EPFL

Whole Body Control Framework for Humanoids

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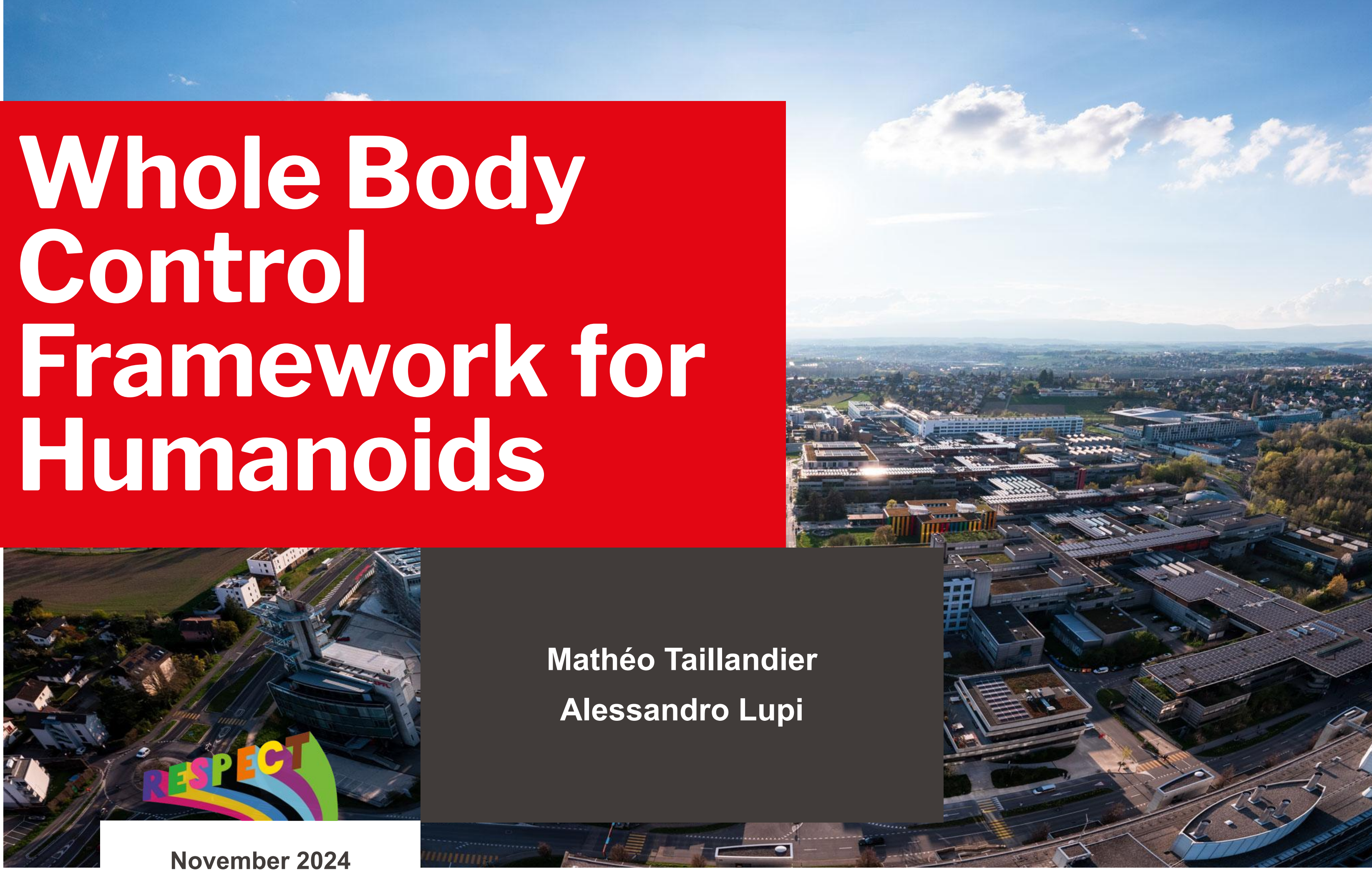


École polytechnique fédérale de Lausanne

Asimo Robot

https://www.youtube.com/watch?v=O4ma1p4DK5A

Executive Summary

- This article implements the control of a biped (humanoid) robot using a hierarchical separation of control primitives. It applies impedance and hybrid (position and force) control using this new framework. The robot is modeled as a 6 virtual DOFs free-floating structure and incorporates non-contact constraints, including joint limits, self-collision, and near-body obstacles.

