EESC · USP
Escola de Engenharia de São Carlos
Universidade de São Paulo

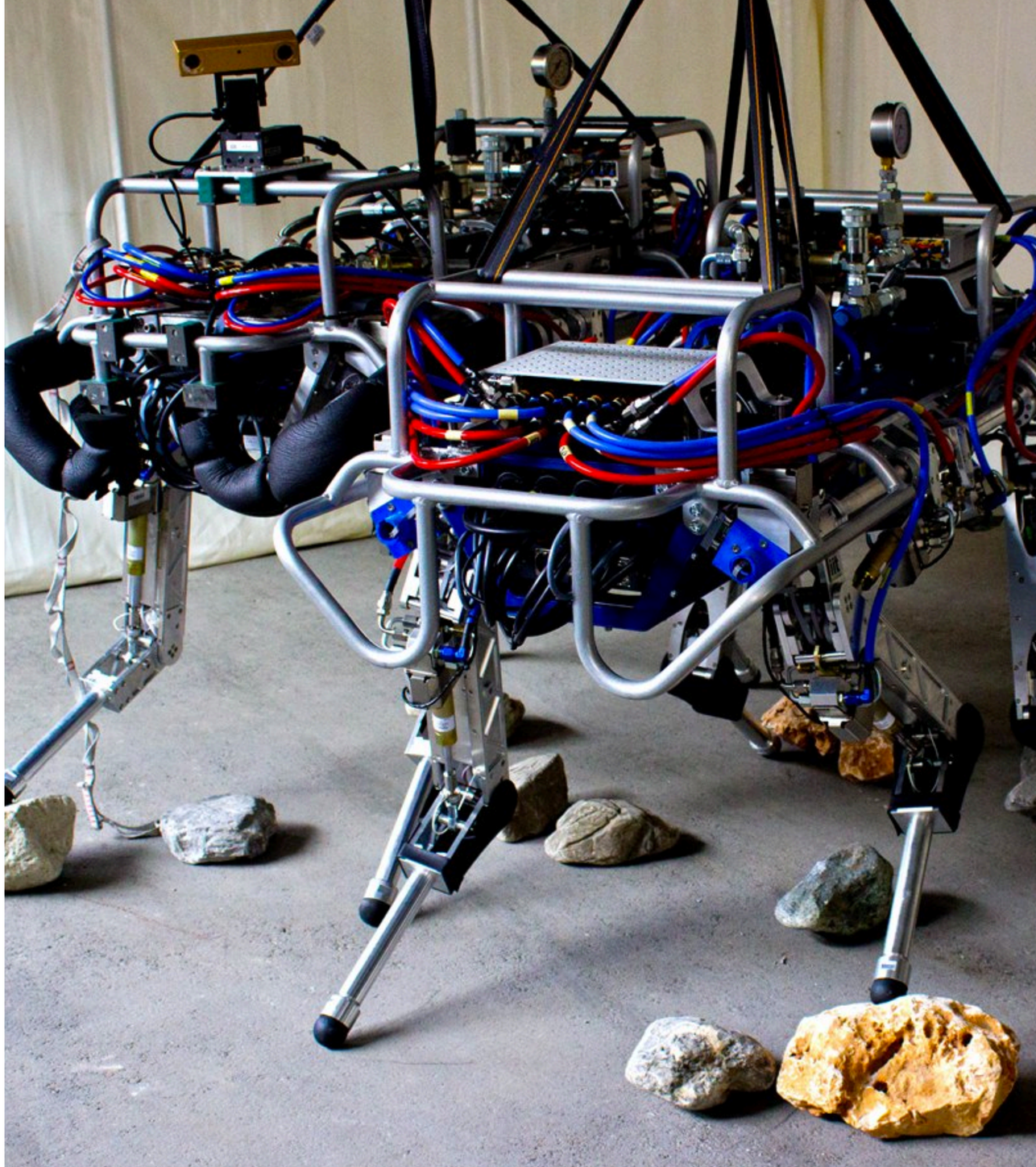
ARC Lab
Advanced Robotics Control Laboratory

SEM5950 - SEM0586
Legged Robots

Aula #7: Controladores de impedância

Prof. Dr. Thiago Boaventura
tboaventura@usp.br

São Carlos, 09/10/20

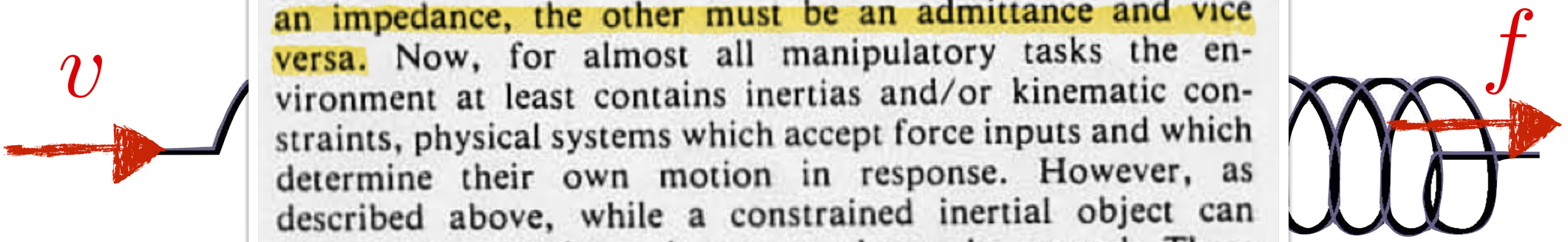


Entrada/Saída ⇔ Causalidade

Impedance Control: An Approach to Manipulation:

Part I—Theory

The most important consequence of dynamic interaction between two physical systems is that one must physically complement the other: Along any degree of freedom, if one is an impedance, the other must be an admittance and vice versa. Now, for almost all manipulatory tasks the environment at least contains inertias and/or kinematic constraints, physical systems which accept force inputs and which determine their own motion in response. However, as described above, while a constrained inertial object can always be pushed on, it cannot always be moved; These systems are properly described as admittances. Seen from the manipulator, the world is an admittance.



[Hogan, 1985]

controlar **impedância** não é controlar **força**…

… nem controlar **posição**…

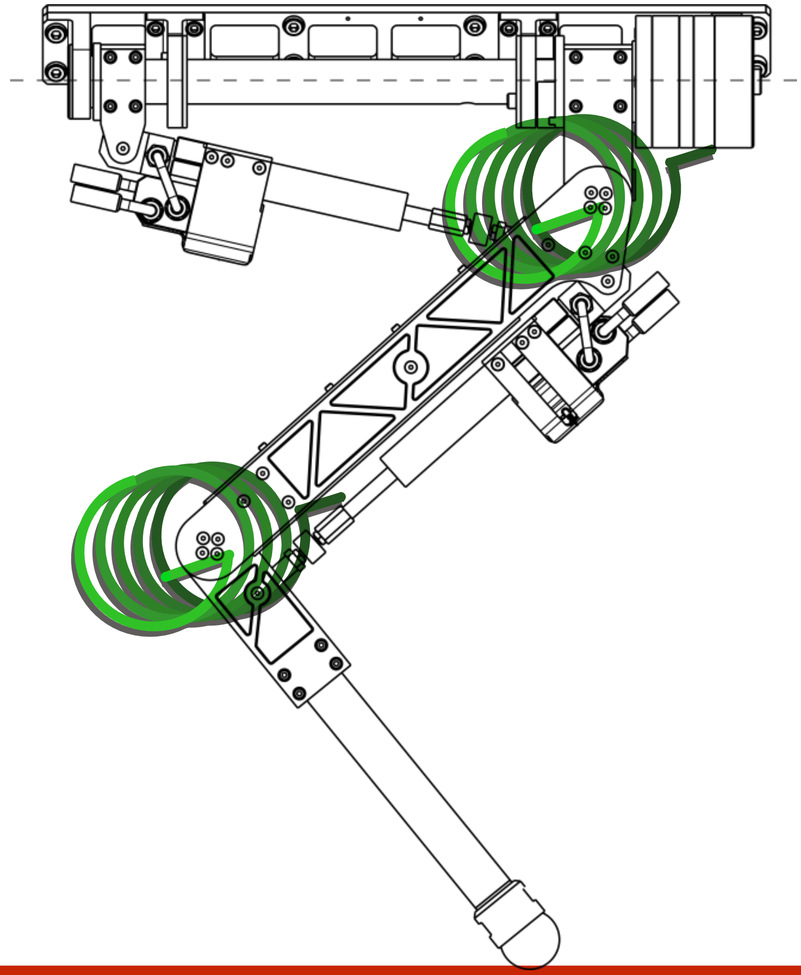
mas sim a **relação** entre eles.

