Advancements in TO and MPC for TALOS
at the Gepetto group

Nahuel A. Villa

Particularities of Talos

Some Features :

32 actuated joints

38 degrees of freedom

Strong actuators with force sensors

Particularities of Talos

Some Features :

32 actuated joints

More than 38 degrees of freedom

Strong actuators with force sensors

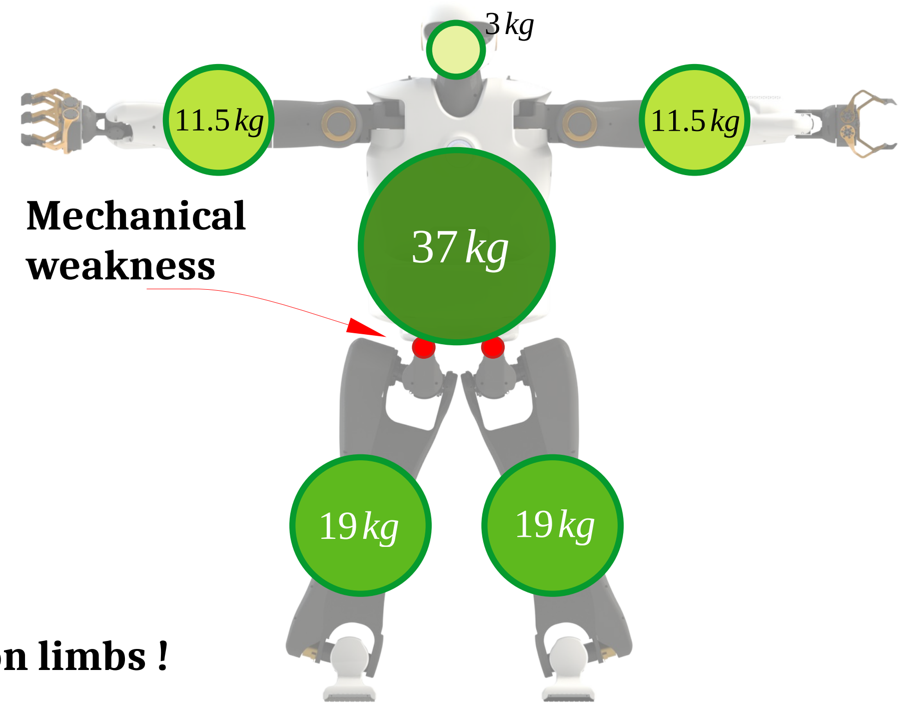
Main Difficulties:

Mechanical weakness on hips

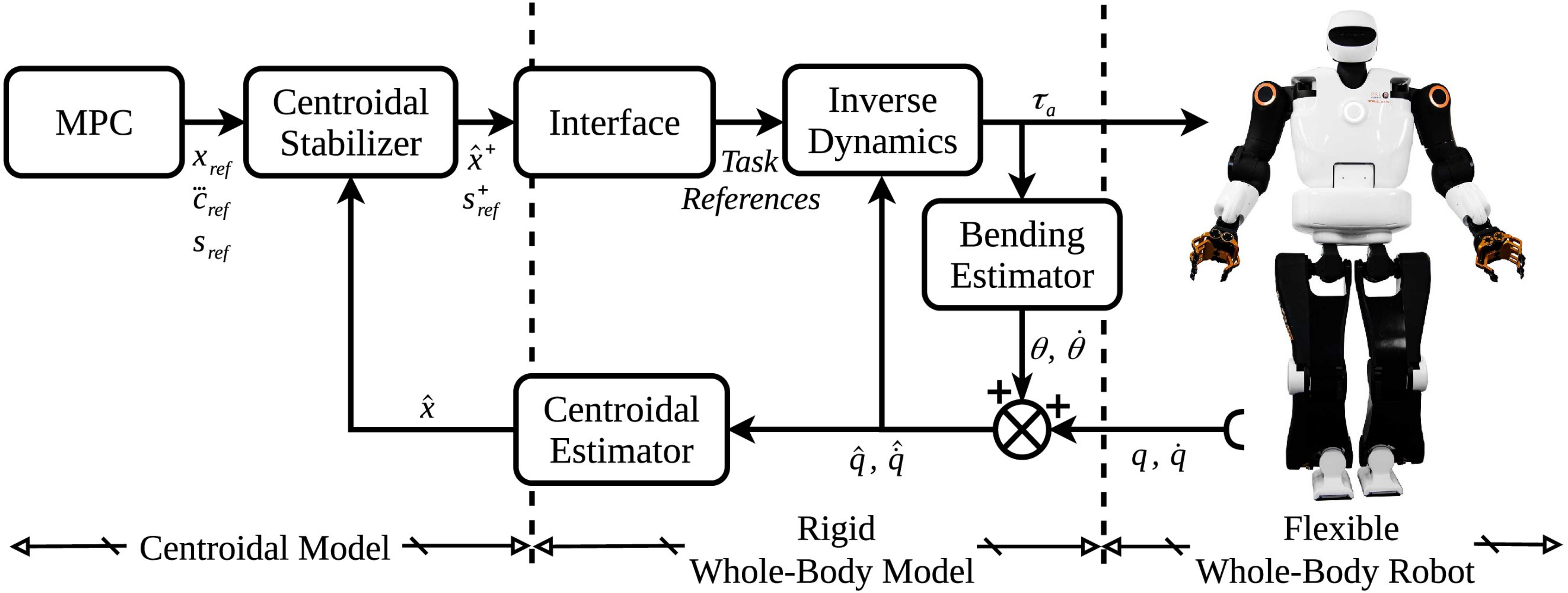
Heavy robot **Total mass :** $\approx 100\,kg$ **!**

