Stochastic control for underwater optimal trajectories

CQFD & DCNS

Inria Bordeaux Sud Ouest & University of Bordeaux
France

CQFD
Inria Bordeaux Sud Ouest

Departamento de Engenharia Elétrica, USP São Carlos, 6 June 2013

Outline

Presentation of CQFD
- Inria
- Themes
- Members
- Grants

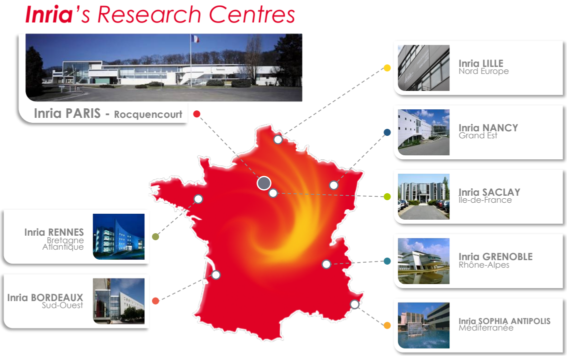
Trajectories optimization for submarines
- Problem
- Solution
- Examples

How to join us
- Job opportunities at inria

What is Inria ?

- Public science and technology institution established in 1967
- Only public research body fully dedicated to computational sciences
- Combining computer sciences with applied mathematics

- 8 research centers in France
- 3,400 researchers 1000 PhD students



Inria team CQFD

Inria research program on Stochastic methods and models

Research themes

- Modeling of random complex systems
- Estimation of model parameters and performances
- Control performance optimization

Tools

Probability and statistics

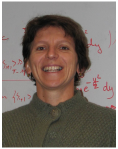
Members

Permanent members

François Dufour
Head of team

Marie Chavent

Benoîte de Saporta

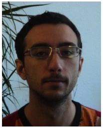


Anne Gégout-Petit

Jérôme Saracco

Huilong Zhang

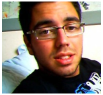
PhD students



Romain Azaïs

Camille Baysse

Isabelle Charlier



Karim Claudio

Raphaël Coudret

Amaury Labenne

Shuxian Li

Laurent Vézard

+ 1 internship Christophe Nivot

Partnerships with industry

Astrium (space transportation)

- stochastic models for crack propagation
- maintenance optimization for a structure subject to corrosion
- optimization of the assembly line of the new generation launcher

DCNS (naval defense)

- optimization of trajectories for submarines

EDF (electricity)

- modeling of the failures in the secondary circuit of a nuclear power plant

Thales optronic (military equipment)

- health monitoring of an optronic equipment

Outline

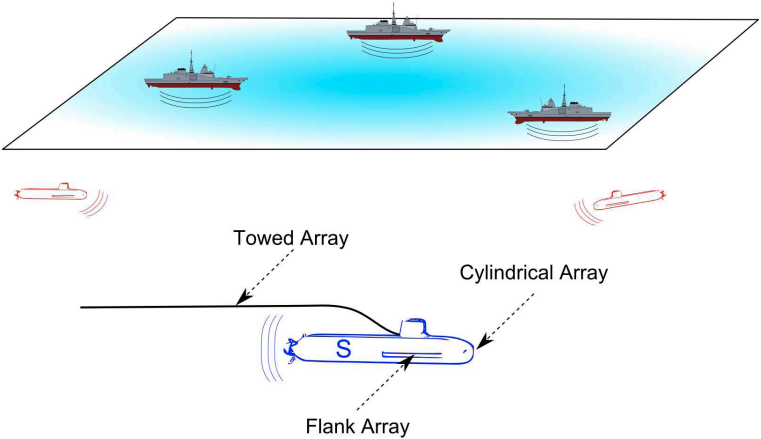
Presentation of CQFD

Trajectories optimization for submarines
- Problem
- Solution
- Examples

How to join us

Problem set by DCNS

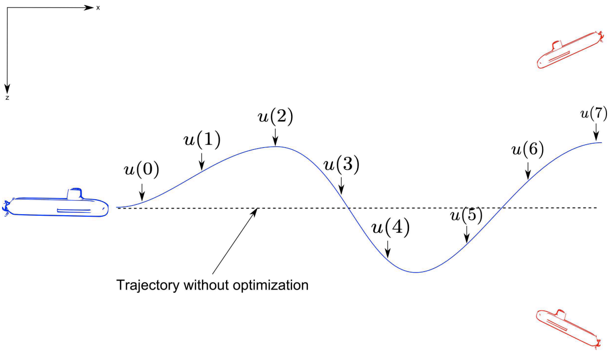
Submarine with sensors surrounded by targets



