Safe Control of a Pneumatic Muscle Powered System

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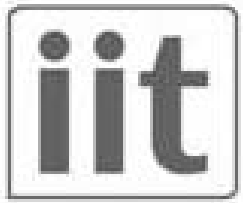
Frank Daerden, Dirk Lefeber



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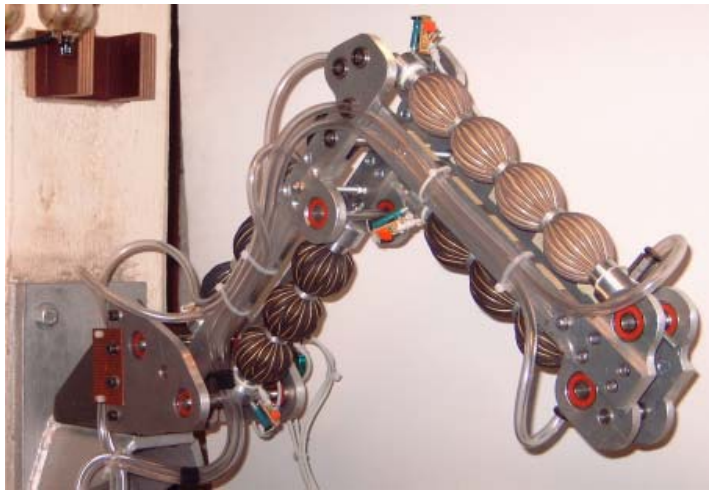
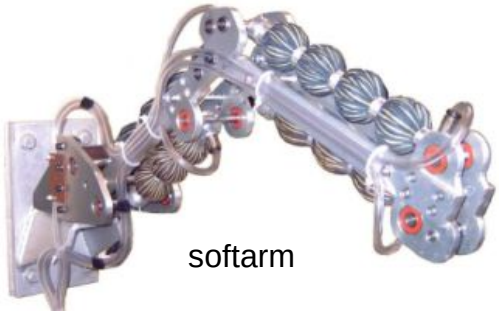
Overview

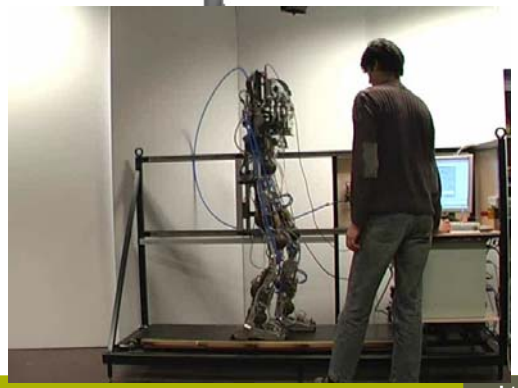
- Actuators
- Safety
- Safe control: PSMC
- Conclusion



Pleated Pneumatic Artificial Muscle

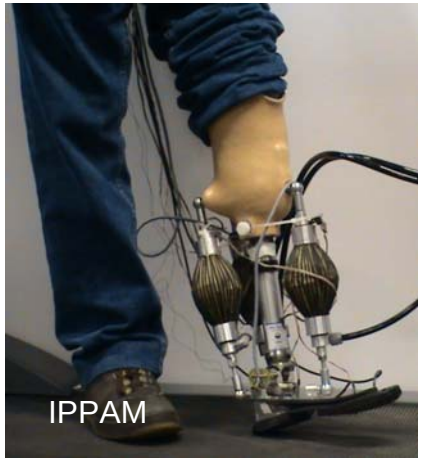


softarm



Lucy

- -Pleated membrane
- -Low weight (< 150 g!)
- -High force levels
- -Scalable
- -No stick-slip
- -No threshold pressure
- -Direct joint attachment
  - → No gear reduction, no backlash
- -Inherent compliance

