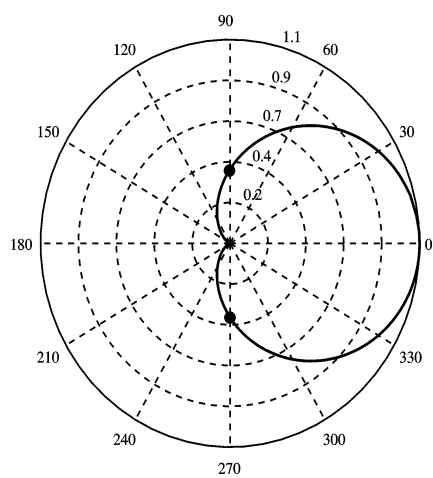
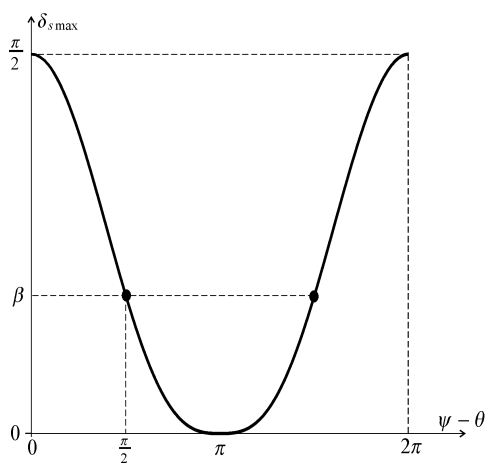


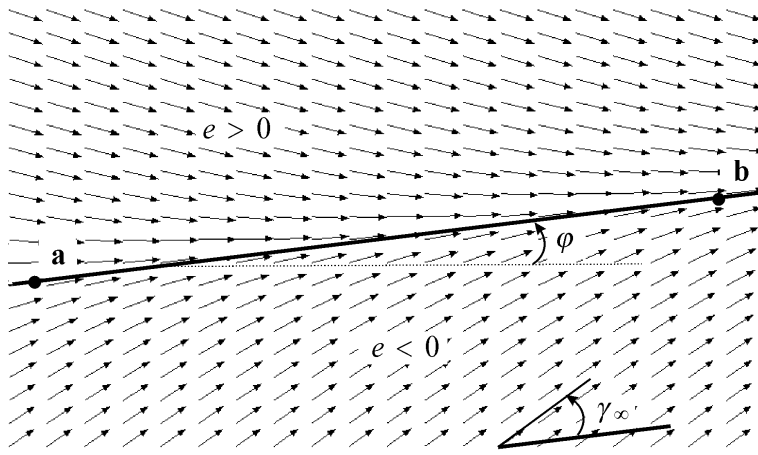
Régulation en cap

$$\begin{cases} \delta_r &= \frac{\delta_r^{\max}}{\pi} . \text{atan}\left(\tan \frac{\theta - \bar{\theta}}{2}\right) \\ \delta_s^{\max} &= \frac{\pi}{2} \cdot \left(\frac{\cos(\psi - \bar{\theta}) + 1}{2} \right) . \end{cases}$$