Controle de impedância

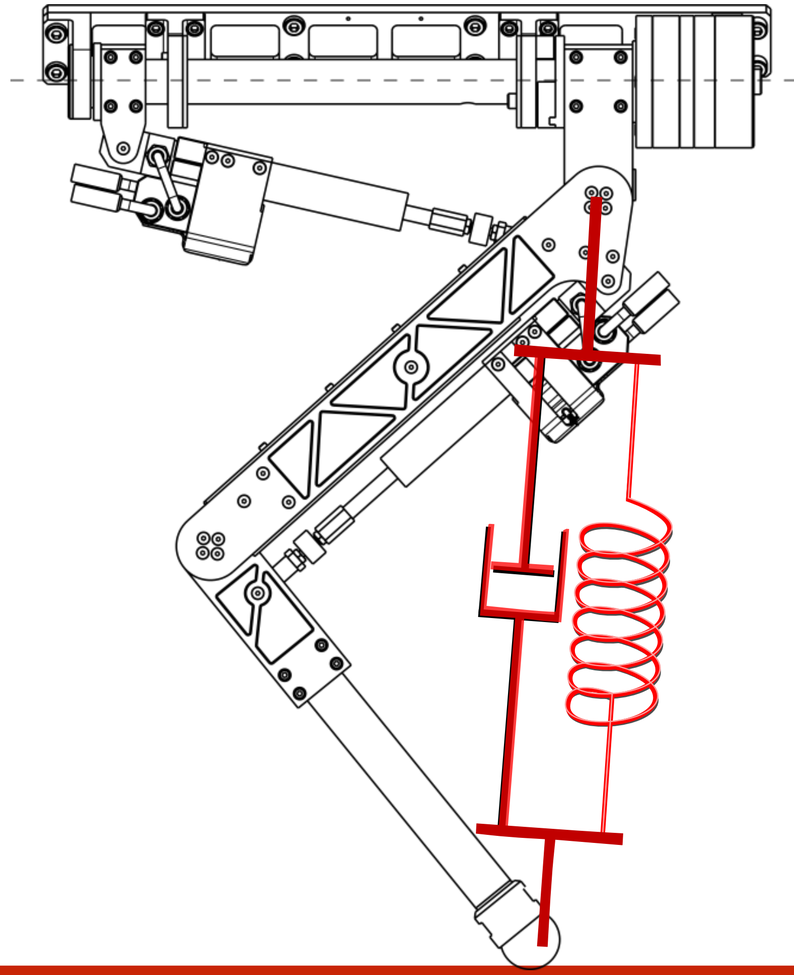
$$F = M\ddot{x} + B\dot{x} + Kx$$

Inércia **Amortecimento** **Rigidez**

Espaço de juntas vs. Espaço de tarefas

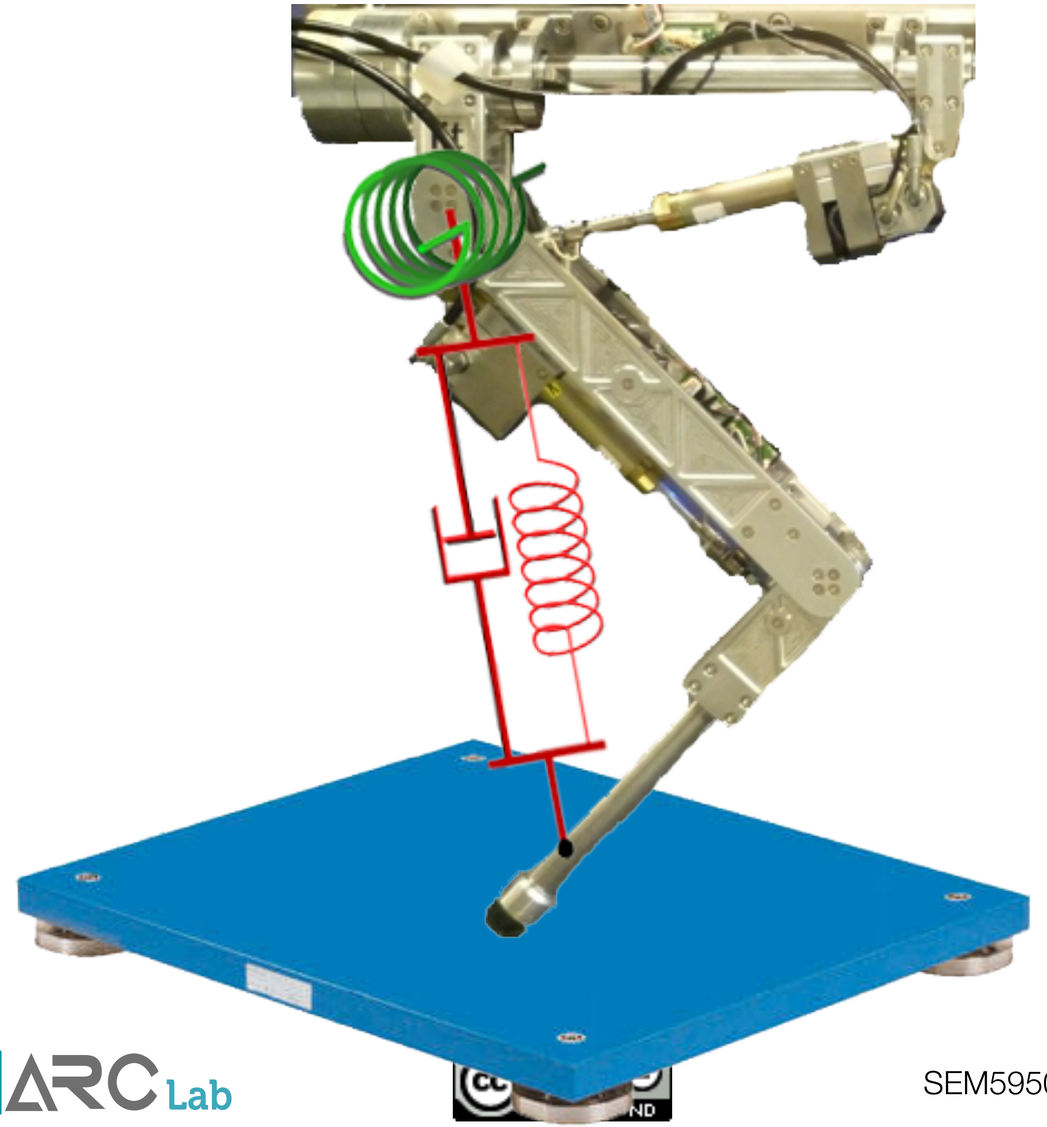


vs.



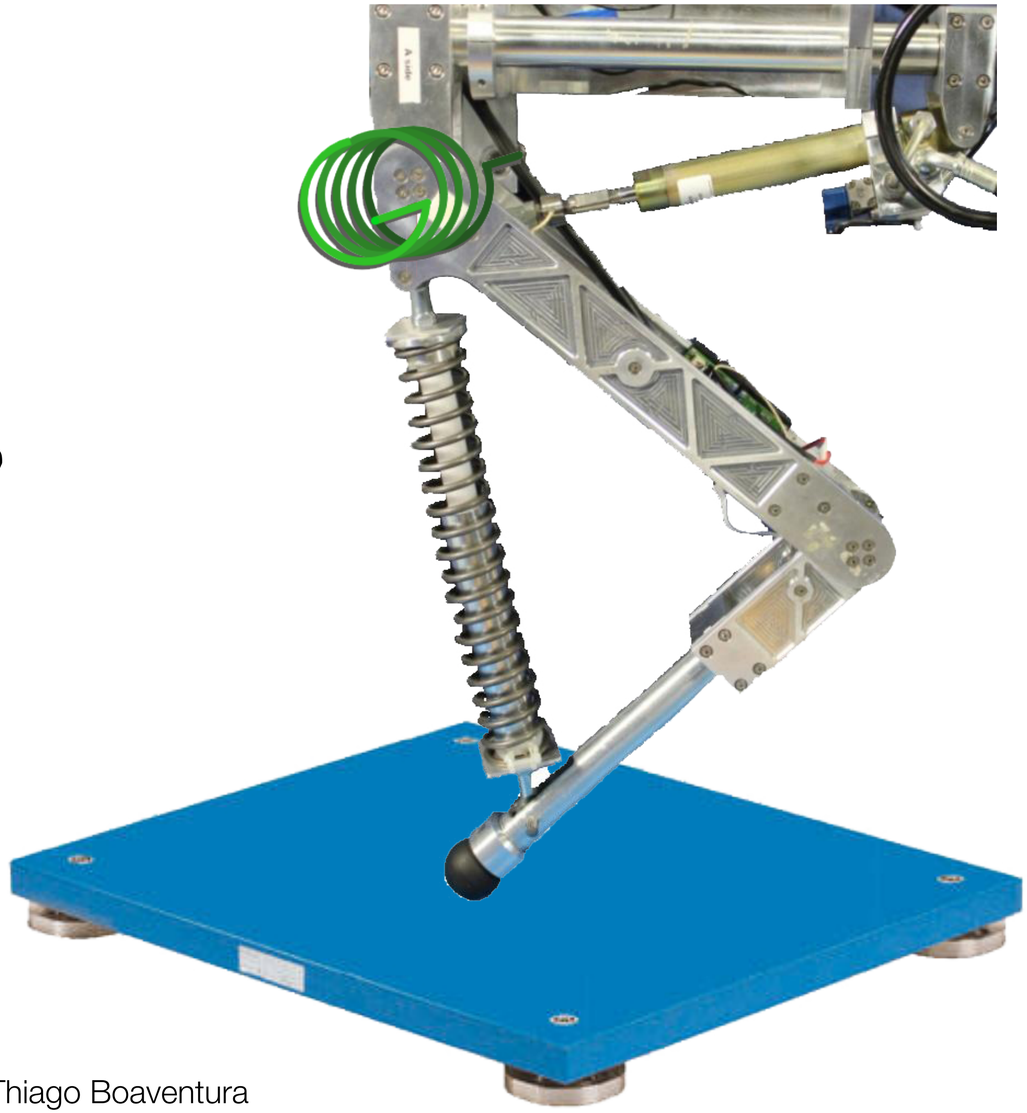
Impedância ativa

(espaço de tarefas)



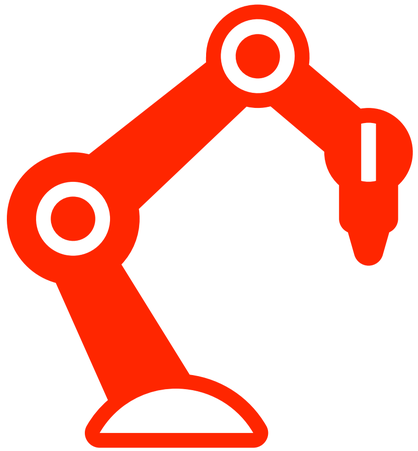
VS.

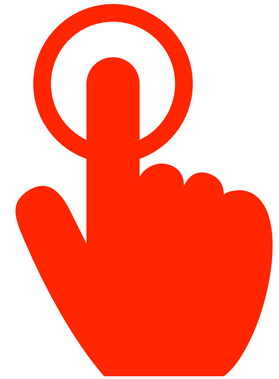
Impedância passiva



Formas de se controlar a impedância de um robô

τ



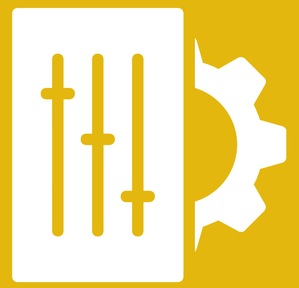


controle das juntas

configuração cinemática

pontos de contato

Conteúdo



- Controle de admitância
- Controle de impedância

Controle de impedância

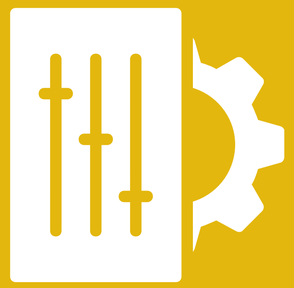
- Realimentação intrínseca da velocidade e sua compensação

