HAL open science

Human based hybrid kinematic/dynamic whole-body control in humanoid robotics

David Galdeano, Ahmed Chemori, Sébastien Krut, Philippe Fraisse

▶ **To cite this version:**

David Galdeano, Ahmed Chemori, Sébastien Krut, Philippe Fraisse. Human based hybrid kinematic/dynamic whole-body control in humanoid robotics. HLR: Humanoid and Legged Robots, May 2014, Heidelberg, Germany. , French-German-Japanese Conference on Humanoid and Legged Robots, 2014. lirmm-00993302

HAL Id: lirmm-00993302

https://hal-lirmm.ccsd.cnrs.fr/lirmm-00993302v1

Submitted on 10 Sep 2019

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

May 12 - 14, 2014 - Heidelberg, Germany

HLR 2014

Human based hybrid kinematic/dynamic whole-body control in humanoid robotics

David Galdeano , Ahmed Chemori , Sébastien Krut , Philippe Fraisse

Laboratory of Informatics, Robotics and Microelectronics of Montpellier
LIRMM, University of Montpellier 2 - CNRS
161, rue Ada 34095
Montpellier, France

Outline of the presentation

- ## Context and motivation
  - ✓ Context
  - ✓ Our main objective
- ## Human-data based control schemes
  - ✓ Motion Capture system
  - ✓ State of art of human-based control
  - ✓ Limitations of human-based control
- ## Proposed control scheme
  - ✓ Basic idea of the proposed control scheme
  - ✓ Prioritized tasks
  - ✓ Tasks definition
  - ✓ ZMP-based nonlinear stabilizer
  - ✓ Summary of the proposed control scheme
- ## Real-time experimental results
  - ✓ Our demonstrator : **HOAP-3 Robot**
  - ✓ **Scenario 1 :** Squat-like motions
  - ✓ **Scenario 2 :** Online adaptation towards slope variation
  - ✓ **Scenario 3 :** Dynamic walking motions
  - ✓ **Scenario 4 :** Toward dynamic walking on irregular ground
- ## Conclusion & future work

Context and motivation

- ✓ Context
- ✓ Our main objective

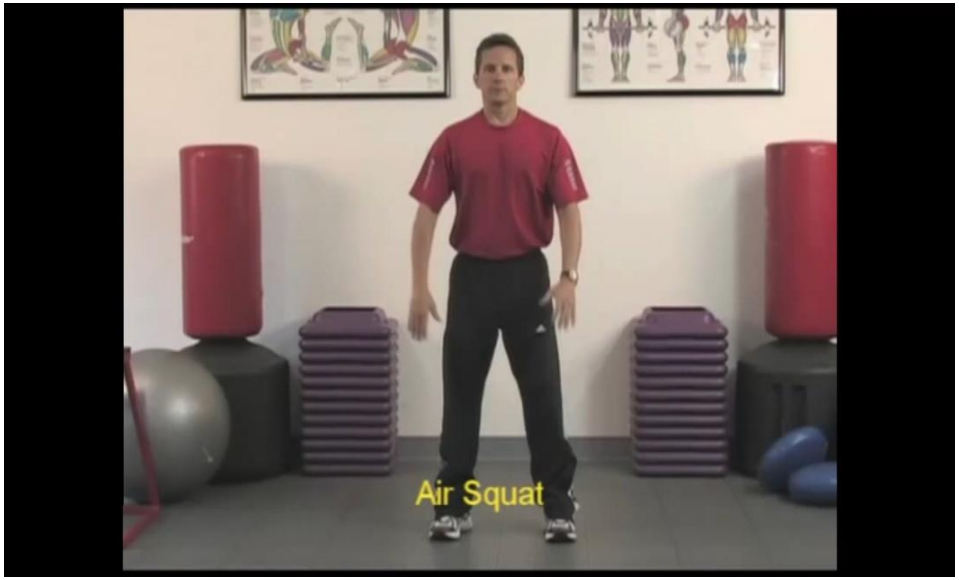
Human whole body motions

Exp 1 : Walking

- ✓ Is one of the main gaits of locomotion
- ✓ Typically slower than running.
- ✓ Alternating the legs
- ✓ Only one foot may leave contact/ground
- ✓ There is also a period of double-support

Exp 2 : Squat

- ✓ It helps building several muscles in legs
- ✓ A cyclic motion
- ✓ Alternating two positions
- ✓ Stand position with extended arms
- ✓ Sit position bent knees



Human versus humanoid walking gaits

A human walking

HRP4 humanoid walking

Our main objective

Reference Trajectories
or
Motion parameters

Issued from human motions

Control scheme

Humanoid robot

Objective : Use of whole body control to perform different tasks
Use of human data in the control scheme
Include the robot's dynamics in the control scheme → dynamic stability

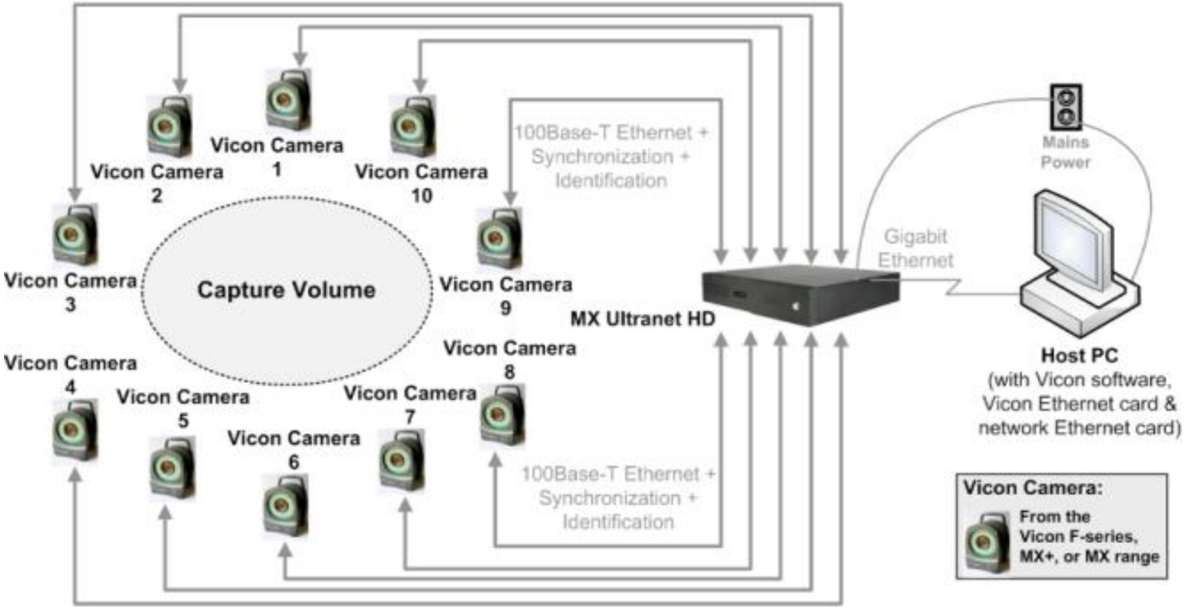
Human-data based control schemes

- ✓ Motion Capture system
- ✓ State of art of human-based control
- ✓ Limitations of human-based control

Motion Capture system

Context: Walking motion analysis project
LABLAB, University of Rome Foro Italico, Pr. Capozzo, Department of Human Movement and Sports Sciences.

