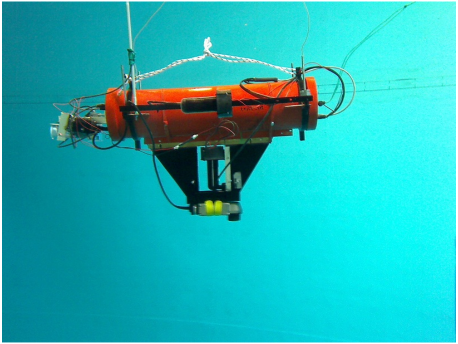
Detection and capture of intruders using robots

L. Jaulin

Southampton, November 2, 2017

October 31, 2017

Robots at ENSTA-LabSTICC

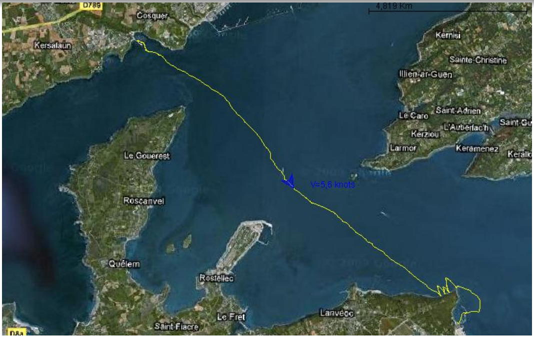


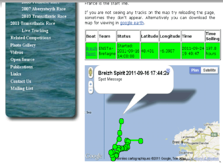
Saucisse (ENSTA Bretagne). First at SAUCE'2016

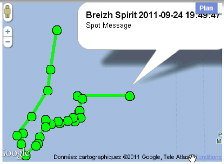
Gouelack (ENSTA Bretagne)

Saiboat robots


BREIZH
ENSIETA
SPIRIT


D789
Cosquer
Kersalaun
4,819 Km
Kernisi
Sainte-Christine
Illien-ar-Guen
Le Caro
Saint-Adrien
L'Auberlac'h
Saint-Gu
Kerziou
Larmor
Keramenez
Keralk
Le Gouerest
V=5,6 knots
Roscanvel
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
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 | -6.3907 | 2011-09-24 19:49:47 | 137.8 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

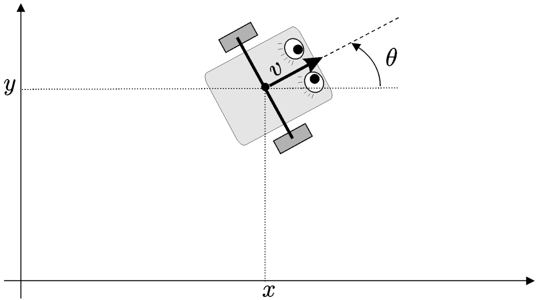
A **vehicle** is a controlled mechanical system [1]

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

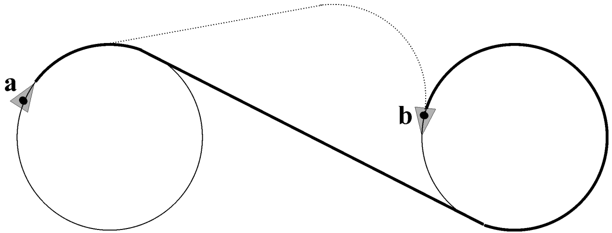
Example. Dubin's car (1957).

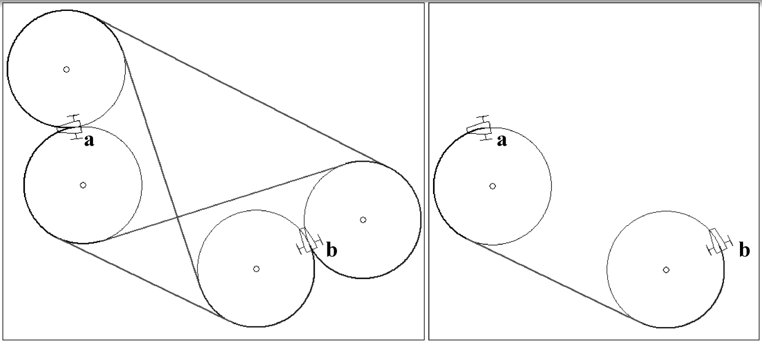
$$\begin{cases} \dot{x} & = & \cos\theta \\ \dot{y} & = & \sin\theta \\ \dot{\theta} & = & u \end{cases}$$

