COPRIN project

Contraintes, OPtimisation et Résolution par INtervalles

Constraints, OPtimization and Resolving through INtervals

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Contraintes, OPtimisation et Résolution par INtervalles

Constraints, OPtimization and Resolving through INtervals

COPRIN has been created in February 2002

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

Robotics

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

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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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    - establishing the robot design parameters so that it will fit given requirements

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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

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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

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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

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Interval analysis

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

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

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

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

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

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- Advantages: **numerical round-off errors** are managed

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

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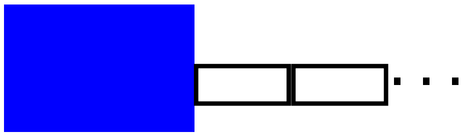
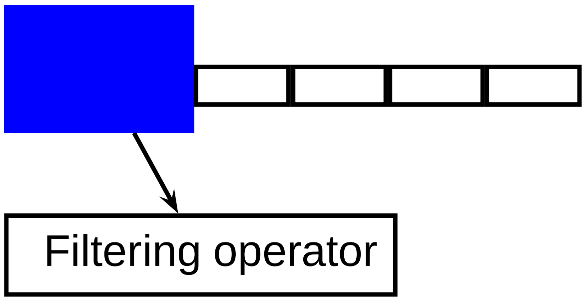
The structure of an IA algorithm

The structure of an IA algorithm



A list of boxes

The structure of an IA algorithm



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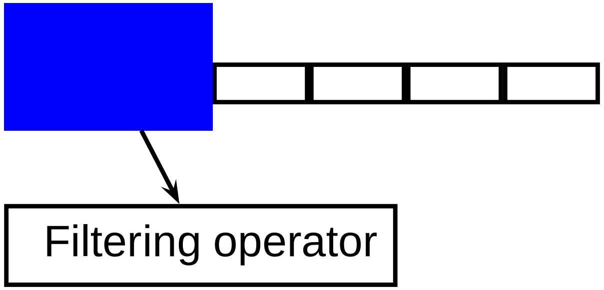
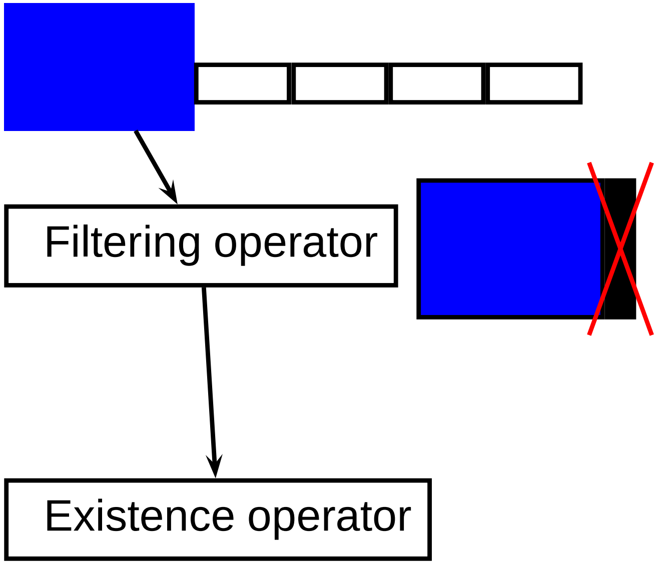


Filtering operator: a set of heuristics that may allow to determine that there is no solution in the current box or may reduce its size