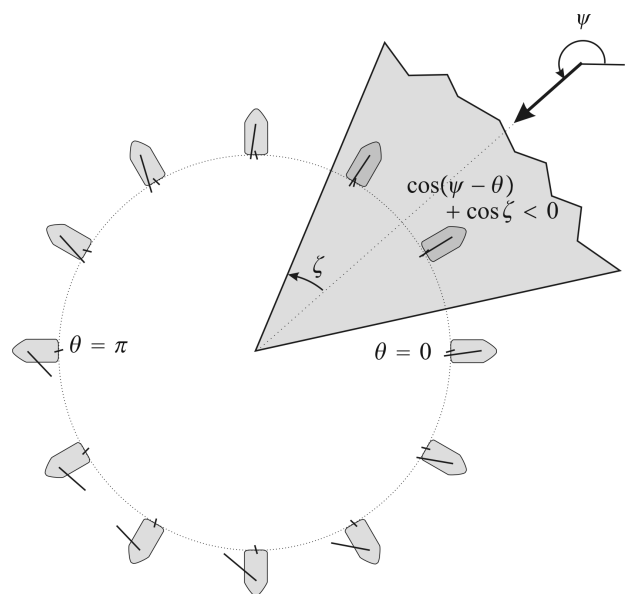


$$\delta_s^{\max} = \frac{\pi}{2} \cdot \left(\frac{\cos(\psi - \bar{\theta}) + 1}{2} \right)$$





$$\theta^* = \varphi - \frac{1}{2} \cdot \text{atan} \left(\frac{e}{r} \right) .$$



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

$$1 \quad e = \frac{\det(\mathbf{b}-\mathbf{a}, \mathbf{m}-\mathbf{a})}{\|\mathbf{b}-\mathbf{a}\|}$$

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

$$3 \quad \bar{\theta} = \text{atan2}(\mathbf{b} - \mathbf{a}) - \frac{1}{2} \cdot \text{atan}\left(\frac{e}{r}\right)$$

$$4 \quad \text{if } \cos(\psi - \bar{\theta}) + \cos \zeta < 0 \text{ then } \bar{\theta} = \pi + \psi - q \cdot \zeta.$$

$$5 \quad \delta_r = \frac{\delta_r^{\max}}{\pi} \cdot \text{atan}\left(\tan \frac{\theta - \bar{\theta}}{2}\right)$$

$$6 \quad \delta_s^{\max} = \frac{\pi}{2} \cdot \left(\frac{\cos(\psi - \bar{\theta}) + 1}{2} \right).$$

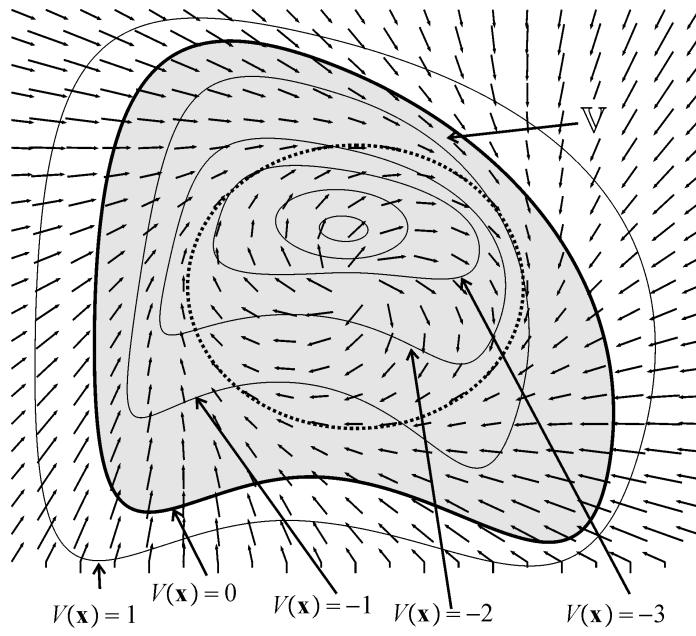
3.3 Validation théorique

Quand le vent est connu, le robot satisfait

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

Définition. Soit $V(\mathbf{x}) : \mathbb{R}^n \rightarrow \mathbb{R}$. Le système est V -stable si