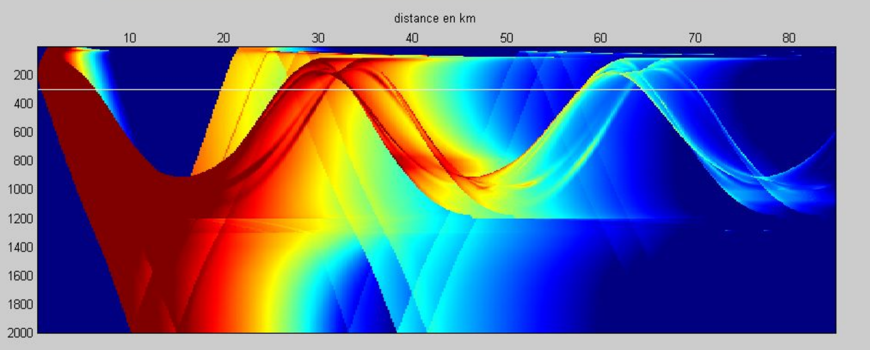
Aim

Optimization

Propose an optimal trajectory for the submarine to hear the targets at best



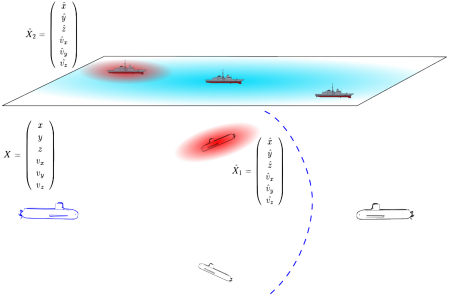
Difficulty: under water sound propagation



Solution proposed by CQFD

First step : Modeling

- position and speed of the submarine known
- position and speed of targets unknown $\longrightarrow$ random
  constant immersion and speed
  + noise



Second step : discretization

Aim

Turn the problem in continuous time and space into a problem in discrete time and space

Time discretization

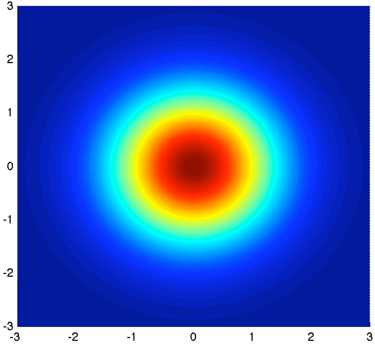
time step $\Delta t = 1$ minute

Discretization of the submarine position

Immersion grid with step $\Delta z = 6$ metres
maximal possible variation in 1minute: $\pm 4\Delta z$

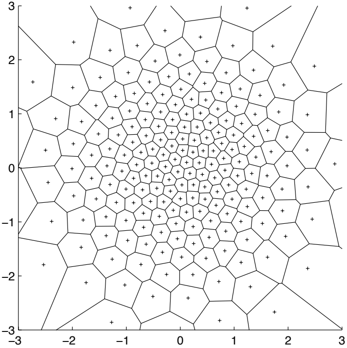
Discretization of targets position

Approximate continuous (position and speed of targets) random variables by discrete ones in an intelligent way



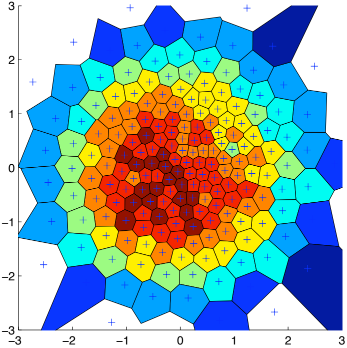
Discretization of targets position

Approximate continuous (position and speed of targets) random variables by discrete ones in an intelligent way