Big limb mass proportion **Most of the mass on limbs !**

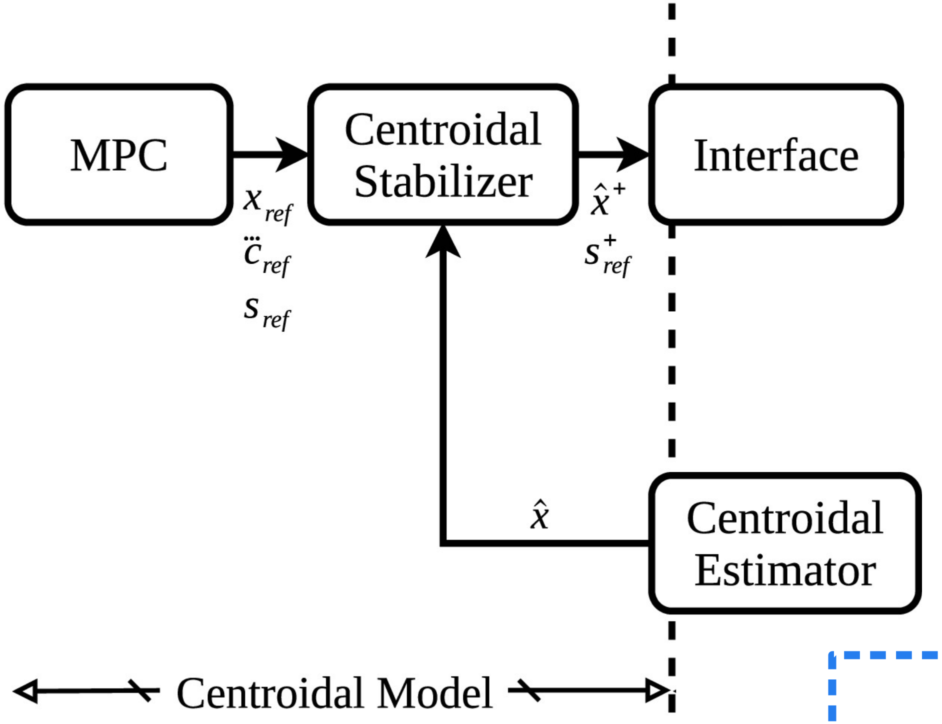
Mass distribution



Centroidal Approach



Centroidal Approach



Centroidal Dynamics

$$\underbrace{p^{x,y} - n^{x,y}}_{v^{x,y}} = c^{x,y} - \frac{\ddot{c}^{x,y}}{\omega^2}$$

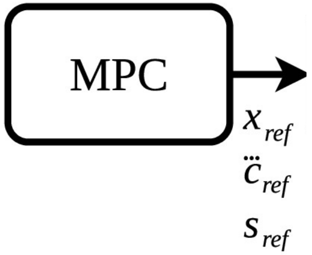
(feedback linearization)

$$n^{x,y} \neq 0$$

LIP

$$p^{x,y} = c^{x,y} - \frac{\ddot{c}^{x,y}}{\omega^2} - \frac{\left(m\ddot{c}^{x,y}c^z - S\dot{L}\right)}{m\left(\ddot{c}^z + g^z\right)} + \frac{\sum_k r_k^z f_k^{x,y}}{\sum_k f_k^z} + \frac{\ddot{c}^{x,y}}{\omega^2}$$

Centroidal Approach



Optimal Control Problem

$$\min_{\ddot{c},\, s} \quad \sum_t \boldsymbol{costs}_t$$

$$s.t. \quad v = c - \frac{\ddot{c}}{\omega^2}$$

constraints

Constraints

Feasible forces

$$p^{x,y} \in \mathcal{P}$$
$$\Downarrow$$
$$v^{x,y} \in \mathcal{P} - n^{x,y}$$

Reachable steps

$$s \in \mathcal{S}$$

Capturability condition (Terminal constraint)

$$c^{x,y} + \frac{\dot{c}^{x,y}}{\omega} \in \mathcal{P} - n^{x,y}$$

Costs

Minimum CoP

$$p^{x,y} \rightarrow s^{x,y}$$
$$\Downarrow$$
$$v^{x,y} \rightarrow s^{x,y} - n^{x,y}$$

