Towards A Novel Control Framework for Robots Continuous Interactions with Environments

Yang TAN

24/06/2014

Supervisor: Philippe BIDAUD
Vincent PADOIS

Context

Control continuity is of primary concern when robots interact with unstructured environments.

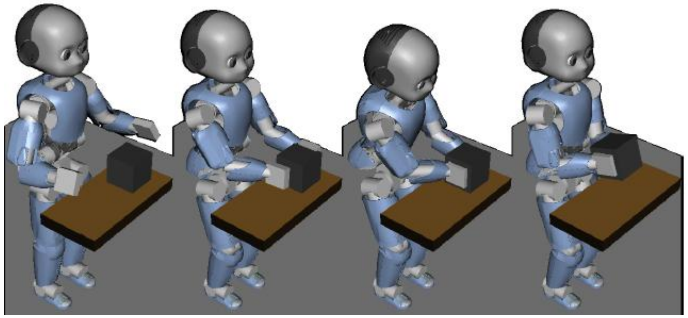
Discrete events on constraints:

- Appearance
- Disappearance
- Discontinuous variations

Discrete changes in the model's structure

Results of discontinuities:

- Discontinuous torques input
- Physical damages to the robot
- Lose balance, ...



Robots should react or anticipate promptly to alleviate these discontinuities

Outline

- Context
- State of the art
- Problem statement
- Current work
- Future work

State of the art: Focus on contact constraints

Pre-contact Phase

Avoid contacts
- Current environment geometry [Ebert2002]
- Motion planning techniques [Makarov2011]

Regulate impact force [Walker1990]
- Design a light weight robot
- Reduce contact velocity
- Minimize apparent inertia

$$F_{impact} = \frac{-(1+e)(v_1 - v_2)^T n}{n^T M_{EE} n}$$

Contact Phase (if inevitable)

- Introducing passive compliance in the system [Pagilla2001]
- Adapting active compliance (control gain adaptation) [Tonietti2005]

Post-contact Phase:

- Detect the contact occurrence [Haddadin 2008]
- Switch to an appropriate reaction strategy [Alessandro2005]
- Perform complex tasks with the environment

Control Framework

Dynamic Model $M(q)\ddot{\boldsymbol{q}} + n(q,\dot{q}) = J_c^{\ T}\boldsymbol{\chi}$

Tasks Definition $\ddot{\boldsymbol{x}}_i = J_i\ddot{\boldsymbol{q}} + \dot{J}_i\dot{\boldsymbol{q}}$

Constraints $A\boldsymbol{\chi} = \boldsymbol{b} \quad G\boldsymbol{\chi} \le \boldsymbol{h}$

Jacobian matrix of contact point

$$J_c^{\ T} = [\boxed{J_{con}^{\ T}} \quad \boxed{S^T}]$$

Selection matrix of actuated DOF

$\chi = [\boldsymbol{w}_c^T \quad \tau^T]^T$:Action variable

LQP Formulation (Weighting Strategy) [Salini2012]

f_i :Different tasks

w_i :Weight gain

$$\min_{\chi} \quad \frac{1}{2}\left(\sum_i (w_i f_i(\chi))^2 + (w_0 f_0)^2\right)$$

$$s.t. \quad J_c^T\chi = M\ddot{\boldsymbol{q}} + n$$

$$f_i(\ddot{\boldsymbol{q}}, \ddot{\boldsymbol{x}}^d) = J_i\ddot{\boldsymbol{q}} + \dot{J}_i\dot{\boldsymbol{q}} - \ddot{\boldsymbol{x}}_i^d$$