The structure of an IA algorithm



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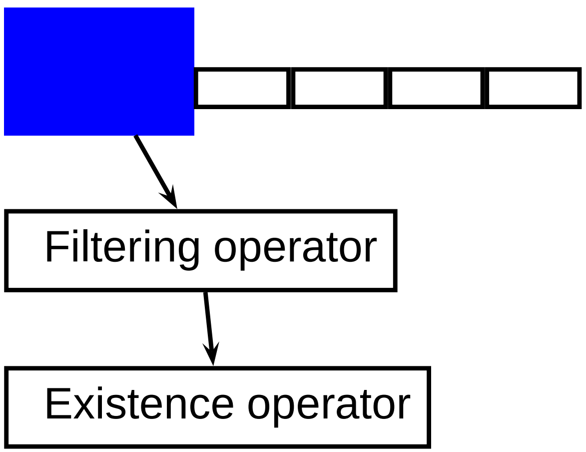
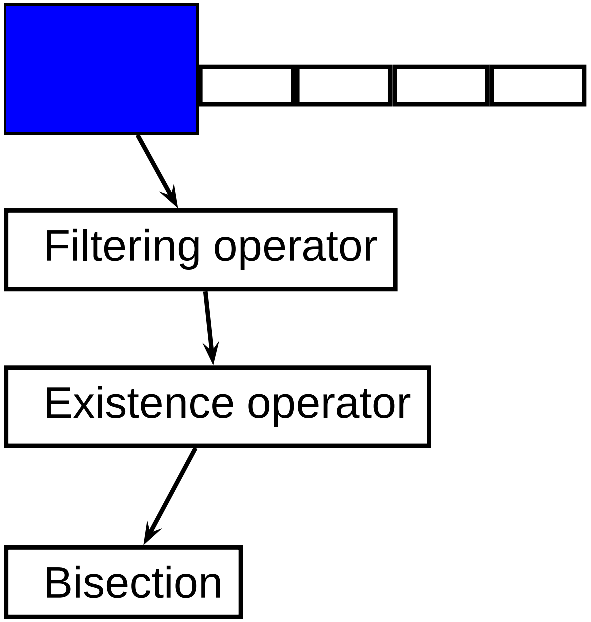


Existence operator: a set of heuristics that may allow to determine that there is a single solution in the current box (e.g Kantorovitch theorem)

The structure of an IA algorithm



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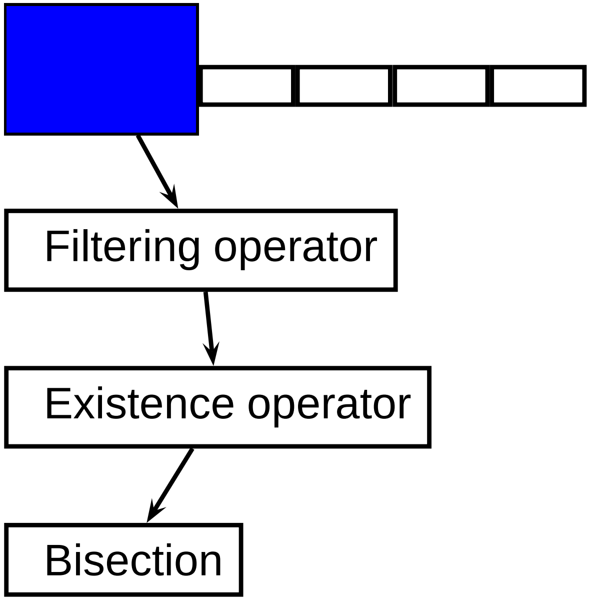
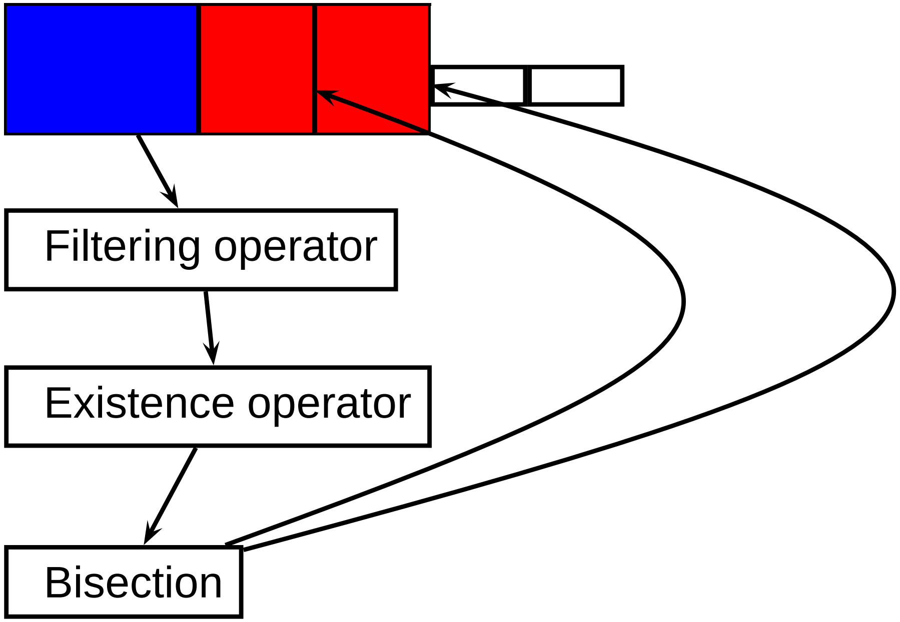


