COPRIN project

Contraintes, OPtimisation et Résolution par INtervalles

Constraints, OPtimization and Resolving through INtervals

INRIA SOPHIA ANTIPOLIS

COPRIN project

Contraintes, OPtimisation et Résolution par INtervalles

Constraints, OPtimization and Resolving through INtervals

COPRIN has been created in February 2002

INRIA SOPHIA ANTIPOLIS

Members of the project

Staff

MERLET Jean-Pierre	(DR 1, scientific head)
DANEY David	(Chargé de Recherche INRIA)
NEVEU Bertrand	(Ingénieur en Chef, P & C, CERTIS)
PAPEGAY Yves	(Chargé de Recherche INRIA)
POURTALLIER Odile	(Chargé de Recherche INRIA, join the team in 2004)
TROMBETTONI Gilles	(Maître de Conférences UNSA)

Students

- 7 PhD students
- 1 post-doc
- 1 engineer

Scientific objectives and Methods

Scientific objectives and Methods

Two main complementary research axis:

Robotics and Interval Analysis

Scientific objectives and Methods

Robotics

- **Robotics Objective 1:** robot modeling and analysis

Scientific objectives and Methods

Robotics

- **Robotics Objective 1:** robot modeling and analysis
  - establishing the performances of a given robot

Scientific objectives and Methods

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  - establishing the performances of a given robot
  - in a **guaranteed manner**

Scientific objectives and Methods

Robotics

- **Robotics Objective 1:** robot modeling and analysis
  - establishing the performances of a given robot
  - in a **guaranteed manner**
  - especially taking into account the uncertainties in the modeling and control

Scientific objectives and Methods

Robotics

- **Robotics Objective 1:** robot modeling and analysis
- **Robotics Objective 2:** design methodology

Scientific objectives and Methods

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  - methodology provides almost **all** design solutions

Scientific objectives and Methods

Robotics

- **Robotics Objective 1:** robot modeling and analysis
- **Robotics Objective 2:** design methodology
  - establishing the robot design parameters so that it will fit given requirements
  - methodology provides almost **all** design solutions
  - methodology is **robust** with respect to manufacturing tolerances

Scientific objectives and Methods

Robotics

- **Robotics Objective 1:** robot modeling and analysis
- **Robotics Objective 2:** design methodology
- **Robotics Objective 3:** parallel robot, prototypes, applications

Example: new wire-driven parallel robot

Example: new wire-driven parallel robot

Highly modular

Example: new wire-driven parallel robot

Highly modular

Linear actuators

Example: new wire-driven parallel robot

Highly modular

Linear actuators

Applications:

service robotics

rehabilitation

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Scientific objectives and Methods

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Interval Analysis/Constraints

- certified solving

Scientific objectives and Methods

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- certified solving
  - of equations and/or inequalities systems

Scientific objectives and Methods

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- certified solving
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  - for real variables, lying in a bounded domain

Scientific objectives and Methods

Interval Analysis/Constraints

- certified solving
  - of equations and/or inequalities systems
  - for real variables, lying in a bounded domain
  - providing results that are guaranteed

Scientific objectives and Methods

Interval Analysis/Constraints

- certified solving
- methods:

Scientific objectives and Methods

Interval Analysis/Constraints

- certified solving
- methods:
  - constraint programming
  - interval analysis
  - symbolic computation

Interval analysis

Interval analysis

Calculating with intervals is (**almost**) as easy than with real numbers

Interval analysis

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Example: $F = x^2 + \cos(x)$, $x \in [0, 1]$

Problem: find $[A, B]$ such that: $A \leq F(x) \leq B \; \forall \; x \; \in [0, 1]$

Interval analysis

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- 0 not included in [0.54,2] $\Rightarrow \; F \neq 0 \; \forall \; x \in [0, 1]$

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- $F > 0 \;\; \forall \; x \in [0,1]$

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- Advantages:**numerical round-off errors** are managed
- Drawbacks: **overestimation**, calculation **sensitive to formulation**

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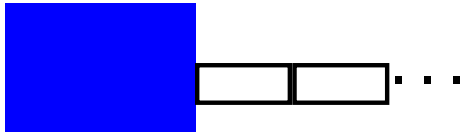
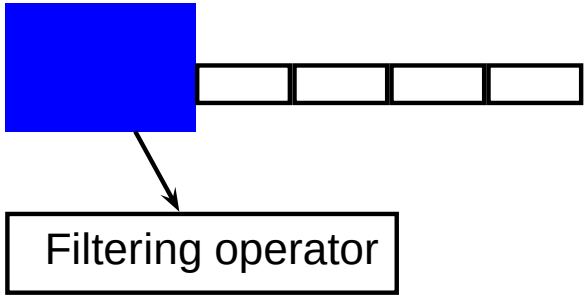
The structure of an IA algorithm