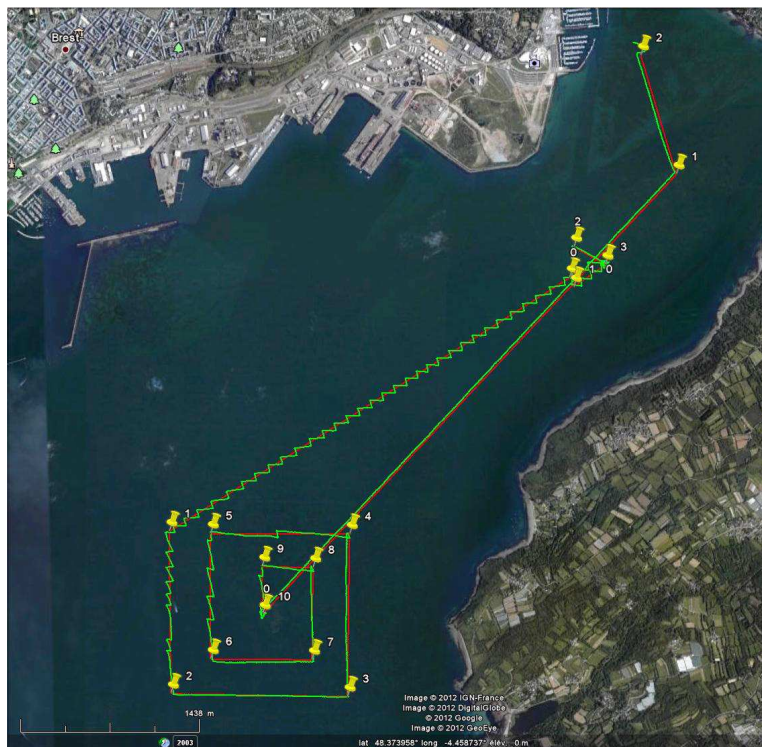
$$\left(V(\mathbf{x}) \geq 0 \Rightarrow \dot{V}(\mathbf{x}) < 0 \right).$$



Théorème.

$$\left\{ \begin{array}{l} \frac{\partial V}{\partial \mathbf{x}}(\mathbf{x}) \cdot \mathbf{f}(\mathbf{x}) \geq 0 \\ V(\mathbf{x}) \geq 0 \end{array} \right. \text{ impossible} \Leftrightarrow \dot{\mathbf{x}} = \mathbf{f}(\mathbf{x}) \text{ is } V\text{-stable.}$$