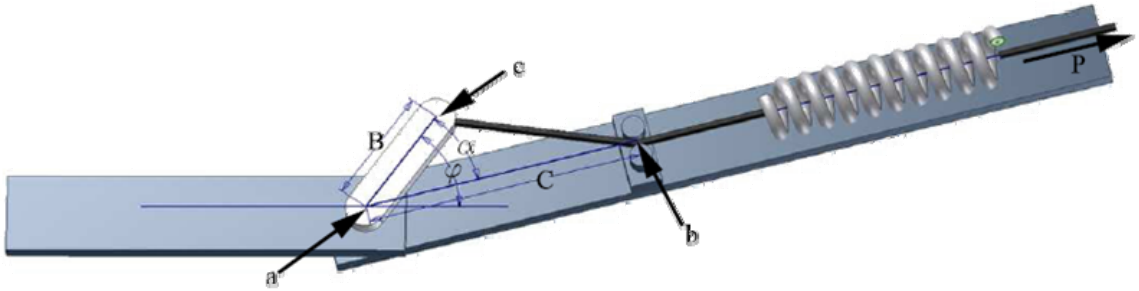


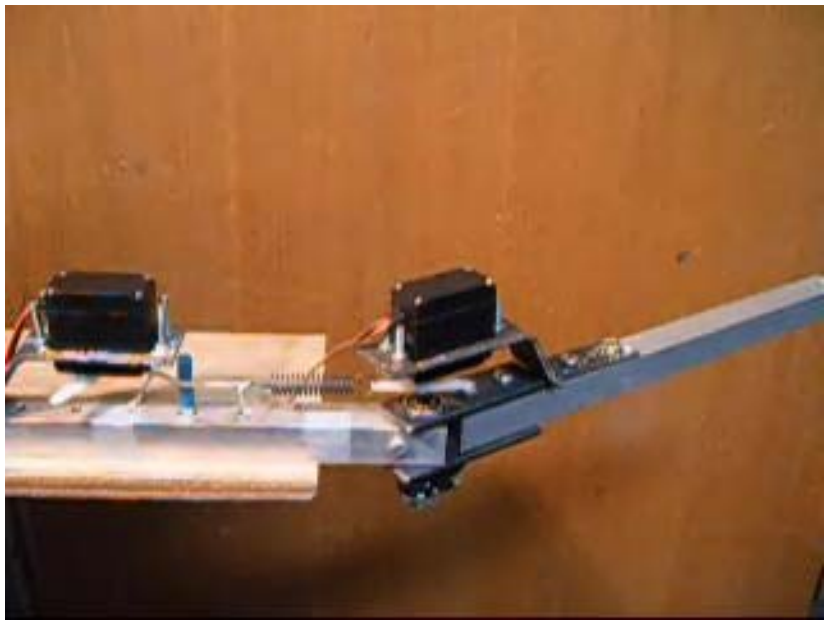
IPPAM

ALTACRO

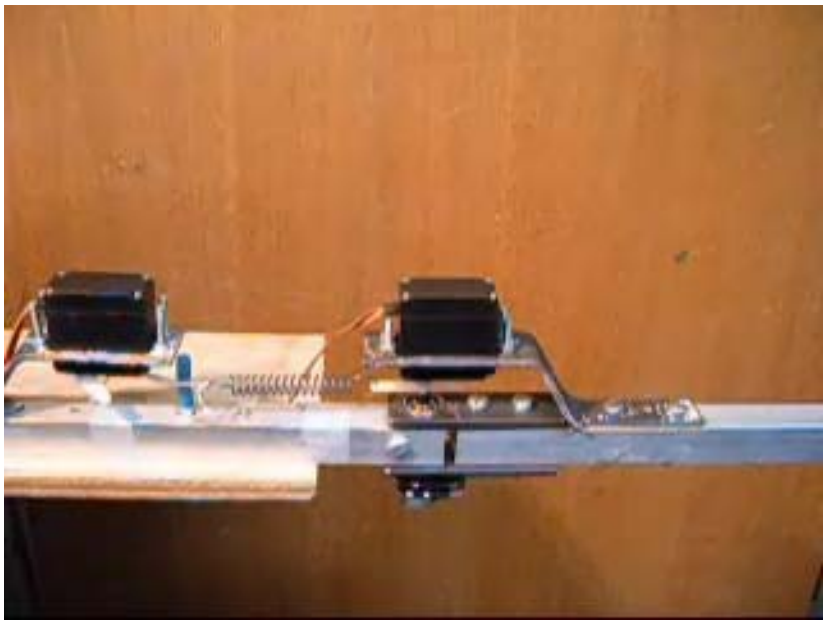
MACCEPA

(Mechanically Adjustable Compliance and Controllable Equilibrium Position Actuator)