The structure of an IA algorithm



. . . A list of boxes

The structure of an IA algorithm



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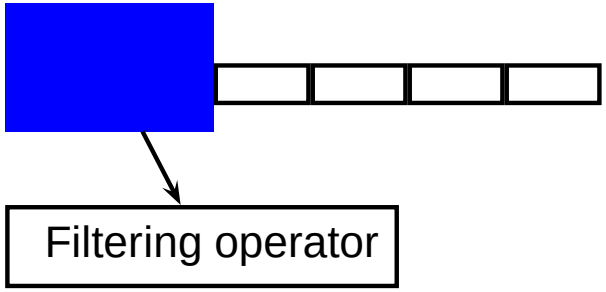
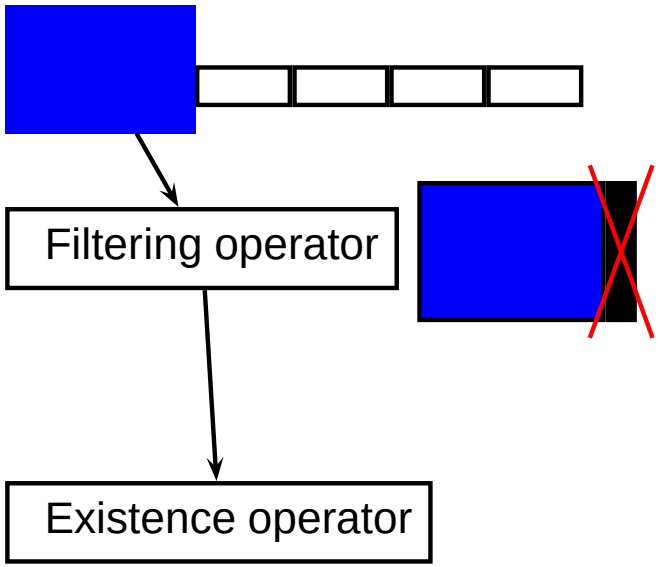


Filtering operator: a set of heuristics that may allow to determine that there is no solution in the current box or may reduce its size

The structure of an IA algorithm



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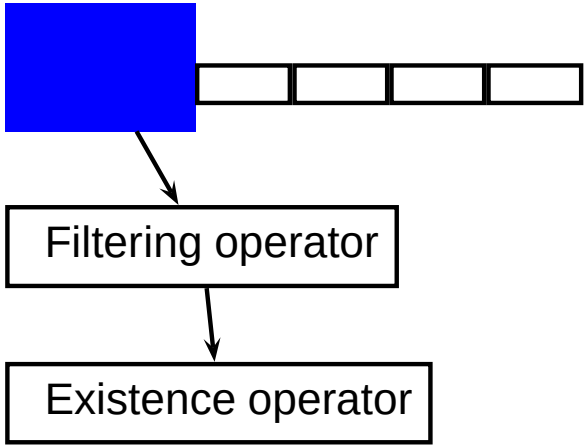
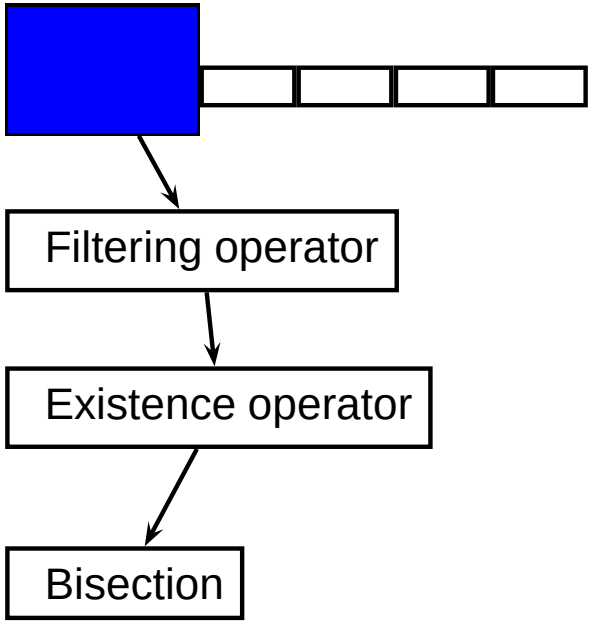


Existence operator: a set of heuristics that may allow to determine that there is a single solution in the current box (e.g Kantorovitch theorem)