Split the current box, usually in two

The structure of an IA algorithm



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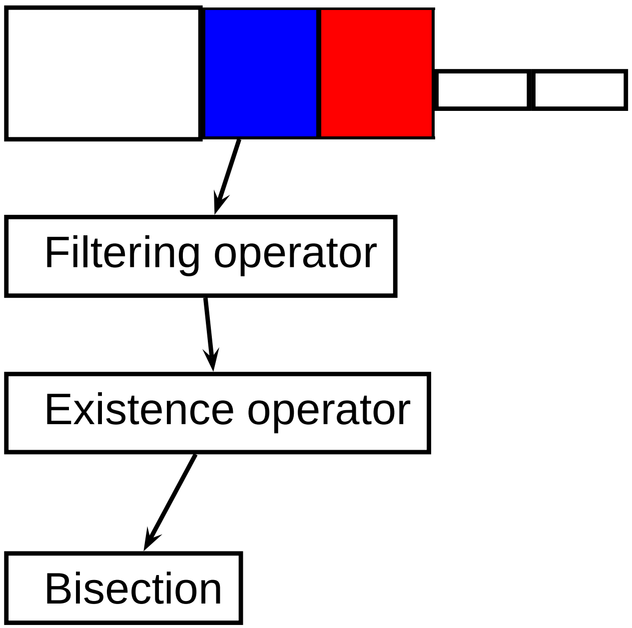

An example

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

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Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

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

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Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

IA Objective 2: Dissemination, software, experimental analysis

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- method is not well known

Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

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- 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

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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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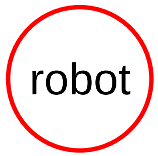

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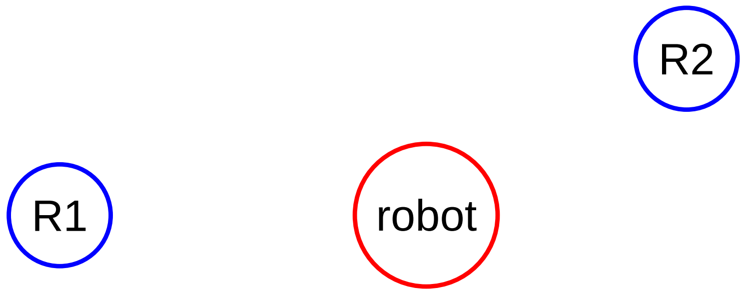

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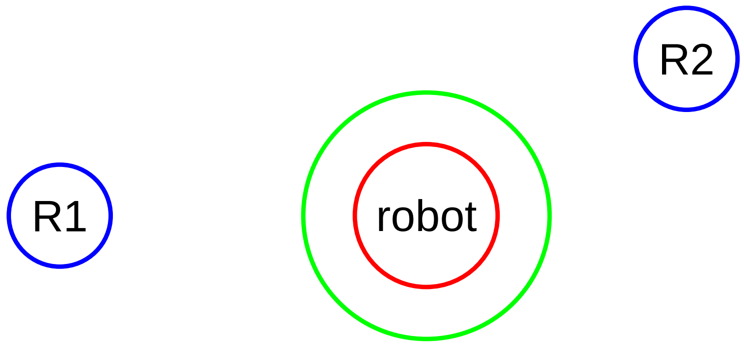