$$A\chi = b$$

$$G\chi \le h$$

$\Rightarrow \boxed{\tau}$

Control torques

Problem and objective

	Control in free space	Control in contact
Model:	$M(q)\ddot{\boldsymbol{q}} + n(q,\dot{q}) = S\boldsymbol{\tau}$	$M(q)\ddot{\boldsymbol{q}} + n(q,\dot{q}) = S\boldsymbol{\tau} + J^T W_{con}$
Actuation constraints:	$\lvert q \rvert \le q_{\max}$	$\lvert q \rvert \le q_{\max}$
	$\lvert \dot{q} \rvert \le \dot{q}_{\max}$	$\lvert \dot{q} \rvert \le \dot{q}_{\max}$
	$\lvert \tau \rvert \le \tau_{\max}$	$\lvert \tau \rvert \le \tau_{\max}$
Force constraints:	NULL	$W_{con} \ge 0 \Rightarrow W_{con} \le \begin{cases} W_1 & t \le t_a \\ W_2 & t \succ t_a \end{cases}$ $J_c \ddot{\boldsymbol{q}} + \dot{J}_c \dot{\boldsymbol{q}} = 0$

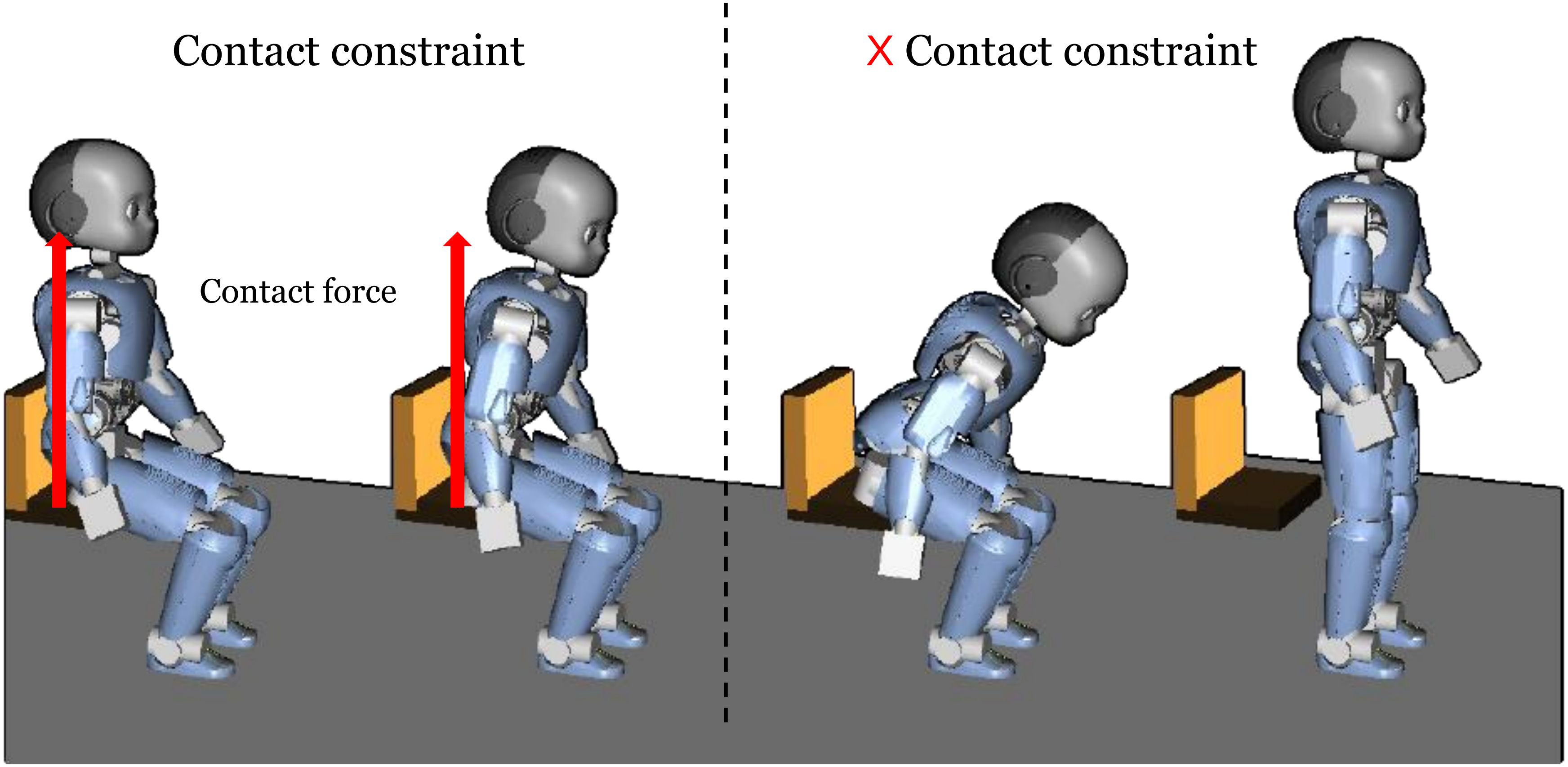
Discontinuous events

Objective

Continuous control torque to guarantee robot's performances under discontinuities