3.4 Validation expérimentale



Rade de Brest

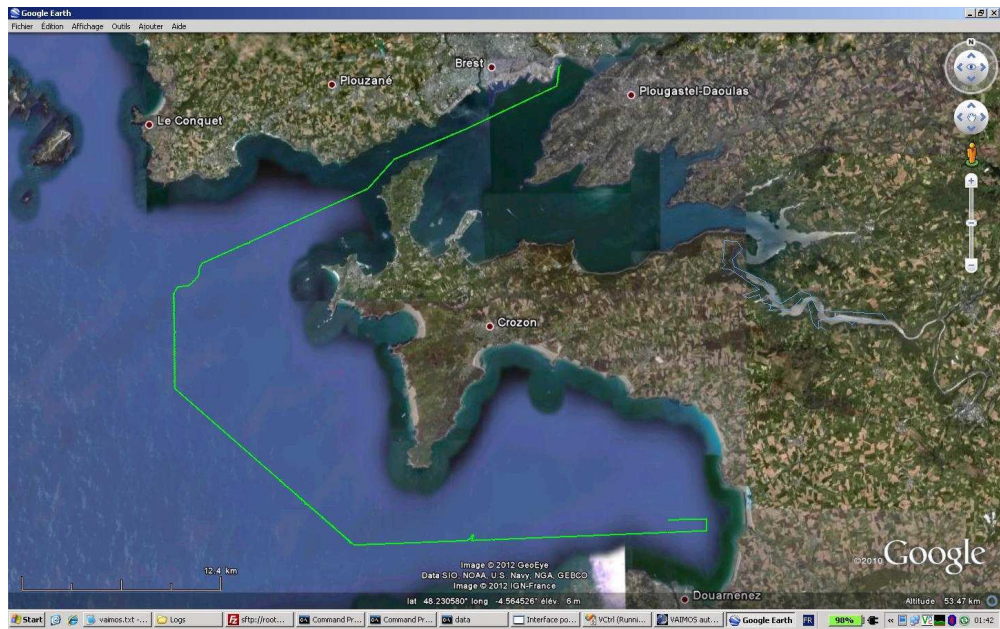
Brest-Douarnenez. January 17, 2012, 8am

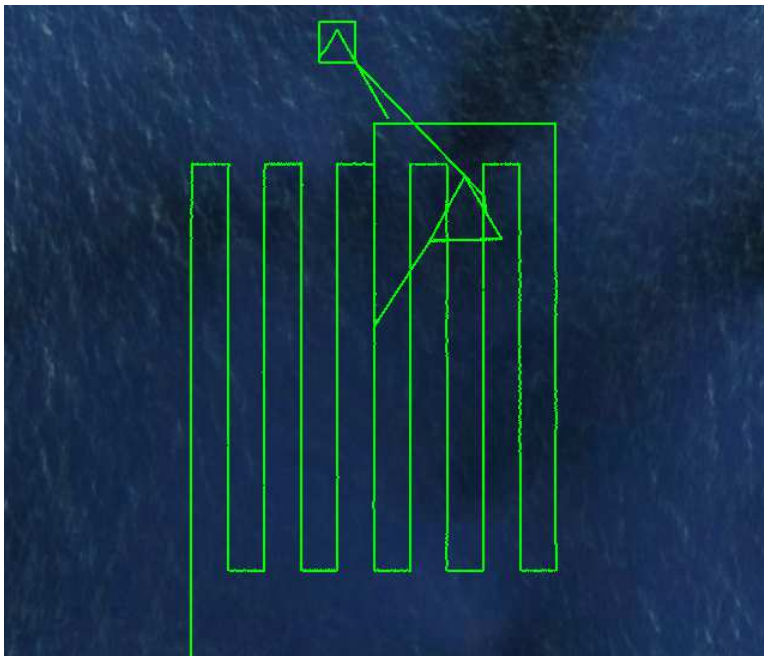












Au milieu de l'Atlantique, 350 km fait par Vaimos en 53h,
sept. 6-9, 2012.

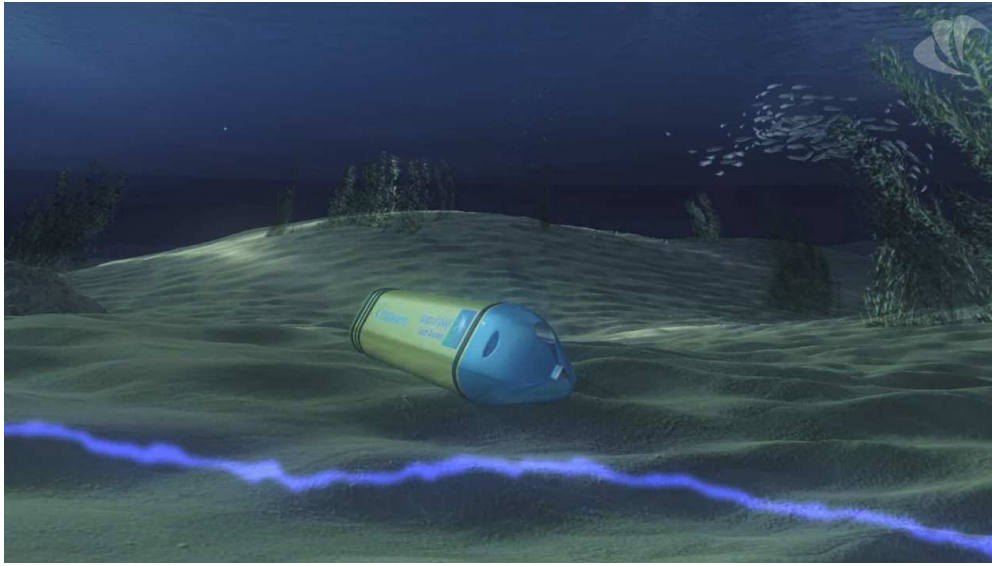
Conséquence.

Il est possible de garantir que le robot restera dans son couloir.