I - Whole-Body Control Framework

Constraints — Tasks — Posture

High priority — Hierarchical Model — Low priority

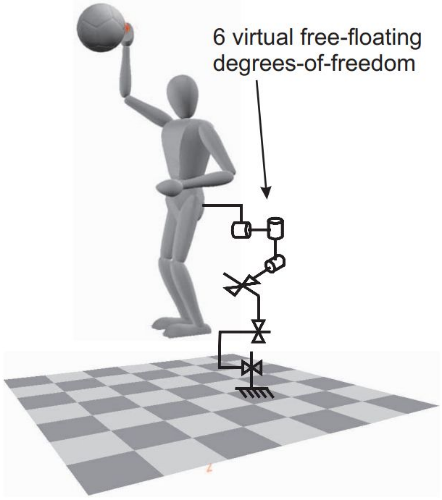
Control Primitives (low level tasks) :

- Constraints primitive : Prevent the controlled robot from violating physical constraints (joint limitation, collisions, etc.)
- Operational Tasks primitive : Execute specific (simple?) actions, such as grabbing an object or moving the head change line of sight
- Posture primitives : Use the residual redundancies for different purposes, such as mimicking humans or minimizing torque effort.

I - Whole-Body Control Framework

Whole-Body Kinematics (use of a free-floating model of the robot) :

- Task and posture kinematics are defined with respect to the origin of the free floating model
- $x_{\text{task}} = T(x_{\text{base}}, q), \qquad \theta_{\text{posture}} = T(x_{\text{base}}, q)$
- Traditional control approaches use local Jacobians defined with respect to the reference frame at the origin of the limb



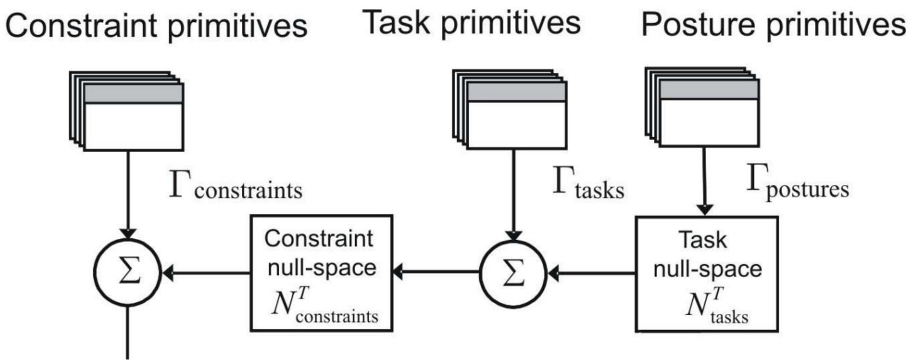
I - Whole-Body Control Framework

Control Hierarchy :

- Using null-space projection, the control hierarchy enforces the constraints of each lower-level control primitive

$$\Gamma = \Gamma_{\text{constraints}} + N^T_{\text{constraints}} \left(\Gamma_{\text{tasks}} + N^T_{\text{tasks}} \Gamma_{\text{postures}} \right)$$

$$\Gamma = \left(J^T_{\text{constraints}} F_{\text{constraints}} \right) + \left(J^T_{t|c} F_{t|c} \right) + \left(J^T_{p|t|c} F_{p|t|c} \right)$$