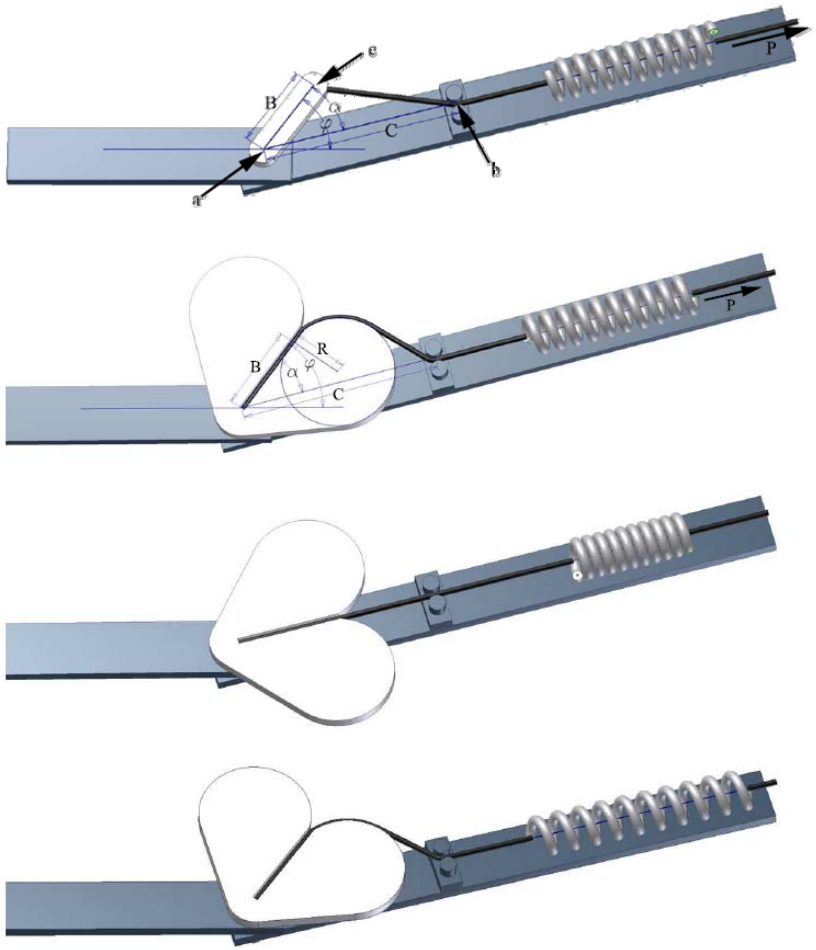


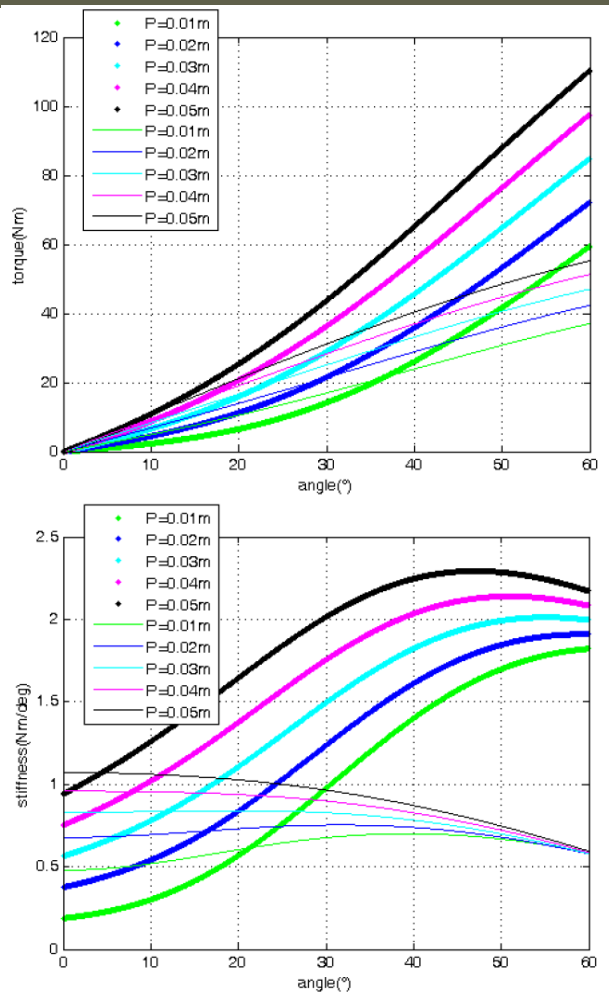
Controlling equilibrium position



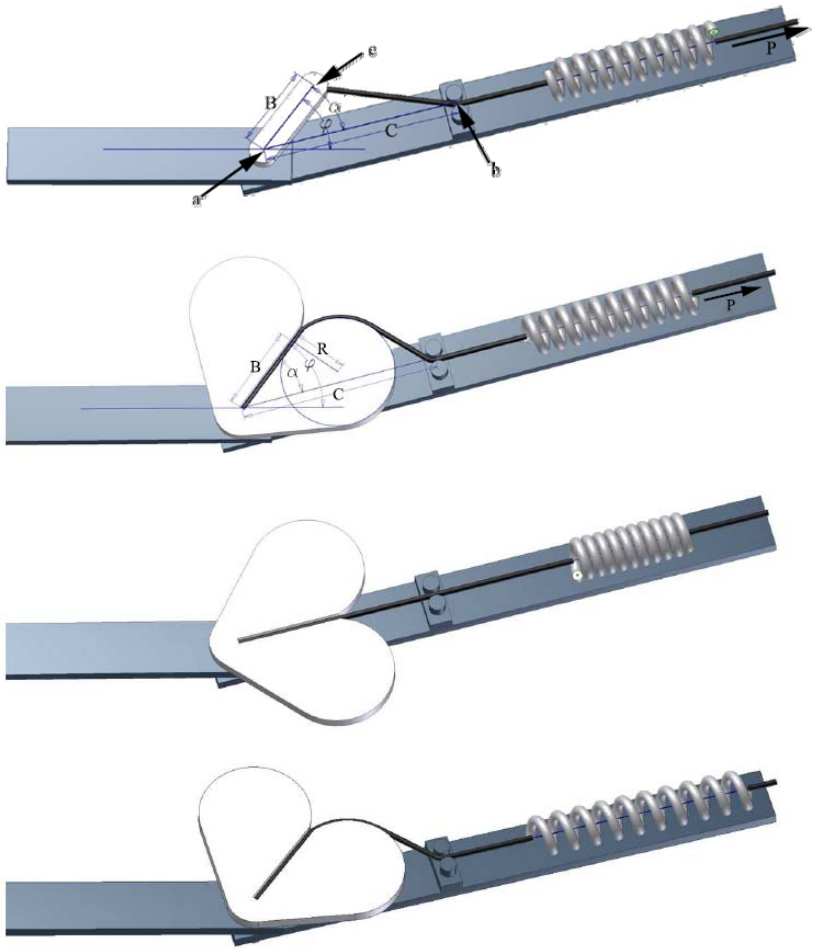
Controlling stiffness

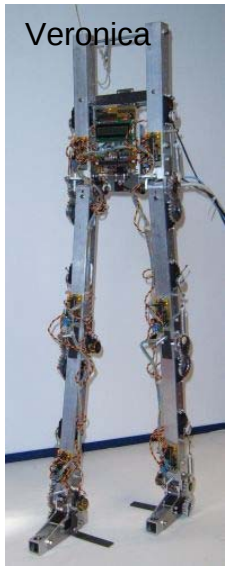
MACCEPA 1.0 + 2.0

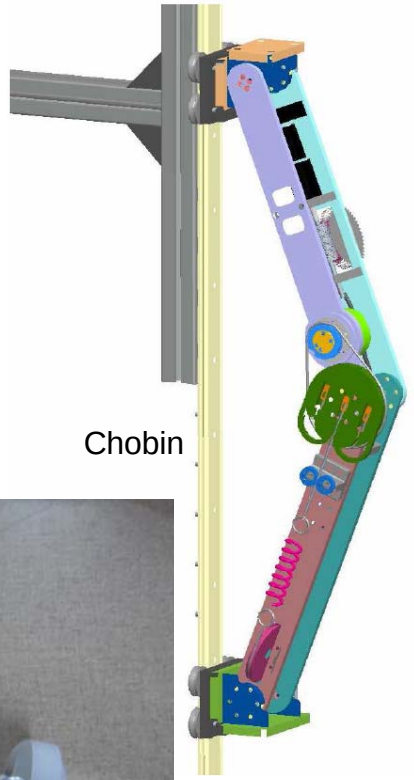


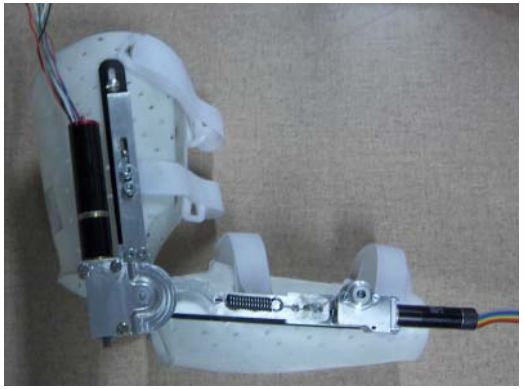


MACCEPA 1.0 + 2.0









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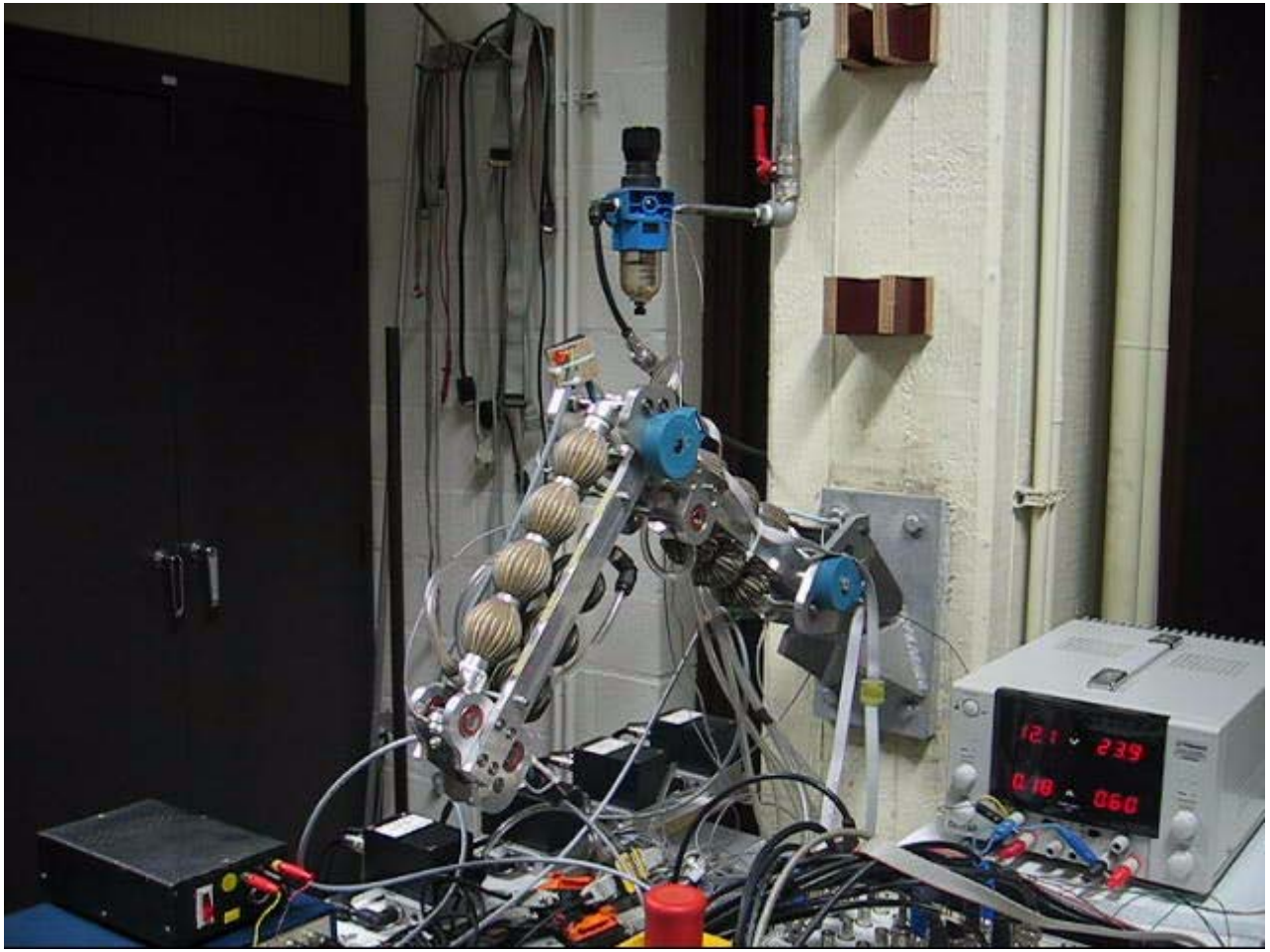
Safety - Motivation

- 2.5 kg
- Compliant actuation
- PID controller

Safe?