Controle de força

- Bibliografia

Conclusão

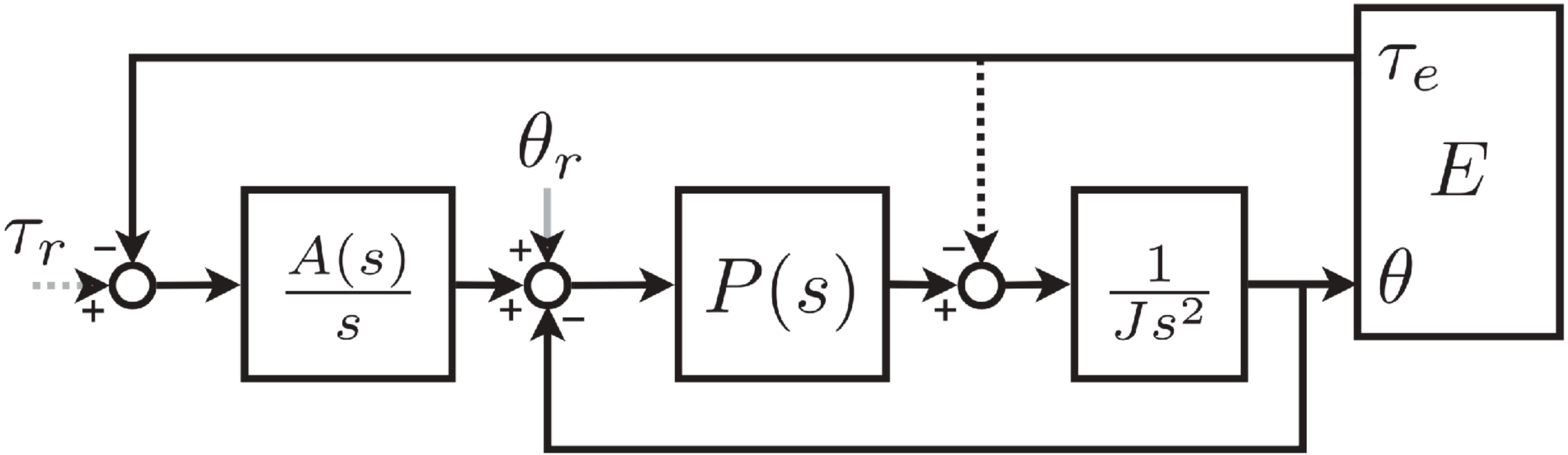
Conteúdo



- Controle de admitância
- Controle de impedância

Controlador de admitância

“Controlador de impedância baseado em posição”



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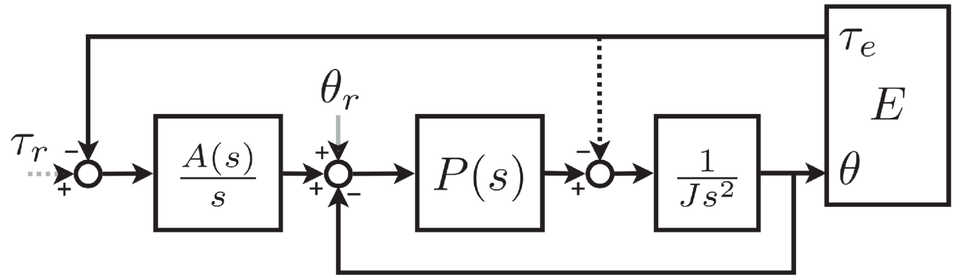

	Impedance	Admittance
Transfer function definition	$z(s) = \frac{f(s)}{v(s)}$	$a(s) = \frac{1}{z(s)} = \frac{v(s)}{f(s)}$
Spring	k/s	s/k
Mass	ms	$1/ms$
Damper	b	$1/b$
Spring-mass-damper	$ms + b + k/s$	$\frac{1}{ms+b+k/s}$

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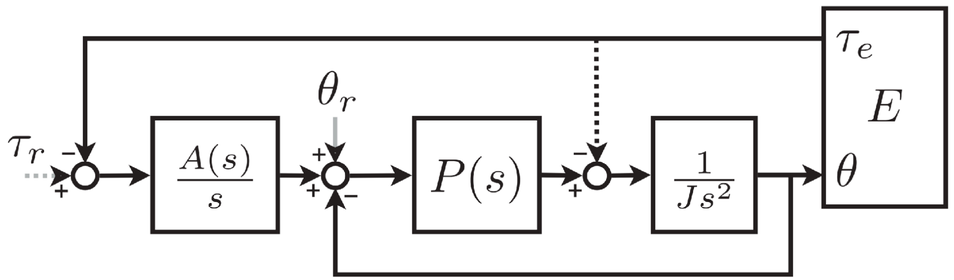

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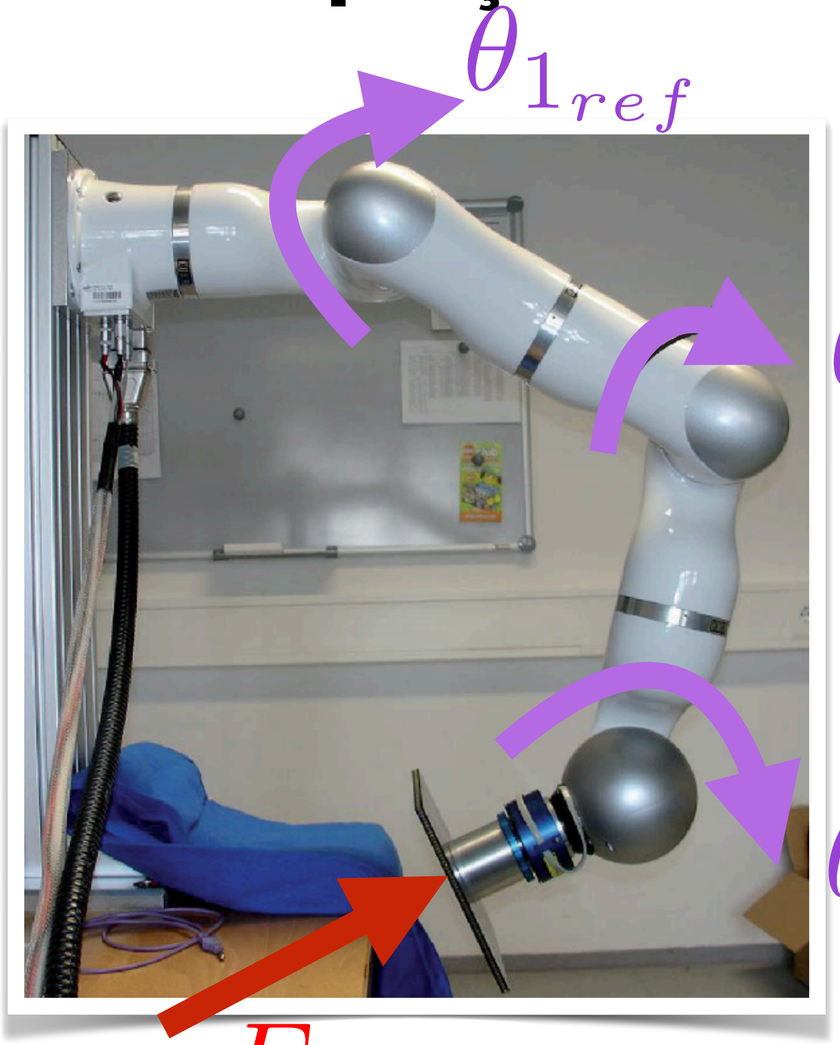

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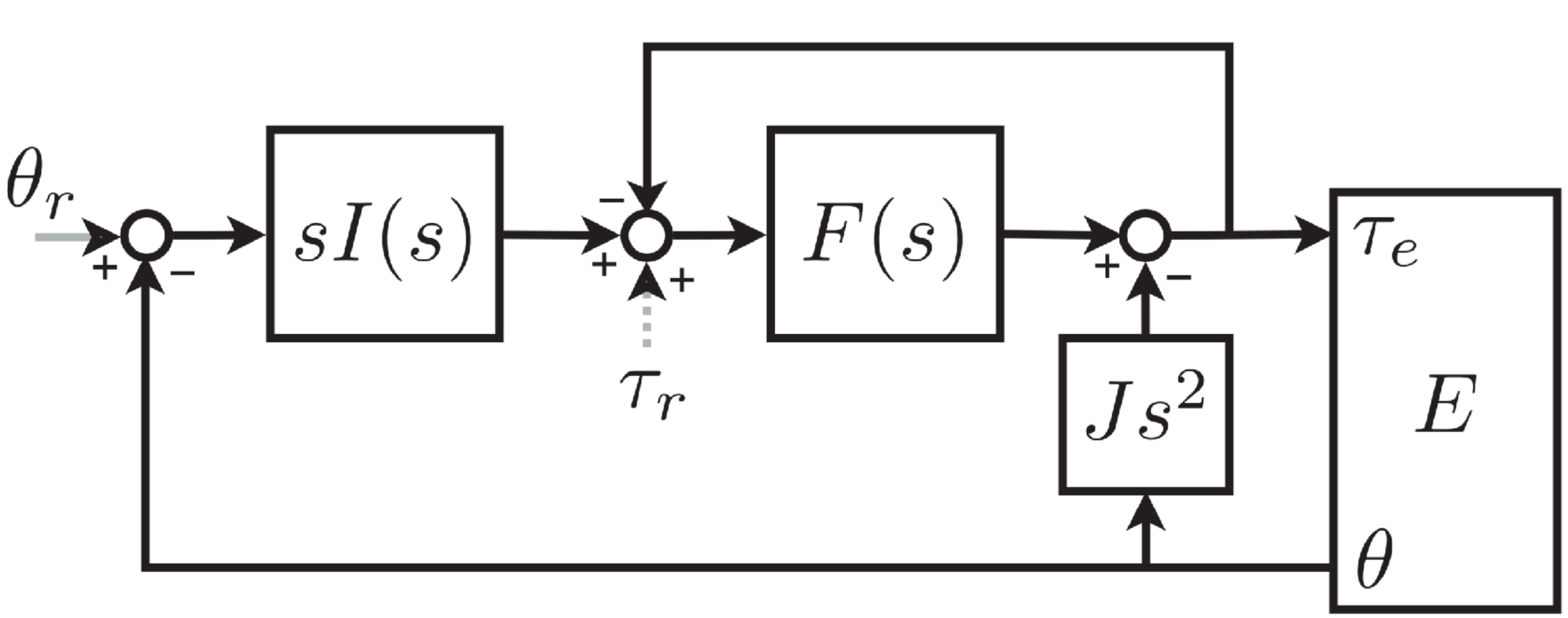

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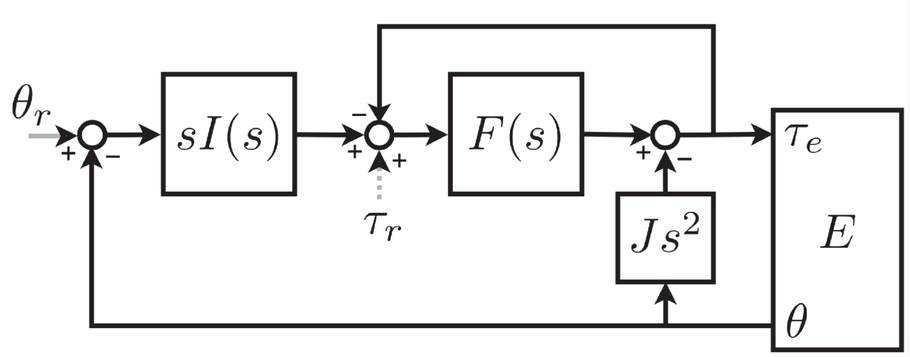

