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Planning and Fast Re-Planning of Safe Motions for Humanoid Robots: Application to a Kicking Motion

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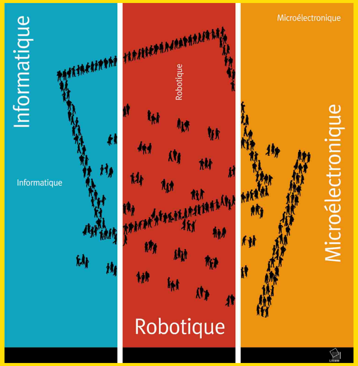

JNRH 2010, Poitiers

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Introduction

Motivations for Safe Motions

- Initially for paraplegic patients.
- Safe motion in term of constraint-satisfying.
- Accuracy during the movement is not needed.
- Safe motion is more important than performance
- The ZMP or CoP inequality constraint must be continuously satisfied.
- Allows to reinforce the robustness of the controller.

Introduction

- We propose a method based on Interval Analysis guaranteeing the ZMP inequality constraint continuously within the motion duration.
- We will compare experimentally this method with a classical one.
- Kicking motion will be used for illustrating the issue of safe motion planning and re-planning.

Introduction

- **A method for planning safe motions based on Interval Analysis:**
  - R.E Moore and F. Bierbaum, *Methods and applications of Interval Analysis, Soc for Industrial & Applied Mathematics, 1979.*
  - H. Fang and J.P. Merlet, *Dynamic interference avoidance of 2-DOF robot arms using interval analysis, IROS 2005.*
  - L. Jaulin, *Path Planning using intervals and graphs, Reliable Computing, 2001.*
  - (Self-Collision avoidance for robot arms, Problem of finding collision-free paths)
- **A new method for generating safe motion and databasing balanced movement:**
  - S. Lengagne, N. Ramdani and P. Fraisse, *A new method for generating safe motions for humanoid robots, IEEE Humanoid 2008.*
  - S. Lengagne, N. Ramdani and P. Fraisse, *Safe Motion planning for databasing balanced movement of Humanoid Robots, IEEE ICRA 2009.*
  - S. Lengagne, N. Ramdani and P. Fraisse, *Planning and Fast Re-Planning of Safe Motions for Humanoid Robots: Application to a Kicking Motion, IEEE IROS 2009.*

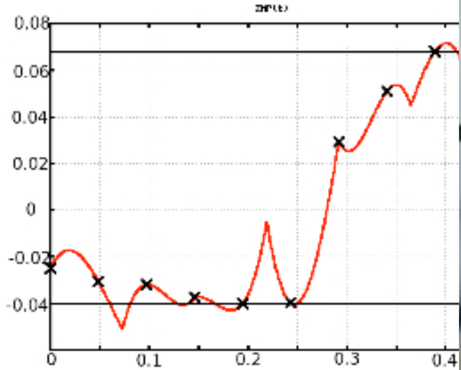
Motion planning

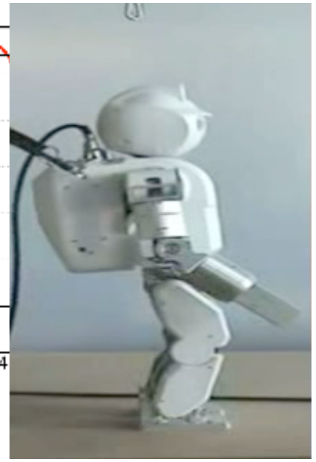
- Solving SIP
  - To be solved, the SIP is transformed into a finite one:

$$\forall i, \forall t_k \in \mathbf{T} \quad g_i(\mathbf{X}, t_k) \leq 0$$

$$\mathbf{T} = \left\{ t_0 = 0, t_1, \ldots, t_{N-1}, t_N = T \right\}$$

ZMP(t)





  - The continuous problem becomes a discrete one.
  - Constraint violation.
  - How can we ensure the constraint validity ?
  - By replacing the time-grid by a time interval discretization.