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



Dubin's paths




a
b
a
b

A robot is an intelligent vehicle

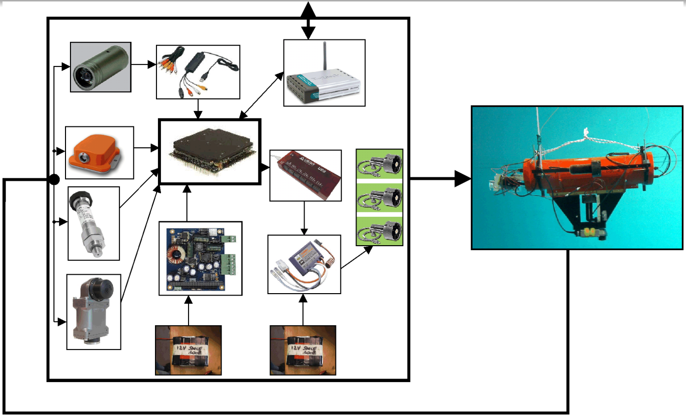
A robot is a vehicle with actuators, sensors, and a brain

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

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.



Vaimos

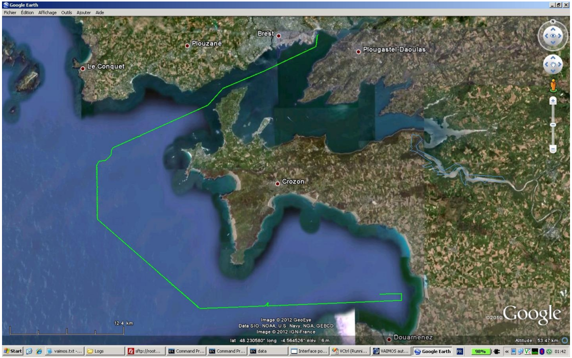
Brest-Douarnenez. January 17, 2012, 8am

Vaimos (IFREMER and ENSTA): from Brest to Douarnenez

youtu.be/XxQ_KWI1q74

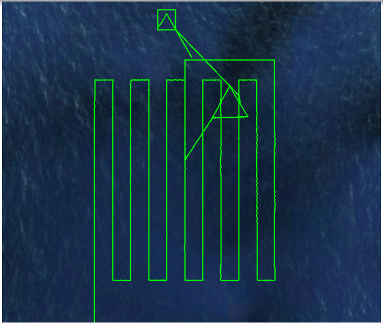
Brest-Douarnenez. January 17, 2012


F78
8ᒣ7


Google Earth
Fichier Édition Affichage Outils Ajouter Aide
Brest
Plouzané
Le Conquet
Plougastel-Daoulas
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
Altitude 53.47 km
©2010 Google

Middle of Atlantic ocean

youtu.be/pb_KhcYZI_A

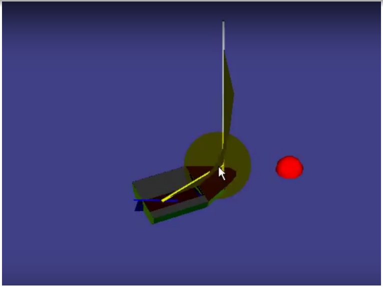


350 km made by Vaimos in 53h, September 6-9, 2012.