Current work

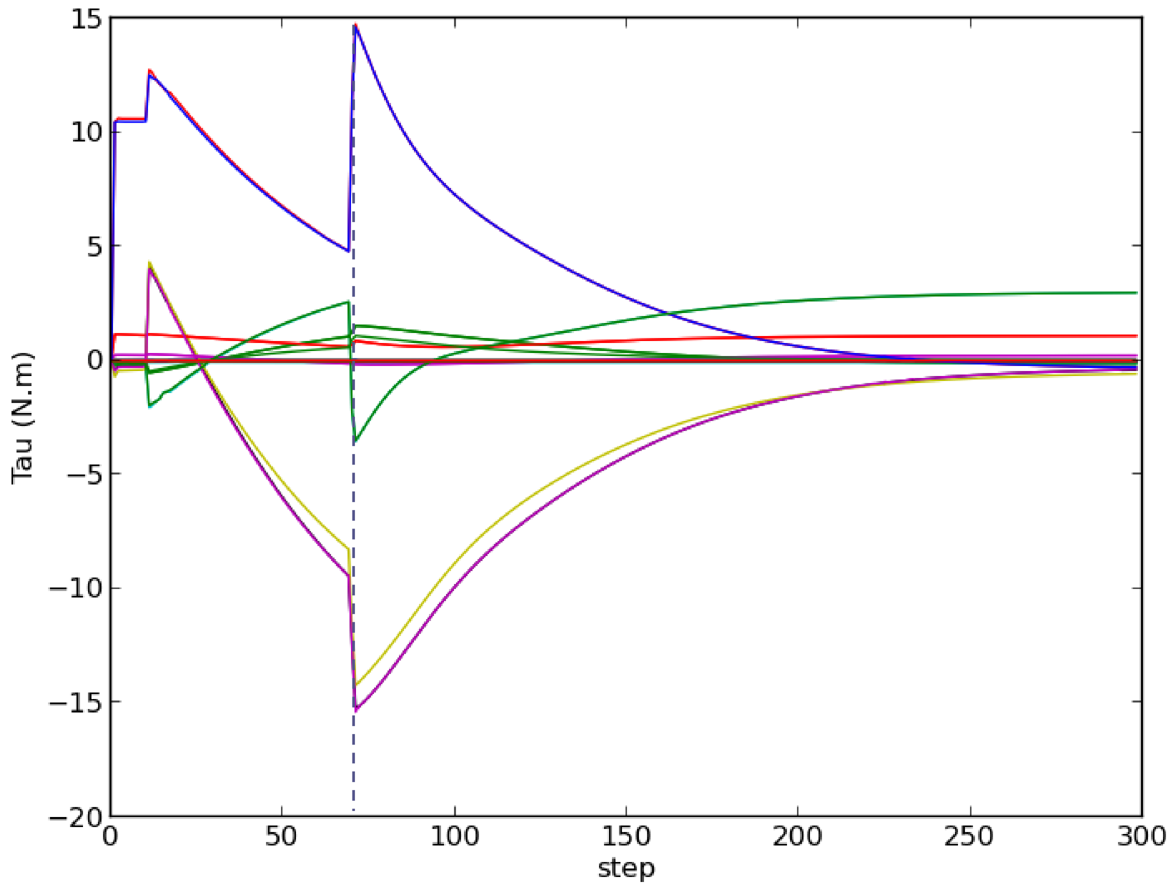
Constraints Disappearance



1-Sitting 2-Moving CoM 3-Breaking contact 4-Standing up

Current work

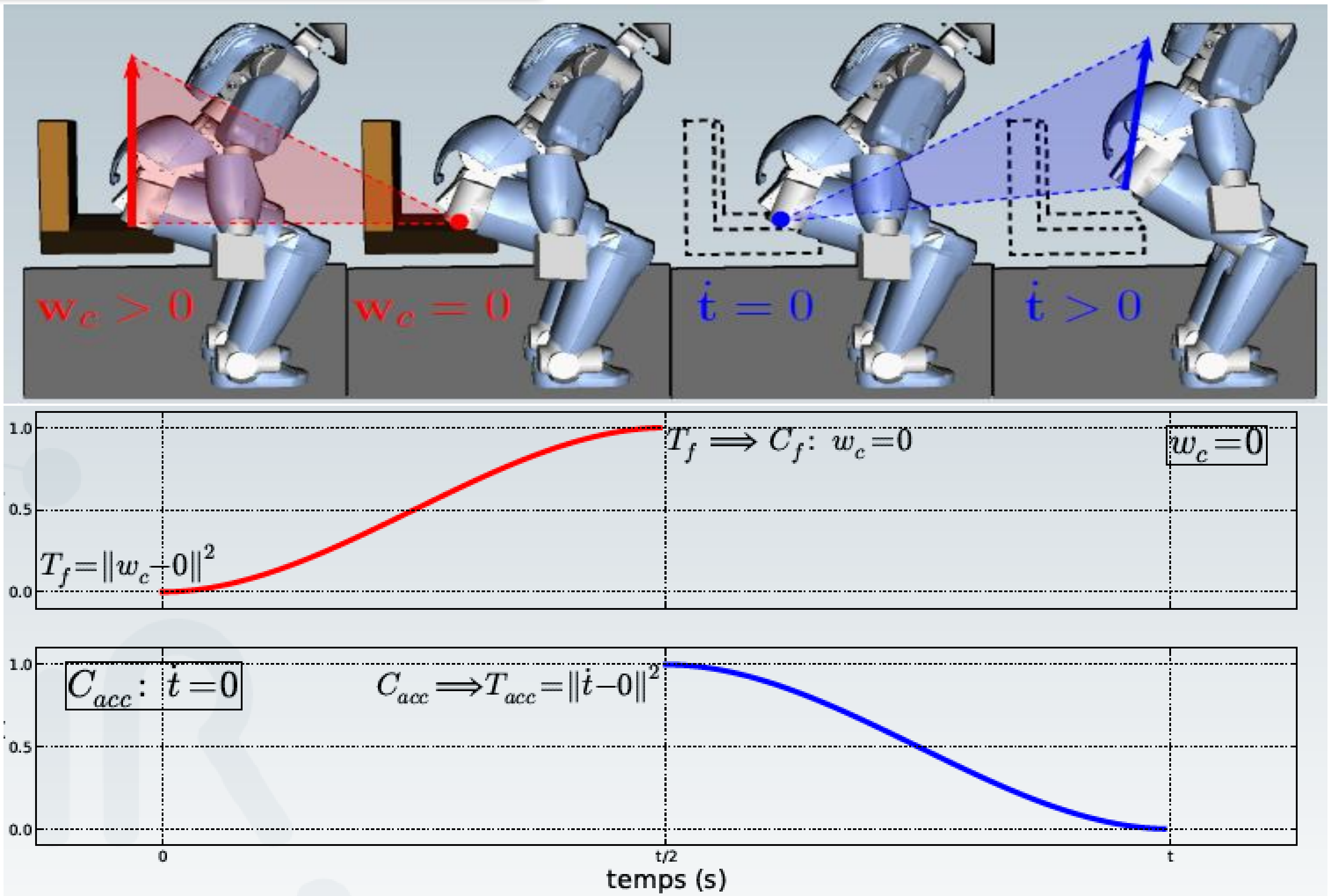
Results



Evolution of control torques

