CODYCO Whole-body Compliant Dynamical Contacts in Cognitive Humanoids

WP5 related activities

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April 16, 2015
Second year CoDyCo review meeting
Université Pierre et Marie Curie
Institut des Systèmes Intelligents et de Robotique
Paris, France

WP5 Related Activities

A rough list

- From balancing towards walking WP3
  co-supervision of the intern Talha Arslan
- JTC for better tracking of desired link torques WP5
  supervision of the intern Raffaello Bonghi
- Calibration of force-torque sensors WP4
  working with Silvio Traversaro
- Adaptive control of underactuated systems WP4
  working with Francesco Romano
- Physical consistent inertial parameters on Lie groups WP4
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Balancing

General definitions of the centroidal momentum

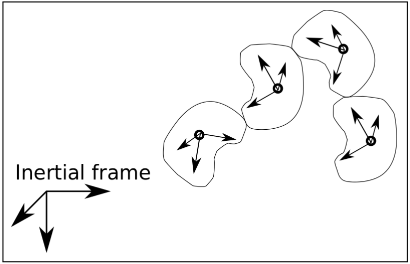
Centroidal Momentum

$$M(q)\dot{v} + C(q,v)v + g(q) = \begin{bmatrix} 0 \\ \tau \end{bmatrix} + J_c^\top f$$

$$J_c(q)\ddot{q} + \dot{J}_c\dot{q} = 0$$

Balancing

General definitions of the centroidal momentum



Centroidal Momentum

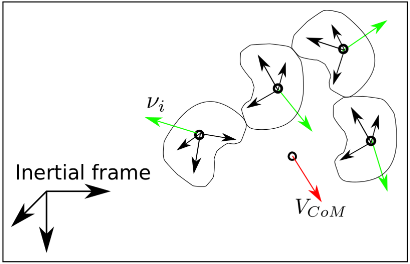
$$H := \sum_{i=0}^{n} I_i \nu_i$$

- ν_i twist of the *ith* body
- I_i : spatial inertia of the *ith* body

H is a coordinate-free (in the sense of Plucker) quantity

Balancing

Centroidal momentum at the center of mass with inertial orientation



Centroidal Momentum

$$H_{CoM} := \begin{pmatrix} m_{tot} V_{CoM} \\ f(q, \dot{q}) \end{pmatrix}$$

- m_{tot}: total mass of the robot, q: joints' positions
- V_{CoM} : velocity of the center of mass

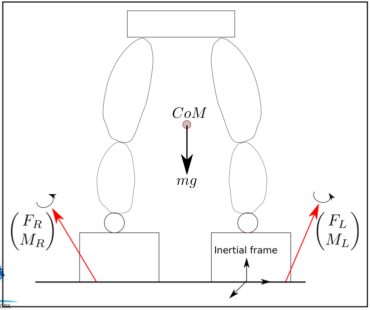
$$\frac{d}{dt} H_{CoM} = f_{Ext}^{CoM}$$

Balancing

Control strategy when balancing on two feet

$$\dot{H}_{CoM} = \text{grav} + A(q)F_{ext}$$

$$M(q)\dot{v} + C(q,v)v + g(q) - J^T F_{ext} = \begin{pmatrix} 0_6 \\ \tau \end{pmatrix}$$



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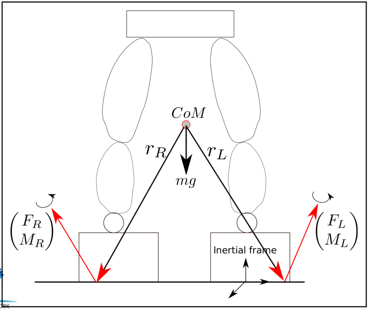

$$A(q) = \begin{pmatrix} I_3 & 0_3 & I_3 & 0_3 \\ r_L\times & I_3 & r_R\times & I_3 \end{pmatrix}$$

$$F_{ext} = \begin{pmatrix} F_L \\ M_L \\ F_R \\ M_R \end{pmatrix}$$

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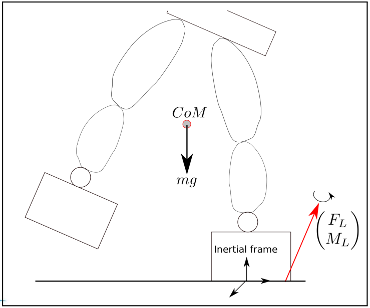