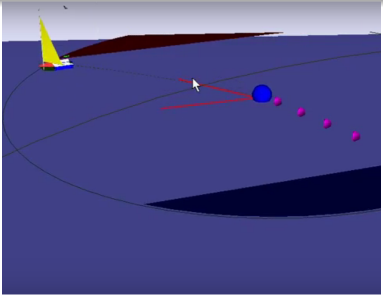
Ocean satellites

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



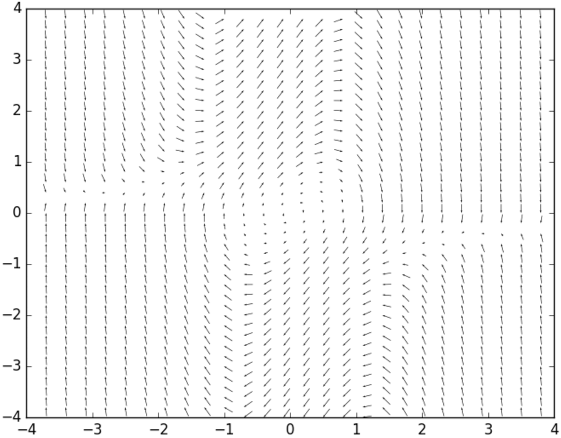
youtu.be/GT0Mcc0ZliQ

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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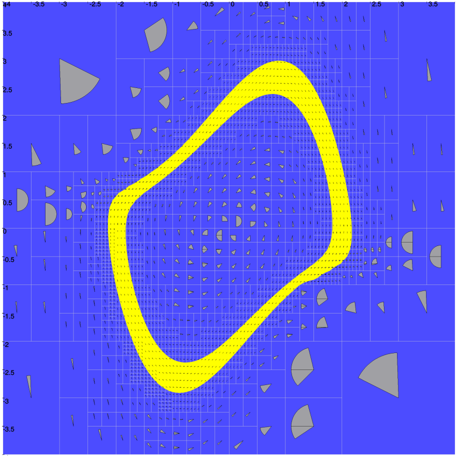
4

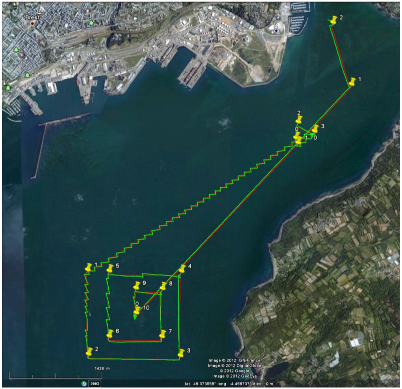
Invariants sets can be computed [3]



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

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

Validation with experiments


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

Try to make the system fail

Forum DGA, Palaiseau

youtu.be/mPGUnsDX9aU

Groups

youtu.be/gwxfMg5oRSA

Teaching, MOOCs and books

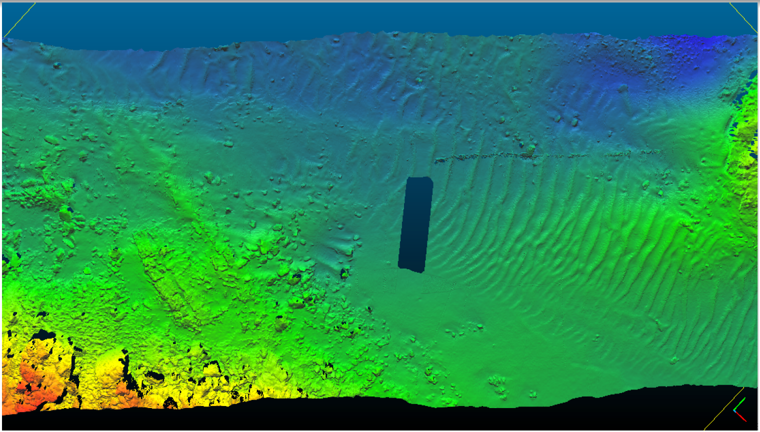
A MOOC made from the book Mobile Robotics [2]

Experiments


Argo


SURVEY
D36 918
HONDA
HONDA


ONDA
ENSTA
caribe
ENSTA



Pris au R2Sonic à 700kHz. On peut avoir le MNT (3D)

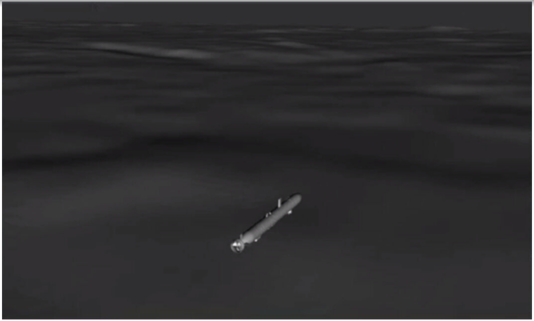
Club and challenges

youtu.be/DFg3K09cMwU

La Cordelière

Reconstitution de la bataille

youtu.be/yP4cM1UGrqY



youtu.be/YAkUw1ggCvgA

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 $\mathscr{R}_1, \dots, \mathscr{R}_n$ at positions $\mathbf{a}_1, \dots, \mathbf{a}_n$ are moving in the ocean.
- If the intruder is in the visibility zone of one robot, it is detected.[4]

Complementary approach

- We assume that a virtual intruder exists inside $\mathbb{G}$.
- We localize it with a set-membership observer inside $\mathbb{X}(t)$.
- The secure zone corresponds to the complementary of $\mathbb{X}(t)$.