Equipment : 1 host PC
10 Vicon cameras
3 Forces plates



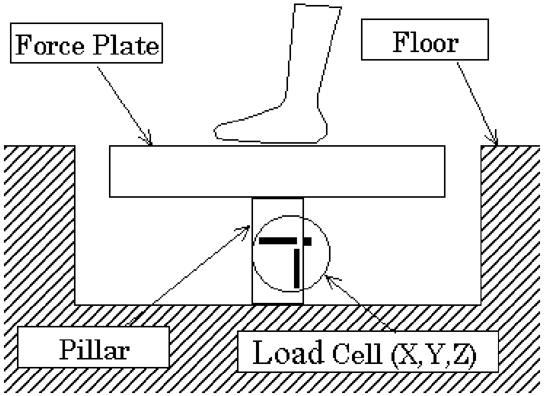
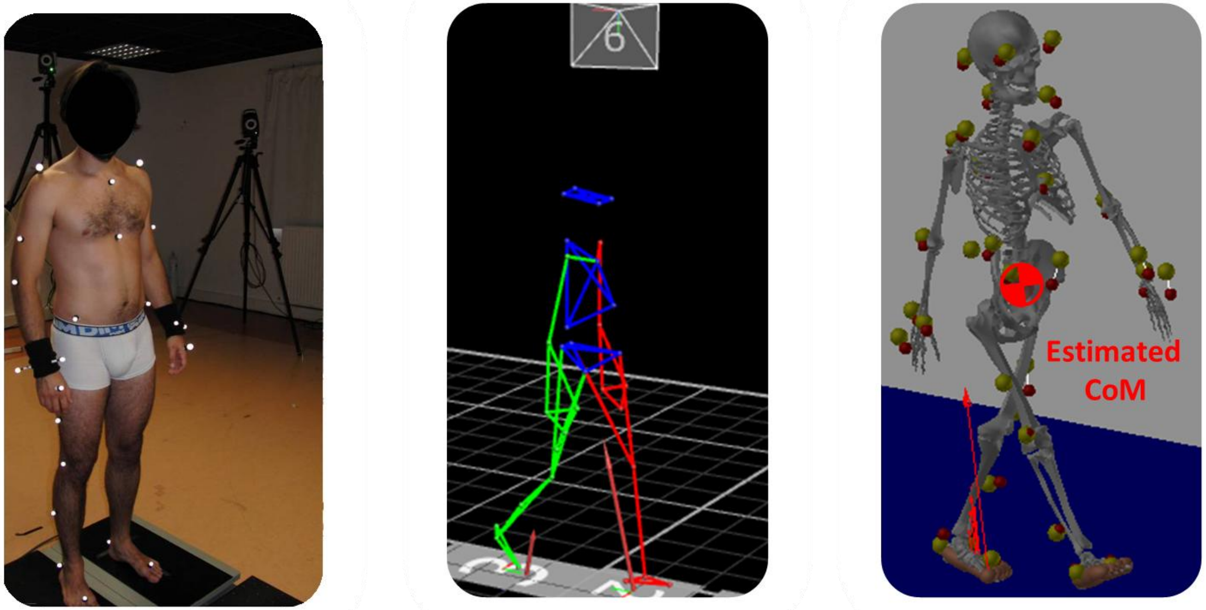


Fig.1 Structure of Force Plate

Motion Capture system



(a) (b) (c)

Study: 15 Subjects
Different walking speed
35 markers using Plug-in Gait template
Reconstruction of movement using Vicon Nexus
Estimation of CoM using Lifemod

Related work

Human-Data based schemes with Whole body motion control

Class 1: Offline computation

Motion Primitives
[Nakaoka et al., 2003-2005]
Gait parameter extraction
[Harada et al.,2009]
Scale and optimization
[Suleiman et al., 2008]

Class 2: Online computation

Balance/Tracking controller
[Yamane et al.,2009-2010]
Imitation
[Shaal et al.,1999-2003, Calderon & Hu 2005]
Human Normalized model
[Montecillo et al.,2010]

Human data based whole body motion control using offline calculation

[Nakaoka et al., 2003, 2005]
Data from human motion capture are used as motion primitives to produce postural imitation (only postural motions, no walking).

[Harada et al., 2009]
Data from human motion capture are used to find gait's parameters.

[Suleiman et al., 2008]
Data from human motion capture are first scaled to humanoid joint position, then an optimization with constraint is used.

:
Offline computations allows optimized motions

:
Offline computation do not allow reactive motions

Human data based whole body motion control using online calculation

[Schaal, 1999 ; Schaal et al., 2003 ; Calderon & Hu, 2005]
Data from human motion capture are used to feed a learning system to produce accurate movement primitives.

[Yamane & Hodgins, 2009 ; Yamane et al., 2010]
Two controllers are used in this application.
First controller : a balance controller.
Second controller : joint space trajectory tracking

[Montecillo-Puente et al., 2010]
Data from human motion capture are performed in real time to produce postural imitation (postural motion, no walking).

 :
Reactive motions using feedback from sensors

 :
No walking motions are reproduced

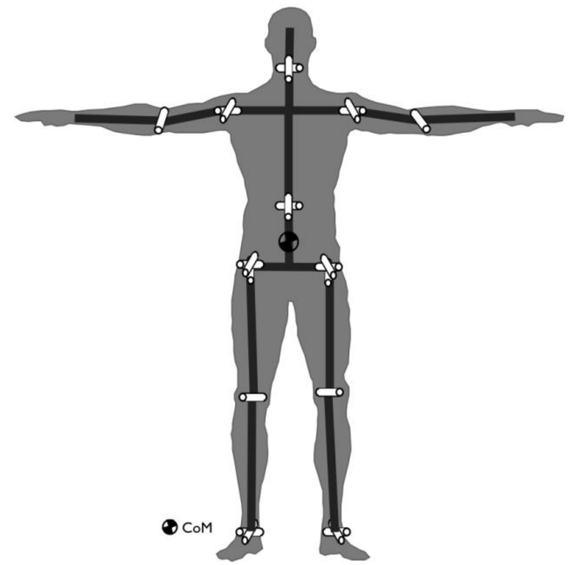
Proposed control scheme

- ✓ Basic idea of the proposed control scheme
- ✓ Prioritized tasks
- ✓ Tasks definition
- ✓ ZMP-based nonlinear stabilizer
- ✓ Summary of the proposed control scheme

Basic idea of the proposed control scheme

Reference motion : from human motion capture

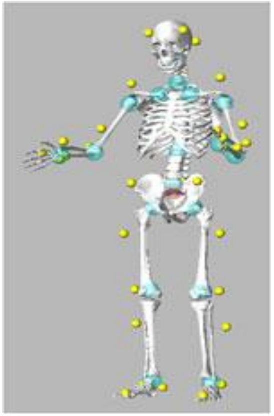
Differences:
Flexible/Rigid
Different DoF
Different Power
Contacts
Similarities:
CoM
Feet cycle



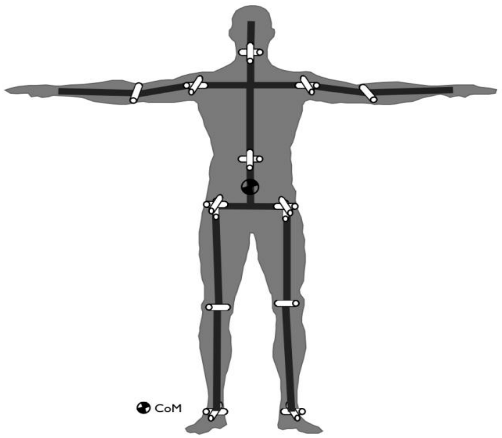
Reduced set of human data:

Relative feet pose (6) + CoM (3) → Articular trajectories (22)

Basic idea of the proposed control scheme



$$P_{rd} \;\&\; CoM_d \longrightarrow$$



Basic idea: Task-priority formalism [Nakamura, 1987]

How : Two tasks

- Relative feet position tracking.
- CoM trajectory tracking.