The structure of an IA algorithm



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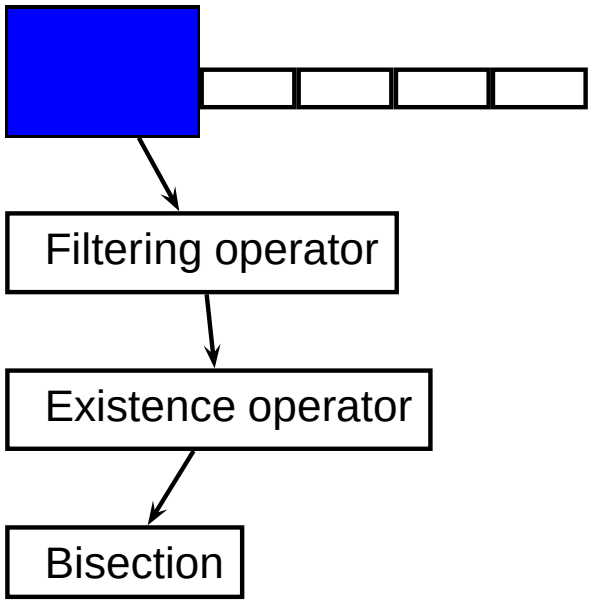
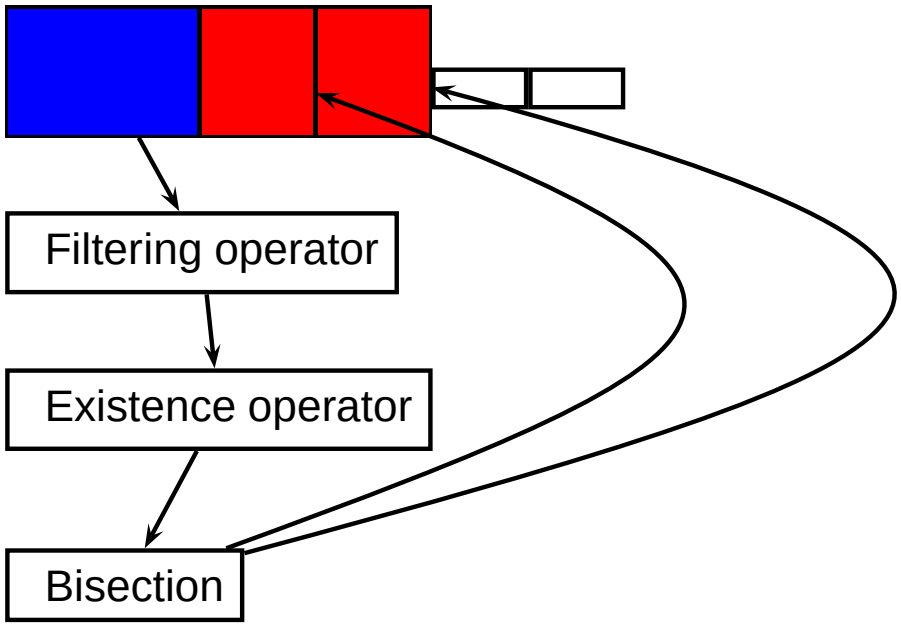


Split the current box, usually in two

The structure of an IA algorithm



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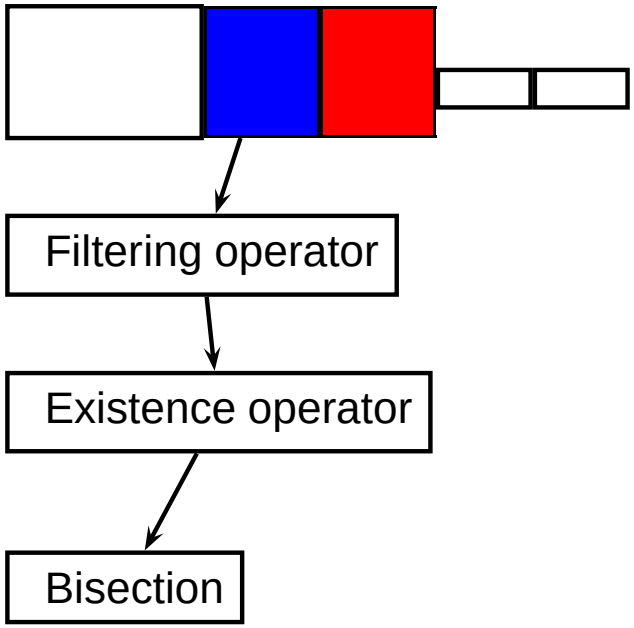

An example

An example

Managing a set of inequalities:

$$x^2 + y^2 \leq 2$$
$$(x-1)^2 + (y-1)^2 \leq 2$$

that play a role in the calculation of a parallel robot workspace

VIDEO

Interval Analysis Objectives

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

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- new filtering operators

Interval Analysis Objectives

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- new filtering operators
- decomposition and solving of geometric constraints

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

- new filtering operators
- decomposition and solving of geometric constraints
- solving of differential equations

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

IA Objective 2: Dissemination, software, experimental analysis

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

IA Objective 2: Dissemination, software, experimental analysis

- method is not well known

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

IA Objective 2: Dissemination, software, experimental analysis

- method is not well known
- lack of available software

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

IA Objective 2: Dissemination, software, experimental analysis

- method is not well known
- lack of available software
- interface not convenient for non expert end-user

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

IA Objective 2: Dissemination, software, experimental analysis

Tools:

- extensive use of symbolic computation
- software (ALIAS library)
- extensive testing

Localization with ultra-sound

Localization of a robot with ultra-sound (joint work with ETH)

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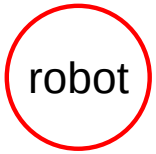