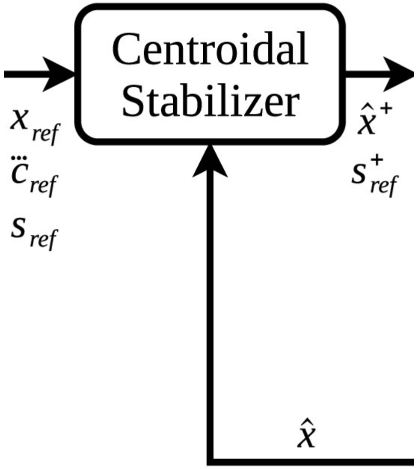
Minimum Jerk

$$\dddot{c} \rightarrow 0$$

Track desired Velocity

$$\dot{c} \rightarrow \dot{c}_{aimed}$$

Centroidal Approach



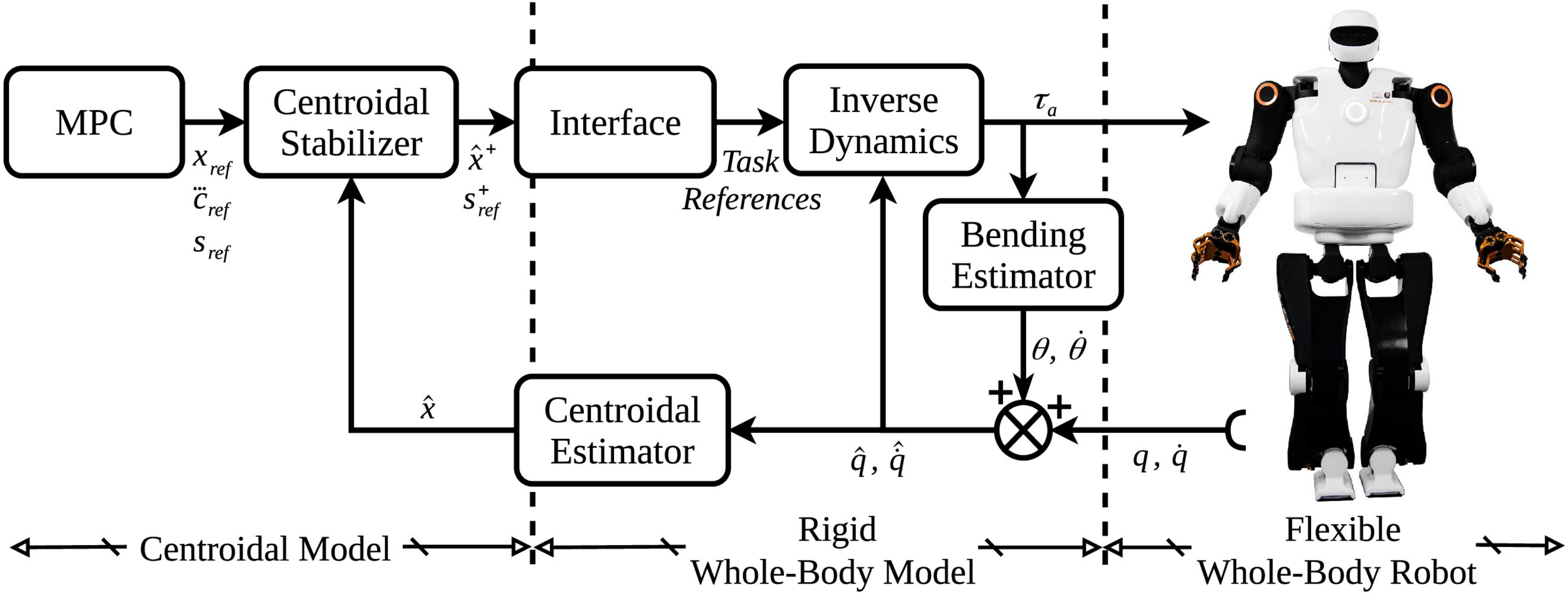
Feedback law

$$\dddot{c}^{x,y} = \dddot{c}^{x,y}_{ref} + K\left(x - x_{ref}\right)$$