Motion planning

- Solving SIP by using Interval Analysis:

$$\forall i, \forall t \in [t_0, t_N] \;\; g_i(\mathbf{X}, t) \le 0$$

  - We decompose:

$$[t_0, t_N] = [t_0, t_1] \cup \ldots \cup [t_{N-1}, t_N]$$

  - We compute:

$$\forall i, \forall j \in \{1, \ldots, N\} \; \max \; g_i(\mathbf{X}, \tau)$$
$$\forall \tau \in [t_{j-1}, t_j]$$

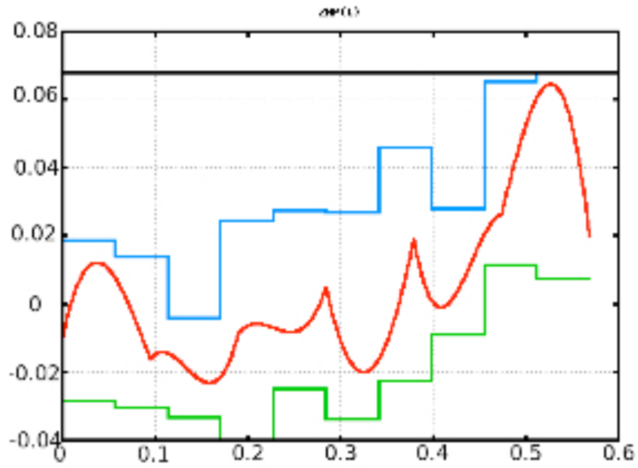


Figure 2: Representation of ZMP(t)

The Guaranteed Discretization Library is available on:
http://www.lirmm.fr/~lengagne/GDL

  - The interval discretization is done through Interval Analysis.

Experimentation on Humanoid Robot

Motions

- **Parameters:** $q_i(t) = \sum_{j=0}^{N_s} p_{i,j} \times B_j(t)$ $\mathbf{X} = [T, \mathbf{p}_1, ..., \mathbf{p}_6]$
  - 5 Coefficients for each dof, the vector X is composed of 61 parameters.
- **Cost Function:** $F(\mathbf{X}) = \int_0^T dt = T$
  - Minimum time

Motion Planning method	Classical	Safe
Minimum time	8s	90s
Minimum energy	39s	168s

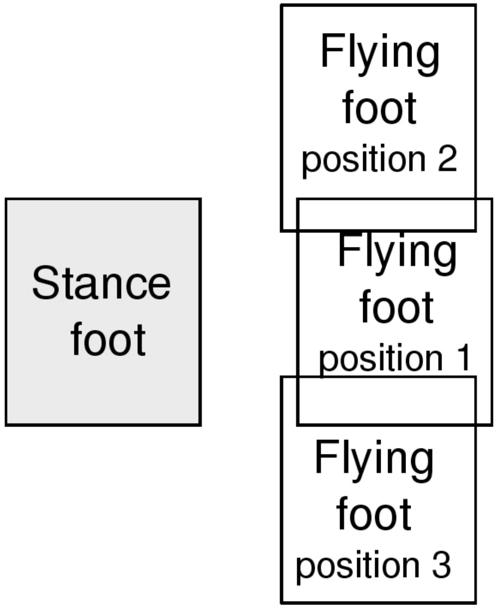
- **Equality constraints**:
  - 12 equality constraints for defining the position and orientation of the flying foot at the beginning and at the end of the motion.
- **Inequality constraints**:
  - 76 continuous constraint functions:
  - Each one is decomposed as:

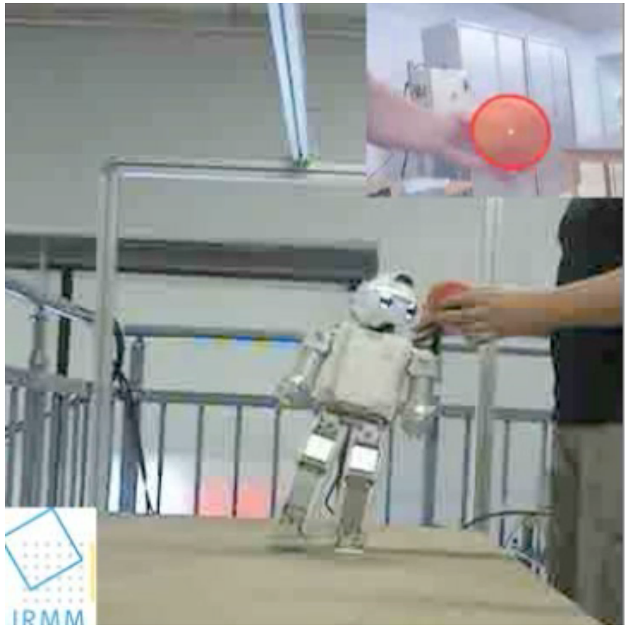
$$\left\{ \begin{array}{c} \underline{q} \leq q(t) \leq \overline{q} \\ \underline{\dot{q}} \leq q(t) \leq \overline{\dot{q}} \\ \underline{\Gamma} \leq \Gamma(t) \leq \overline{\Gamma} \\ \underline{ZMP}_s \leq ZMP_s \leq \overline{ZMP}_s \\ \underline{ZMP}_f \leq ZMP_f \leq \overline{ZMP}_f \end{array} \right.$$

$$\underline{y} \leq y(t) \leq \overline{y} \equiv \left\{ \begin{array}{l} \underline{y} - y(t) \leq 0 \\ -\overline{y} + y(t) \leq 0 \end{array} \right.$$