Safety - HIC

$$\mathrm{HIC} = \max_{\Delta t} \left\{ \Delta t \left(\frac{1}{\Delta t} \int_{t_1}^{t_2} \|\ddot{\boldsymbol{r}}_H\| \, dt \right)^{2.5} \right\}$$

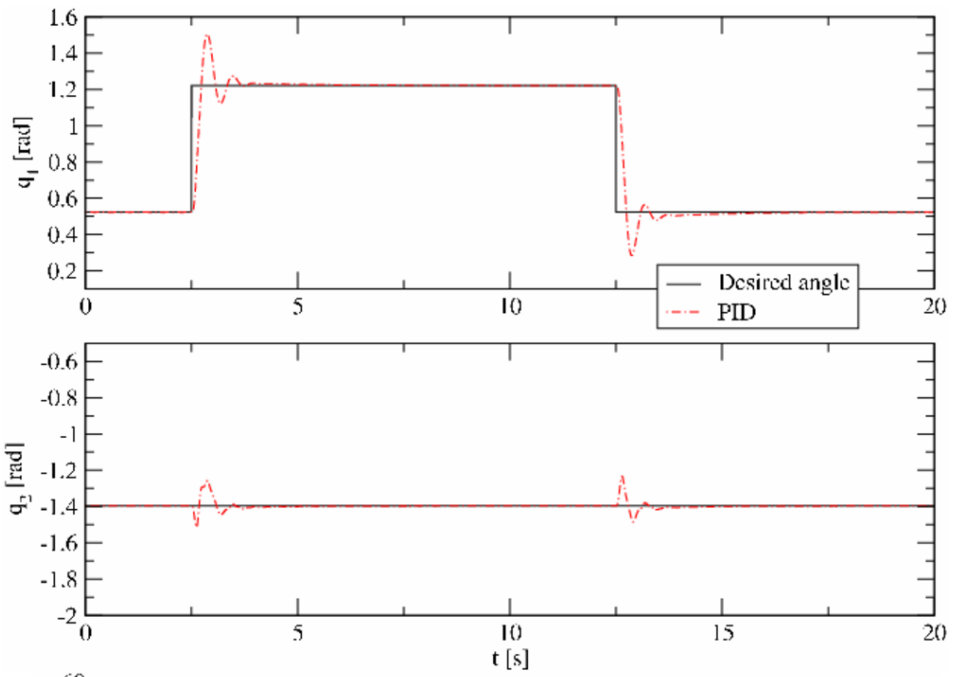
With:

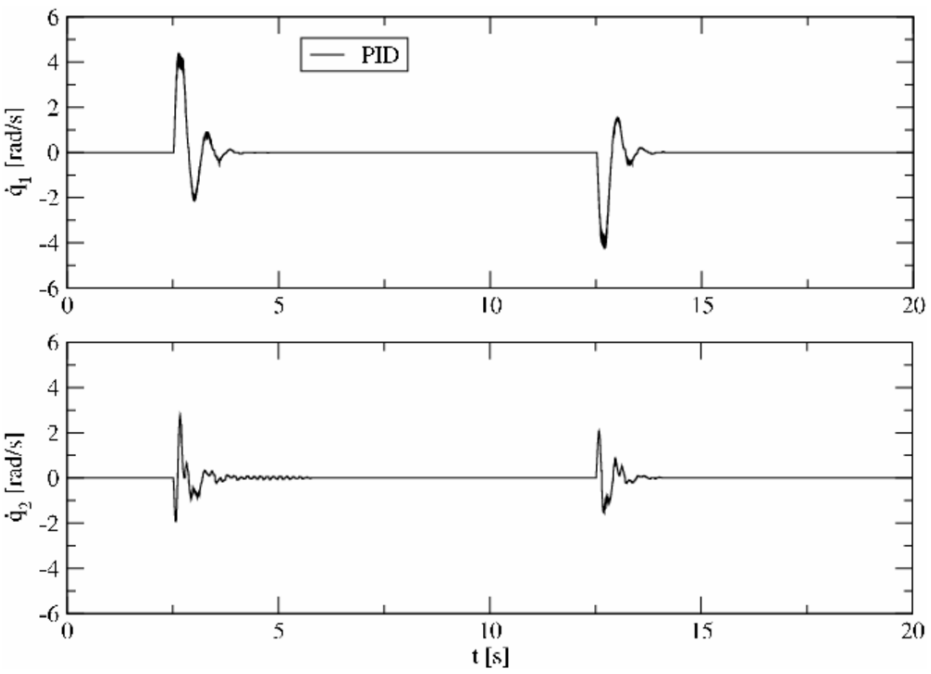
- $\Delta t = t_2 - t_1 \leq 36\,ms$
- $\|\ddot{\boldsymbol{r}}_H\|$ measured in *g*

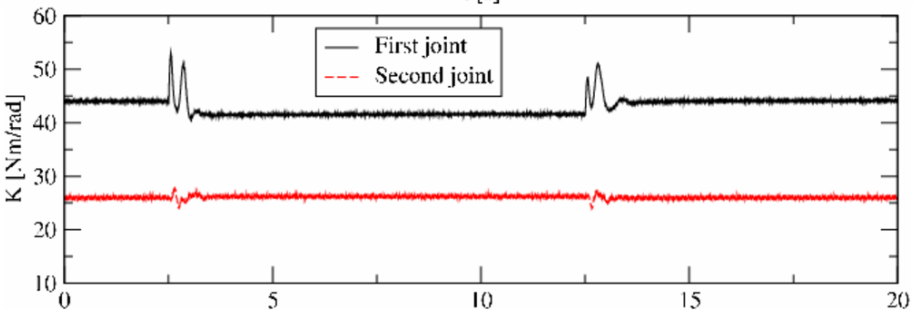
Introduced in robotics in:

- Zinn, M., Roth, B., Khatib O., and Salisbury, J. K.,
A New Actuation Approach for Human Friendly Robot Design,
The International Journal of Robotics Research, 23(4-5):379-398, 2004
- Bicchi, A. and Tonietti, G., Fast and Soft Arm Tactics: Dealing with the Safety-Performance Trade-Off in Robot Arms Design and Control,
IEEE Robotics and Automation Magazine 11(2):22-33, 2004