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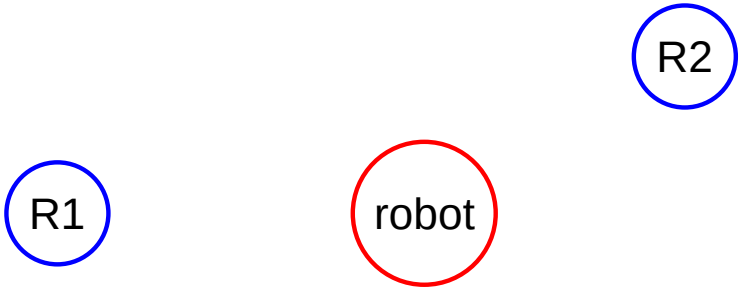

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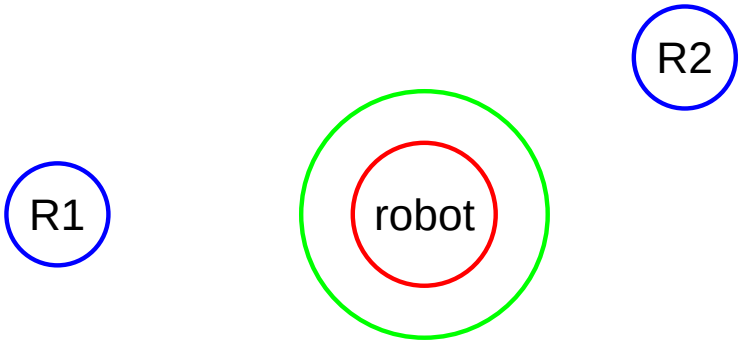

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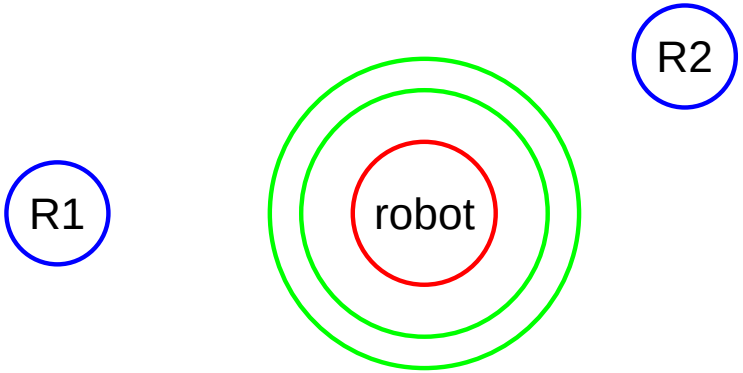

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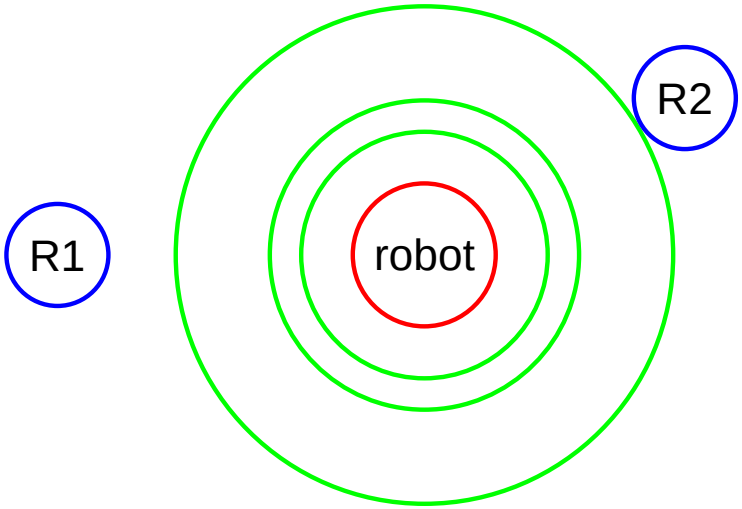
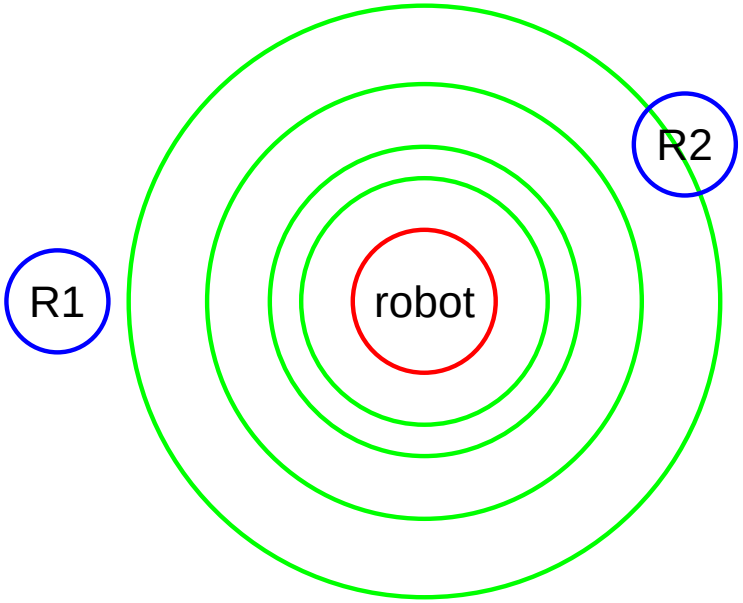