Advantages:

Continuous control framework:

No decomposition into distinct phases, one control law.

Brief overview on task formalism

- ✓ Task formalism is used to control a robot for tracking several objectives
- ✓ In the operational space
- ✓ Use the high redundancy of robots
- ✓ Concept initially proposed by [Nakamura 1987] and [Siciliano 1991]

- ✓ The task formalism has been used recently in humanoid robotics
- ✓ In [Sentis et al 2006] for multi-contact dynamic motions
- ✓ In [Mansard 2009] has generalized the formalism by using the addition and removal of tasks during the control execution

- ✓ In the literature, several tasks are needed to produce stable whole-body motions
- ✓ In this work, the proposed architecture is focused on only 4 main tasks
  - Task 1 :The relative feet position and orientation tracking,
  - Task 2 : CoM position tracking with nonlinear ZMP regulation,
  - Task 3 : Body orientation and the
  - Task 4 : Joints’ limits avoidance

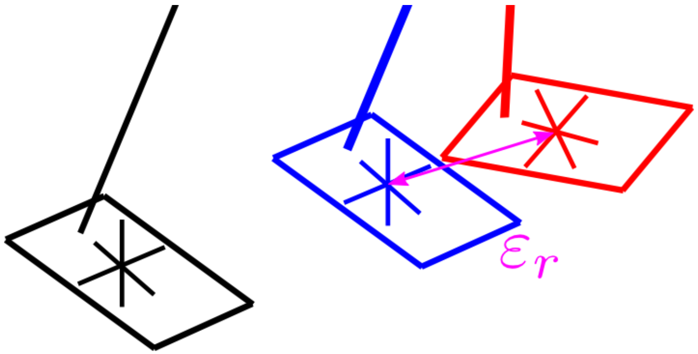
Tasks definition

First task

Feet relative-pose

$$\varepsilon_r = [E_{pos}^T \;\; E_{ori}^T]^T$$

- ✓ Position and orientation error
- ✓ Place one foot / the other one
- ✓ Manage the feet walking cycle



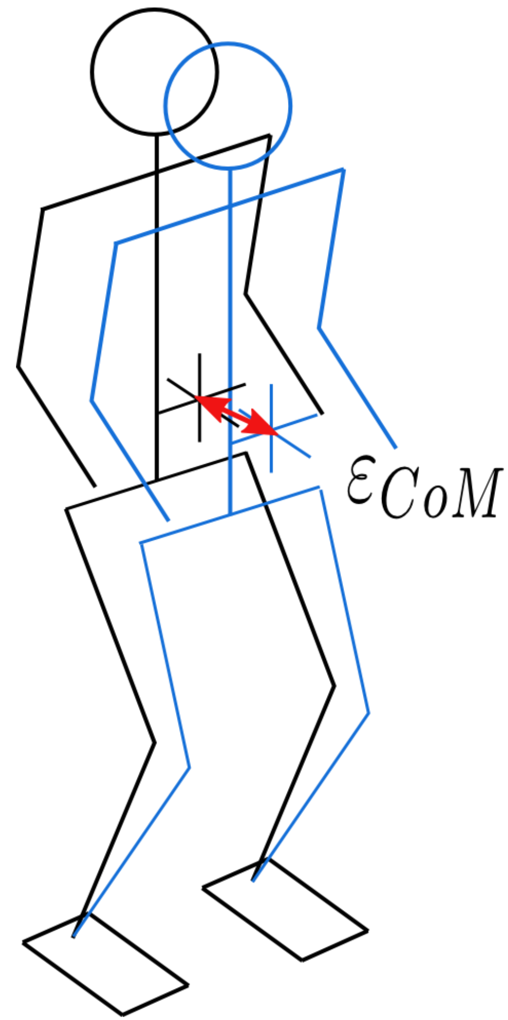
Tasks definition

Second task

Center of Mass position

$$\varepsilon_{CoM} = CoM_d - CoM$$

- ✓ Position error
- ✓ Place the CoM
- ✓ To follow a specific trajectory



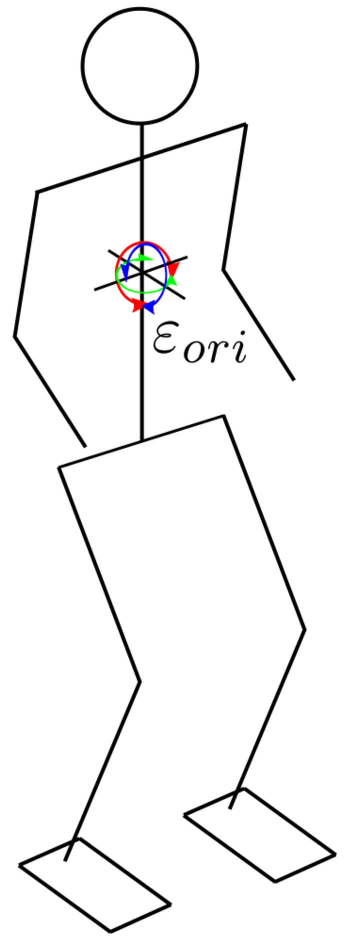
Tasks definition

Third task

Body orientation

$$\varepsilon_{ori} = R_{Ref} \; (\ln(R_{Ref}^{-1} \; R_{Body} \; R_{BodyDes}))^{\vee}$$