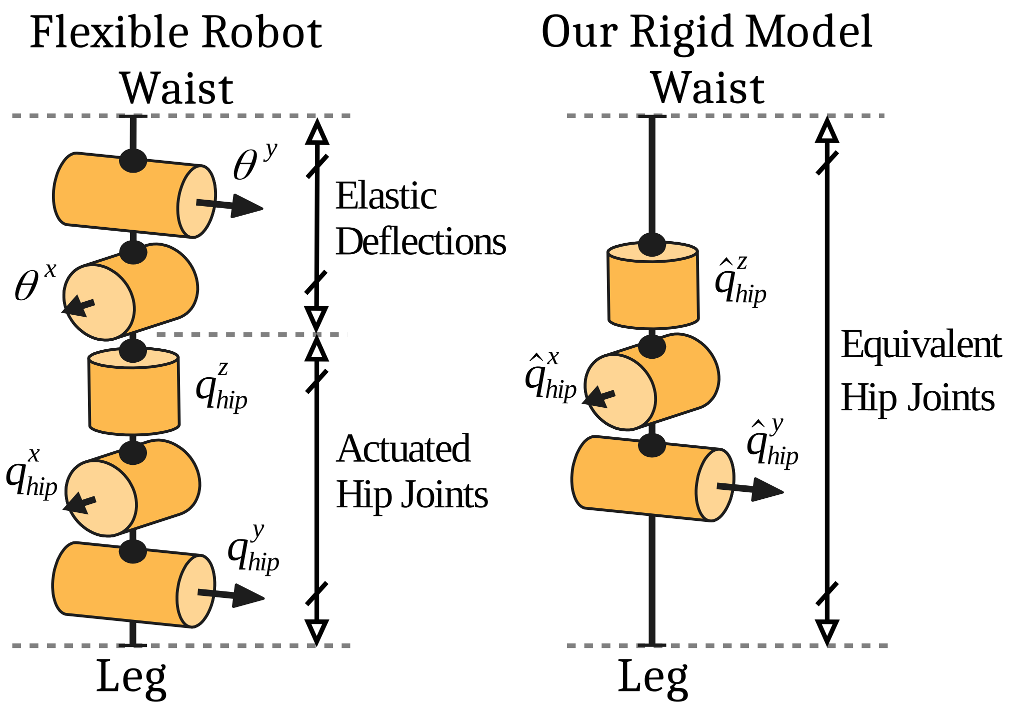
Saturated to ensure :

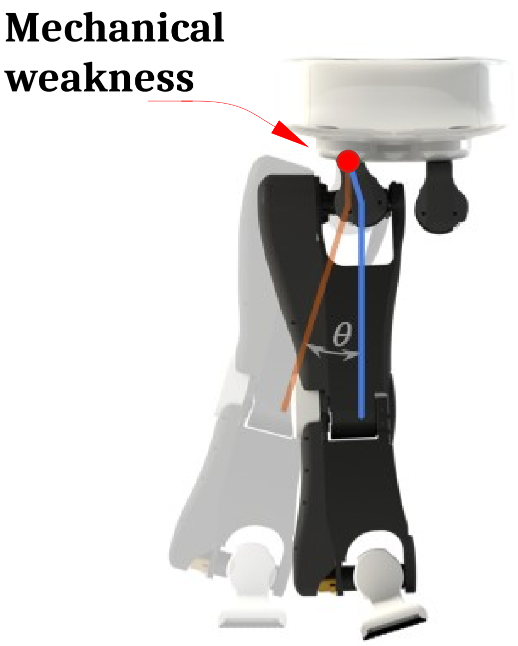
$$p^{x,y} \in \mathcal{P}$$
$$\Downarrow$$
$$v^{x,y} \in \mathcal{P} - n^{x,y}$$

Centroidal Approach



Bending Estimator and Posture Correction





posture correction:

$$R(\theta^{yx})\,R(q_{hip}^{zxy}) = R(\hat{q}_{hip}^{zxy})$$

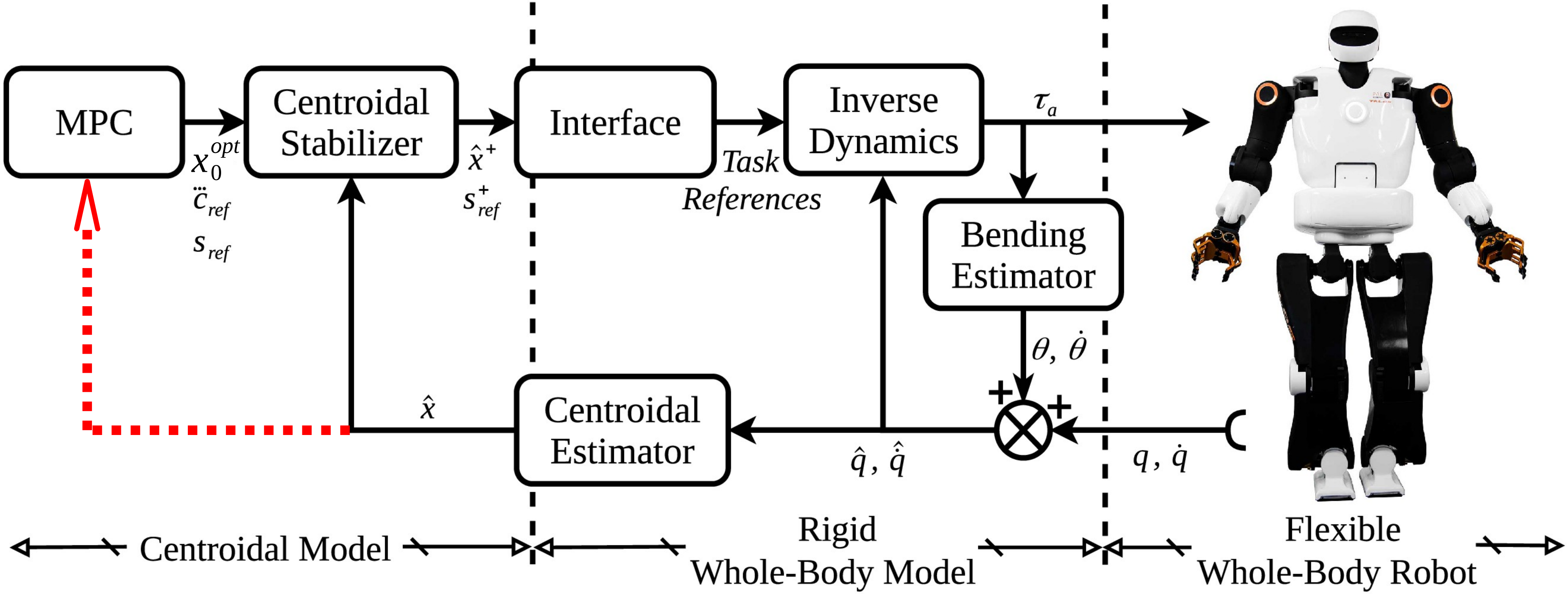
spring-damper model

$$\tau_f = -k_f\,\theta - d_f\,\dot{\theta}$$

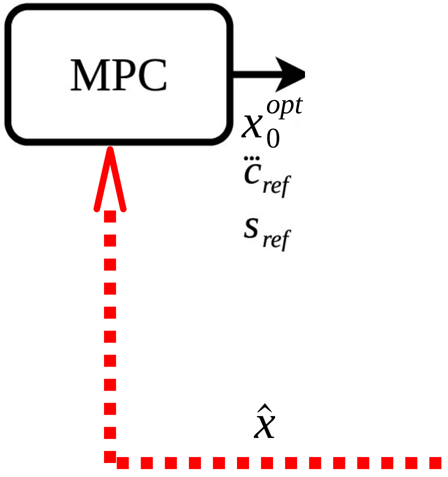
Videos

- ▷ Walking around
- ▷ Dynamic walking

Closed-Loop MPC

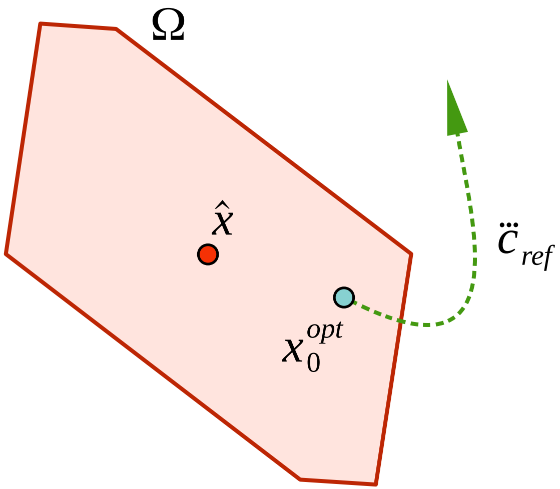


Closed-Loop MPC



Initial constraint