R2 receives the ping at time t_2

Localization with ultra-sound

Localization of a robot with ultra-sound (joint work with ETH)



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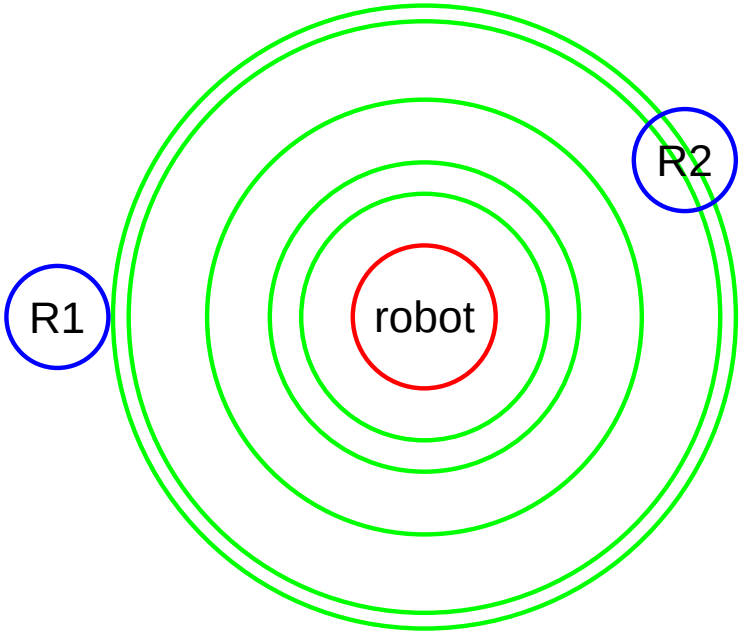

R1 receives the ping at time t_1

Localization with ultra-sound

Localization of a robot with ultra-sound (joint work with ETH)

Localization is based on the measurement of $t_2 - t_1$

With 2 receivers: assuming perfect Dirac ping

- $||RR_2|| - ||RR_1|| = c(t_2 - t_1) \Rightarrow$ robot lie on a hyperbola

Localization with ultra-sound

Localization of a robot with ultra-sound (joint work with ETH)

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With 2 receivers: assuming perfect Dirac ping:

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In practice we have sinusoidal ping:

- measured time is an interval
- robot lie on a "thick" hyperbola

Localization with ultra-sound

Localization of a robot with ultra-sound (joint work with ETH)

With three receivers

- measurement of $t_2 - t_1, t_3 - t_1$
- robot located at the intersection of 2 "thick" hyperbola

Analysis

Analysis

Usually f, c are assumed to be perfectly known

Analysis

but in practice f, c are uncertain

- c in [1465,1496] m/s ($\pm$ 5 degrees temperature variation)
- f in [295,305] kHz

Influence of these uncertainties on the robot localization ?

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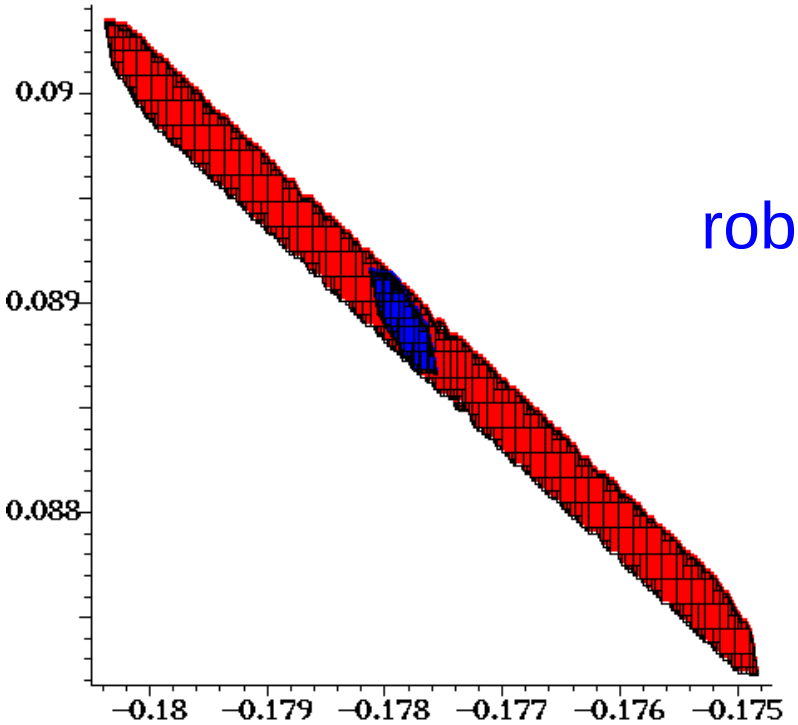


robot location discarding uncertainties

possible real location

Synthesis

Synthesis

not satisfied with the localization accuracy ?