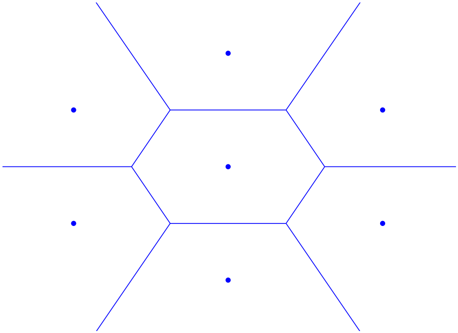
Discretization of targets position

Approximate continuous (position and speed of targets) random variables by discrete ones in an intelligent way



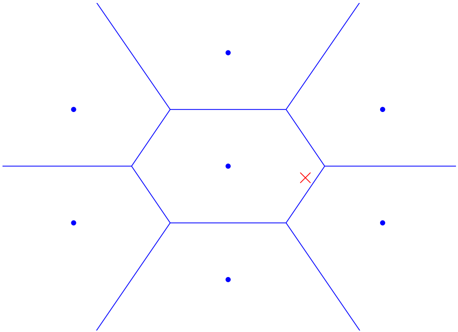
Algorithm

Model ⟶ simulator of trajectories ⟶ grids



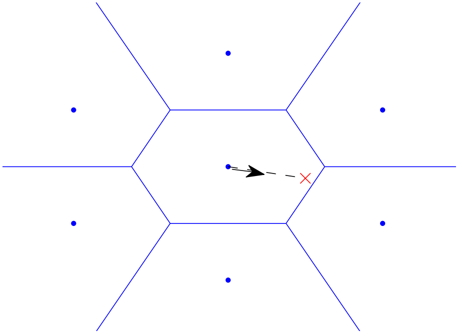
Algorithm

Model ⟶ simulator of trajectories ⟶ grids



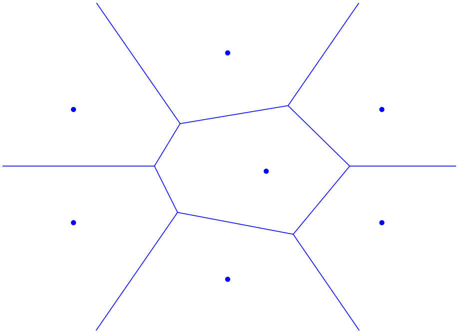
Algorithm

Model ⟶ simulator of trajectories ⟶ grids



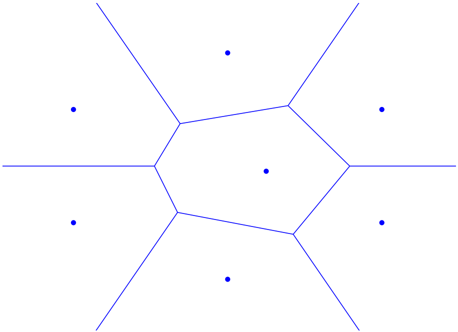
Algorithm

Model ⟶ simulator of trajectories ⟶ grids



Algorithm

Model ⟶ simulator of trajectories ⟶ grids



New observed position ⟶ nearest neighbor projection in the grid

Third step : mathematical formulation of the problem

Markov decision process (MDP)

$$(X, A, \{A(x), x \in X\}, Q, c)$$

- X state space, possible positions for the submarine and targets
- A action space, possible maneuvers for the submarine
- A(x) possible actions at state x
- Q Markov kernel, gives the new relative positions of targets given the action chosen
- c performance function, acoustic loss

Dynamic programming

Optimal control problem for MDP

Find the policy $(a_0, a_2, \ldots, a_{N-1})$ that minimizes the loss

$$J^*(x_0) = \min_{(a_0,a_2,\ldots,a_{N-1})} \mathbb{E}\left[\sum_{n=0}^{N-1} c(x_n, a_n) + c(x_N)\right]$$

Solution by dynamic programming

- $J_N(x) = c(x)$
- $J_n(x) = \min_{a \in A(x)} \mathbb{E}\left[c(x, a) + \int J_{n+1}(y) Q(x, a; dy)\right]$
- $J_0(x) = J^*(x)$