I - Whole-Body Control Framework

Hybrid Control and Impedance Control

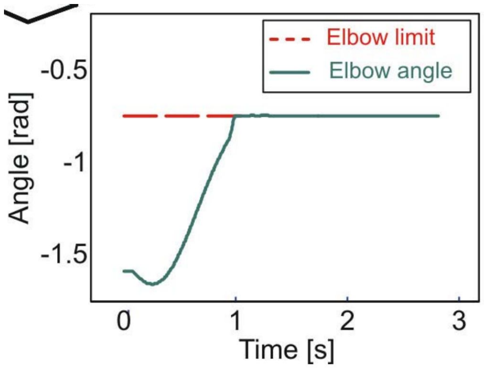
- Impedance control - controlled interaction with environment
  - $$M_{\text{des}}(\ddot{x}_{\text{task}} - a_{\text{des}}) + D_{\text{des}}(\dot{x}_{\text{task}} - v_{\text{des}}) + K_{\text{des}}(x_{\text{task}} - x_{\text{des}}) = \hat{f}_{\text{int}}$$
- Hybrid control - simultaneous force and position control
  - $$F^*_{\text{task}} = \Omega_m F^*_m + \Omega_f F^*_f$$

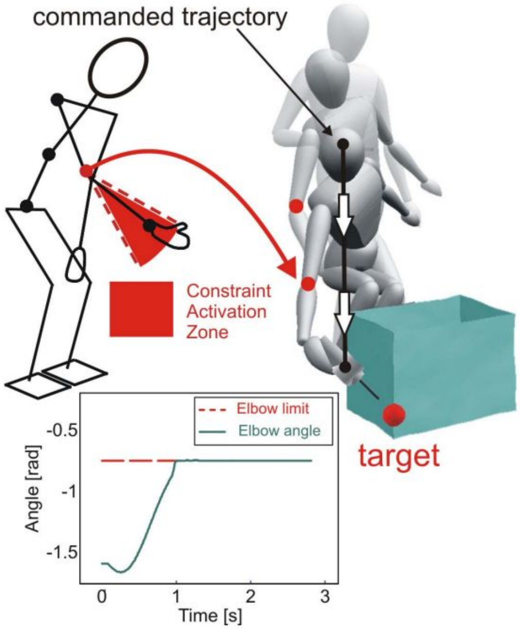
II - Non-contact Constraints

Joint Limits

- Direct joint-limit monitoring and activation of constraint-avoidance control

$$\Gamma = \left(J_{\text{task}}^{T} F_{\text{task}}\right) \Longrightarrow \text{“upon activation”} \Longrightarrow$$
$$\Gamma = \left(J_{\text{jointLimits}}^{T} F_{\text{jointLimits}}\right) + \left(J_{t|c}^{T} F_{t|c}\right)$$





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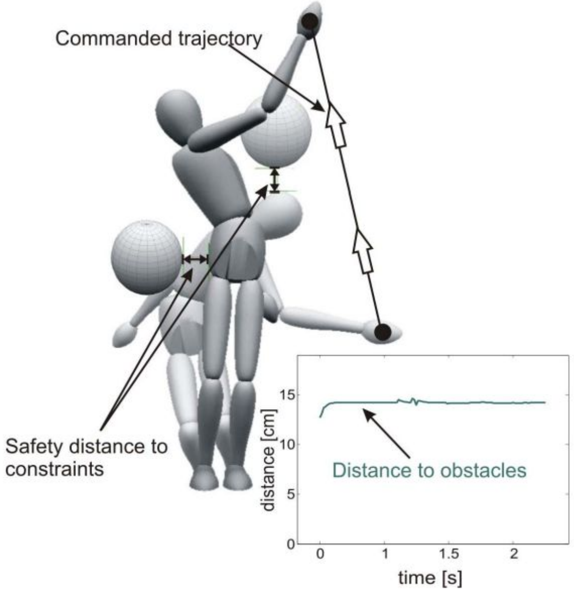
II - Non-contact Constraints

Near-Body Obstacle Avoidance for short range manipulation or near-body obstacles

- Highest priority level, and therefore the controller can detect feasibility

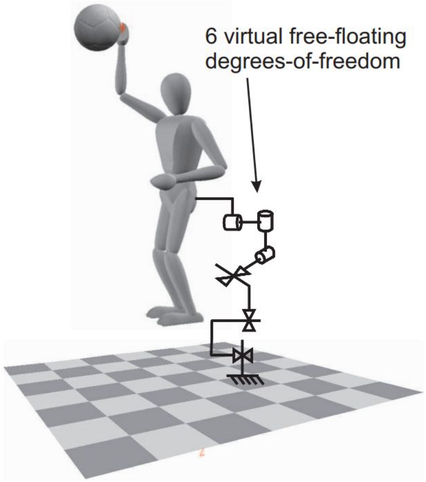
$$\Gamma = (J_{\text{obstacle}}^T F_{\text{obstacle}}) + (J_{t|c}^T F_{t|c})$$