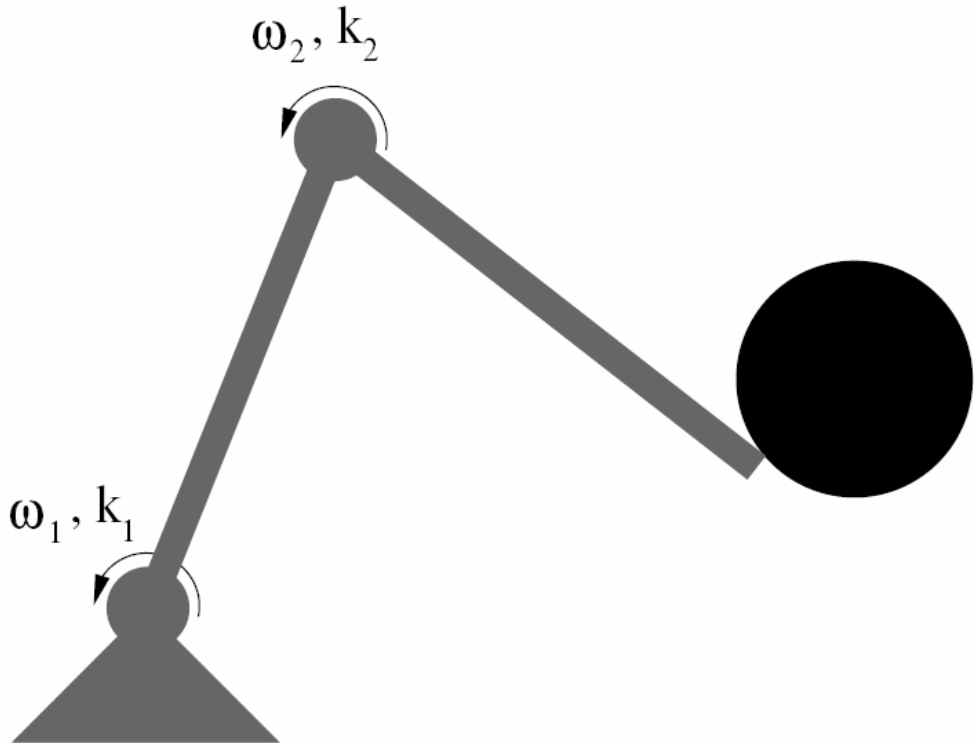
Safety – PID Step







Safety - Simulations



Hunt-Crossley contact model: Haddadin, S., Albu-Schäffer, A., and Hirzinger, G., Safety Evaluation of Physical Human-Robot Interaction via Crash-Testing. RSS2007.

Safety - Results

HIC: 4.81

F_{max}: 1524 N

- 2.5 kg
- Compliant actuation
- PID controller

Unsafe!

Overview

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Control

Issues:

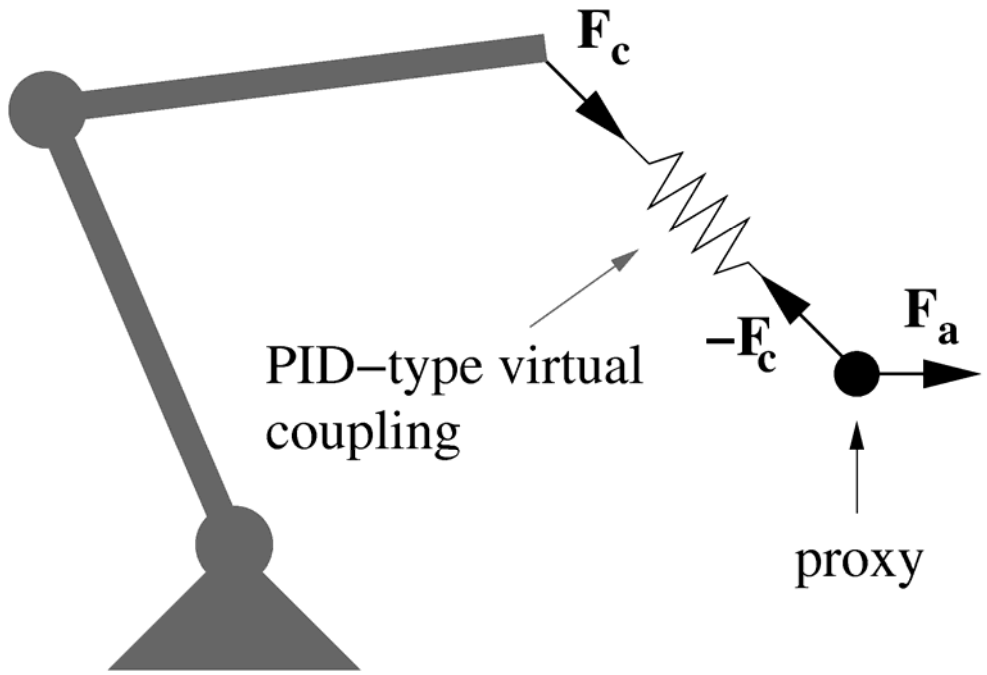
- Nonlinearity in actuators and pressure regulating valves
- Imprecise knowledge of actuator parameters (slenderness)
- Gauge pressure settling time
- Coupling between gauge pressures and link angles and angular velocities
- Compliance

Control - PID

PID + Gravity compensation

- Low gains: safe, very bad performance
- Higher gains: unsafe, acceptable performance
- Even higher gains: unstability

Proxy-Based Sliding Mode Control: Idea



$$\boldsymbol{\tau} = J^T \boldsymbol{F}_c$$

- No Chattering
- Safe response to large position errors

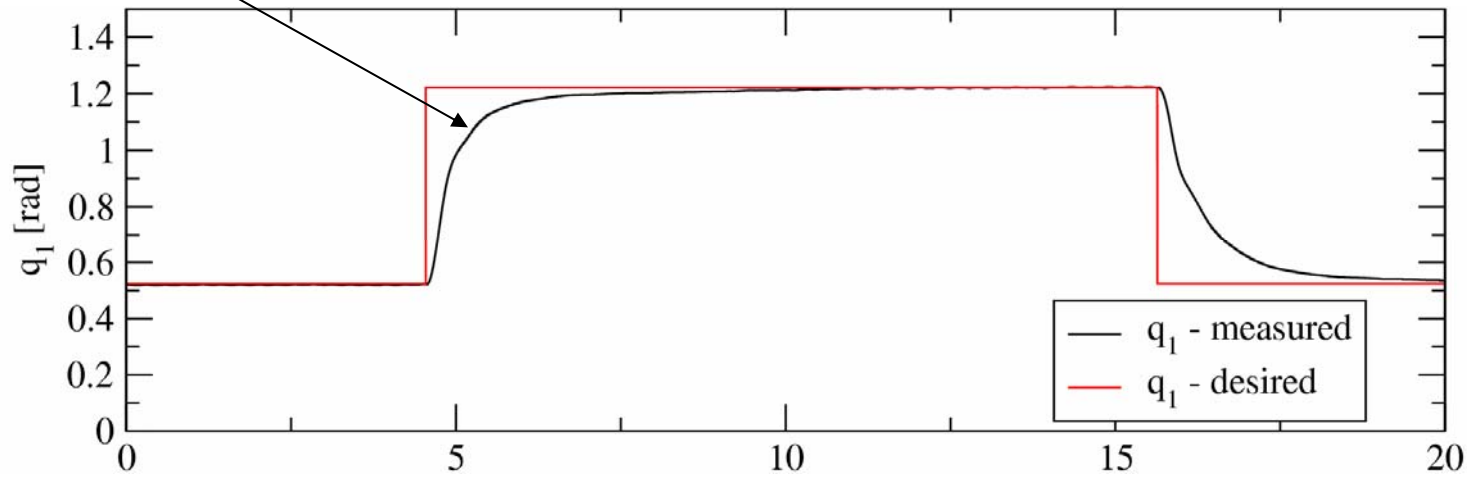
Ryo Kikuuwe and Hideo Fujimoto, "Proxy-based sliding mode control for accurate and safe position control", Proceedings of the 2006 IEEE International conference on Robotics and Automation, 2006, pp. 25-30.