Fourth step: numerical solution

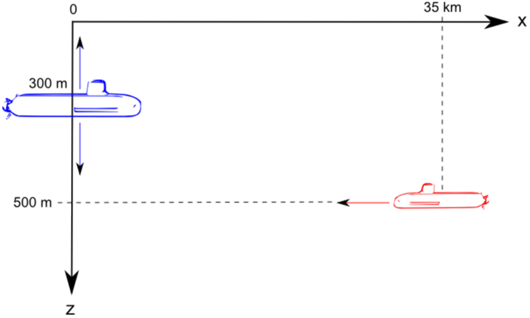
Start with a simplified model and make it more realistic step by step

First models studied

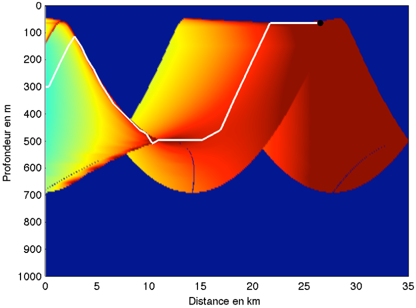
- one target, known constant immersion, submarine maneuvers only in immersion
- two targets, known constant immersion, submarine maneuvers only in immersion
- several targets, constant + noise mmersion, submarine maneuvers only in immersion

Problem: one target

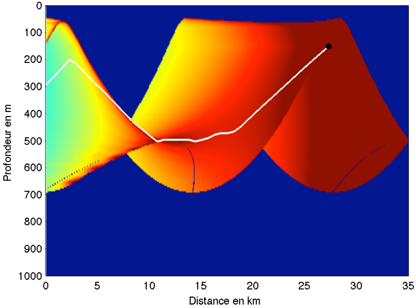
- immersion of target: $500m$, of submarine: $300m$
- initial distance between target and submarine: $35km$
- initial relative speed of target wrt submarine: $-10ms^{-1}$
- computation horizon: $45min$



Results: one target



$\Delta z = 12m$



$\Delta z = 6m$

Results: two targets

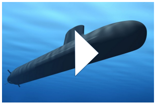
Two targets

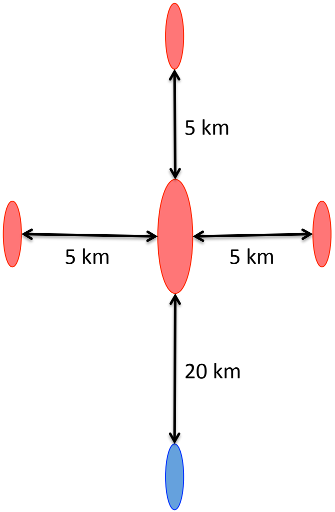
- immersion of targets: $500m$ and $100m$, of submarine: $300m$
- initial distance between targets and submarine: $35km$ $50km$
- initial relative speed of target wrt submarine: $-12ms^{-1}$
- computation horizon: $45min$

Results: four targets

Four targets

- immersion of targets: 600m, 300m, 100m et 400m, of submarine: 300m
- initial speed of targets 20 knots of submarine: 25 knots
- computation horizon: 45 minutes





Validation

Simple models

Advantages

- simpler problems to solve
- easy visual validation
- validation of practical feasability

Drawbacks

- little realistic

Further works

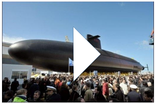
- 3D maneuvers for submarine $\longrightarrow$ long computation time

Further works

- 3D maneuvers for submarine ⟶ long computation time
- other types of mission: hear without being heard ⟶ constraints

Further works

- 3D maneuvers for submarine ⟶ long computation time
- other types of mission: hear without being heard ⟶ constraints
- ongoing work
  use data from tracking algorithms to update target positions
  ⟶ sequence of short-term optimization problems



How to join us

Job opportunities at Inria

- internships
- PhD theses
- Post doc positions
- Permanent researcher positions

Have a look at Inria website
http://www.inria.fr/en/centre/bordeaux/overview/offers/
or contact the head of team François Dufour
francois.dufour@math.u-bordeaux1.fr