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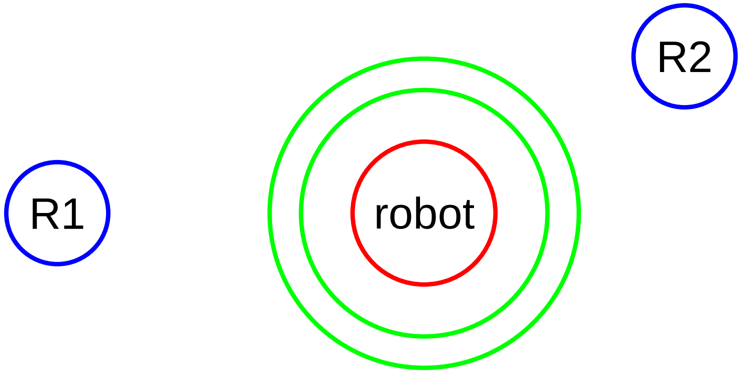

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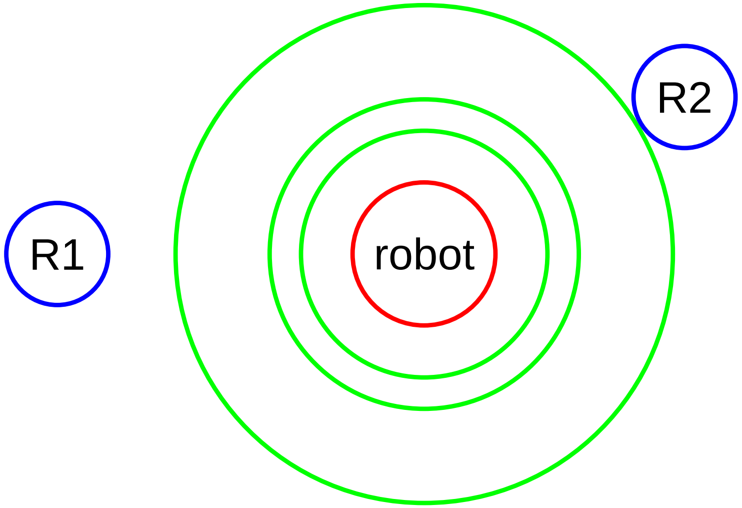

R2 receives the ping at time t_2

Localization with ultra-sound

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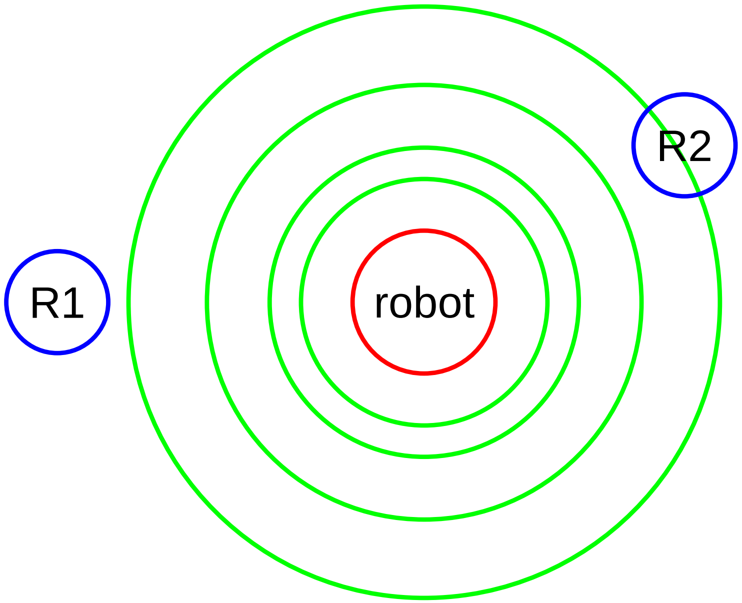