Why?

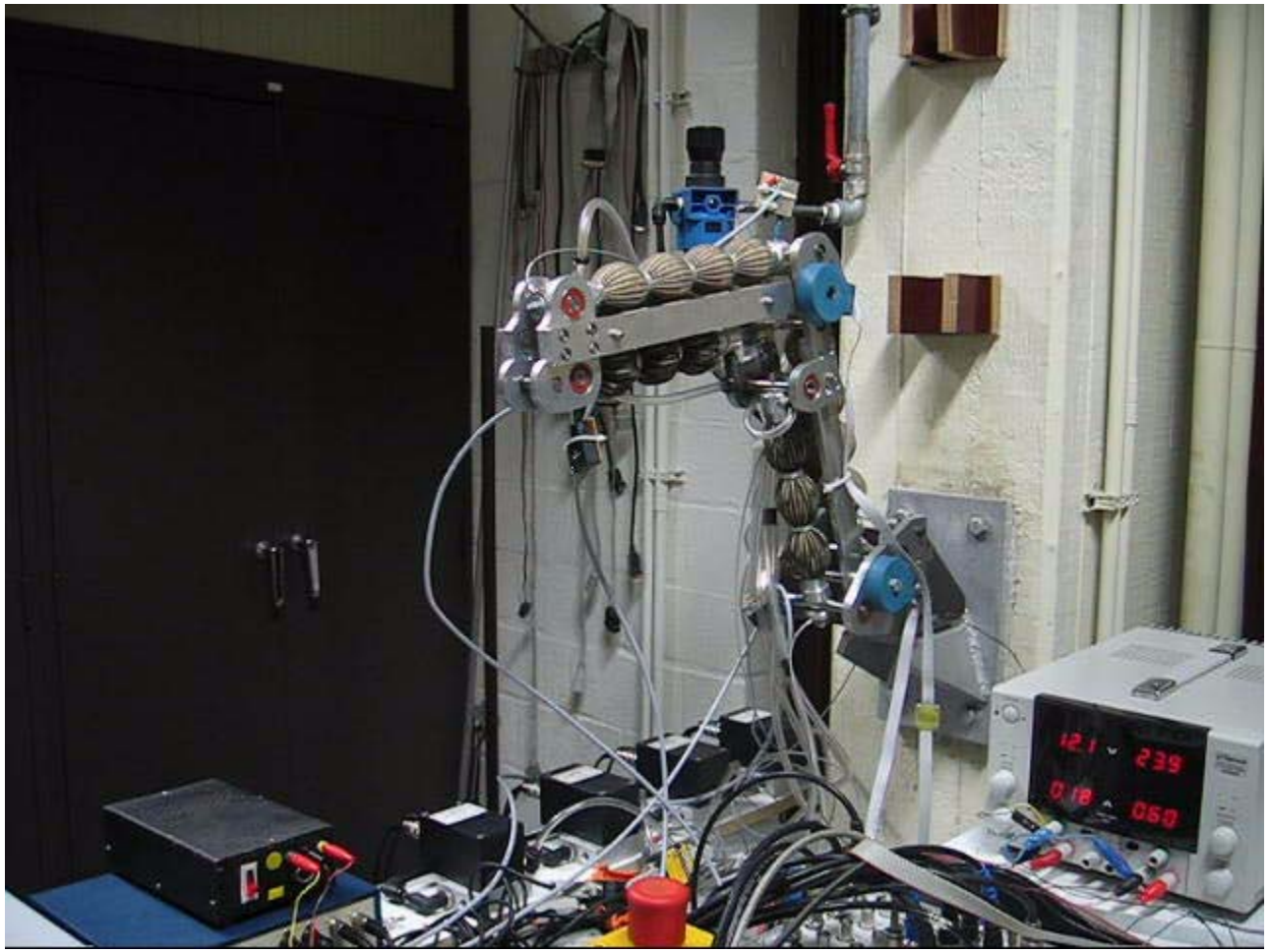
$$\boldsymbol{s} = 0 = (\boldsymbol{r}_d - \boldsymbol{r}_p) + \lambda (\dot{\boldsymbol{r}}_d - \dot{\boldsymbol{r}}_p)$$

$$\Rightarrow \dot{\boldsymbol{r}}_p = \frac{1}{\lambda} (\boldsymbol{r}_d - \boldsymbol{r}_p) + \dot{\boldsymbol{r}}_d$$