- ✓ Orientation error
- ✓ Keeps the torso upright



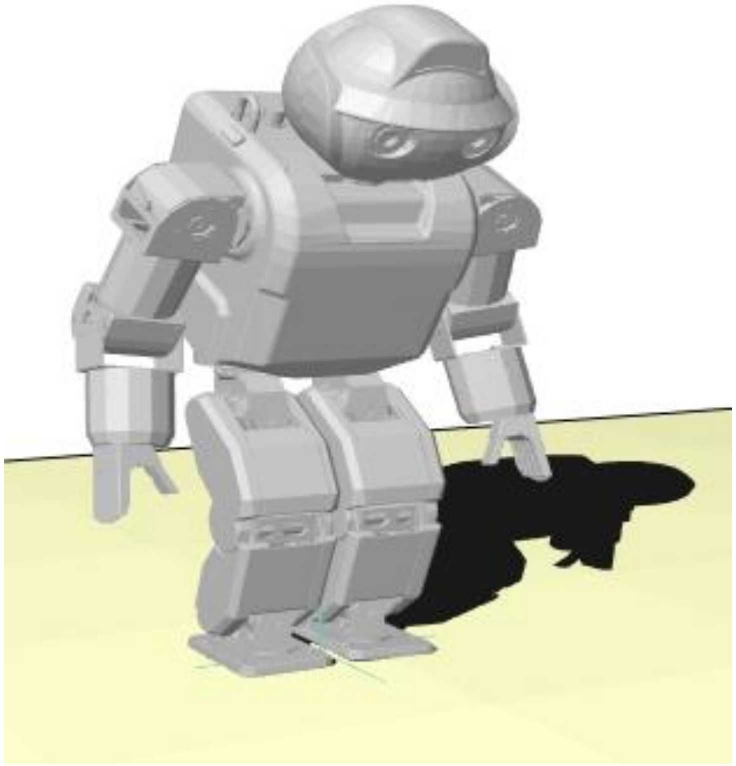
Tasks definition

Fourth task

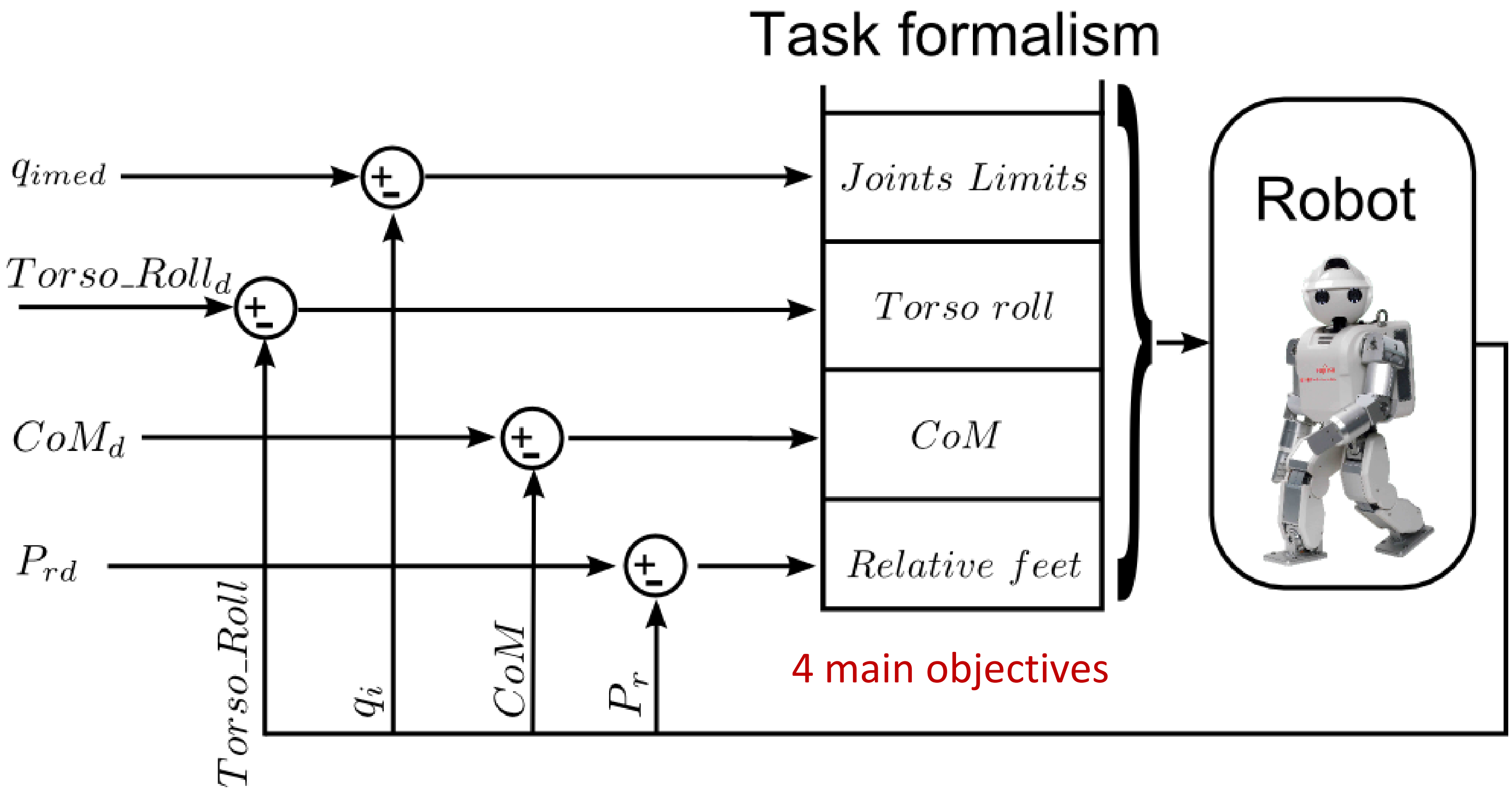
Joints' limits avoidance

$$\varepsilon_{q_i} = \frac{2\ (q_i - q_{imed})}{(q_{imax} - q_{imin})^2}$$

- ✓ Attractive potential fields
- ✓ Define a comfort position



Brief overview on task formalism



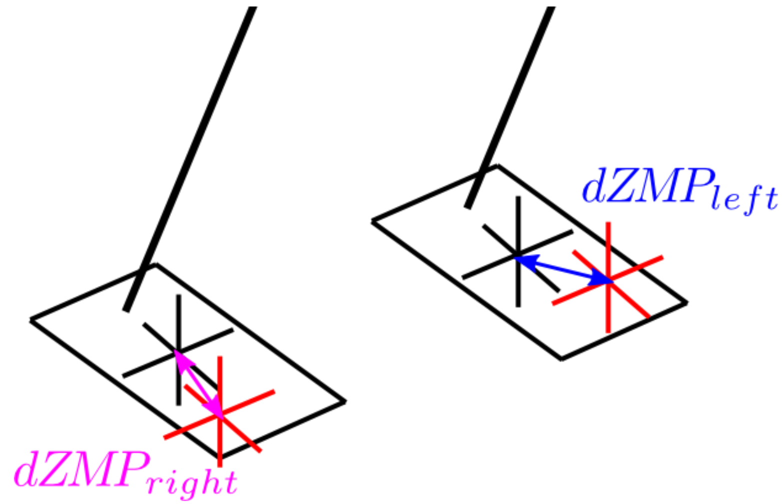
Tasks definition

ZMP regulation

$$\varepsilon_{ZMP} = \alpha \; dZMP_{left} + (1-\alpha) \; dZMP_{right}$$

Feedback based ZMP regulation

- ✓ Weighted distribution
- ✓ Dynamic feedback



Tasks definition

Nonlinear PID

$$u_{ZMP} = k_p(\varepsilon_{ZMP})\varepsilon_{ZMP} + k_d(\varepsilon_{ZMP})\varepsilon_{Z\dot{M}P} + k_i \int \varepsilon_{ZMP}$$