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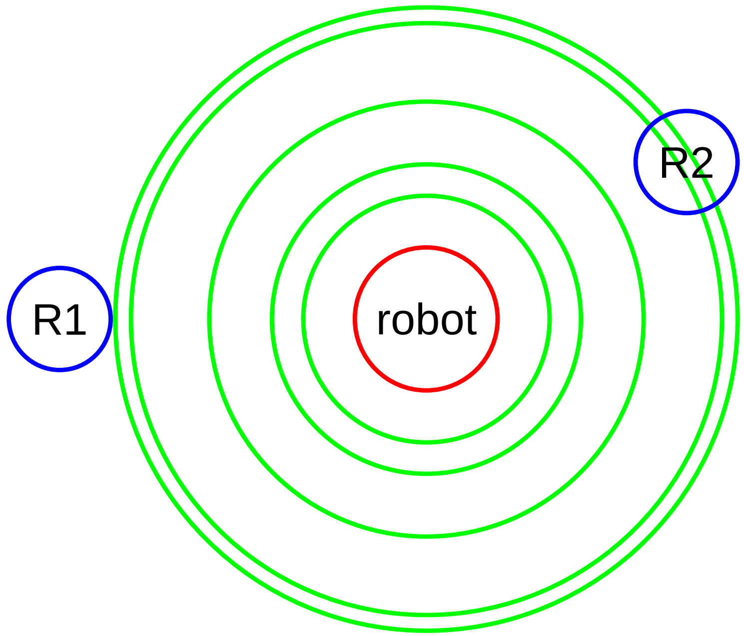

R1 receives the ping at time t_1

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)

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

In practice we have sinusoidal ping:

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

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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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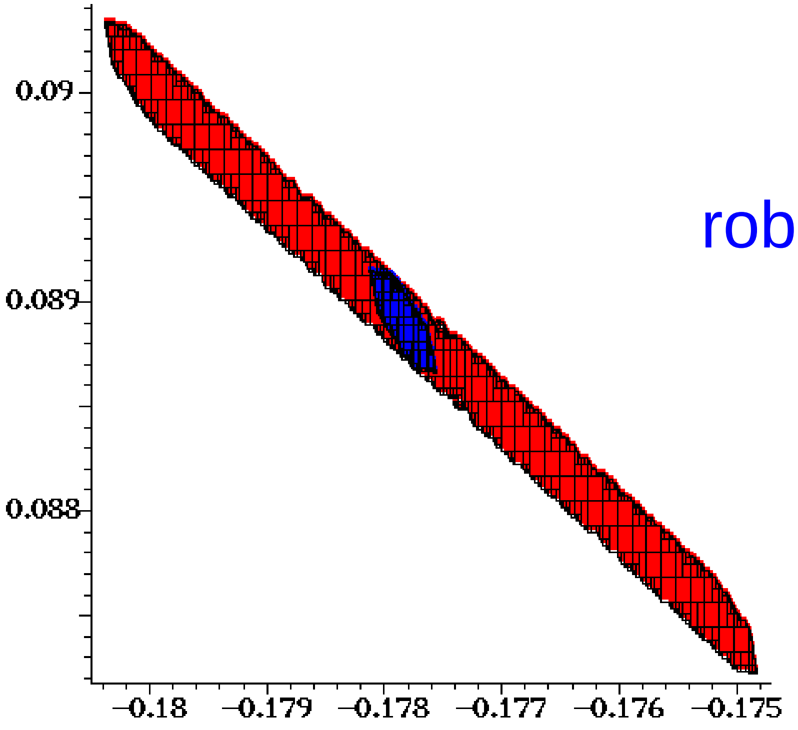