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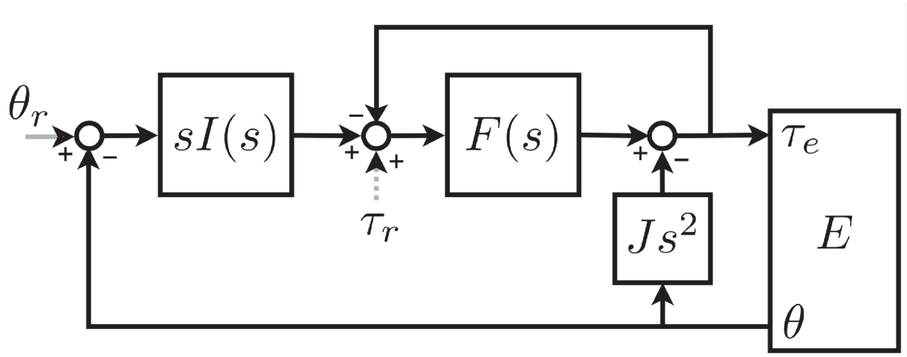

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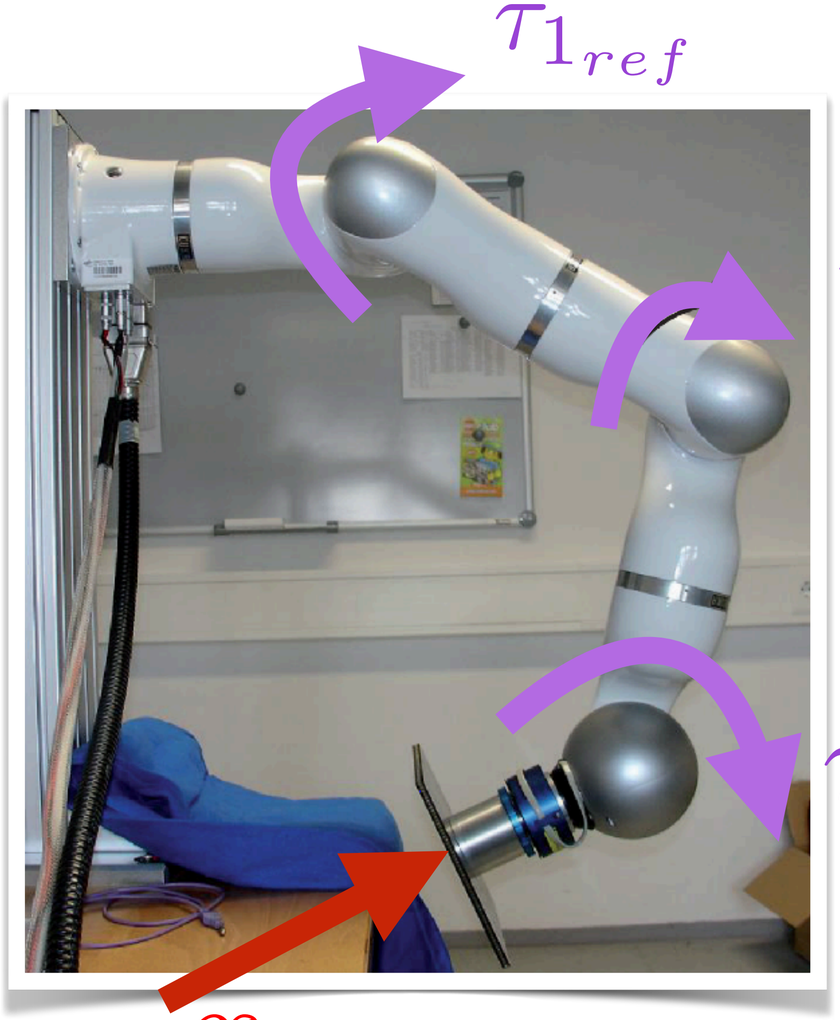

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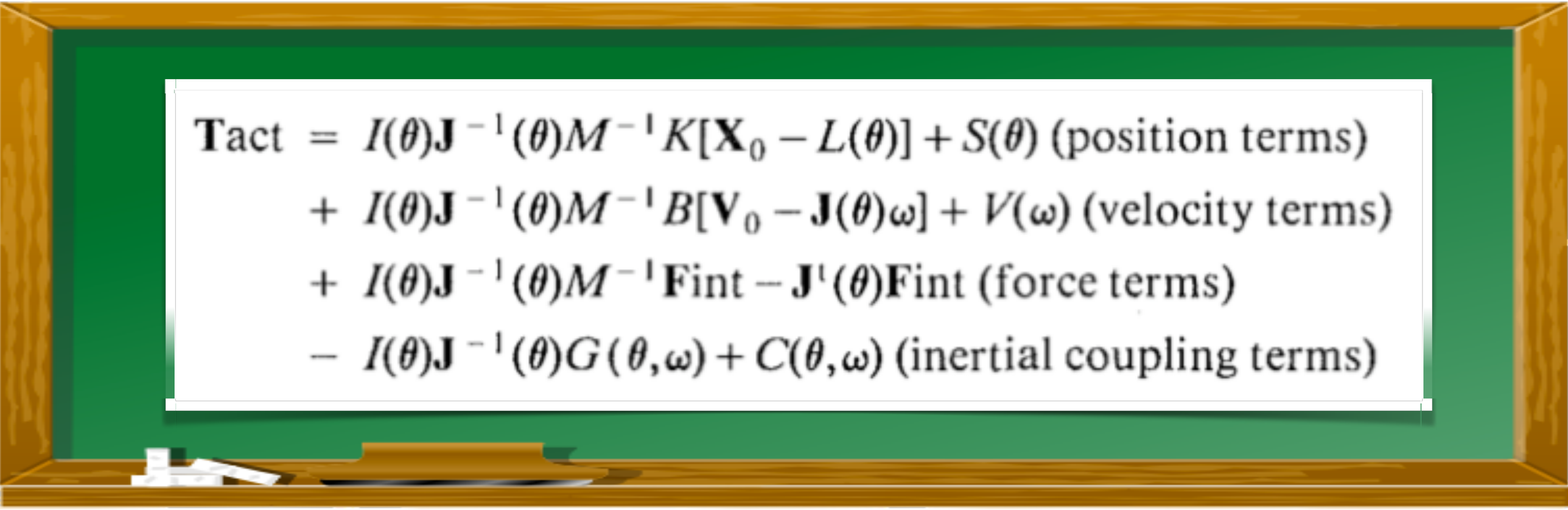
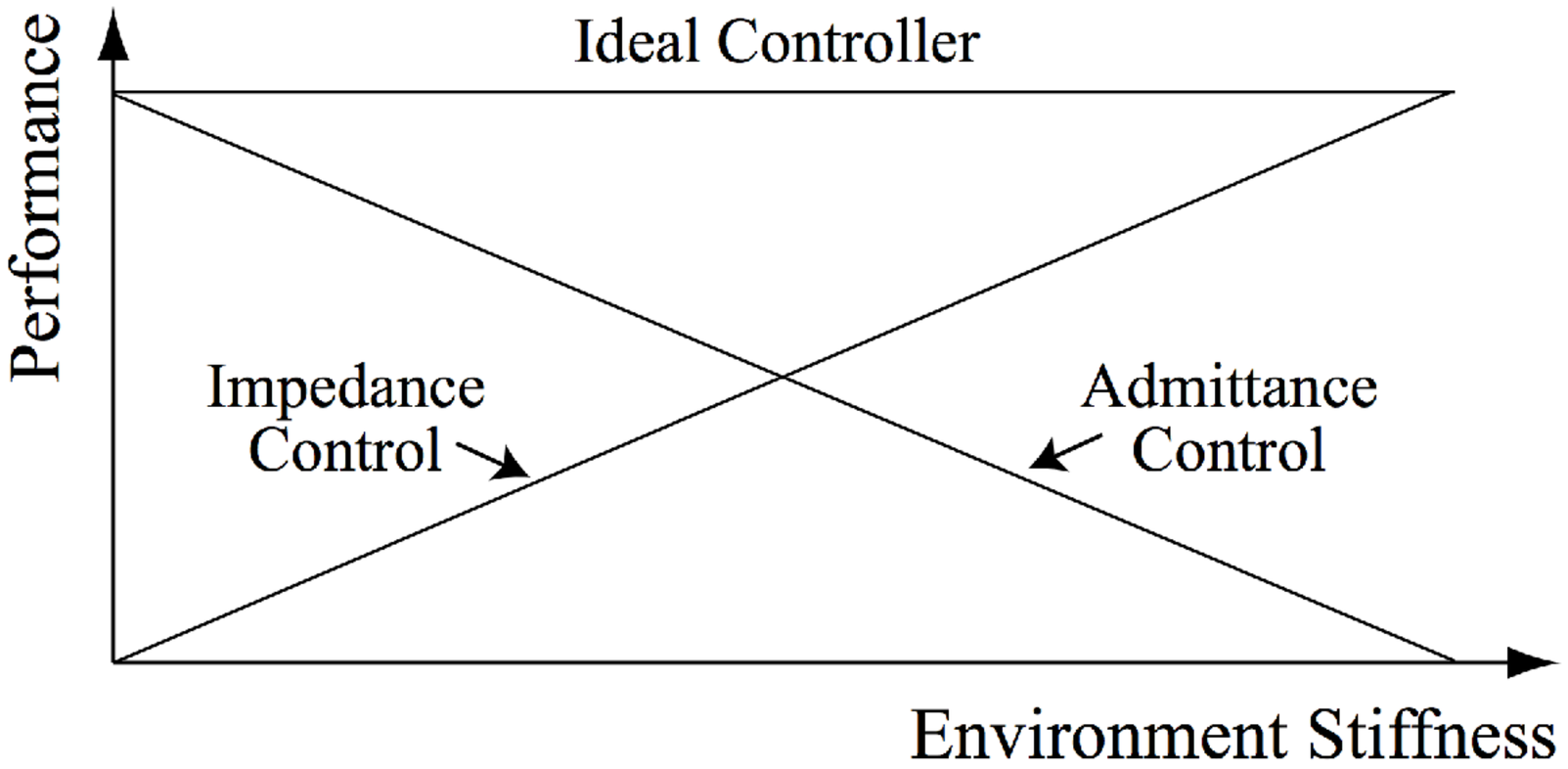


Hogan, N. (1985). Impedance control: An approach to manipulation: Part II—Implementation. journal of dynamic systems, measurement, and control, 107(1), 8-16.