$$x_0^{opt} \in \Omega + \hat{x}$$



Optimal Control Problem

$$\min_{\ddot{c},\, s,\, x_0^{opt}} \quad \sum_t \boldsymbol{costs}_t$$

$$s.t. \quad v = c - \frac{\ddot{c}}{\omega^2}$$

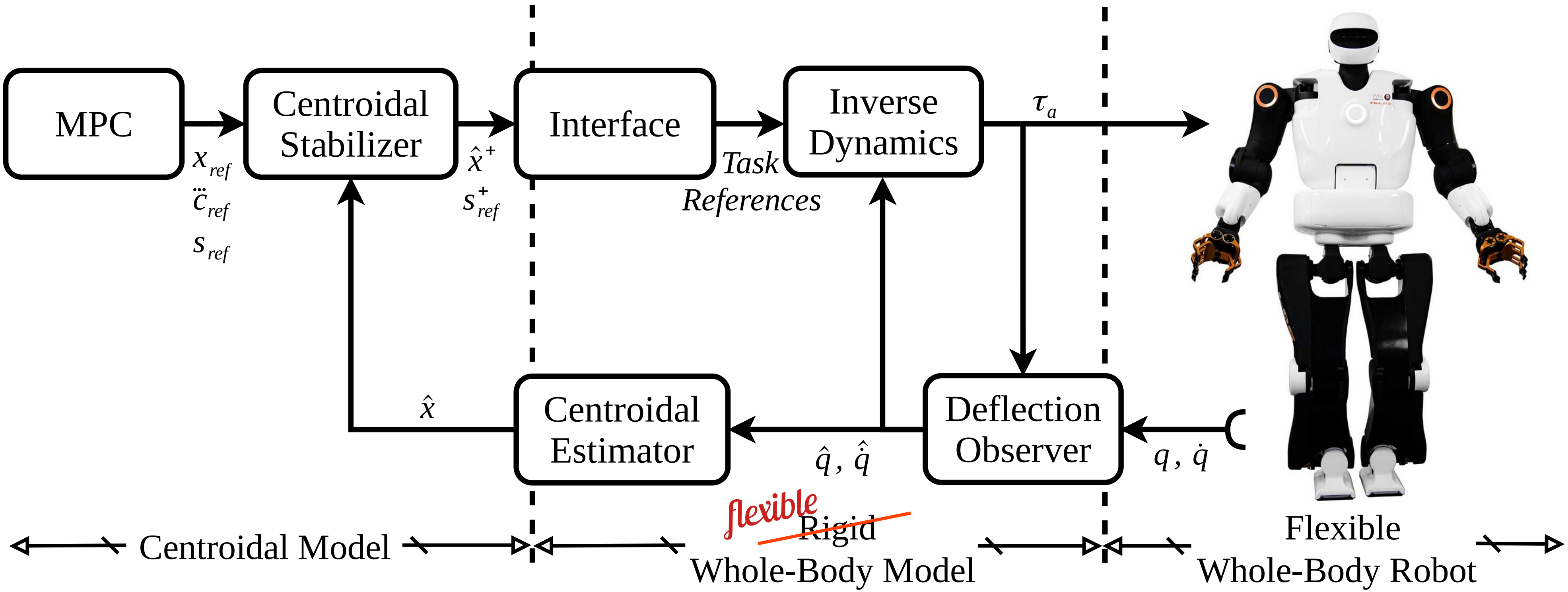
constraints

[From Nahuel Villa et al. 2017]

Videos

▷ Frontal Collision Simulations

Flexible Whole-Body Model



[From Giulio Romualdi]