Assumptions

- The intruder satisfies

$$\dot{\mathbf{x}} \in \mathbb{F}(\mathbf{x}(t)).$$

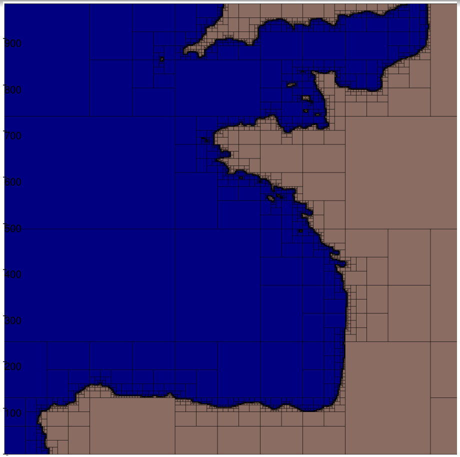
- Each robot $\mathscr{R}_i$ has the visibility zone $g_{\mathbf{a}_i}^{-1}([0, d_i])$ where d_i is the scope.

Theorem. An (undetected) intruder has a state vector $\mathbf{x}(t)$ inside the set

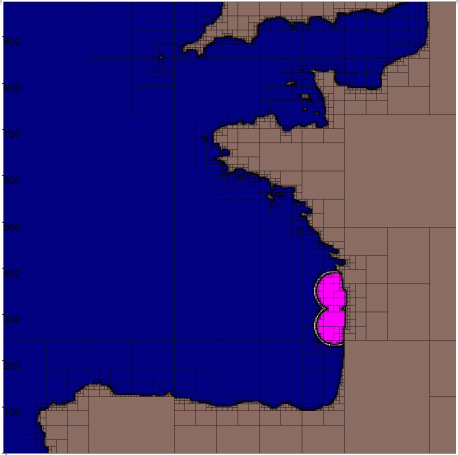
$$\mathbb{X}(t) = \mathbb{G} \cap (\mathbb{X}(t - dt) + dt \cdot \mathbb{F}(\mathbb{X}(t - dt)) \cap \bigcap_i g^{-1}_{\mathbf{a}_i(t)}([d_i(t), \infty]),$$

where $\mathbb{X}(0) = \mathbb{G}$. The secure zone is

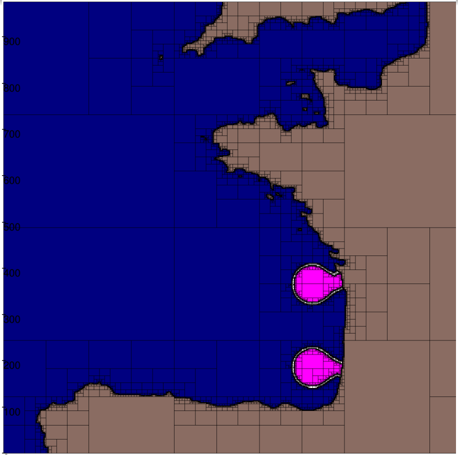
$$\mathbb{S}(t) = \overline{\mathbb{X}(t)}.$$



Set $\mathbb{G}$ in blue

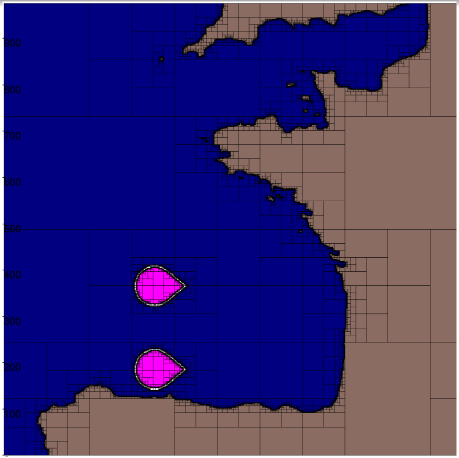


Magenta: $\mathbb{G} \cap \bigcup_i g_{\mathbf{a}_i(t)}^{-1}([0, d_i(t)])$ Blue:$\mathbb{G} \cap \bigcap_i g_{\mathbf{a}_i(t)}^{-1}([d_i(t), \infty])$



Blue:

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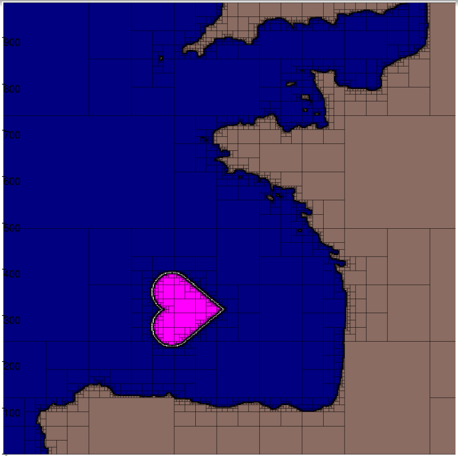
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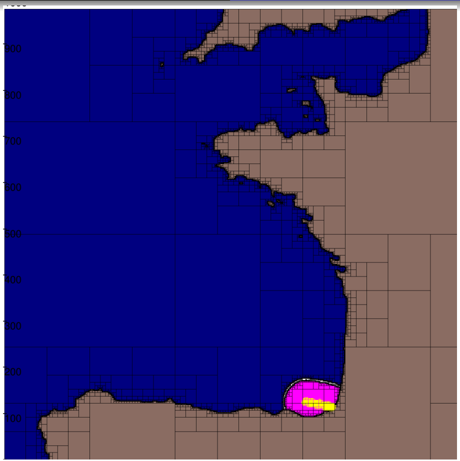
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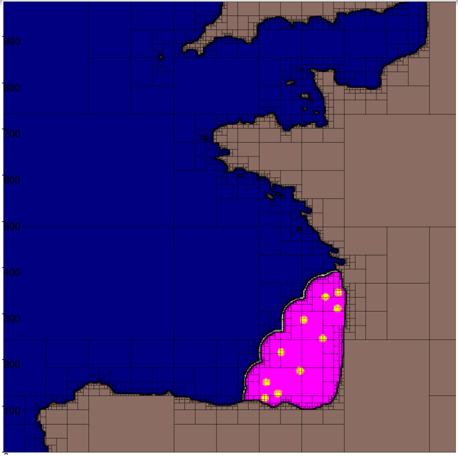
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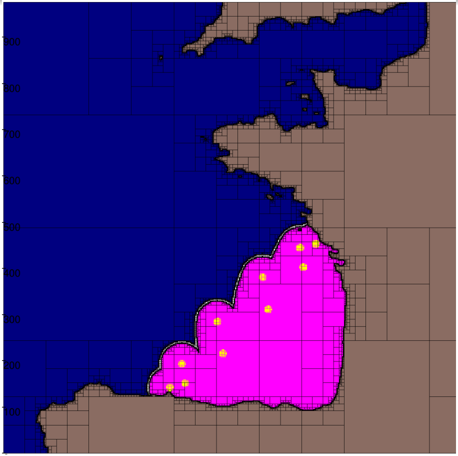
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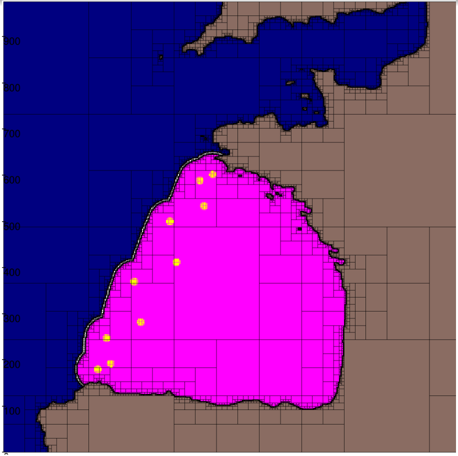

Video : https://youtu.be/rNcDW6npLfE

Smoother

Idea: Take into account the future.
The feasible set can be obtained by the following contractions

$$\begin{array}{rcl} \overrightarrow{\mathbb{X}}(t) & = & \overrightarrow{\mathbb{X}}(t) \cap (\mathbb{X}(t-dt) + dt \cdot \mathbb{F}(\mathbb{X}(t-dt))) \\ \overleftarrow{\mathbb{X}}(t) & = & \overleftarrow{\mathbb{X}}(t) \cap (\mathbb{X}(t+dt) - dt \cdot \mathbb{F}(\mathbb{X}(t+dt))) \\ \mathbb{X}(t) & = & \overrightarrow{\mathbb{X}}(t) \cap \overleftarrow{\mathbb{X}}(t) \end{array}$$

with the initialization

$$\mathbb{X}(t) = \overrightarrow{\mathbb{X}}(t) = \overleftarrow{\mathbb{X}}(t) = \mathbb{G}.$$

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

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

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

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Secure the zone from intruders with a group robots.
Special Issue on Ocean Engineering and Oceanography, Springer, 2018.