Qual arquitetura
escolher?

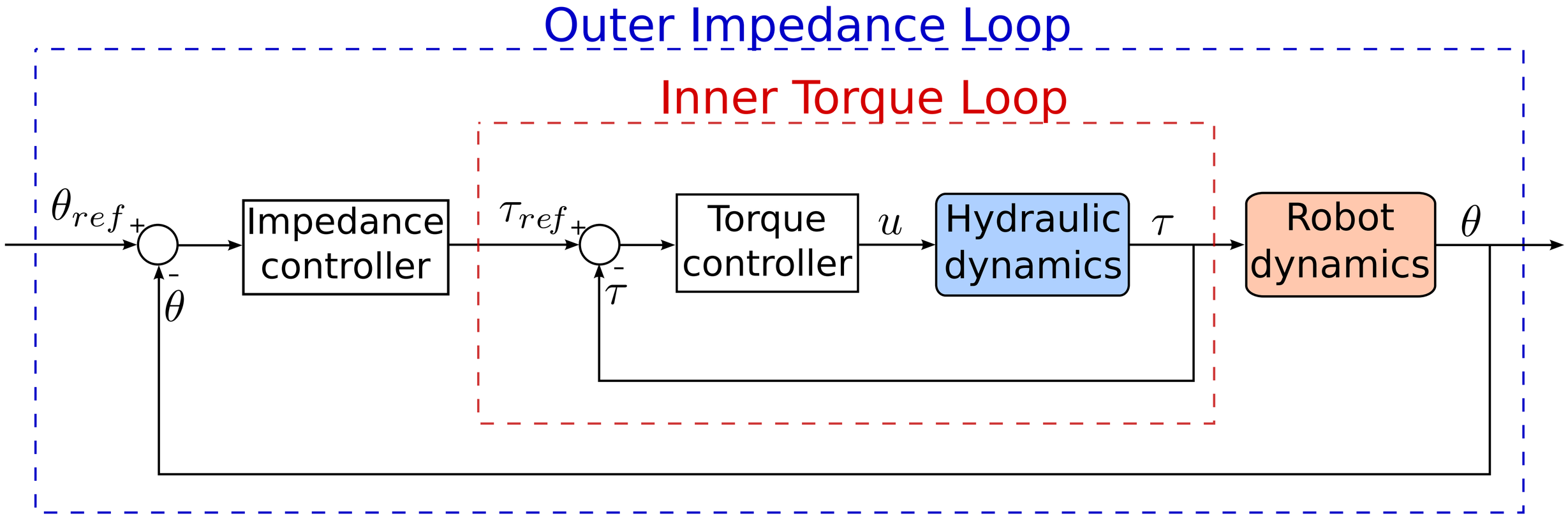
Prós e contras



Prós e contras

	Admittance	Impedance	
	Explicit	Implicit	Explicit
Good for	rendering high impedance [46] in a low impedance environment [47]	rendering low impedance [46] in a high impedance environment [47]	rendering low impedances in a high impedance environment
Adv.	robustness [48]	accuracy [48], full-body compliance	accuracy
Disadv.	low accuracy because inner position loop dynamics	it needs high torque motors and accurate robot model	stability issues of force control [31], [36], fast actuator needed [52]
Mechanics	it works good also on nonbackdrivable motors	the lighter the better. Backdrivability is necessary	softness and lightweightness can improve robustness. Backdrivability is not necessary but helps

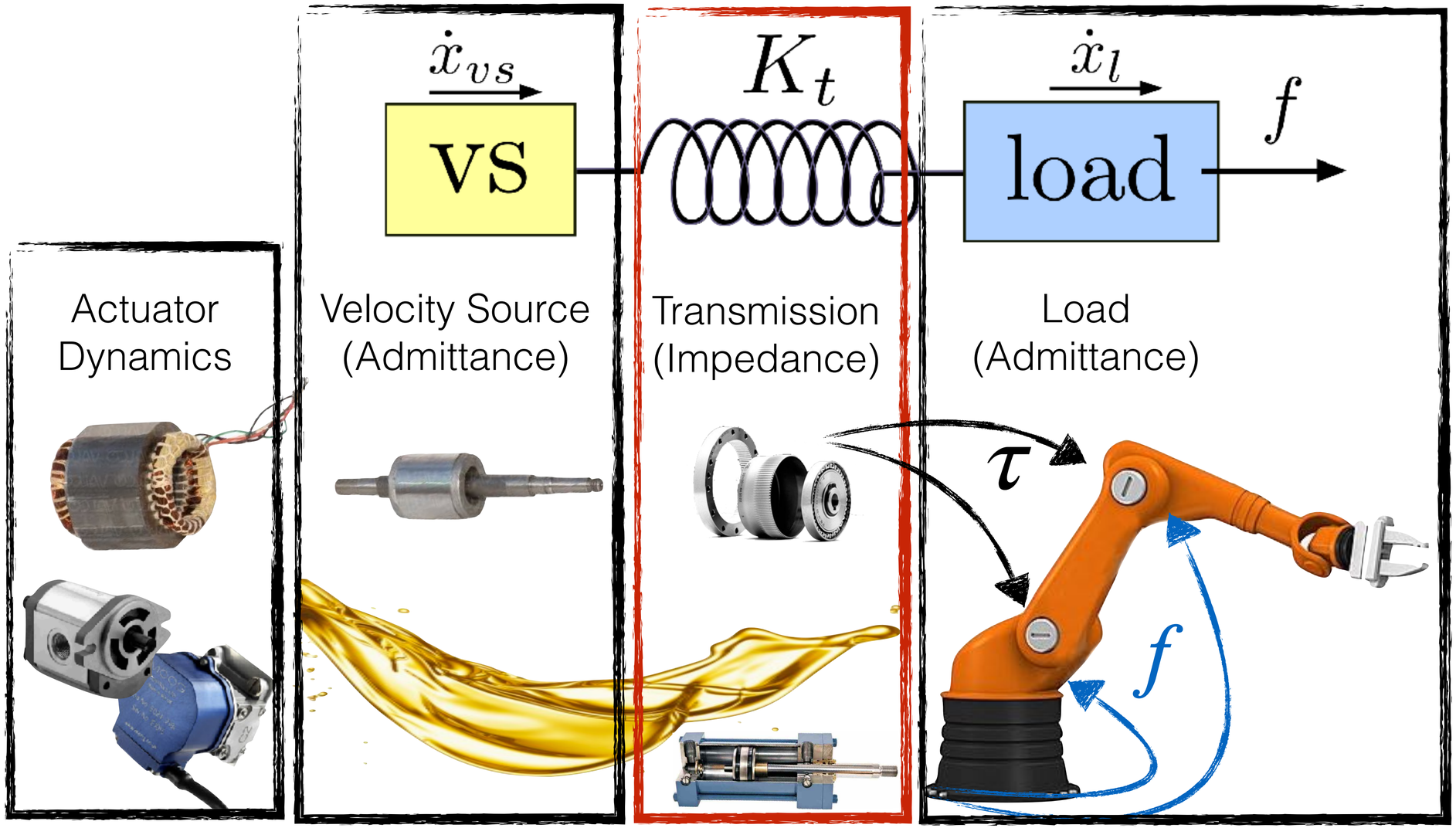
Arquitetura clássica



Conteúdo

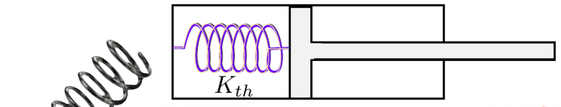
- Realimentação intrínseca da velocidade e sua compensação