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Constraints on feet

$$J(q) := \begin{pmatrix} J_L \\ J_R \end{pmatrix}$$

$$J(q)\dot{v} + \dot{J}(q)v = 0$$

Find τ such that

(1) $\dot{H}_{CoM} = \dot{H}^d_{CoM}, F^d_{Ext} \in FC$

(2) $q \approxeq q_d$ s.t. $x(q_d) = x_d$

Constraints on feet

$$J(q) := \begin{pmatrix} J_L \\ J_R \end{pmatrix} \quad \rightarrow \quad J(q) := \begin{pmatrix} I_n \alpha_l(t) & 0_n \\ 0_n & I_n \alpha_r(t) \end{pmatrix} \begin{pmatrix} J_L \\ J_R \end{pmatrix}$$

Balancing

Control strategy when balancing on two feet

$$H_{CoM} = \begin{pmatrix} mV_{CoM} \\ H_\omega \end{pmatrix} \Rightarrow \dot{H}_{CoM} = \begin{pmatrix} m\dot{V}_{CoM} \\ \dot{H}_\omega \end{pmatrix} = \text{grav} + A(q)F_{ext}$$

SEVENTH FRAMEWORK PROGRAMME

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We choose F^d_{Ext} such that

$$\dot{H}_{CoM} = \dot{H}^d_{CoM} = \text{grav} + A(q)F^d_{ext}$$

We choose $\dot{H}^d_{CoM}$ such that

$$x_{CoM} \rightarrow x^d_{CoM} \quad H_\omega \rightarrow 0$$

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A choice for F^d_{Ext} is

$$F^d_{ext} = A^\dagger(\dot{H}^d_{CoM} - \text{grav})$$

Pseudo-inverse suggests that there might be some null space to exploit (internal torques).

Balancing

Control strategy when balancing on two feet

Given a desired CoM trajectory,
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These contact forces lie in a 12-dimensinal space, and are generated by the links' torques

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These contact forces lie in a 12-dimensinal space, and are generated by the links' torques

The links' torques lie in a 25-dimensinal space

Balancing

Control strategy when balancing on two feet

Given a desired CoM trajectory,
we find the contact forces to stabilize it

These contact forces lie in a 12-dimensinal space, and are generated by the links' torques

The links' torques lie in a 25-dimensinal space

How do can we choose the remaining 13-dimensinal space of the links' torques (inputs)?

Balancing

Control strategy when balancing on two feet

$$\tau = \tau_f(F^d_{ext}) + N\tau_0$$

Balancing

Control strategy when balancing on two feet

$$\tau = \tau_f(F^d_{ext}) + N\tau_0$$

τ_0 is chosen as a proportional feedback (impedance behaviour around q_d) plus gravity and external force compensation:

$$\tau_0 = g(q) + K_p(q - q_d) + J^\top F^d_{ext}$$

q_d, the postural configuration, is chosen to coincide with the solution of the Cartesian controller to perform goal directed actions with the hands and/or feet.

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A choice for F^d_{Ext} is

$$F_{ext} = A^\dagger(\dot{H}^d_{CoM} - \text{grav})$$

- No friction cones
- Even worse..

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A better choice for F^d_{Ext} is

$$F^d_{ext} = A^\dagger(\dot{H}^d_{CoM} - \text{grav}) + N_A F_0$$

Then, the torques are

$$\tau = \tau_f(F_0) + N\tau_0(F_0)$$

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$$\tau = \tau_f(F_0) + N\tau_0(F_0)$$

$$\tau_c = \arg\min_{F_0} |\tau(F_0)|$$

$$\text{s.t. } F^d_{ext}(F_0) \in FC$$

Balancing

Conlcusions, perspectives, and future work

- Smooth switching from double to single support
- Walking
- Implementation on the robot

Publications

Submitted papers

- "iCub Whole-body Control through Force Regulation on Rigid Noncoplanar Contacts" in Frontiers in Robotics
- "Collocated Adaptive Control of Underactuated Mechanical Systems" in Transaction on Robotics
- "In Situ Calibration of Six-Axes Force Torque Sensors using Accelerometer Measurements" in ICRA

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