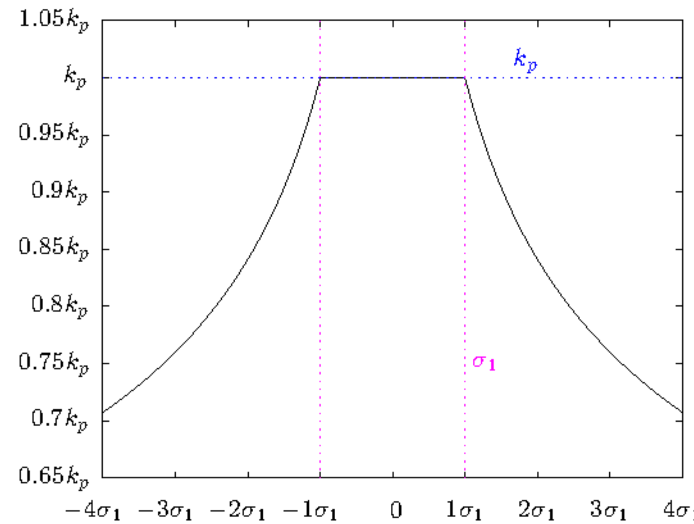
Nonlinear proportional gain

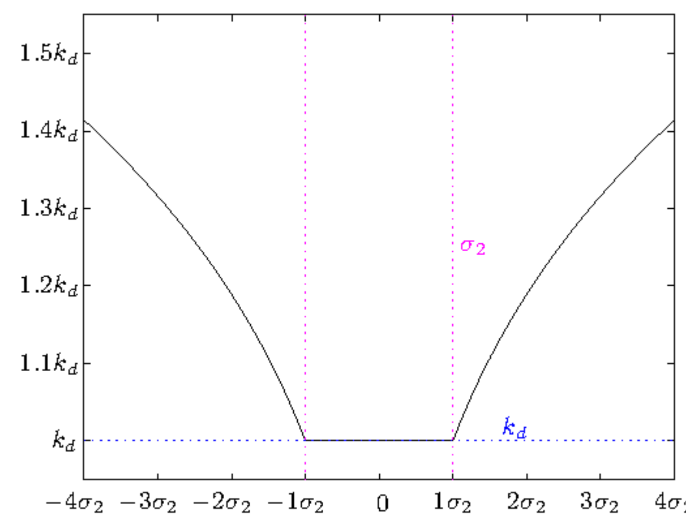
$$k_p(\varepsilon_{ZMP}) = \begin{cases} k_p|\varepsilon_{ZMP}|^{\alpha_1 - 1}, & |\varepsilon_{ZMP}| > \delta_1, \\ k_p \delta_1^{\alpha_1 - 1}, & |\varepsilon_{ZMP}| \leqslant \delta_1. \end{cases}$$

Nonlinear derivative gain

$$k_d(\varepsilon_{Z\dot{M}P}) = \begin{cases} k_d|\varepsilon_{Z\dot{M}P}|^{\alpha_2 - 1}, & |\varepsilon_{Z\dot{M}P}| > \delta_2, \\ k_d \delta_2^{\alpha_2 - 1}, & |\varepsilon_{Z\dot{M}P}| \leqslant \delta_2. \end{cases}$$

Faster response with favorable damping





Tasks definition

Spherical projection

$$\varepsilon_{SPX} = h_{CoM} \sin\left(\frac{u_{ZMPX}}{h_{CoM}}\right),$$
$$\varepsilon_{SPY} = h_{CoM} \sin\left(\frac{u_{ZMPY}}{h_{CoM}}\right),$$
$$\varepsilon_{SPZ} = h_{CoM} \cos\left(\frac{u_{ZMPX}}{2h_{CoM}} + \frac{u_{ZMPY}}{2h_{CoM}} - 1\right).$$

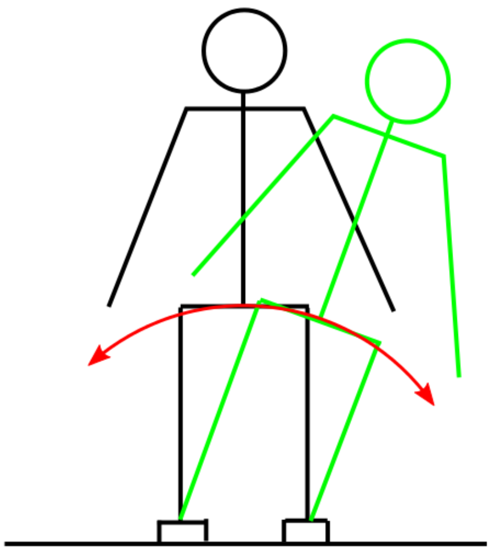
ZMP regulation in the COM workspace

$$\varepsilon_{CoM\&ZMP} = \varepsilon_{CoM} + \varepsilon_{SP}$$

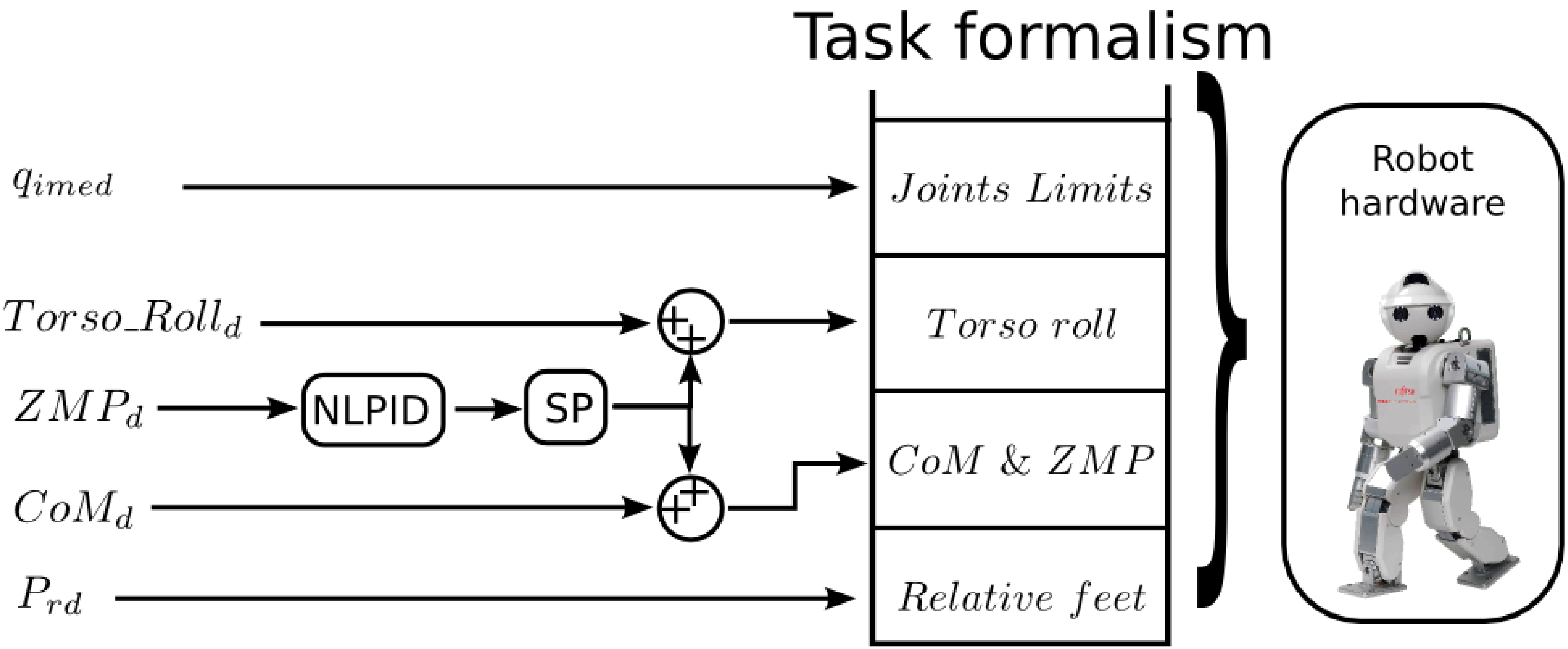
Body orientation adjustment

$$\begin{aligned}
\varepsilon_{ori_sp}(r) &= \varepsilon_{ori}(r) + \mathrm{atan2}(u_{ZMP}(y), h_{CoM}),\\
\varepsilon_{ori_sp}(p) &= \varepsilon_{ori}(p) + \mathrm{atan2}(u_{ZMP}(x), h_{CoM}),\\
\varepsilon_{ori_sp}(y) &= \varepsilon_{ori}(y).
\end{aligned}$$