Cadeia de atuação

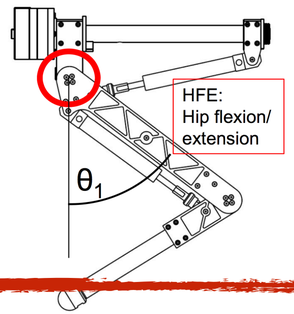


Rigidez da transmissão

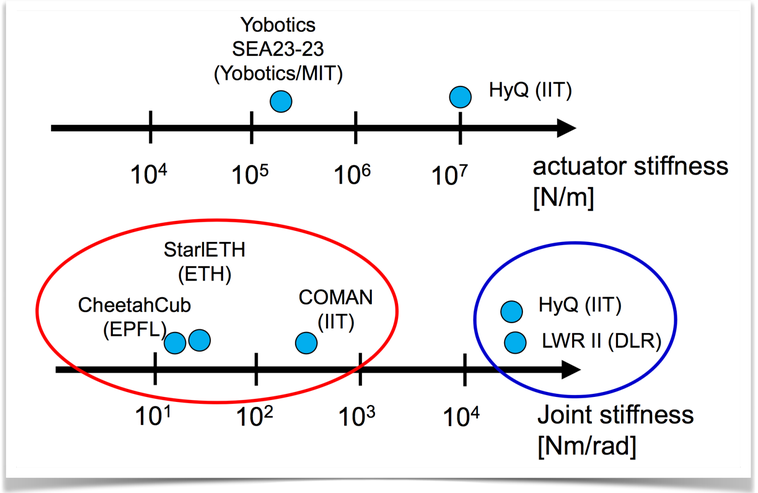
2.7 x 10⁴ Nm/rad

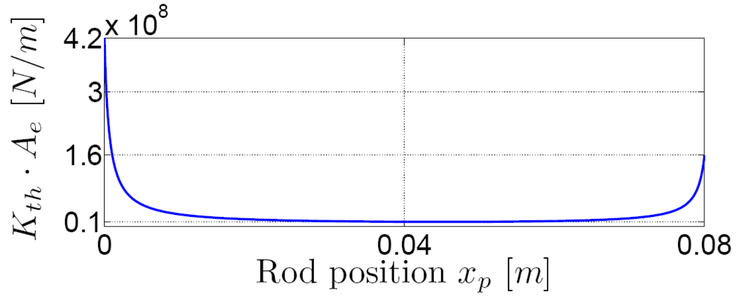


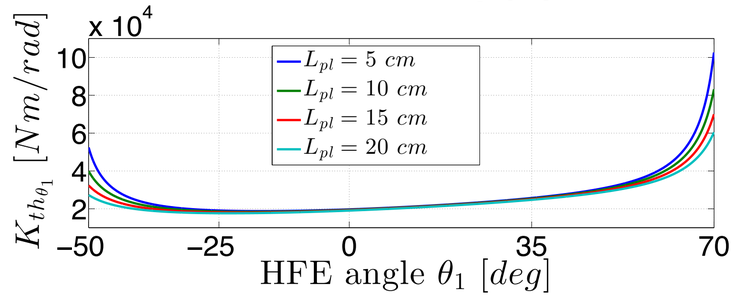
0.9 x 10⁷ N/m



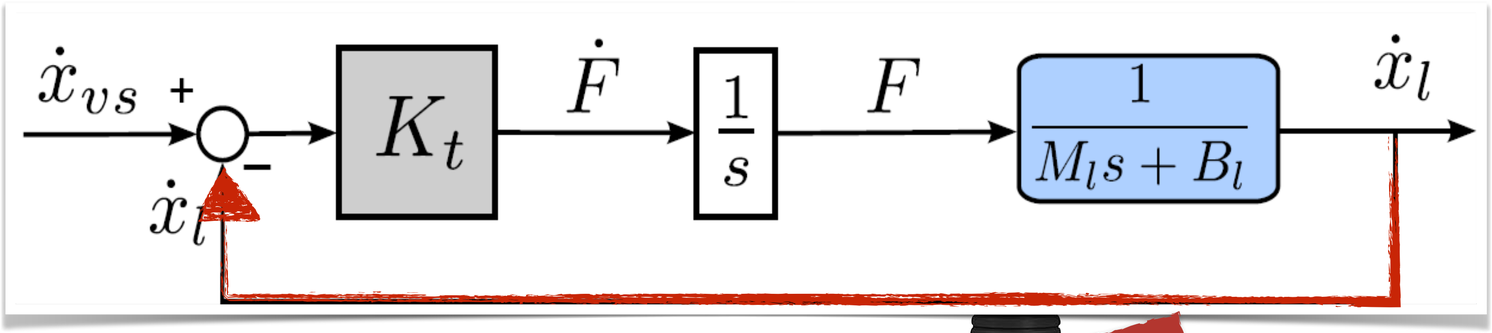
2.1 x 10⁴ Nm/rad

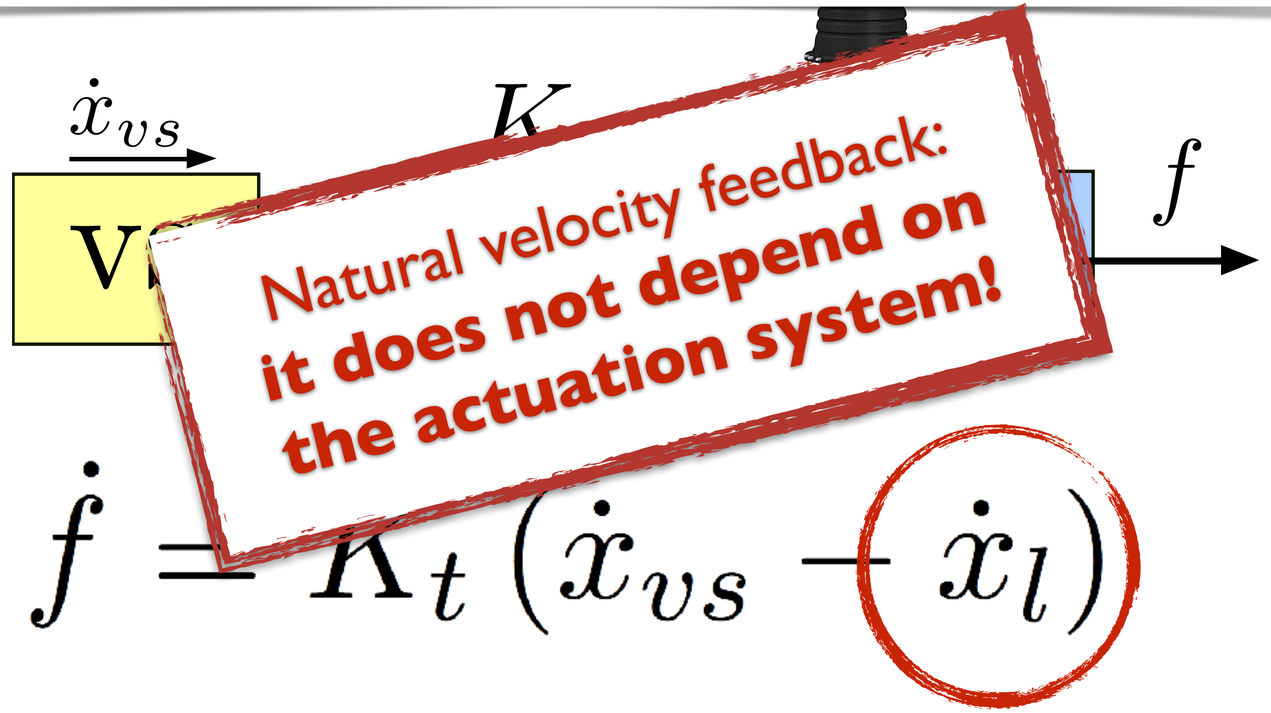






Realimentação intrínseca da velocidade



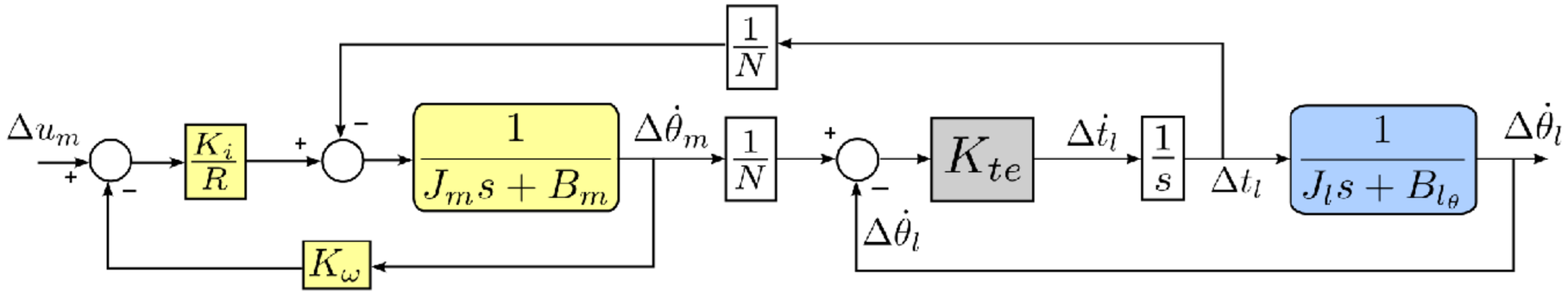


Boaventura, T., et al. On the role of load motion compensation in high-performance force control. IROS, 2012

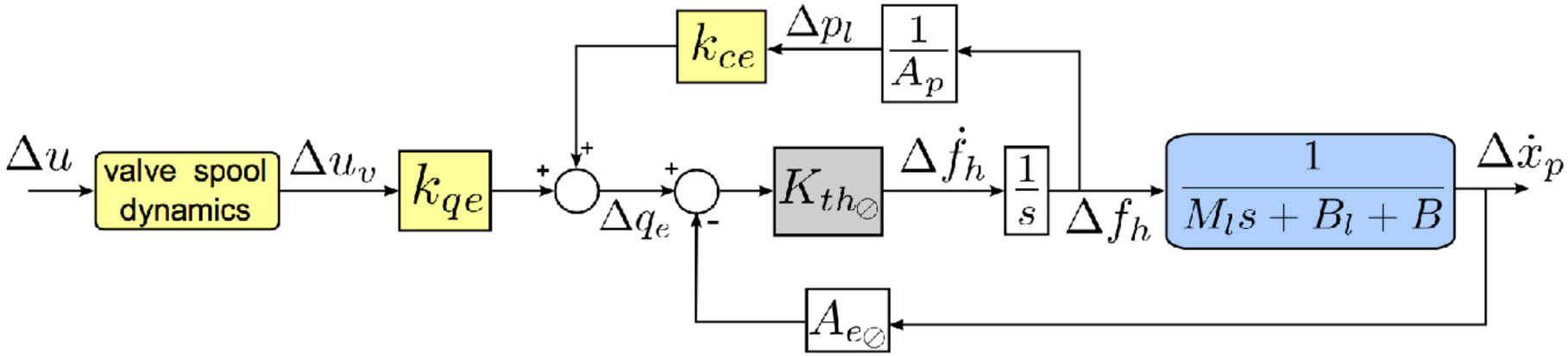
Realimentação intrínseca da velocidade

Open-loop torque/force dynamics

Electric actuation



Hydraulic actuation



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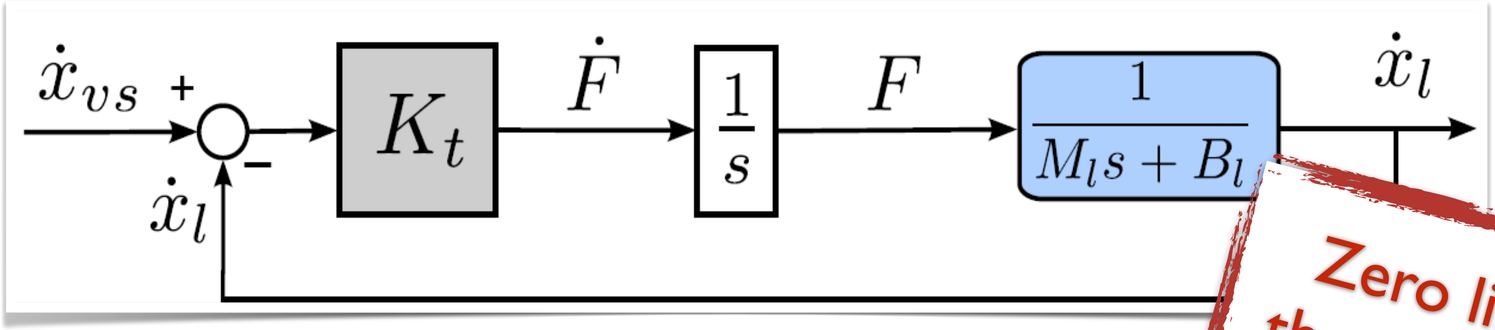
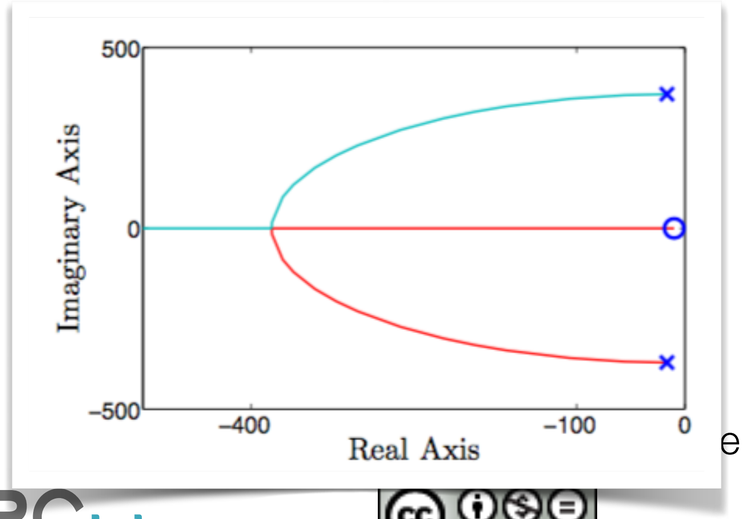
Realimentação intrínseca da velocidade



Zero limits the response.