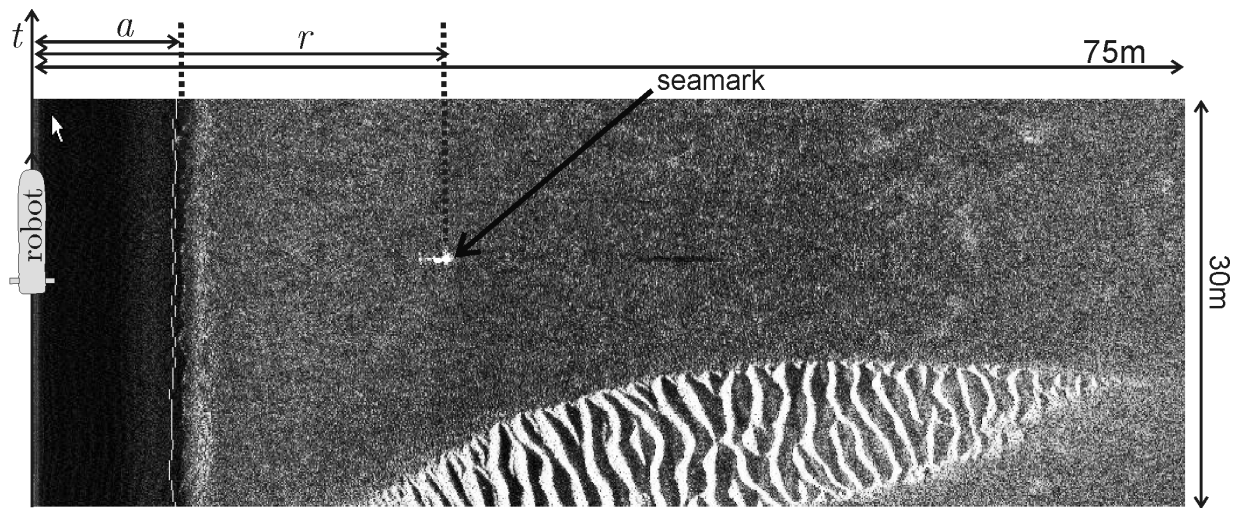
Indispensable pour établir des règles de circulation.

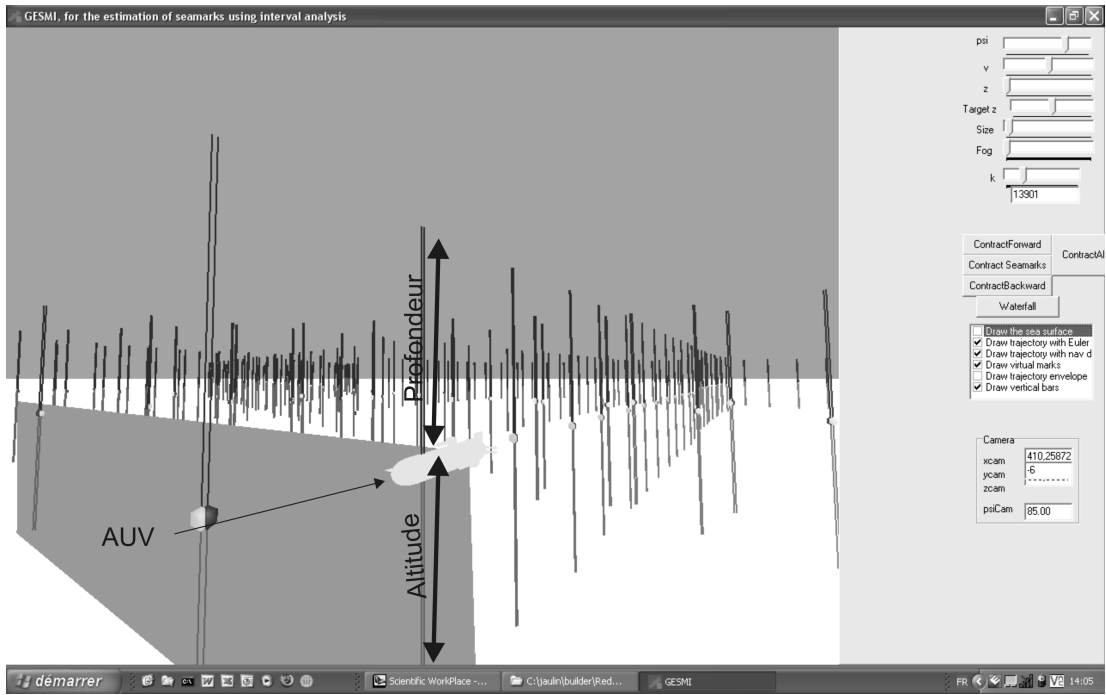
Indispensable pour identifier le responsable en cas d'accident.