robot location discarding uncertainties

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

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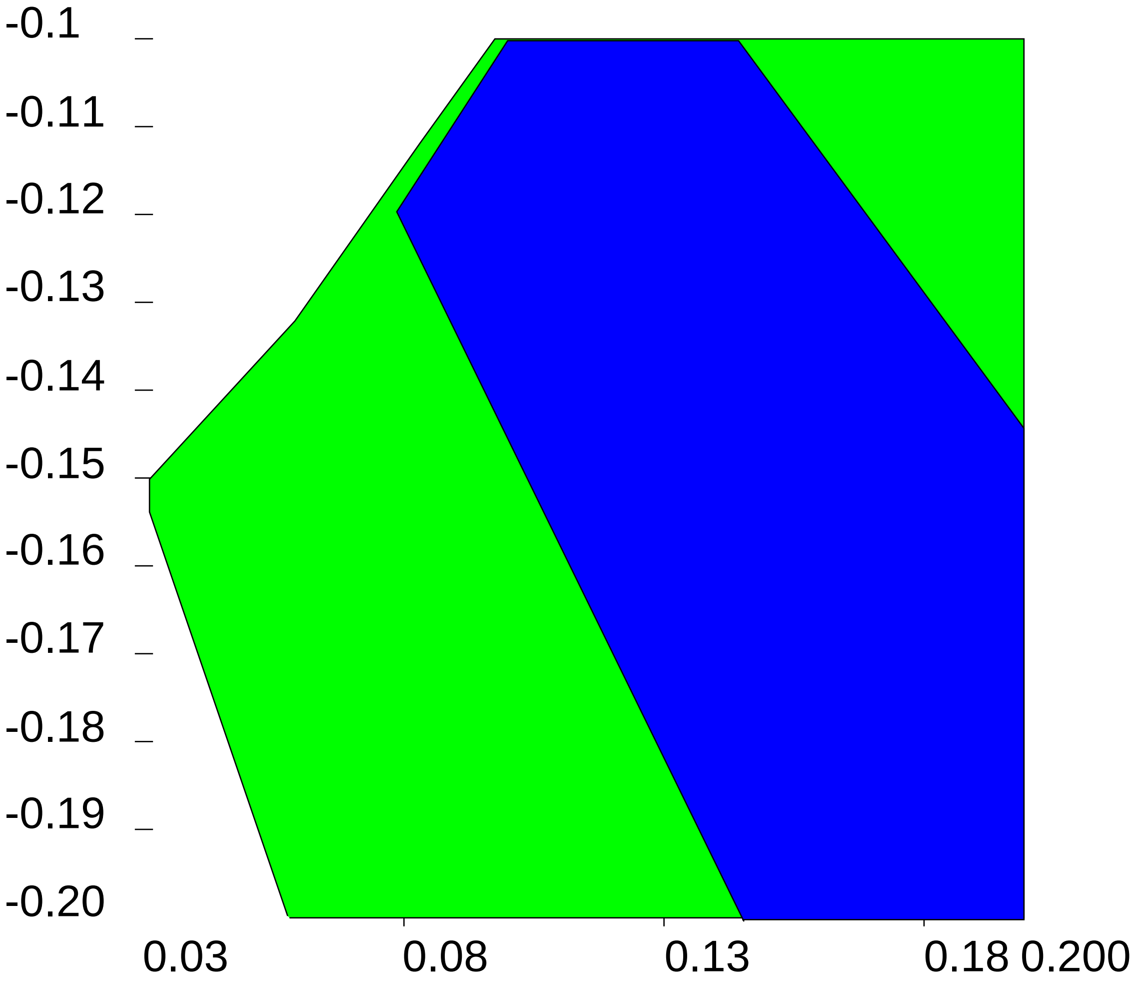
Synthesis