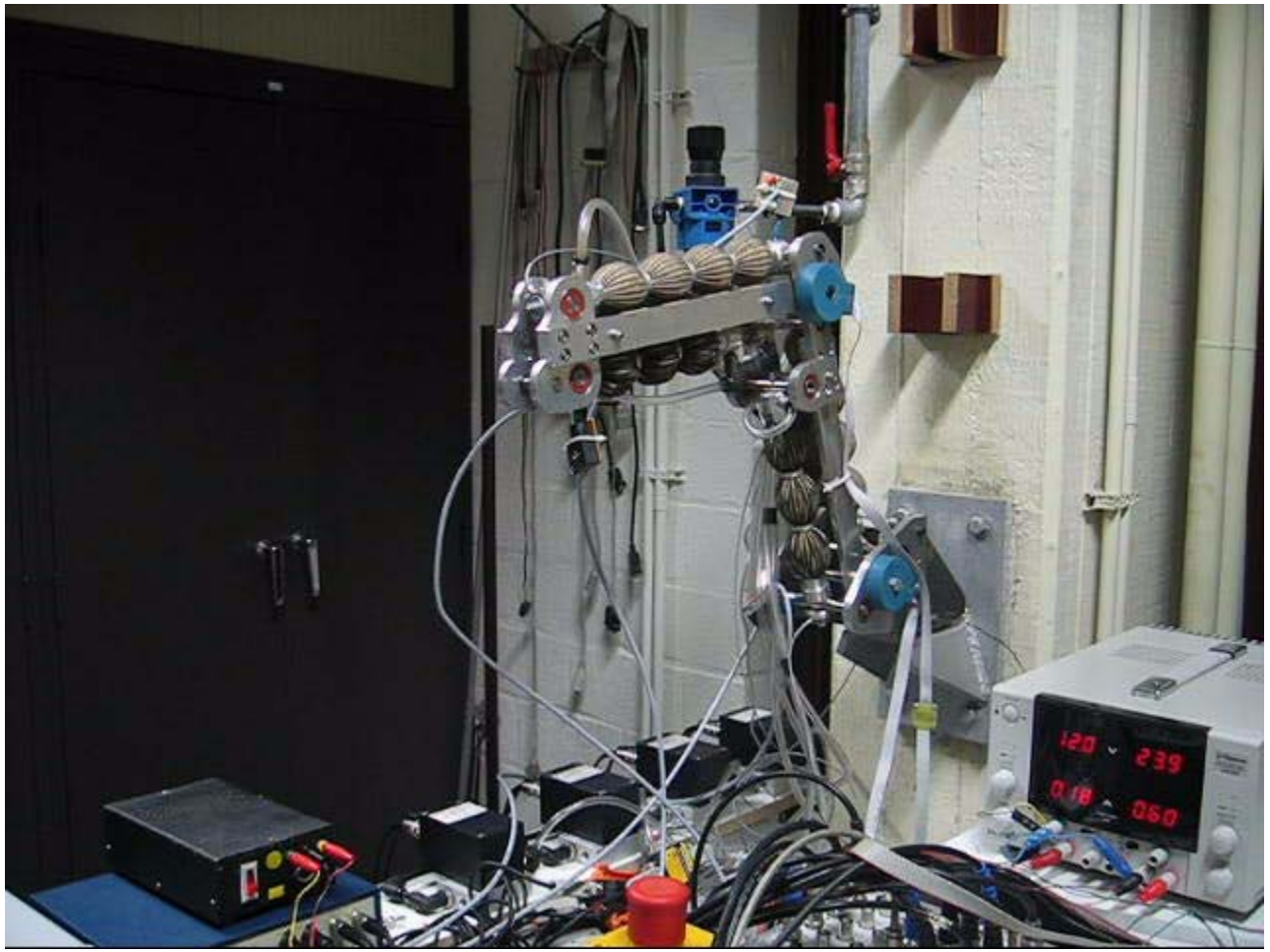
Overdamped respons



Step response (λ=0.4)



Step response (λ=0.8)



Safety

PID:

HIC: 4.81

F_{max}: 1524 N

Unsafe!

PSMC:

(λ = 0.4)

HIC: 0.29

F_{max}: 375 N

safe!

PSMC:

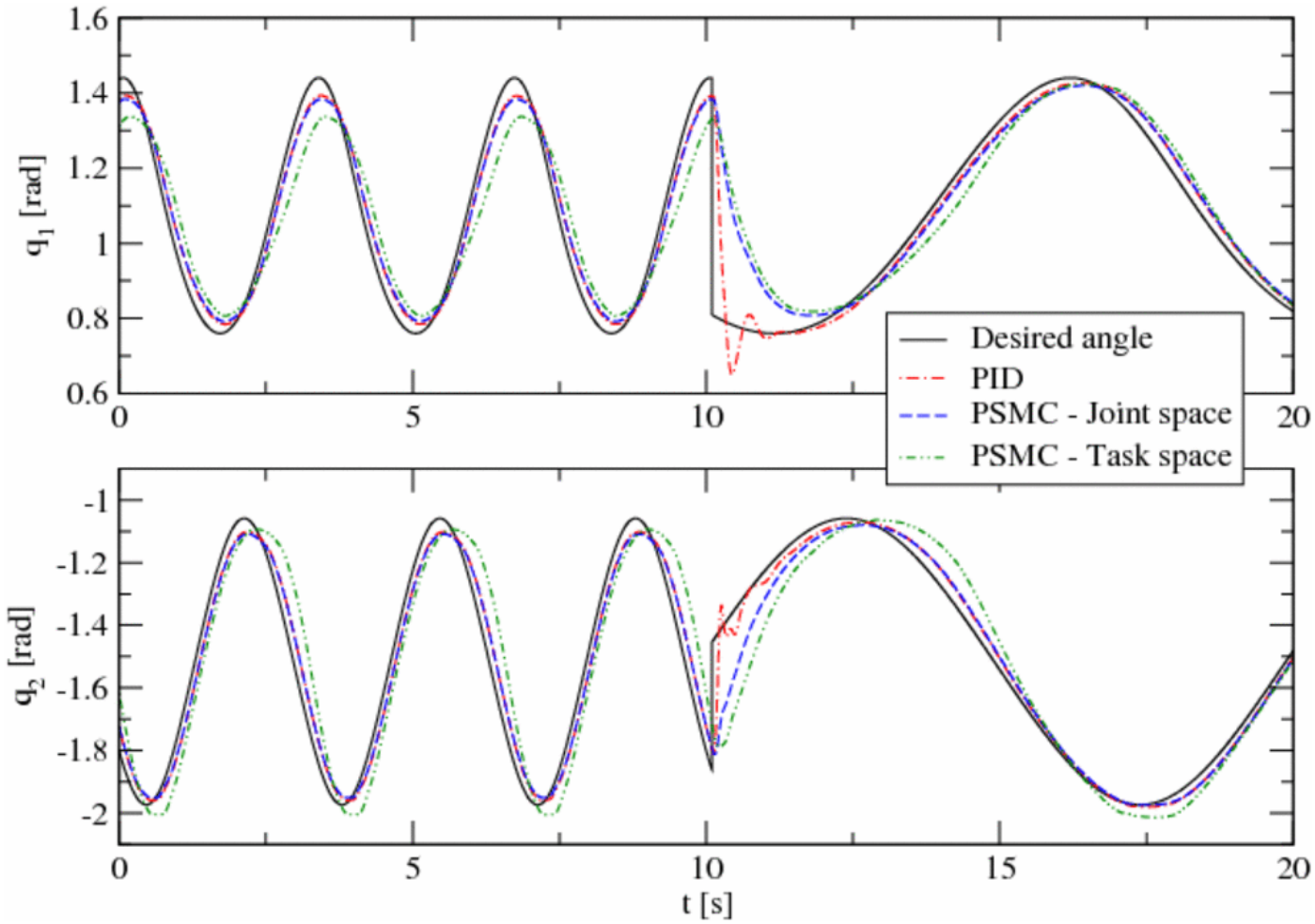
(λ = 0.8)