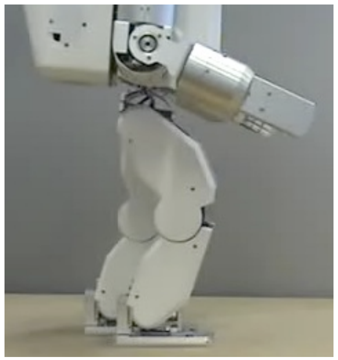
Experimentation on Hoap3

- Creating database to walk.
- Hoap3 experimentations (l=7cm)
- We use three motions:
  - Start motion (1 to 2)
  - Cycle motion (3 to 2)
  - End motion (3 to 1)



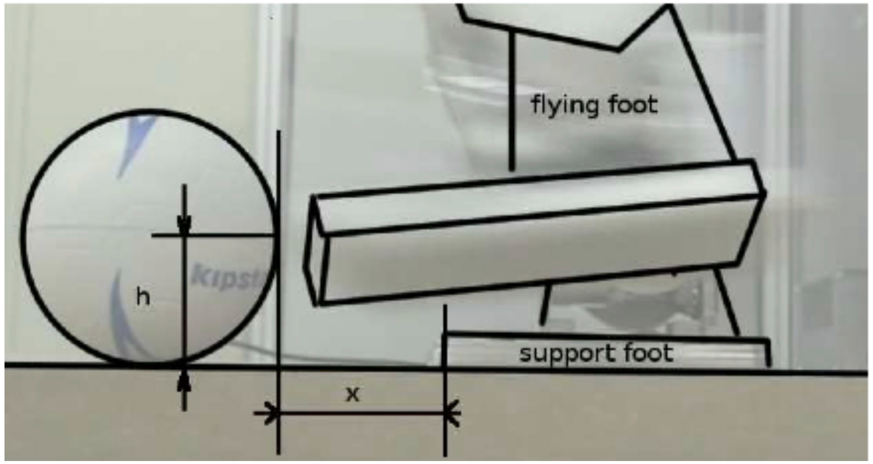


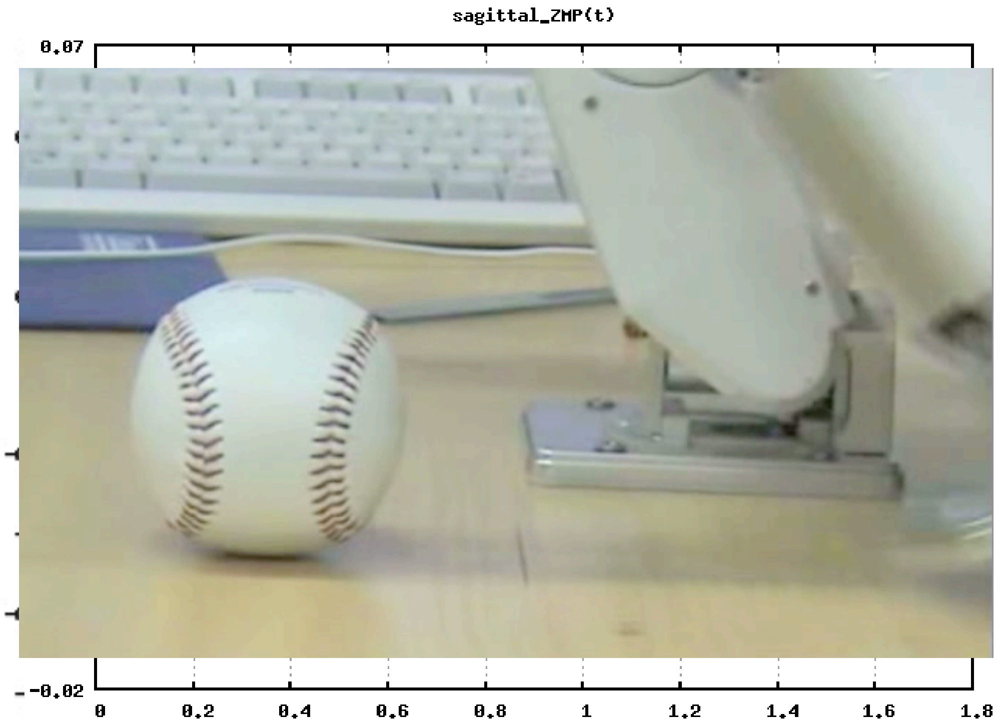
12 dof

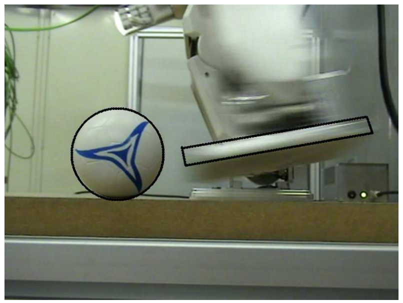


Optimal Kicking Motion

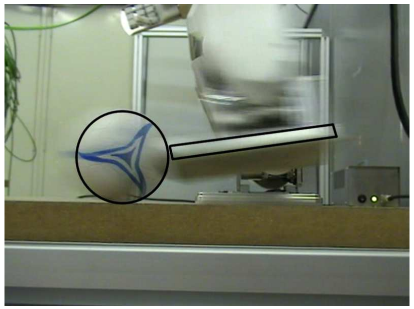