$\Downarrow$

find the location of the 3rd receiver so that the localization accuracy is lower than a given threshold

Synthesis

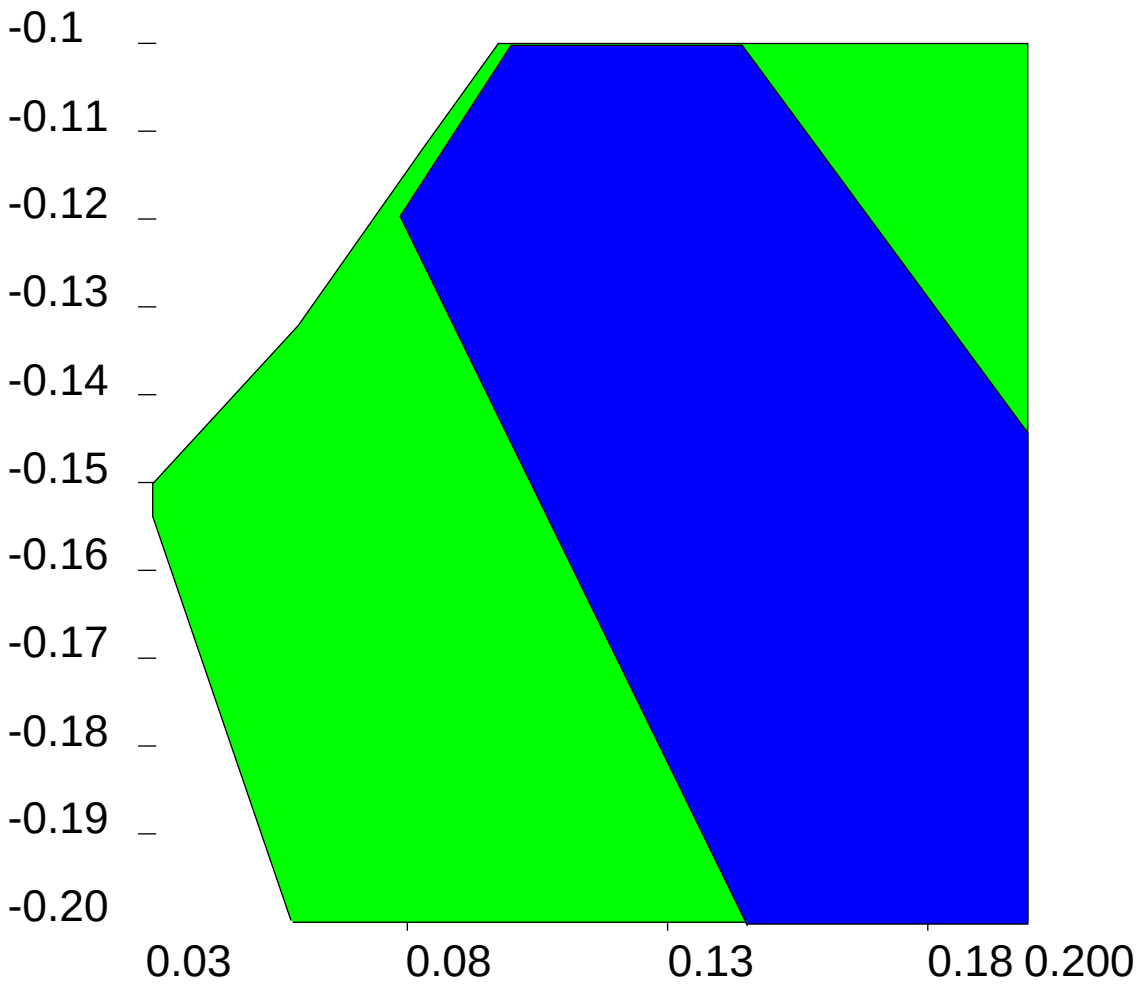
not satisfied with the localization accuracy ?

$\Downarrow$

find the location of the 3rd receiver so that the localization accuracy is lower than a given threshold

IA methods allows to find all 3rd receiver location that allow to respect this requirement