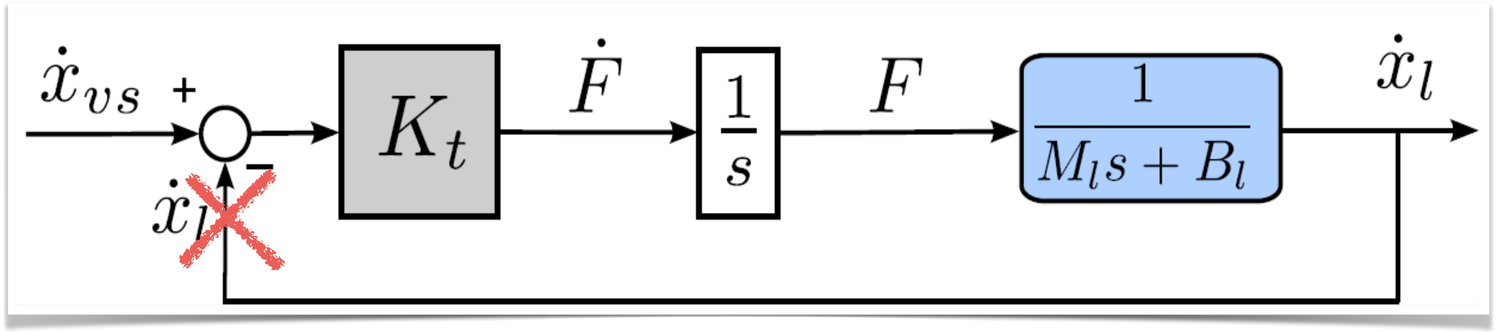
$$\frac{f(s)}{\dot{x}_{vs}(s)} = \frac{K_t (M_l s + B_l)}{s (M_l s + B_l) + K_t}$$



It does not depend on the actuation

e of load motion compensation in high-performance force control. IROS, 2012

Compensação de velocidade baseada em modelo



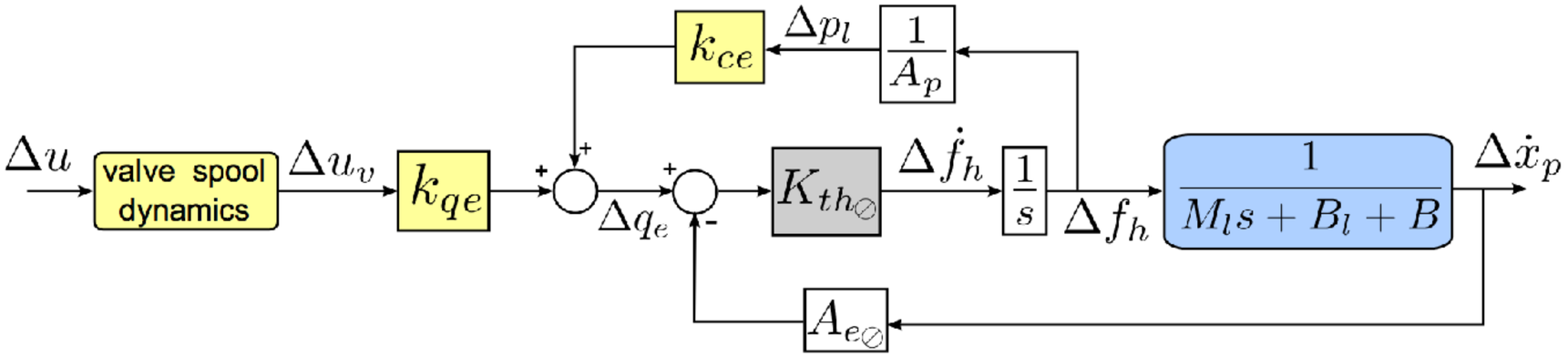
$$\frac{f(s)}{\dot{x}_{vs}(s)} = \frac{K_t\left(M_l s + B_l\right)}{s\left(M_l s + B_l\right) + K_t} = \frac{K_t}{s}$$

$$\dot{x}_{ex} = \dot{x}_l$$

Boaventura, T., et al. On the role of load motion compensation in high-performance force control. IROS, 2012

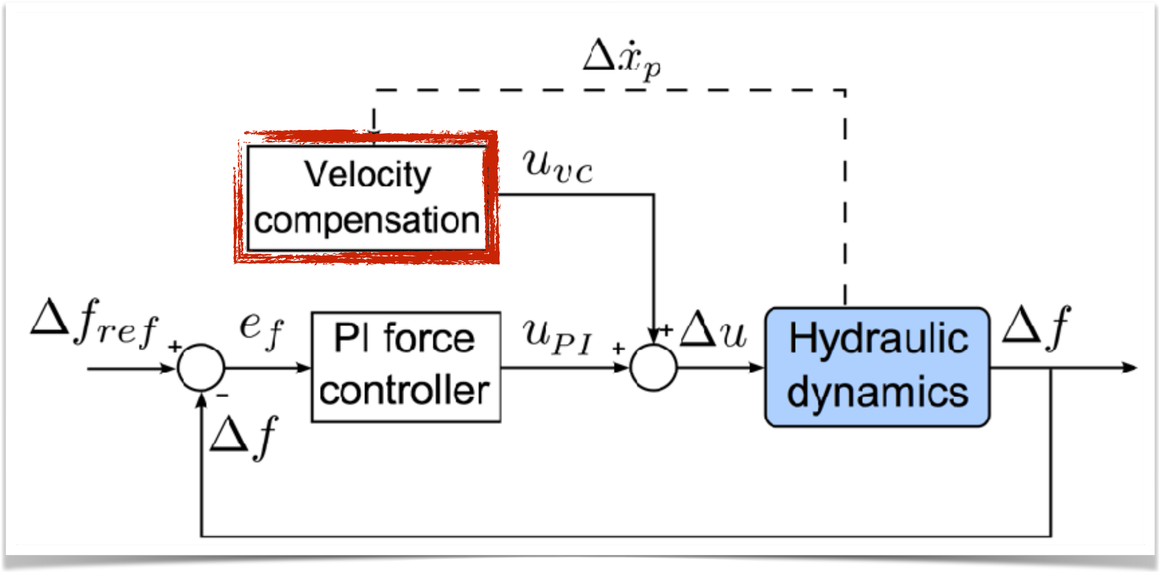
Compensação de velocidade baseada em modelo

Hydraulic actuation



Feedforward command:

$$u_{vc} = \frac{A_{e\oslash} \Delta \dot{x}_p}{K_{qe}}$$



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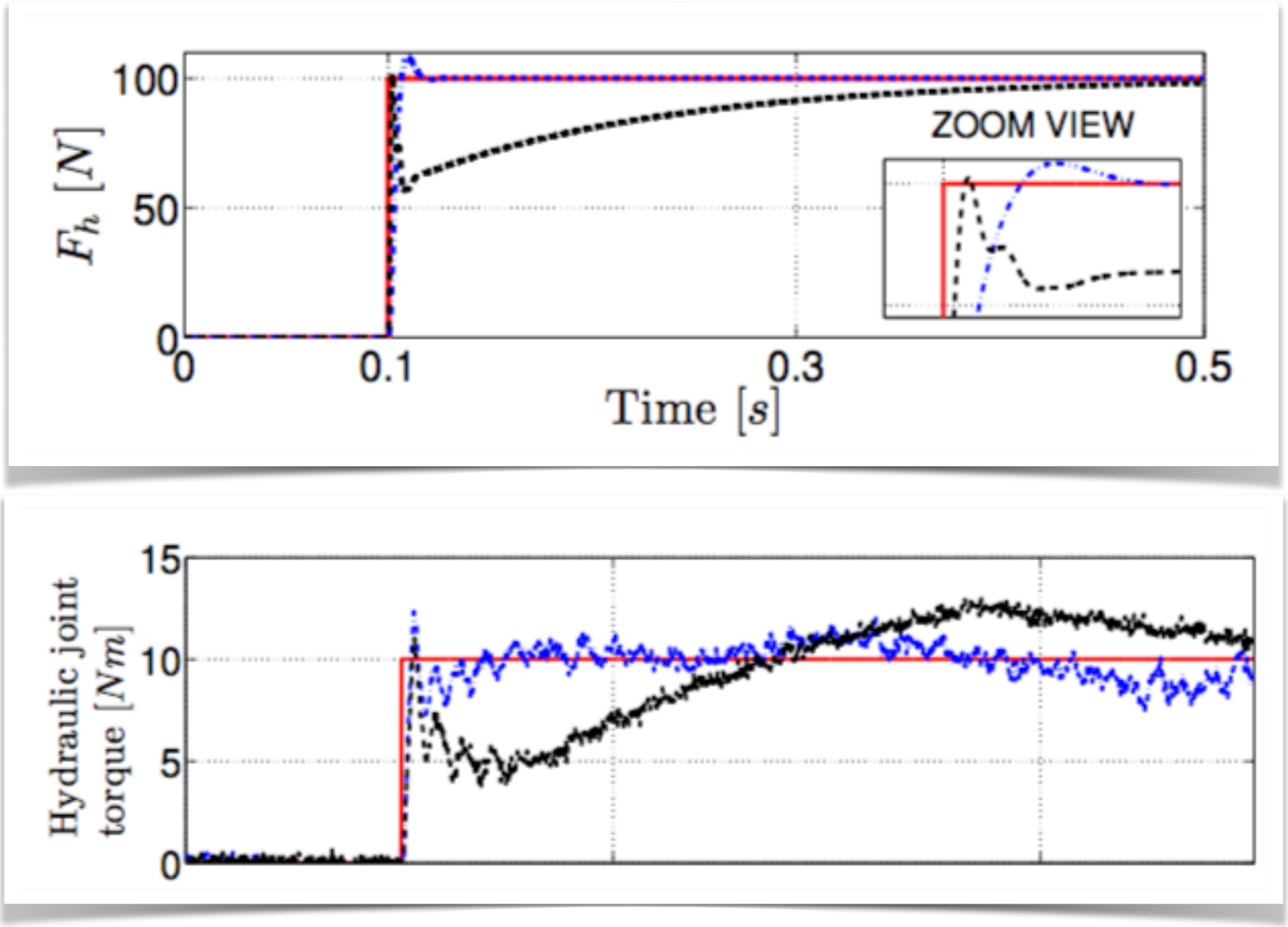