- Kicking Motion
  - V=0,6m/s x=1cm, h=3cm



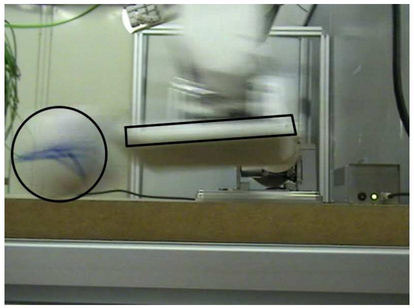




Before collision



Collision



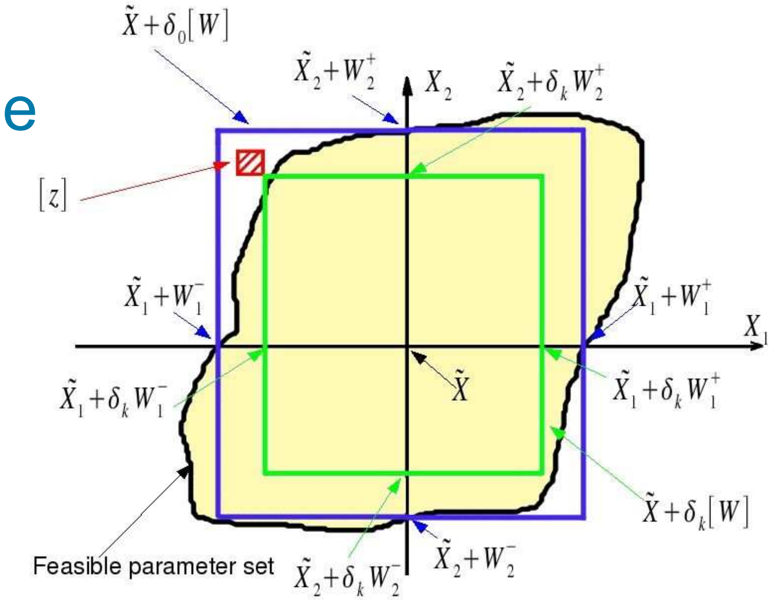
After collision

How to adapt the kicking motion?

If x≠1cm?

Fast Re-Planning

- Computation of the feasible subset
  - Satisfying all the inequality constraints
  - Inner approximation of it
  - We define a box as large as possible