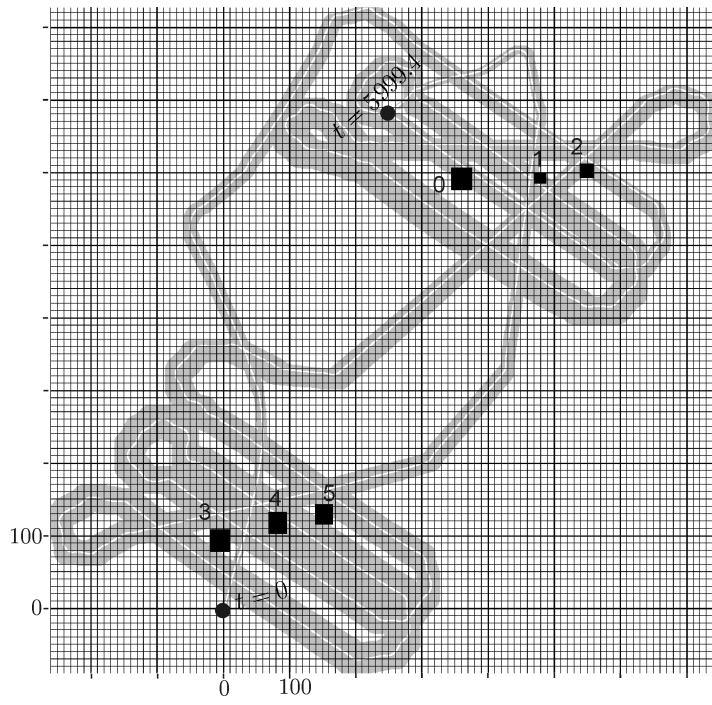
4 Sous la mer

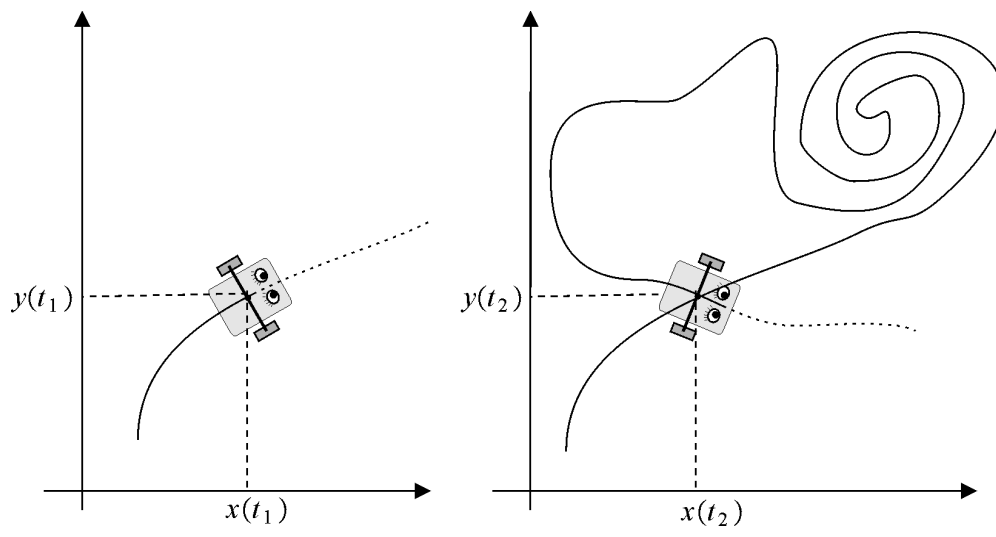


Localisation d'un groupe de robot (avec CGG)