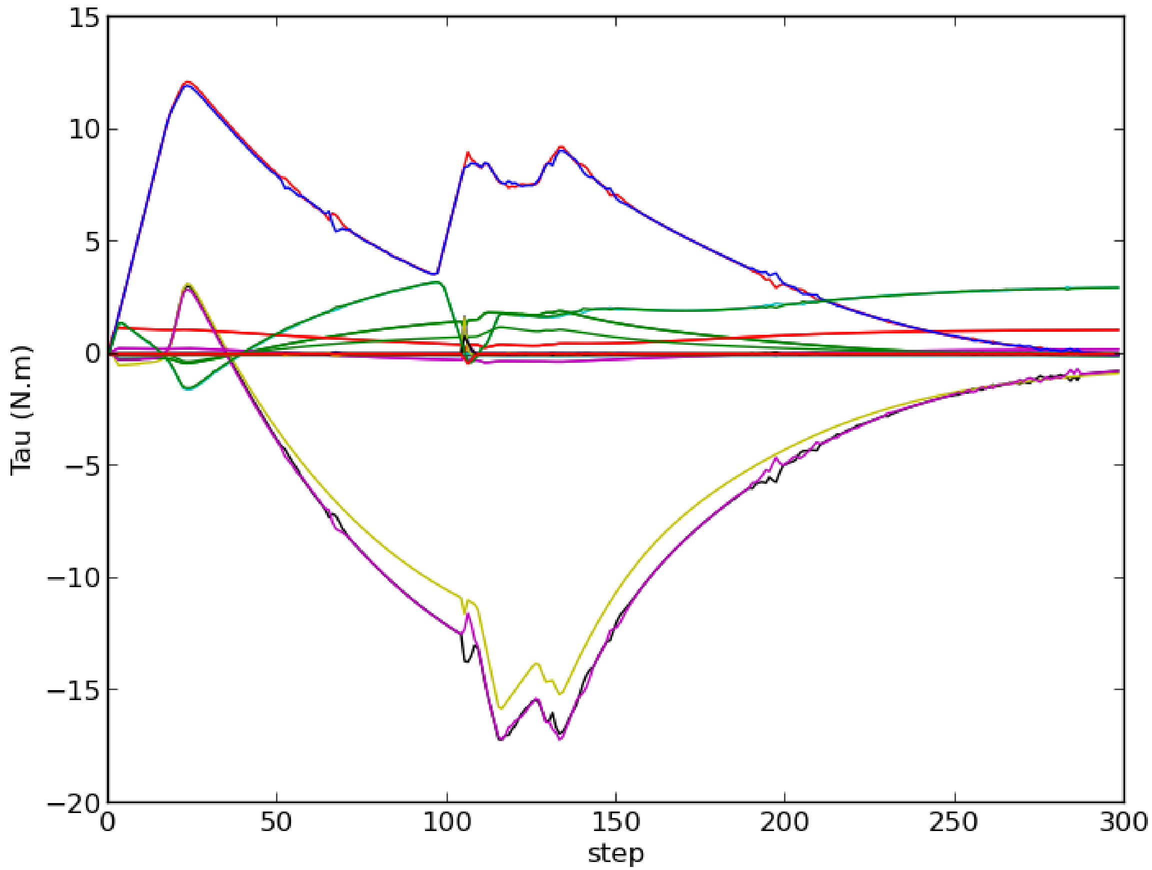
Current work

Constraint transition strategy



Current work

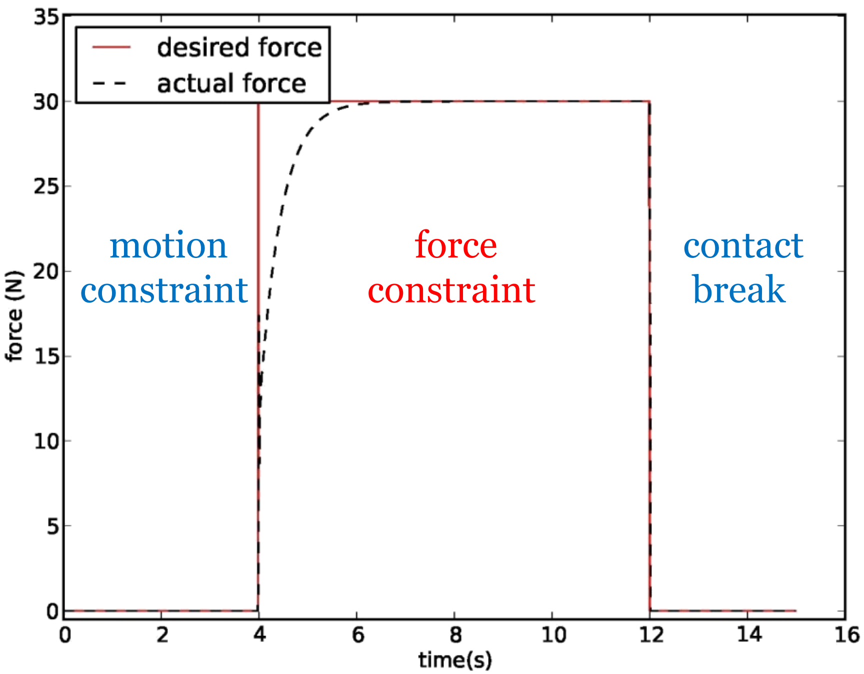
Results



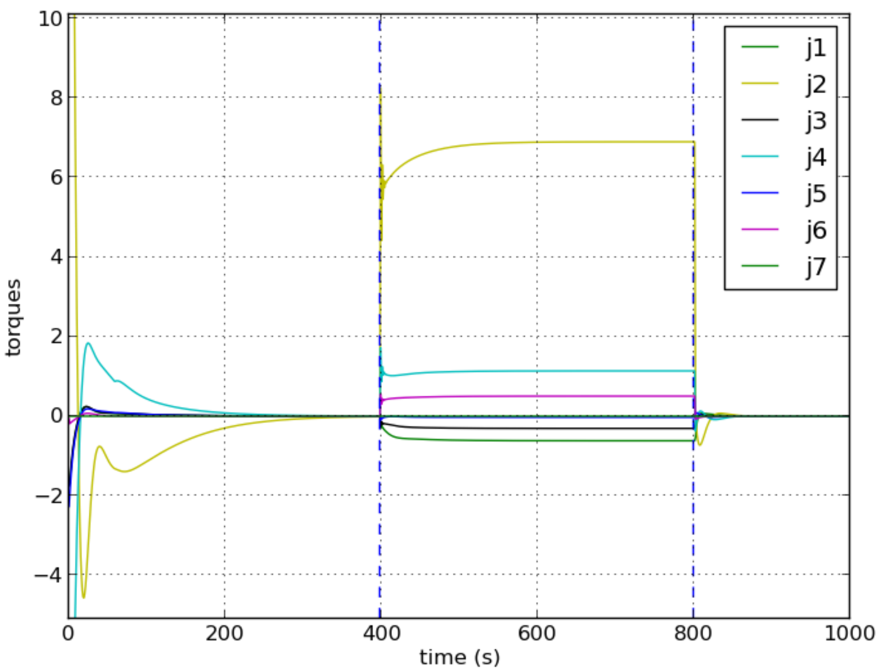
Evolution of control torques

Current work