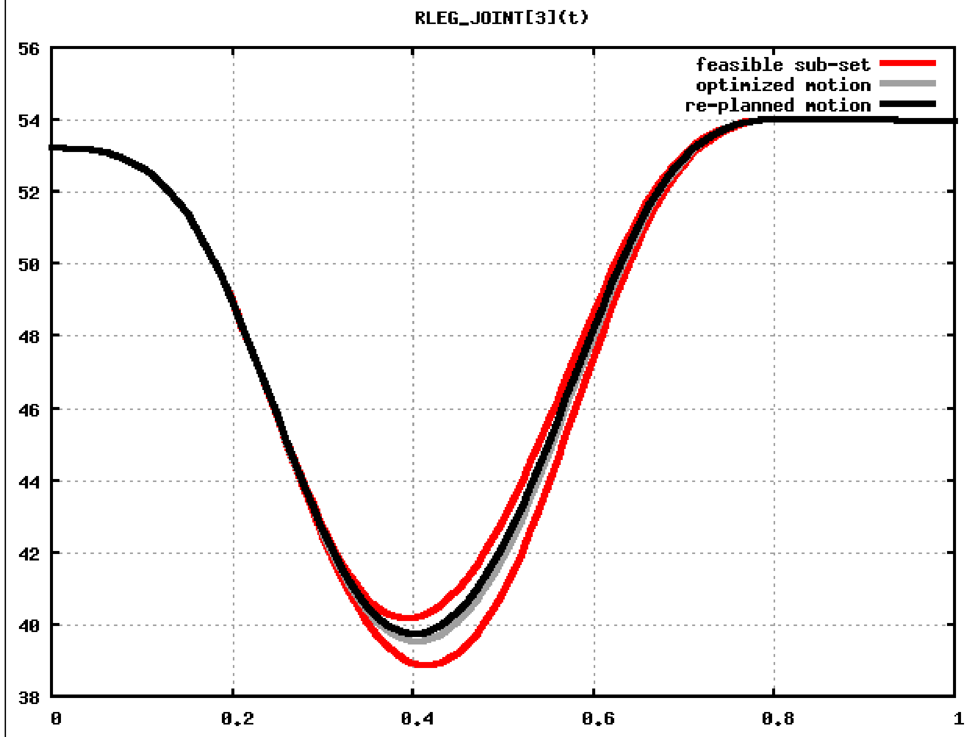


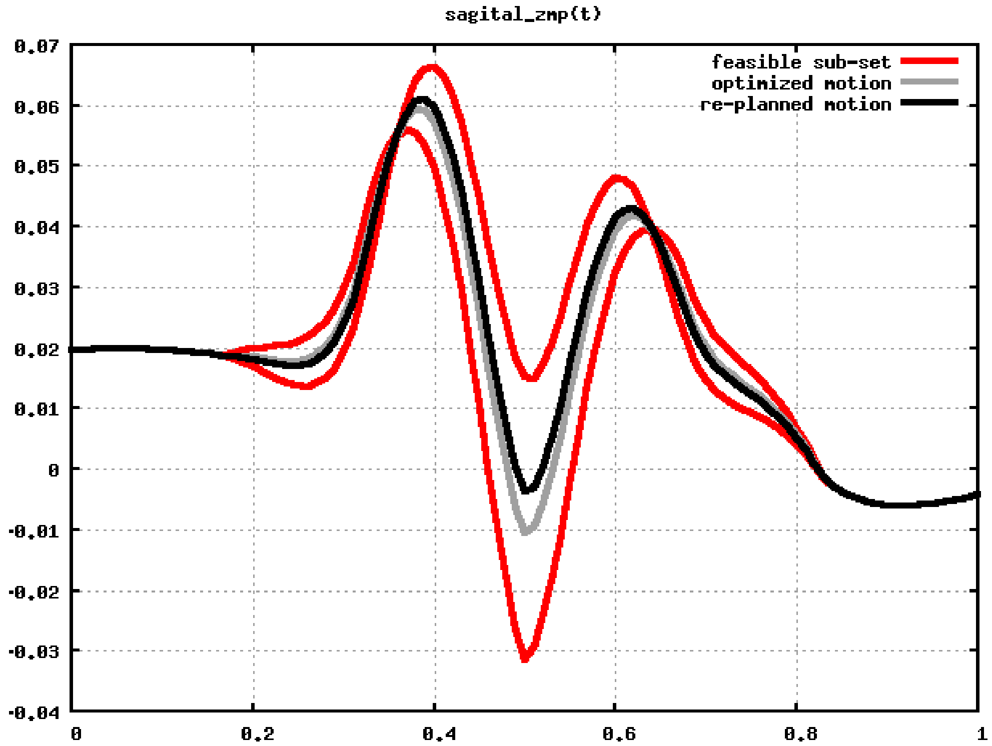
Re-Planning for h=3cm and x=1,5cm

position	$\tilde{X}_i$	$\hat{X}_i$
Right Hip Pitch	-22.60	-21.90
Right Knee	39.68	40.17
Right Ankle Pitch	-17.33	-18.82
Left Hip Pitch	-17.12	-18.12
Left Knee	19.56	19.21
Left Ankle Pitch	4.51	5.34