Adaptation toward large ZMP correction



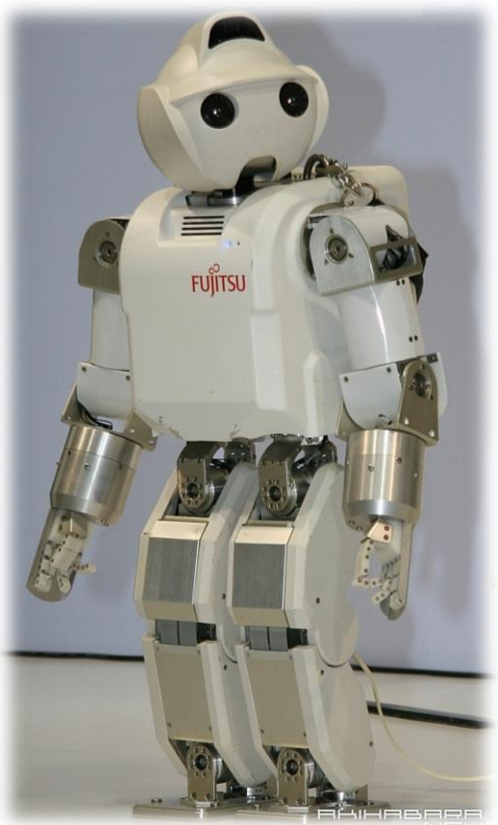
Block diagram of the proposed control scheme

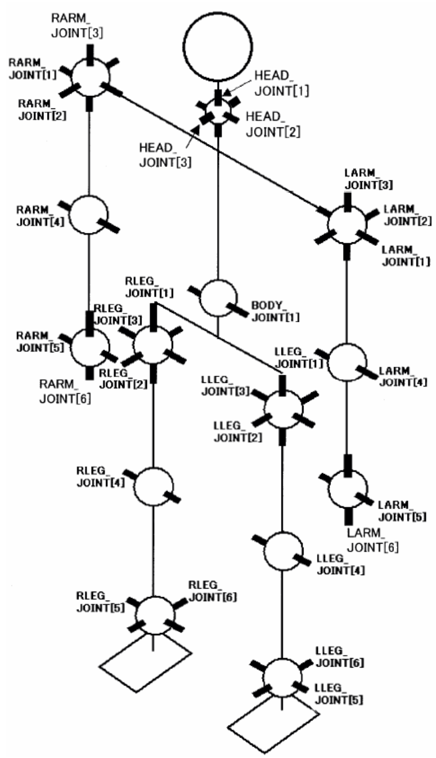


Real-time experimental results

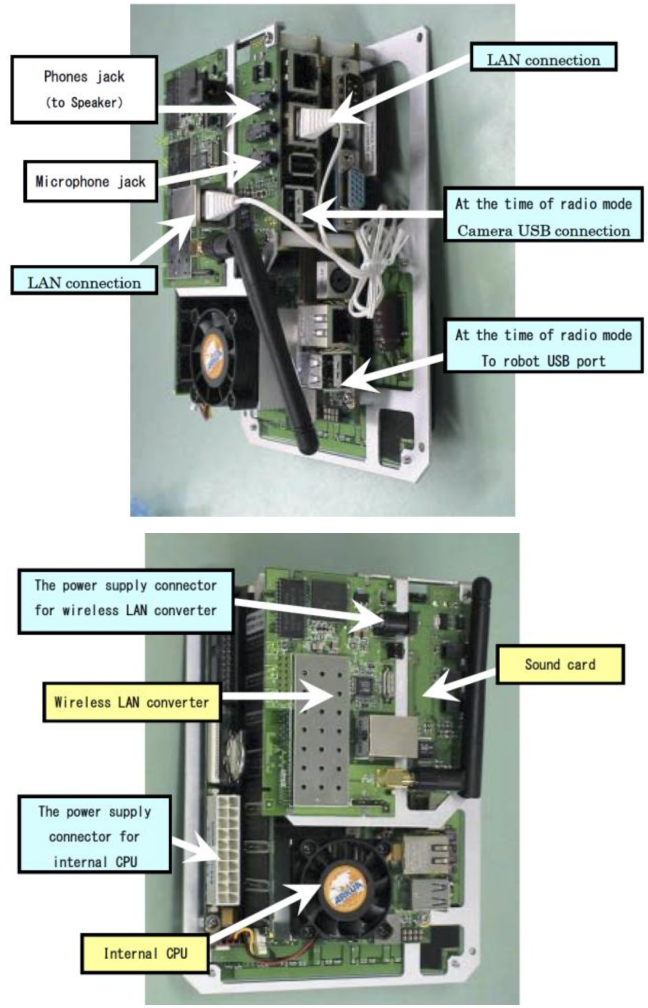
- ✓ Our demonstrator : HOAP-3 Robot
- ✓ Scenario 1 : Squat-like motions
- ✓ Scenario 2 : Online adaptation towards slope variation
- ✓ Scenario 3 : Dynamic walking motions
- ✓ Scenario 4 : Toward dynamic walking on irregular ground

HOAP3 : Architecture





Electronic boards inside



28 dof : 6 dof/**leg** - 6dof/**arm** - 3dof/**head** - 1dof/**body**

HOAP3 : Actuators and sensors

Distance sensor

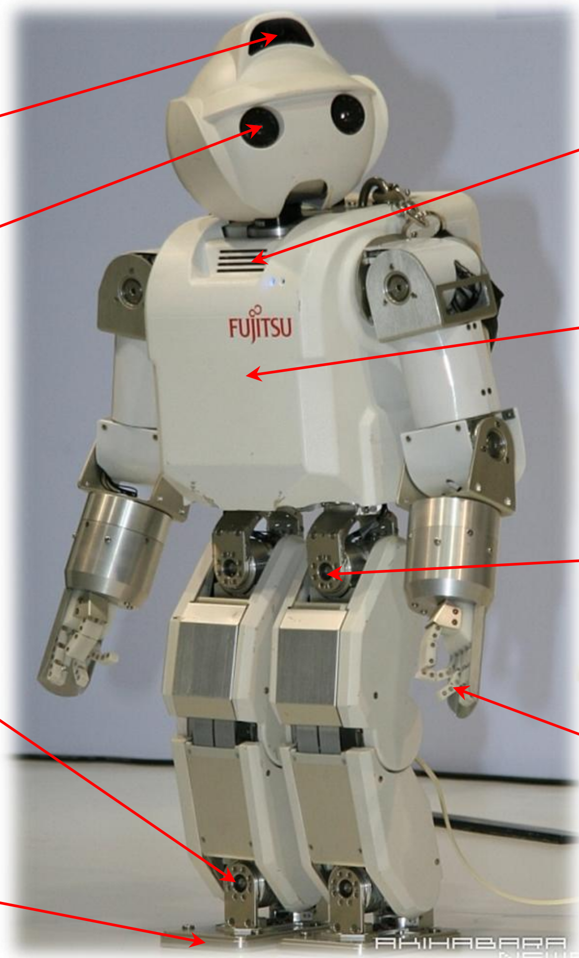
USB Cameras

Joint sensors

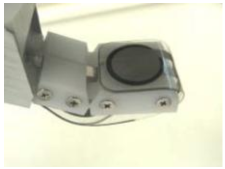
Speaker

Posture sensor
3-axis acc sensor
Angular velocity sensor (gyro)

28 actuators
(21 DC, 7 Stepper)



Force sensors
(4/foot)



Grip sensors

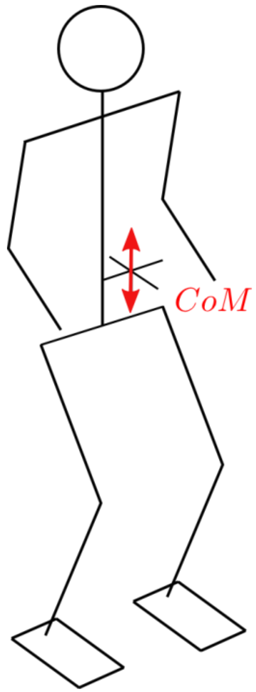
This demonstrator is useful for whole body motion control