Switches between motion constraint and force constraint



Reference force and actual force



Control torques

Current work

Proposed strategy with MPC

Force control model: $F(t+1) = AF(t) + Bu(t)$

$$A = 1 \qquad B = 1$$

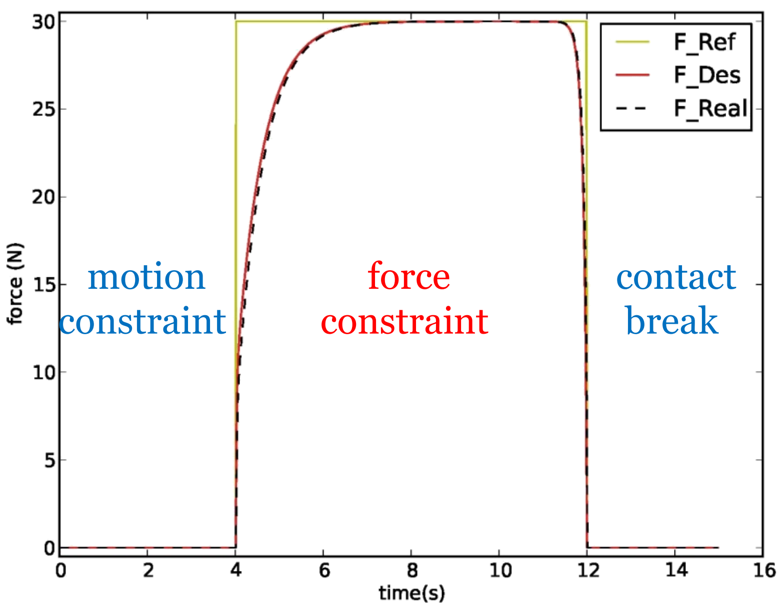