Videos

▷ Comparison to standard control scheme

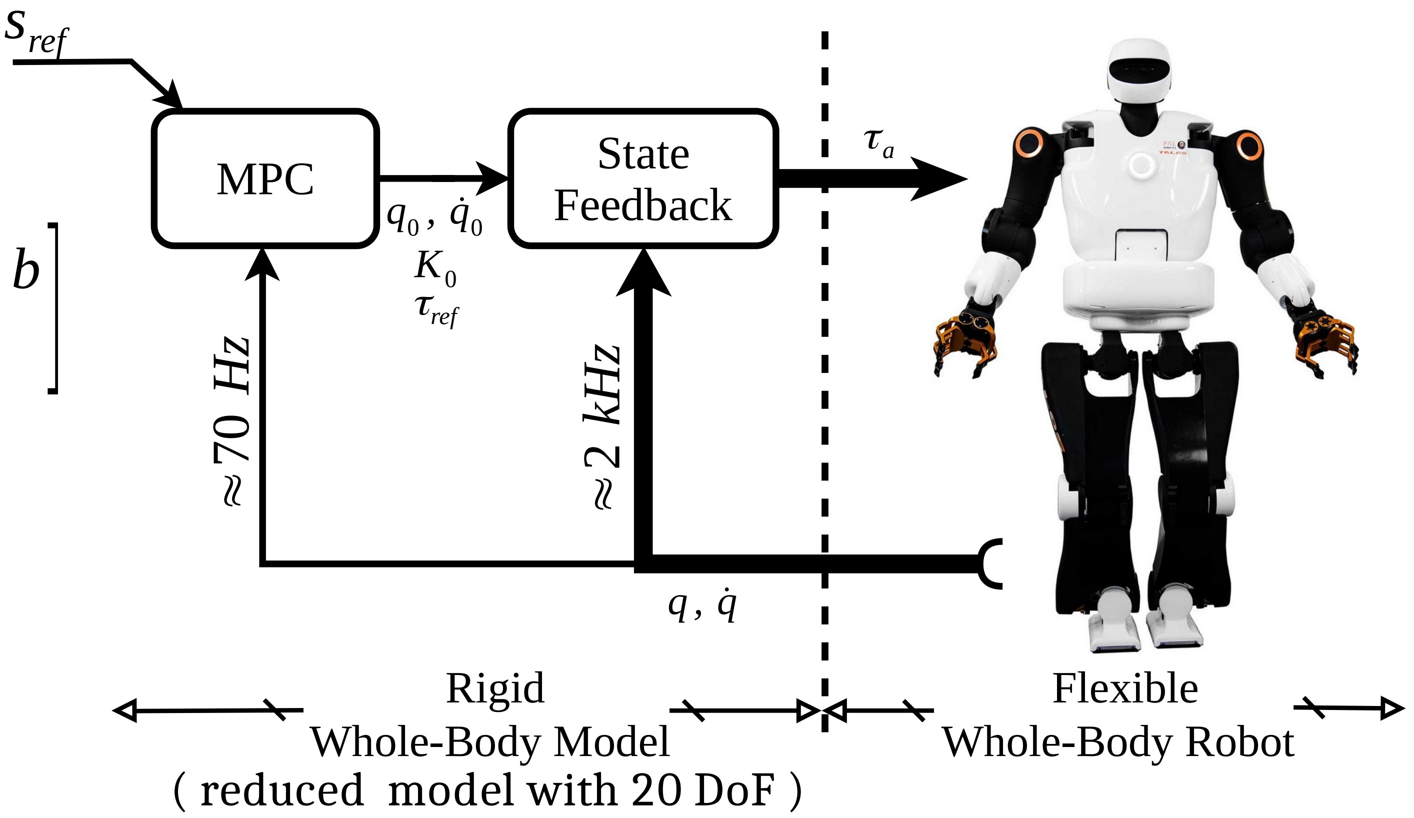
Whole-Body Approach

Whole-Body Dynamics

$$\begin{bmatrix} M & J_c^T \\ J_c & 0 \end{bmatrix} \begin{bmatrix} \ddot{q} \\ -\lambda \end{bmatrix} = \begin{bmatrix} S^T \tau_a - b \\ -\dot{J}_c \dot{q} \end{bmatrix}$$

State : $q\,,\ \dot{q}$

Control : τ_a

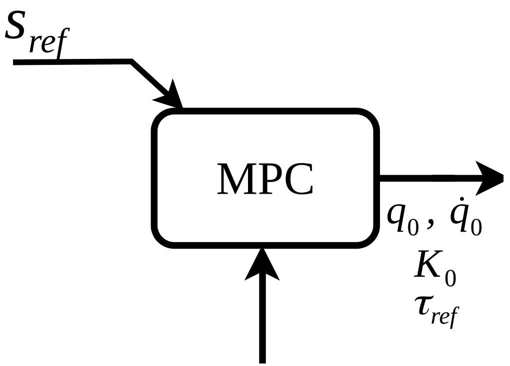


Differential Dynamic Programming

crocoddyl
Contact Robot Optimal Control by Differential Dynamic Library

[From Ewen Dantec]

Whole-Body Cost Functions



Optimal Control Problem

$$\min_{\tau} \quad \sum_t \textbf{costs}_t$$
$$s.t. \quad \textbf{Whole-Body Dynamics}$$

Cost function expressions

$$cost \;=\; weight * activation\left(residual\left(z, z_{ref}\right)\right)$$

State cost

$q, \dot{q} \rightarrow q_{ref}, \dot{q}_{ref}$

Control cost

$\tau \rightarrow \tau_{ref}$

Joint limits (soft constraint)

$q_{min} \prec q \prec q_{max}$

Feet trajectories

$s \rightarrow s_{ref}$

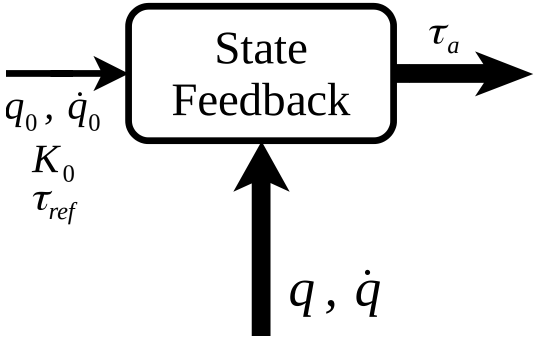
Minimum CoP

$p \rightarrow s_{ref}$

Contact Wrench cost

$w \rightarrow w_{ref}$

Whole-Body State Feedback



Feedback Law

$$\tau_a = \tau_{ref} + K_0 \left(\begin{bmatrix} q_0 \\ \dot{q}_0 \end{bmatrix} - \begin{bmatrix} q \\ \dot{q} \end{bmatrix} \right)$$

Videos

- ▷ Dynamic walking (30 cm steps)
- ▷ Stair-step crossing (10 cm high)