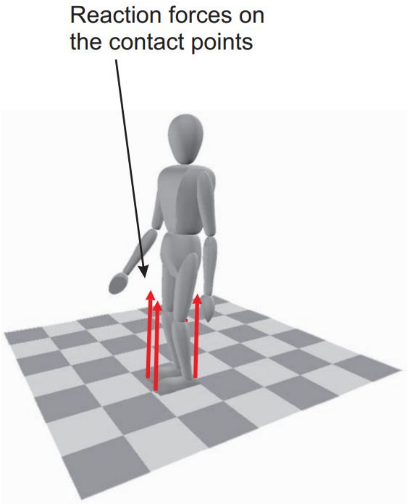


III - Accounting for Free Floating DOF and supporting contacts

The framework accounts for **Free Floating dynamics** and **supporting contacts:**

- Gravity grounds body parts into the support contacts
- Make indirect use of support to balance





III - Accounting for Free Floating DOF and supporting contacts

The **Free Floating Jacobian of the Task:**

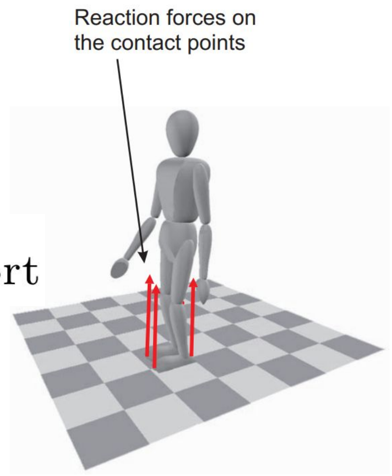
$$J_{\text{taskFF}} = J_{\text{task}}\left(\overline{S}_{\text{act}} S_{\text{act}}\right)$$

which we prioritize using the support null-space:

$$J_t = J_{\text{taskFF}} N_{\text{support}} = J_{\text{task}}\left(\overline{S}_{\text{act}} S_{\text{act}}\right) N_{\text{support}}$$

and incorporate the constraints which gives:

$$\boxed{J_{t|c} = J_{\text{task}} N_{\text{constraints}}\left(\overline{S}_{\text{act}} S_{\text{act}}\right) N_{\text{support}}.}$$



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Article citations

- **309 citations** on Google Scholar
- **190 citations** on Scopus
- Has influenced other labs and has been used on other robots
- Is widely adopted as an example of hierarchical whole-body control on bipeds.

Scopus metrics

190 99th percentile

Citations in Scopus

Cited in: Perceptive Locomotion Through Nonlinear Model-Predictive Control

Ruben Grandia , Fabian Jenelten , Shaohui Yang , Farbod Farshidian , and Marco Hutter

- The approach was used in this article to control the ANYmal robot through rough terrain.

- “A high-frequency whole-body controller (WBC) is used to convert the desired acceleration tasks into torque commands” p.11

Soft constraints "critic"

- **"Optimization Based Full Body Control for the Atlas Robot"** Siyuan Feng, Eric Whitman, X Xinjilefu and Christopher G. Atkeson, 2014
- **"Optimization-based Full Body Control for the DARPA Robotics Challenge"** Siyuan Feng, Eric Whitman, X. Xinjilefu, and Christopher G. Atkeson, 2014

Pros and Cons

Pros:

- Builds a solid structure for whole-body control
- Accounts for constraints, task, posture optimization and both free floating DOF and reaction forces
- Makes for a safe and reactive humanoid robot perfect for unpredictable human environment.

Cons:

- Usage of hard constraints over soft constraints.
- Very theoretical paper and little detail about how to actually implement certain solutions

Exam Questions

How is the Whole-Body Framework structured ?

- Hierarchically separated into control primitives going from high priority to low priority : constraints, tasks, posture

How are joint limits implemented ?

- The task control is projected into the null space of the joint limit upon activation (constant joint limit monitoring). Activation happens when reaching a user-set constraint activation zone.

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Questions ?