$F(t)$:Force state vector

$u(t)$:Force Control input

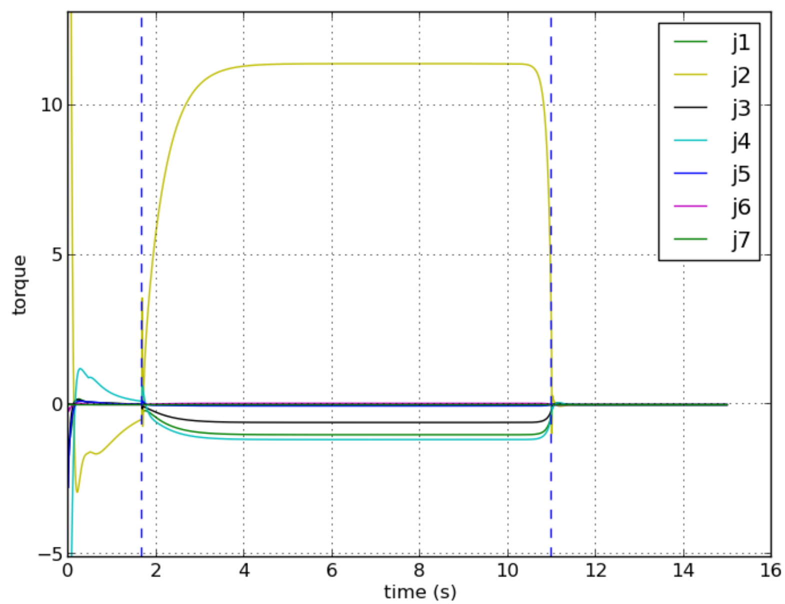
P, Q, R :Gains

Cost function: (Horizon N)

$$J := \min_U \; \frac{1}{2} F_N^T P F_N + \frac{1}{2} \sum_{k=0}^{N-1} (F_k^T Q F_k + u_k^T R u_k)$$



Reference force and actual force



Control torques

Future work

1. Intelligent constraint transition strategy
2. MPC can deal with whole dynamics of robots
3. General control framework combines both 1 and 2
4. Verify this control framework on real iCub robot

Thank you