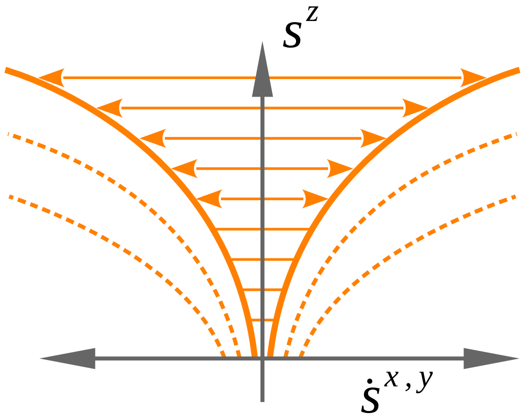
Whole-Body Walk without Thinking

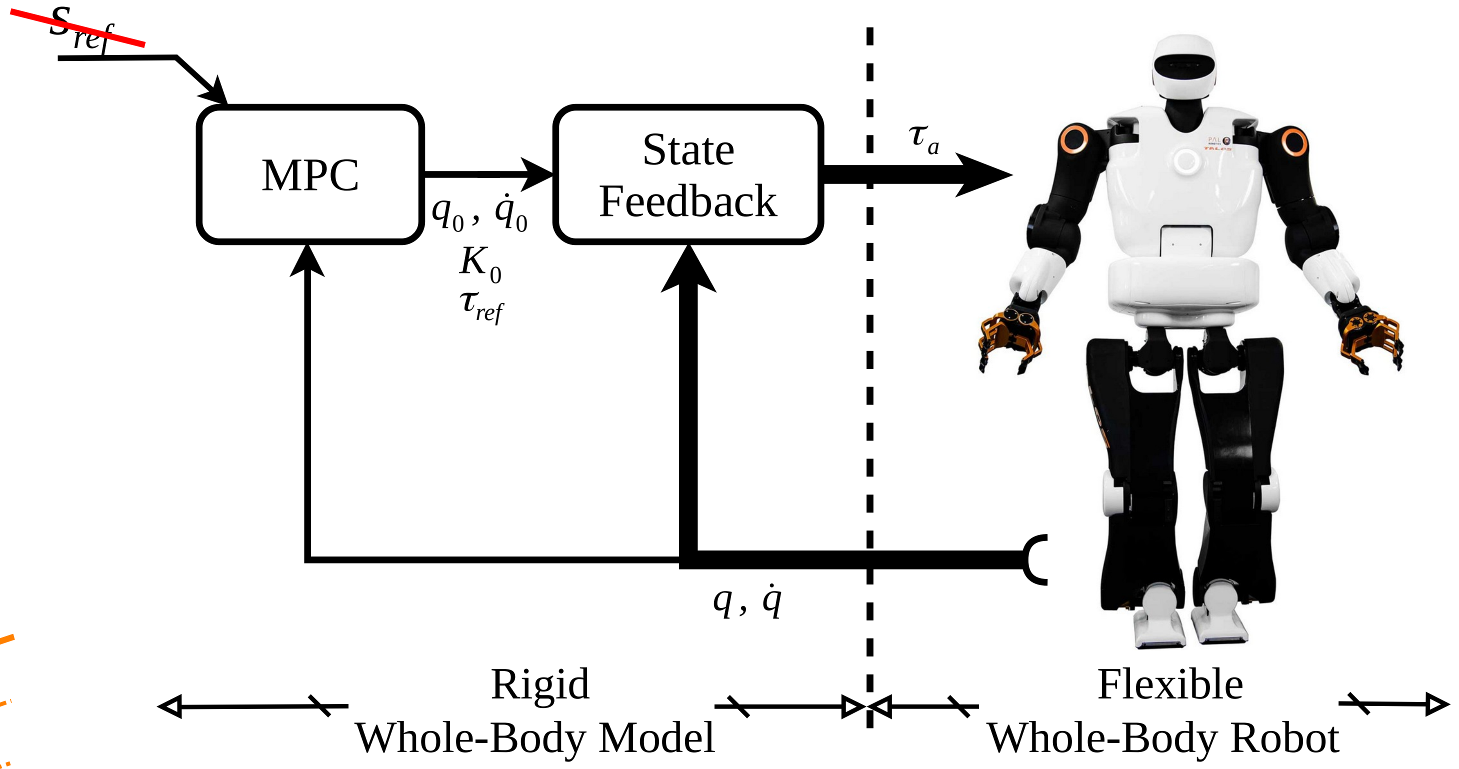
New Cost

Flying foot cost

$cost\left(\dot{s}^{x,y},\ s^{z}\right)$

Isocost Curves





Whole-Body Walk without Thinking

▷ Solo-12, walking and push recovery

Robot Solo-12

[From Alessandro Assirelli, Fanny Risbourg et al.]

Whole-Body Walk without Thinking

- Talos, walking and push recovery

[From Ewen Dantec]

Summary

- Talos finally walks dynamically **!**
  We achieved it with two control approaches.

- Centroidal approach:
  - Computed on-board.
  - close to the *state of the art*.

- Whole-Body approach:
  - Simpler control scheme.
  - General controller for different tasks.

~ Work in progress ~