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
Scientific objectives and Methods

Robotics

• Robotics Objective 1: robot modeling and analysis
• Robotics Objective 2: design methodology
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
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
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
Scientific objectives and Methods
Scientific objectives and Methods

Interval Analysis/Constraints

• certified solving
Scientific objectives and Methods

Interval Analysis/Constraints

• certified solving
  • of equations and/or inequalities systems
Scientific objectives and Methods

Interval Analysis/Constraints

- certified solving
  - of equations and/or inequalities systems
  - 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

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

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

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

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

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

\[
F = [0, 1]^2 + \cos([0, 1])
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Interval analysis

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

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\[ F = \left[0, 1\right]^2 + \cos\left([0, 1]\right) \]
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\[ F = [0,1]^2 + \cos([0,1]) = [0,1] + \cos([0,1]) \]
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Interval analysis

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

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

$$F = [0, 1]^2 + \cos([0, 1]) = [0, 1] + [0.54, 1]$$
Interval analysis

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

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

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

\[
F = [0, 1]^2 + \cos([0, 1]) = [0,1]+[0.54,1]
\]
Interval analysis

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

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

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

$$F = [0, 1]^2 + \cos([0, 1]) = [0, 1]+[0.5, 1] = [0.54, 2]$$
Interval analysis

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

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

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

\[
F = [0, 1]^2 + \cos([0, 1]) = [0, 1] + [0.54, 1] = [0.54, 2]
\]

\[\bullet\] 0 not included in \([0.54, 2]\) \(\Rightarrow\) \( F \neq 0 \ \forall \ x \in [0, 1] \)
Interval analysis

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

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

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

\[
F = [0, 1]^2 + \cos([0, 1]) = [0,1] + [0.54, 1] = [0.54, 2]
\]

• 0 not included in [0.54,2] \( \Rightarrow \) \( F \neq 0 \) \( \forall \, x \in [0, 1] \)
• \( F > 0 \) \( \forall \, x \in [0, 1] \)
Interval analysis

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

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

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

\[
F = [0,1]^2 + \cos([0,1]) = [0,1]+[0.54,1] = [0.54,2]
\]

- Advantages: numerical round-off errors are managed
Interval analysis

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

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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F = [0, 1]^2 + \cos([0, 1]) = [0,1]+[0.54,1] = [0.54, 2]
\]

• **Advantages**: numerical round-off errors are managed
• **Drawbacks**: overestimation, calculation sensitive to formulation
The structure of an IA algorithm
The structure of an IA algorithm

... A list of boxes
The structure of an IA algorithm

Filtering operator
The structure of an IA algorithm

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

- Filtering operator
- Existence operator
The structure of an IA algorithm

Existence operator: a set of heuristics that may allow to determine that there is a single solution in the current box (e.g. Kantorovich theorem)
The structure of an IA algorithm

- Filtering operator
- Existence operator
- Bisection
The structure of an IA algorithm

Split the current box, usually in two
The structure of an IA algorithm

- Filtering operator
- Existence operator
- Bisection
The structure of an IA algorithm

- Filtering operator
- Existence operator
- Bisection
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
Interval Analysis Objectives
Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology
Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

• new filtering operators
Interval Analysis Objectives

IA Objective 1: Improvement of IA methodology

- 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)
Localization with ultra-sound

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

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

R1

R2

robot
Localization with ultra-sound

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

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

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

R2 receives the ping at time $t_2$
Localization with ultra-sound

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

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

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
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 (± 5 degrees temperature variation)
- $f$ in $[295, 305]$ kHz

Influence of these uncertainties on the robot localization?
Analysis

but in practice \( f, c \) are uncertain

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

Influence of these uncertainties on the robot localization?
Synthesis
Synthesis

not satisfied with the localization accuracy ?

⇓

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 ?

⇓

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)  Space telescope (Alcatel)
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

Potential applications:

- **domestic robotics**: windows washing
- **entertainment**: actor motion in theater, fast change in scenes
Wire-driven parallel robot

Potential applications:

• **domestic robotics**: windows washing
• **entertainment**: actor motion in theater, fast change in scenes
• **catastrophe**: portable multi-dof crane (ADT)
Wire-driven parallel robot

Potential applications:

• **domestic robotics:** windows washing
• **entertainment:** actor motion in theater, fast change in scenes
• **catastrophe:** portable multi-dof crane (ADT)
• **haptic interface:** virtual reality, training with force-feedback
Wire-driven parallel robot

Potential applications:

• **domestic robotics**: windows washing
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• **catastrophe**: portable multi-dof crane (ADT)
• **haptic interface**: virtual reality, training with force-feedback
• **assistance robotics**: lifting of elderly people (lifting video)
Wire-driven parallel robot

Potential applications:

- **domestic robotics**: windows washing
- **entertainment**: actor motion in theater, fast change in scenes
- **catastrophe**: portable multi-dof crane (ADT)
- **haptic interface**: virtual reality, training with force-feedback
- **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

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
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
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
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

Patient suffering from loss of arm coordination after a cardiovascular stroke

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

Focus on service robotics

- developing various **low-cost assistance robotized devices**
- **user-centered** (systematic collaboration with end-users)
- developing **methodologies** to adapt the device to the end-user and its surrounding
Recent objectives

Focus on service robotics

- developing various low-cost assistance robotized devices
- user-centered (systematic collaboration with end-users)
- developing methodologies to adapt the device to the end-user and its surrounding
- developing various interfaces to manage the end-user abilities
Recent objectives

Focus on service robotics

• developing various low-cost assistance robotized devices
• user-centered (systematic collaboration with end-users)
• developing methodologies to adapt the device to the end-user and its surrounding
• developing various interfaces to manage the end-user abilities
• active participation to the large scale initiative PAL (Personnaly Assisted Living)

Example: assistance for elderly people (video)

Questions ?