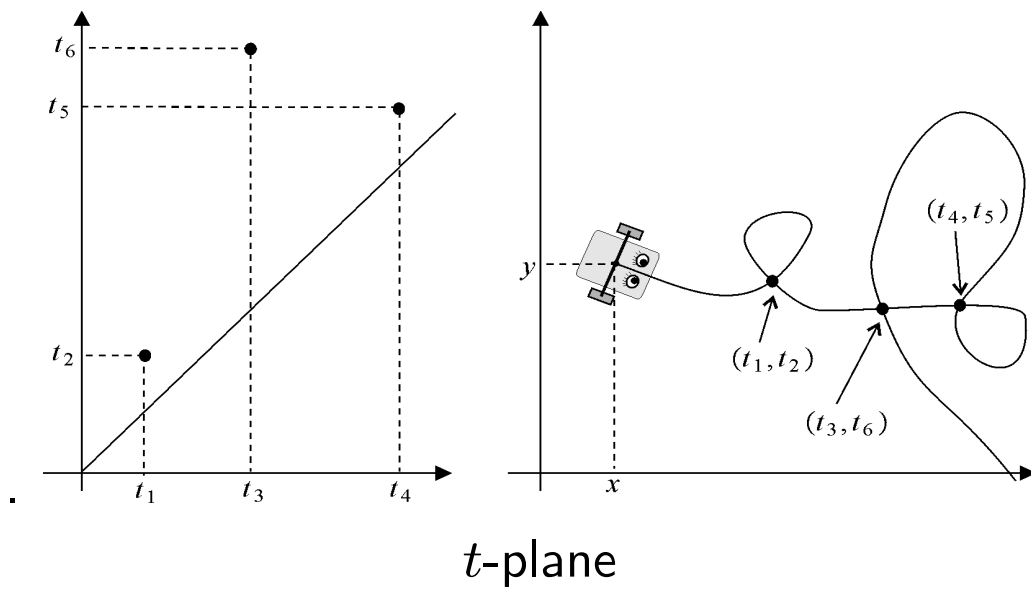


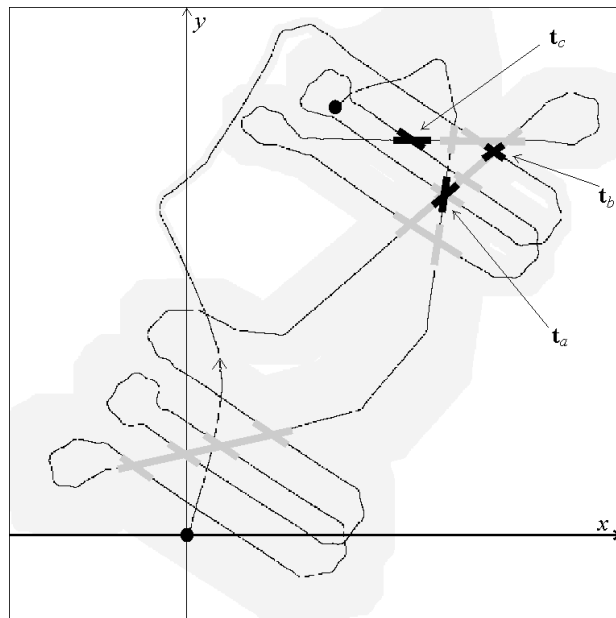






Un robot effectuant une boucle





Tube enfermant la trajectoire du robot. On devine 28 boucles.