HIC: 0.05

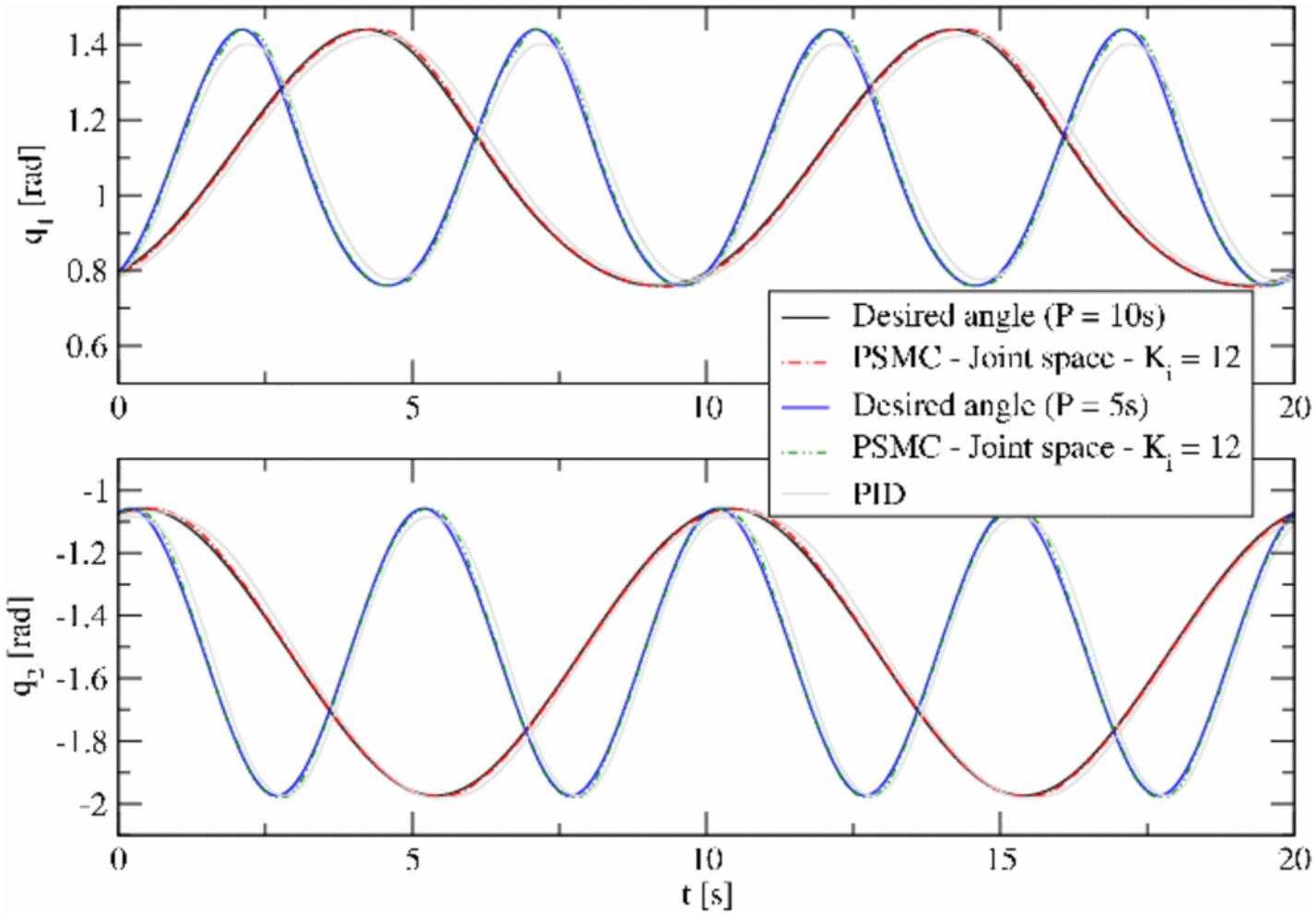
F_{max}: 170 N

safe!

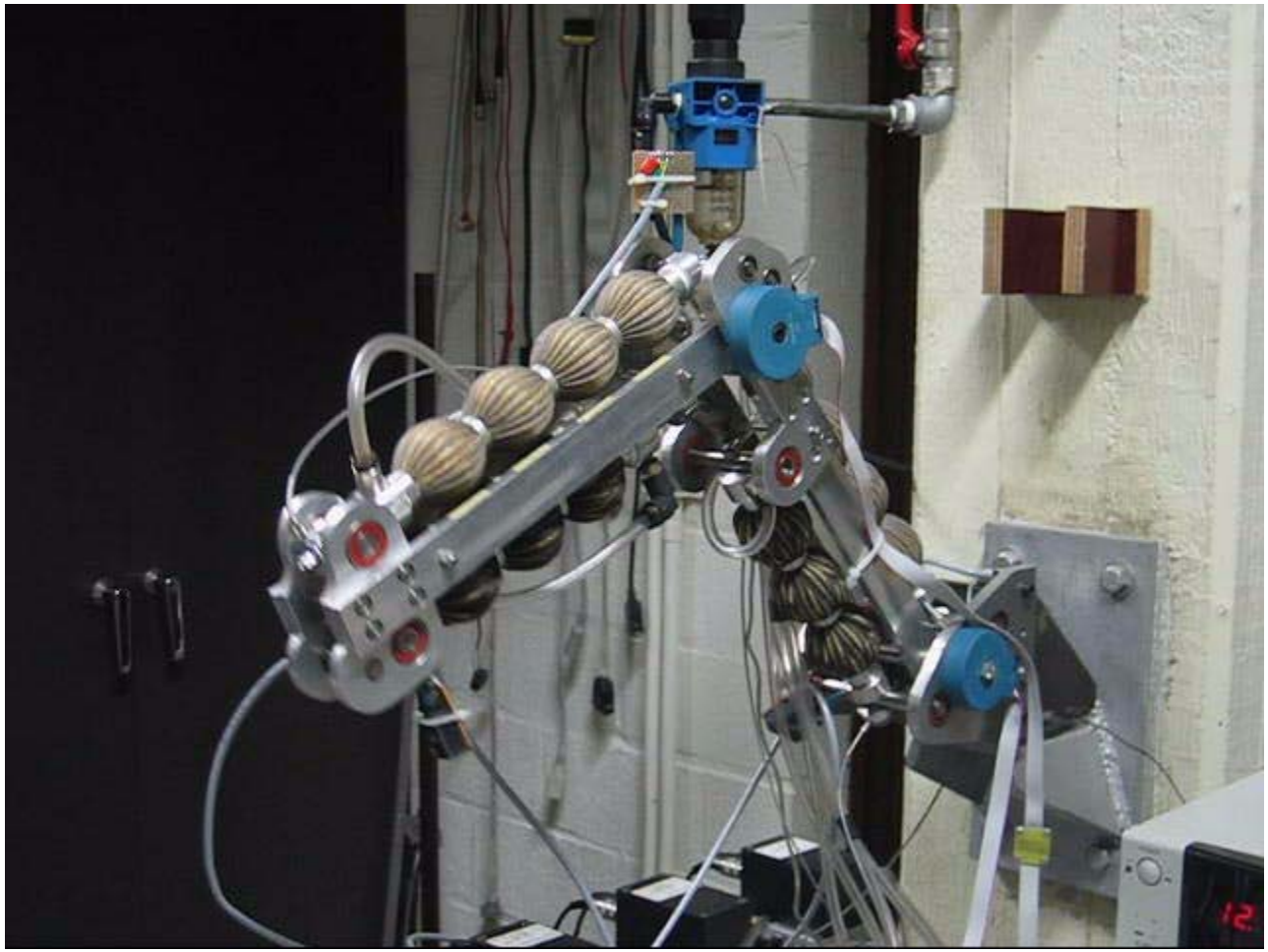
Tracking Performance



Tracking Performance



Safe hardware + controller



Conclusion

- Hardware safety features alone are not enough
  - System unsafe when under PID control
- Control has to be designed with safety in mind
- PSMC improves safety and provides good tracking performance for pneumatic muscle systems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Design and Control Stategies of Robotic Stiffness Actuators
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Thank you!