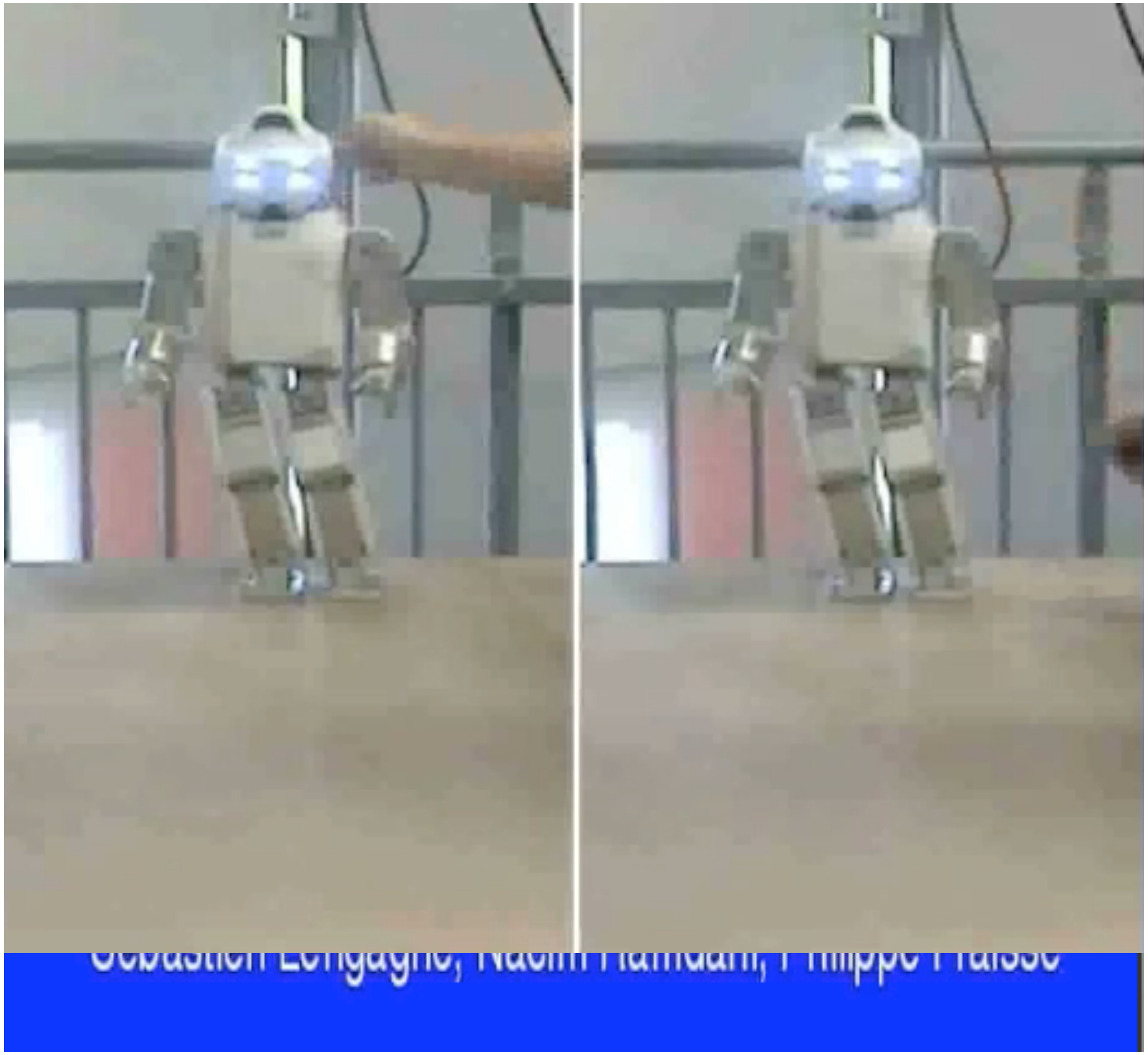
Tc < 1 second

Fast Re-Planning





Experimentations



Conclusion and ongoing work

- Time-grid discretization can lead to any constraint violation.
- It improves the balance during the movement.
- Motion re-planning for adapting movement to unexpected events (ex: kicking motion)
- This method has been experimentally validated. Useful for specific movements.
- Embedded applications on small humanoid robot should benefit of this approach.
- The next objective will be to study the aspects of safe motion planning for multi-contact.