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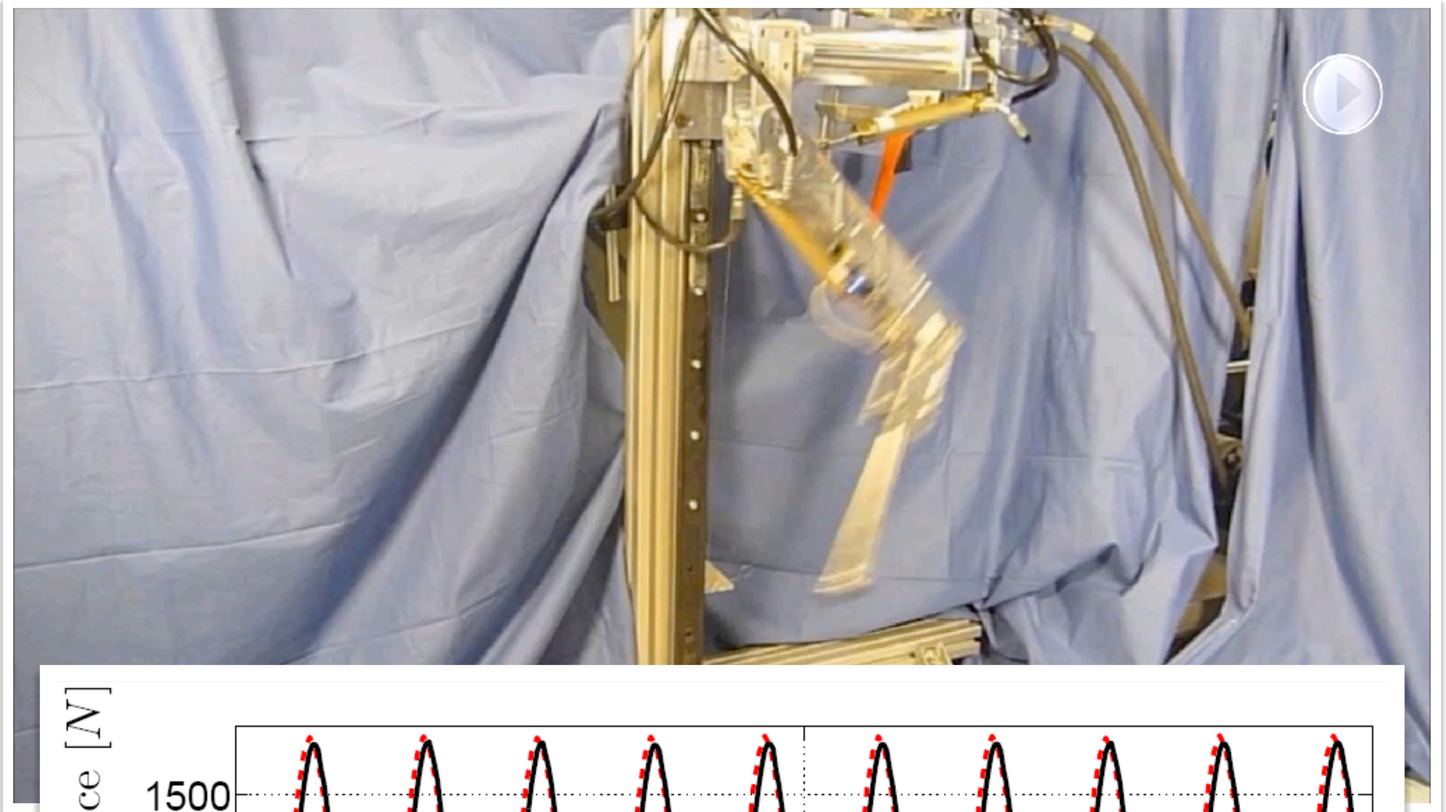

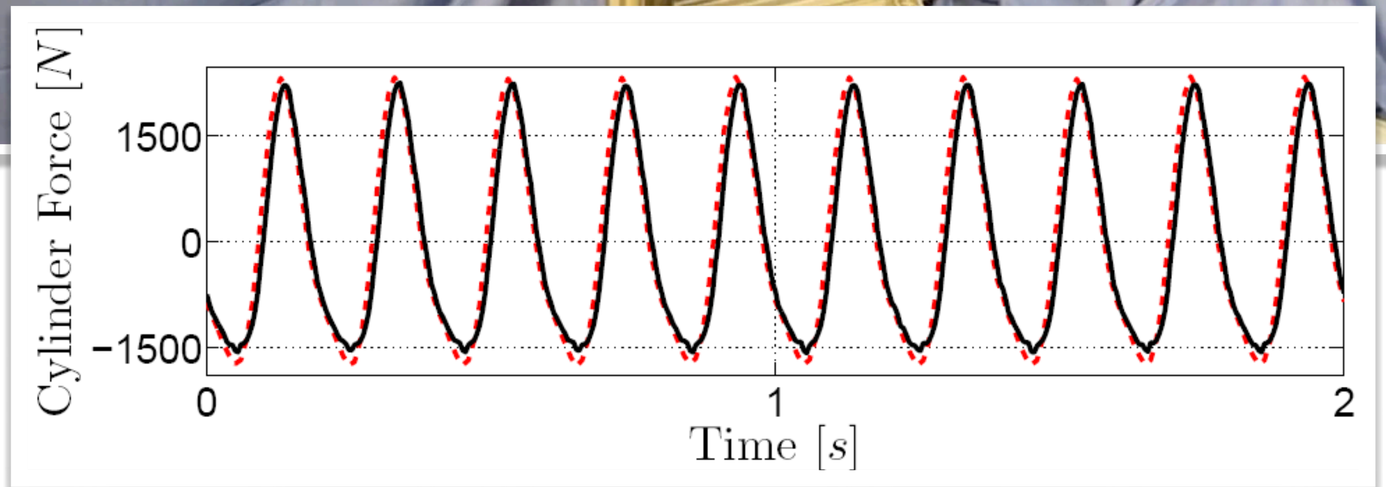

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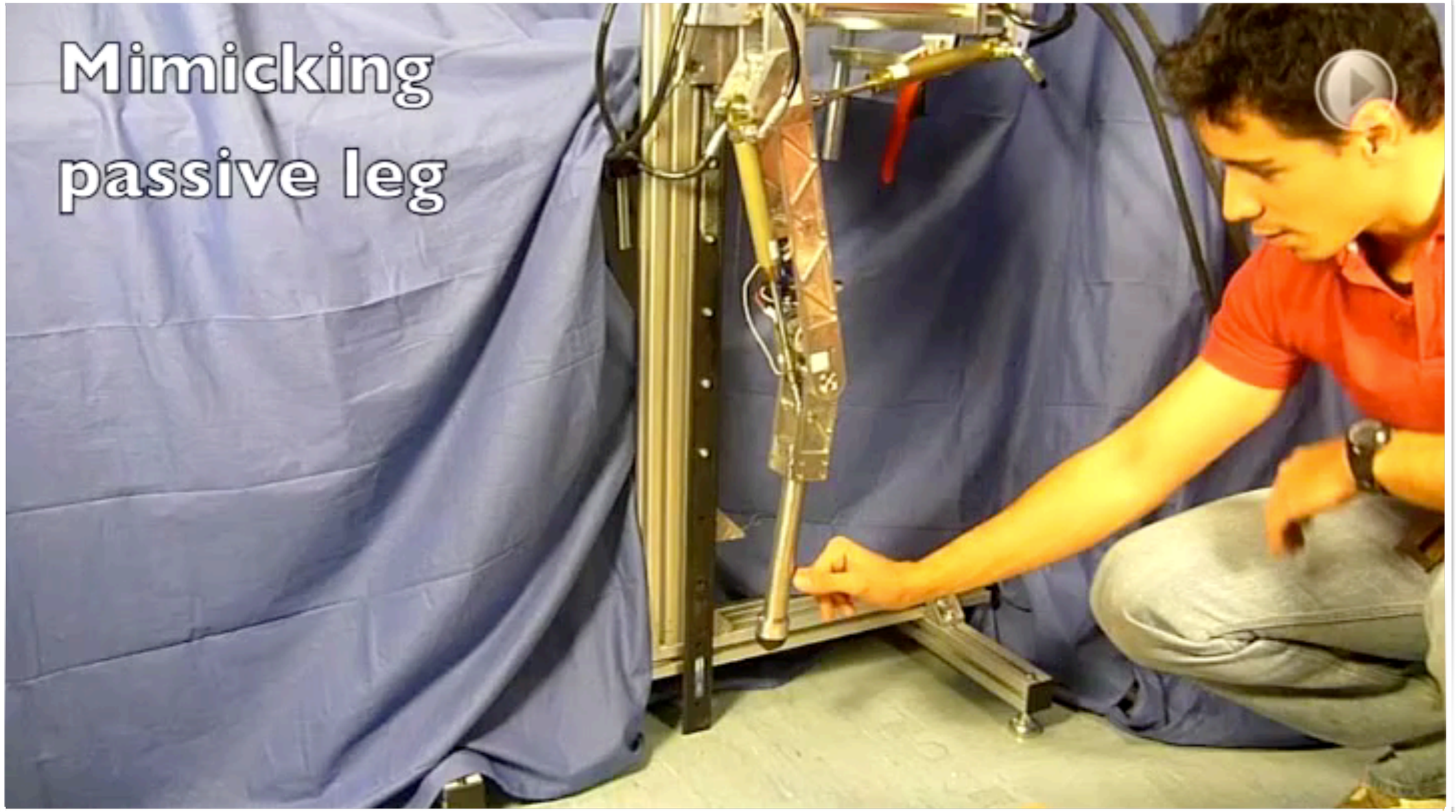

Conteúdo

Talk on "Interaction Control for Contact Robotics" by Neville Hogan

https://www.youtube.com/watch?v=GjKy3EFs3g8
https://www.youtube.com/watch?v=Dkc1LkTDXXk&t=2693s

Hogan, N. (1985). Impedance control: An approach to manipulation: Part II—Implementation. Journal of dynamic systems, measurement, and control

Hogan N, Buerger S. P. Impedance and interaction control. Robotics and automation handbook. 2005;1

Calanca, A., et al. (2016). A review of algorithms for compliant control of stiff and fixed-compliance robots. IEEE/ASME Transactions on Mechatronics

Boaventura, T., et al. On the role of load motion compensation in high-performance force control. IROS, 2012

Ott, C., Mukherjee, R., & Nakamura, Y. (2010). Unified impedance and admittance control. ICRA, 2010, pp. 554-561.


That's all Folks!