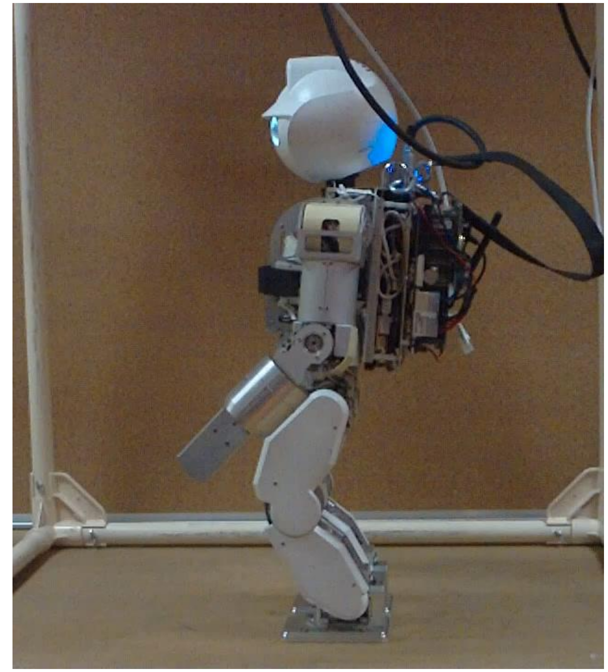
Application of the proposed control scheme

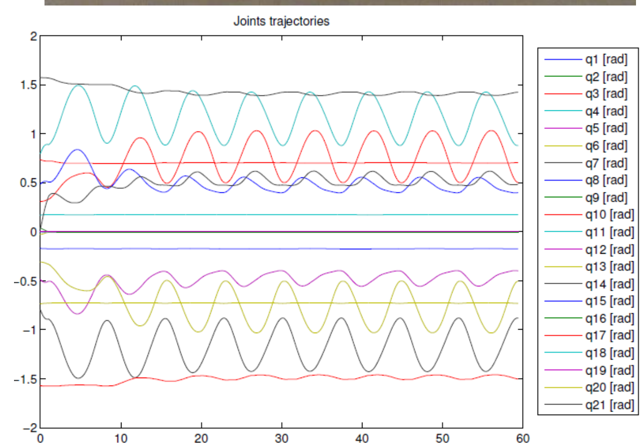
Scenario 1

Squat task

- ✓ *No feet movement*
- ✓ *Only CoM moves*
- ✓ *Up and down*





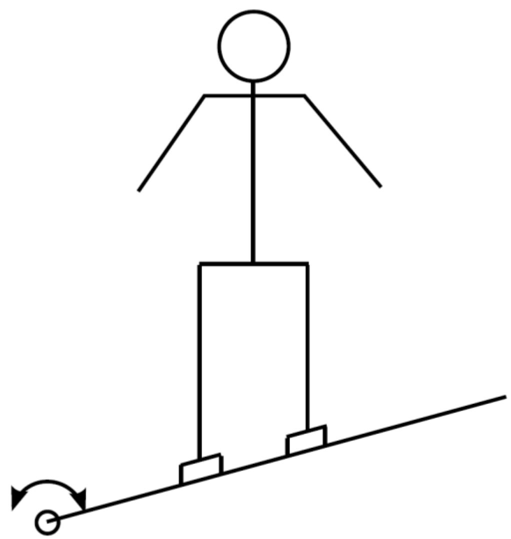


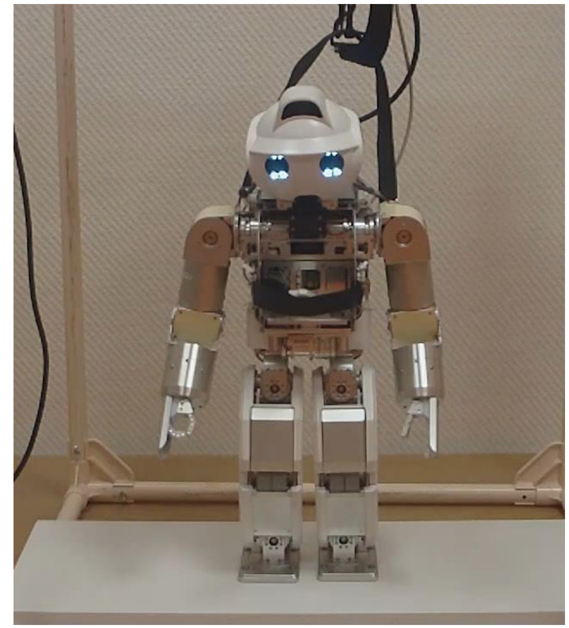
Application of the proposed control scheme

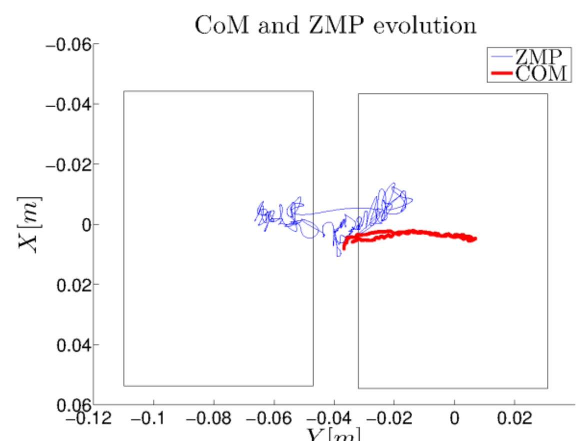
Scenario 2

Online adaptation towards slope variation

- ✓ *No feet movement*
- ✓ *No CoM movement*
- ✓ *Ground inclination variation*
- ✓ *Only ZMP regulation*