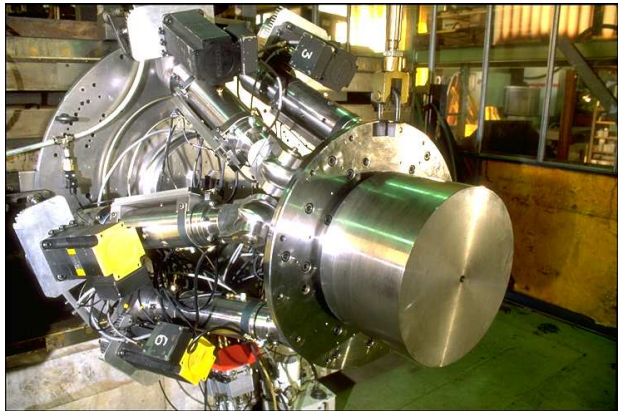
Synthesis



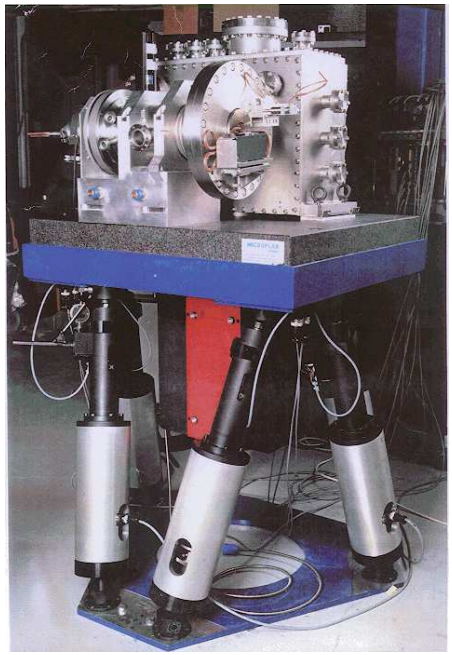
Synthesis

- this methodology allows to design robots that fit a list of requirements
- it has been used for designing industrial robots and our own prototypes

machine-tool (CMW)

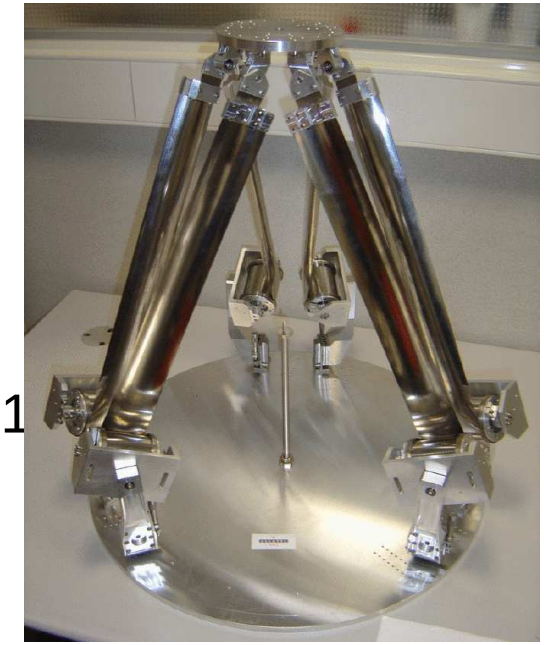


Fine positioning (ESRF)

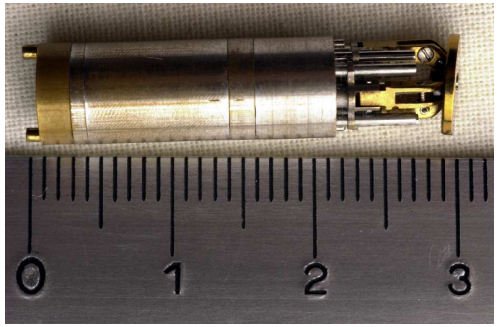


1

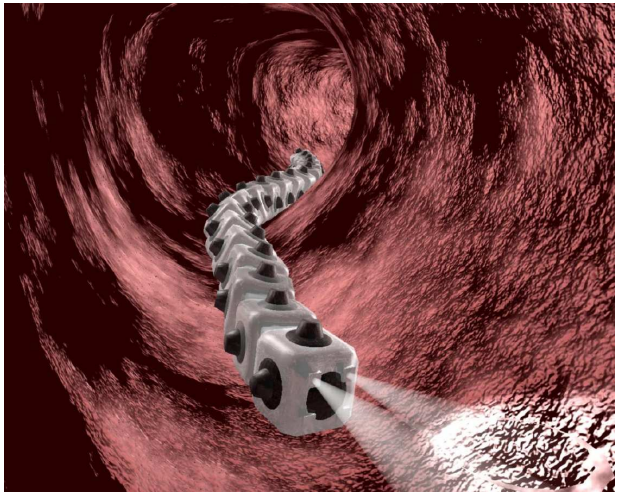
Space telescope (Alcatel)



MIPS micro robot



ARES micro-robot



wire robot

this methodology is used to manage the modularity of our wire-driven parallel robot

- find the geometry that allows to lift an elderly people whatever his/her location in a given room

Wire-driven parallel robot

Wire-driven parallel robot

All purpose device with 1 to 6 d.o.f., redundant or not

- highly modular: geometry, amplification of actuator motion
- powerful: high ratio load/mass
- fast: potentially faster than the speed of sound

Examples:

4 dof crane motion video , fast planar motion (3.5m/s)

Wire-driven parallel robot

Potential applications:

- domestic robotics: windows washing

Wire-driven parallel robot

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- entertainment: actor motion in theater, fast change in scenes

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- assistance robotics: lifting of elderly people (lifting video)

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- assistance robotics: lifting of elderly people (lifting video)
- rehabilitation