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

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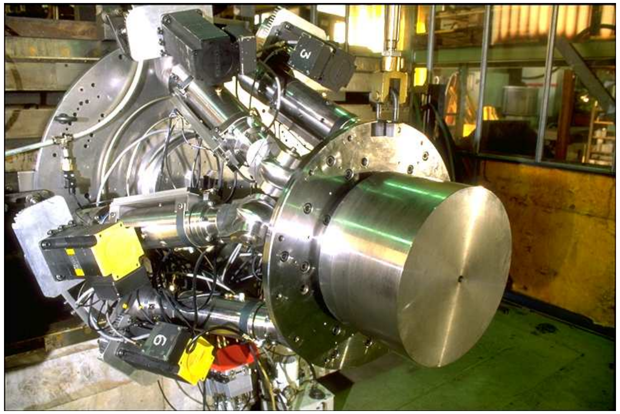
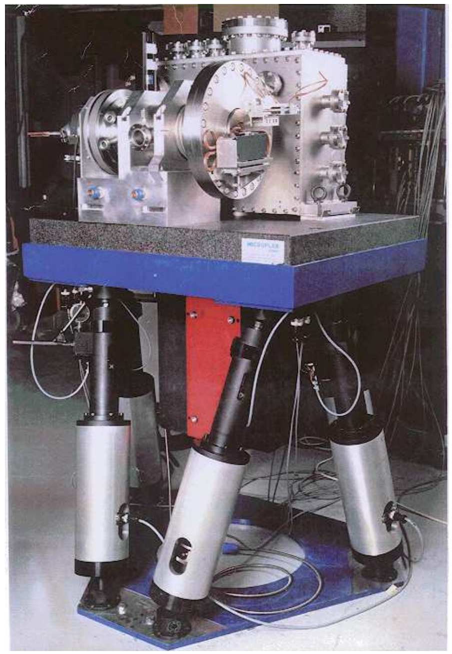
machine-tool (CMW)

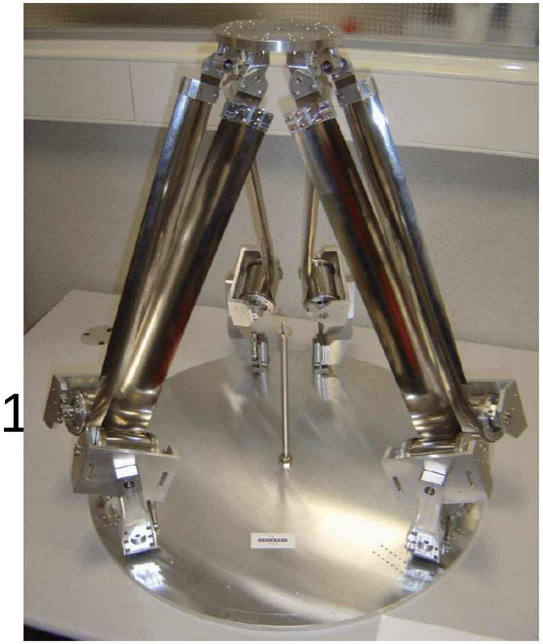


Fine positioning (ESRF)



1

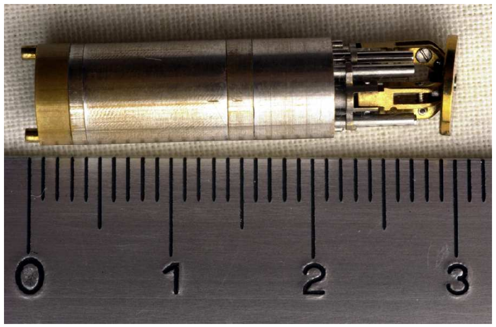
Space telescope (Alcatel)