Application of the proposed control scheme

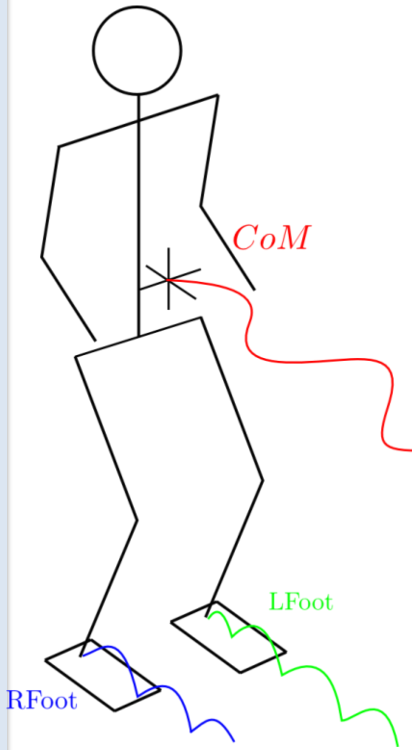
Scenario 3

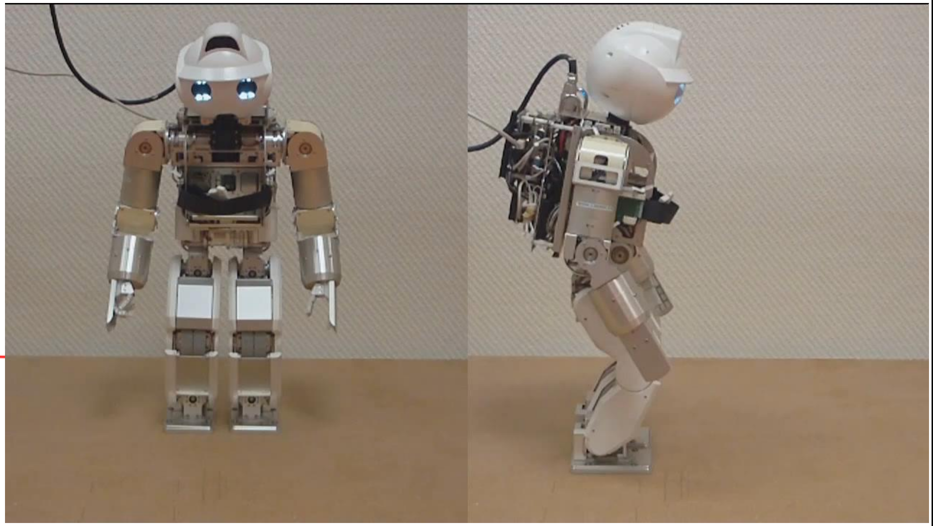
Dynamic walking motions

✓ *B-spline based reference trajectories*

✓ *ZMP stabilizer improves stability margins*

✓ *Stable dynamic walking*



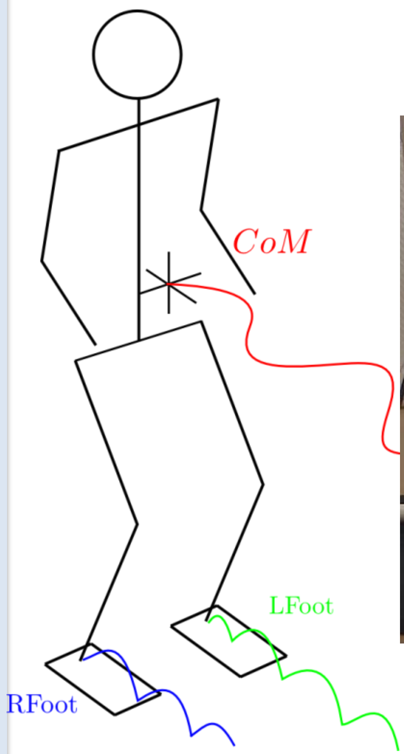


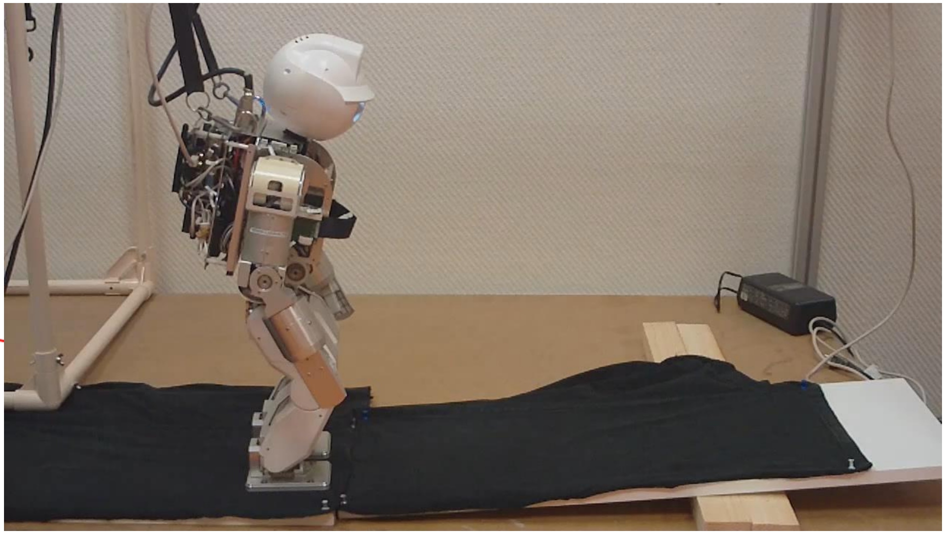
Application of the proposed control scheme

Scenario 4

Toward dynamic walking on irregular ground

- ✓ *Feet cycle and CoM motions from nominal case*
- ✓ *Online adaptation to ground inclination*





Conclusion & future work

- ✓ Conclusion
- ✓ Future work

Conclusion & future work

Addressed problem: Whole-body motion control with dynamic stability

Proposed Solution: Task based whole-body control

(i) the CoM with a nonlinear ZMP regulation,
(ii) the relative pose of robot's feet,
(iii) the body orientation and
(iv) joint's limit avoidance

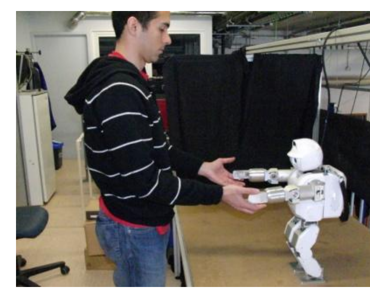
Validation: Real-time experiments on HOAP-3 humanoid robot

Advantages of the proposed solution :

- ✓ Whole body motion
- ✓ Continuous control framework
- ✓ Natural and smooth motions

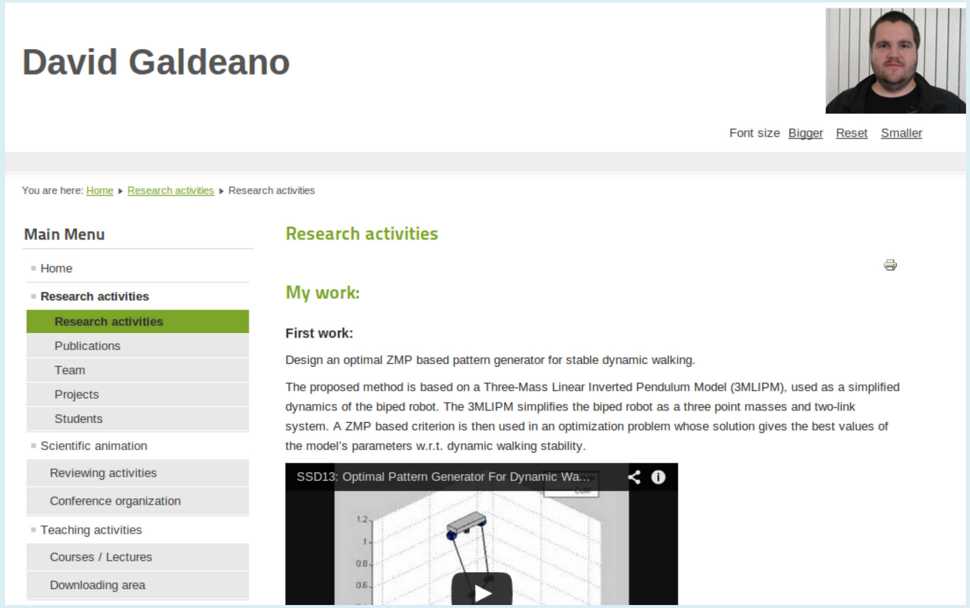
Future work : Validation for more complex tasks

- ✓ Interaction with human
- ✓ Use of human data
- ✓ Improve the ZMP regulation
- ✓ Experiments on HRP4 robot



Contact details

www.lirmm.fr/~galdeano/



David GALDEANO

Galdeano@lirmm.fr

Ph.D.

LIRMM – UMR CNRS/UM2 N° 5506

161, Rue Ada 34095, Montpellier

Tel : 04.67.41.85.62

Fax : 04.67.41.85.00

View publication stats