Example: rehabilitation

Example: rehabilitation

Patient suffering from loss of arm coordination after a cardiovascular stroke

Example: rehabilitation

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Classical rehabilitation training: arm pointing to colored marks moving randomly on a computer screen

Example: rehabilitation

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Drawbacks:

- no monitoring of the arm motion

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Classical rehabilitation training: arm pointing to colored marks moving randomly on a computer screen

Drawbacks:

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Example: rehabilitation

Patient suffering from loss of arm coordination after a cardiovascular stroke

Classical rehabilitation training: arm pointing to colored marks moving randomly on a computer screen

Drawbacks:

- no monitoring of the arm motion
- no objective mean to qualify the motion quality
- fatigue induced by pointing the arm

Example: rehabilitation

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Robot assisted rehabilitation

Example: rehabilitation

Patient suffering from loss of arm coordination after a cardiovascular stroke

Robot assisted rehabilitation

- use trajectory tracking to **monitor** and **qualify** motions

Example: rehabilitation

Patient suffering from loss of arm coordination after a cardiovascular stroke

Robot assisted rehabilitation

- use trajectory tracking to **monitor** and **qualify** motions
- relieve partly arm gravity for focusing on coordination

Example: rehabilitation

Patient suffering from loss of arm coordination after a cardiovascular stroke

Robot assisted rehabilitation: (rehabilitation video)

Example: rehabilitation

Patient suffering from loss of arm coordination after a cardiovascular stroke

Robot assisted rehabilitation: (rehabilitation video)

- gravity effects decreased by 50%

Example: rehabilitation

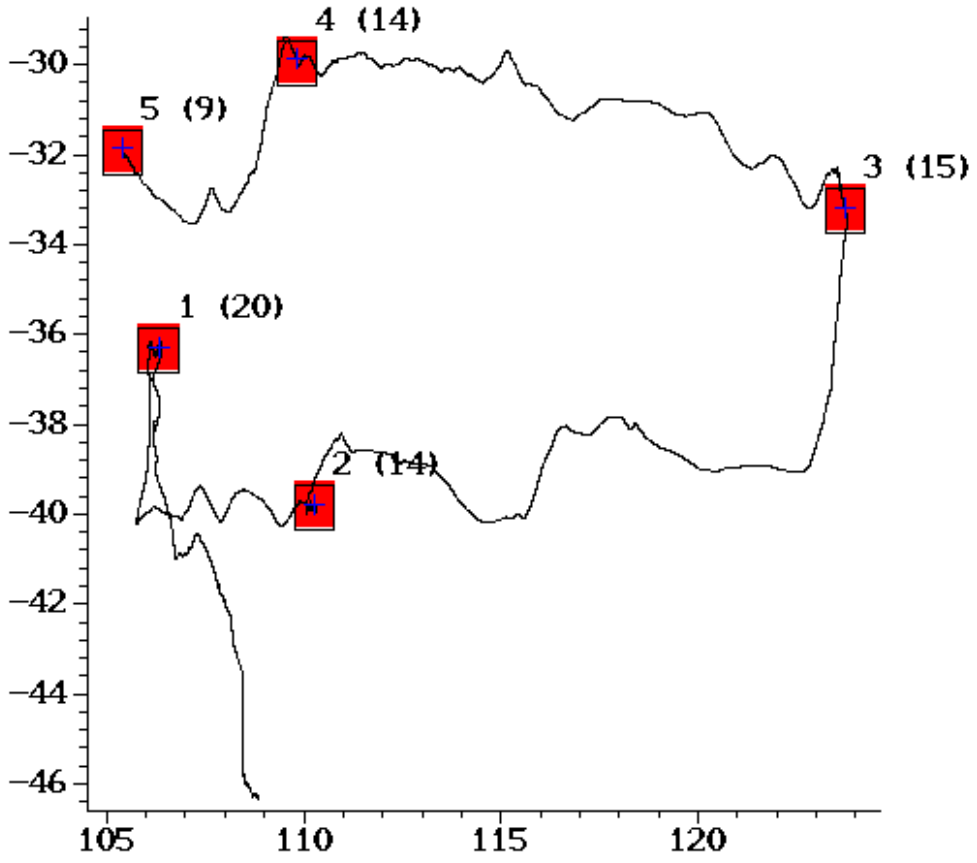
Patient suffering from loss of arm coordination after a cardiovascular stroke

Robot assisted rehabilitation: (rehabilitation video)

- gravity effects decreased by 50%
- trajectory tracking: straightness of the trajectory allows to qualify motion quality

Example: rehabilitation

Trajectory tracking



Recent objectives

Recent objectives

Focus on service robotics

Recent objectives

Focus on service robotics

- developing various low-cost assistance robotized devices

Recent objectives

Focus on service robotics

- developing various low-cost assistance robotized devices
- user-centered (systematic collaboration with end-users)

Recent objectives

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- active participation to the large scale initiative PAL (Personnaly Assisted Living)

Example: assistance for elderly people (video)

Questions ?

INRIA SOPHIA ANTIPOLIS