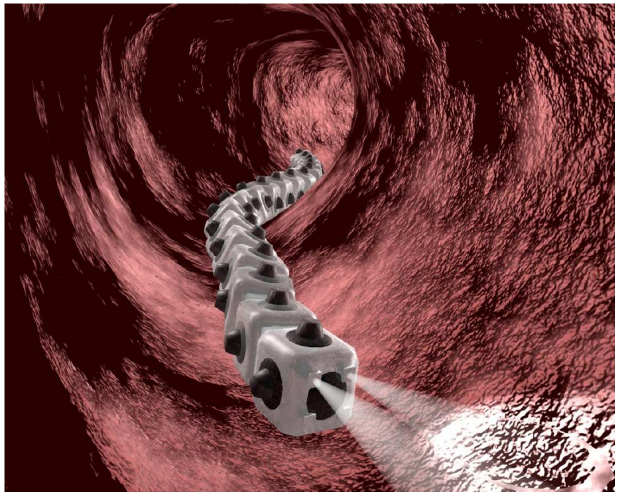


MIPS micro robot

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

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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)

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Wire-driven parallel robot

Potential applications:

- domestic robotics: windows washing

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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

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

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- no monitoring of the arm motion

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Example: rehabilitation

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Example: rehabilitation

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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

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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

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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

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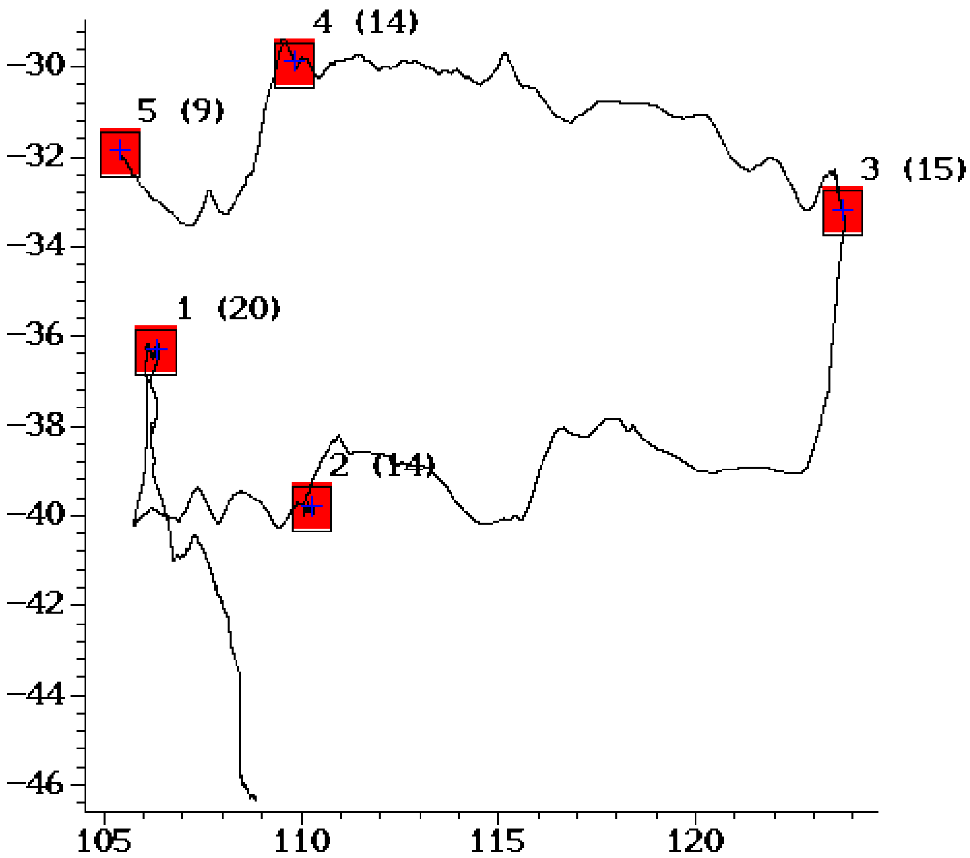
Example: rehabilitation

Trajectory tracking



Recent objectives

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Focus on service robotics

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- developing various low-cost assistance robotized devices

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- user-centered (systematic collaboration with end-users)

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- developing methodologies to adapt the device to the end-user and its surrounding

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Recent objectives

Focus on service robotics

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- developing various interfaces to manage the end-user abilities

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INRIA SOPHIA ANTIPOLIS

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

Example: assistance for elderly people (video)