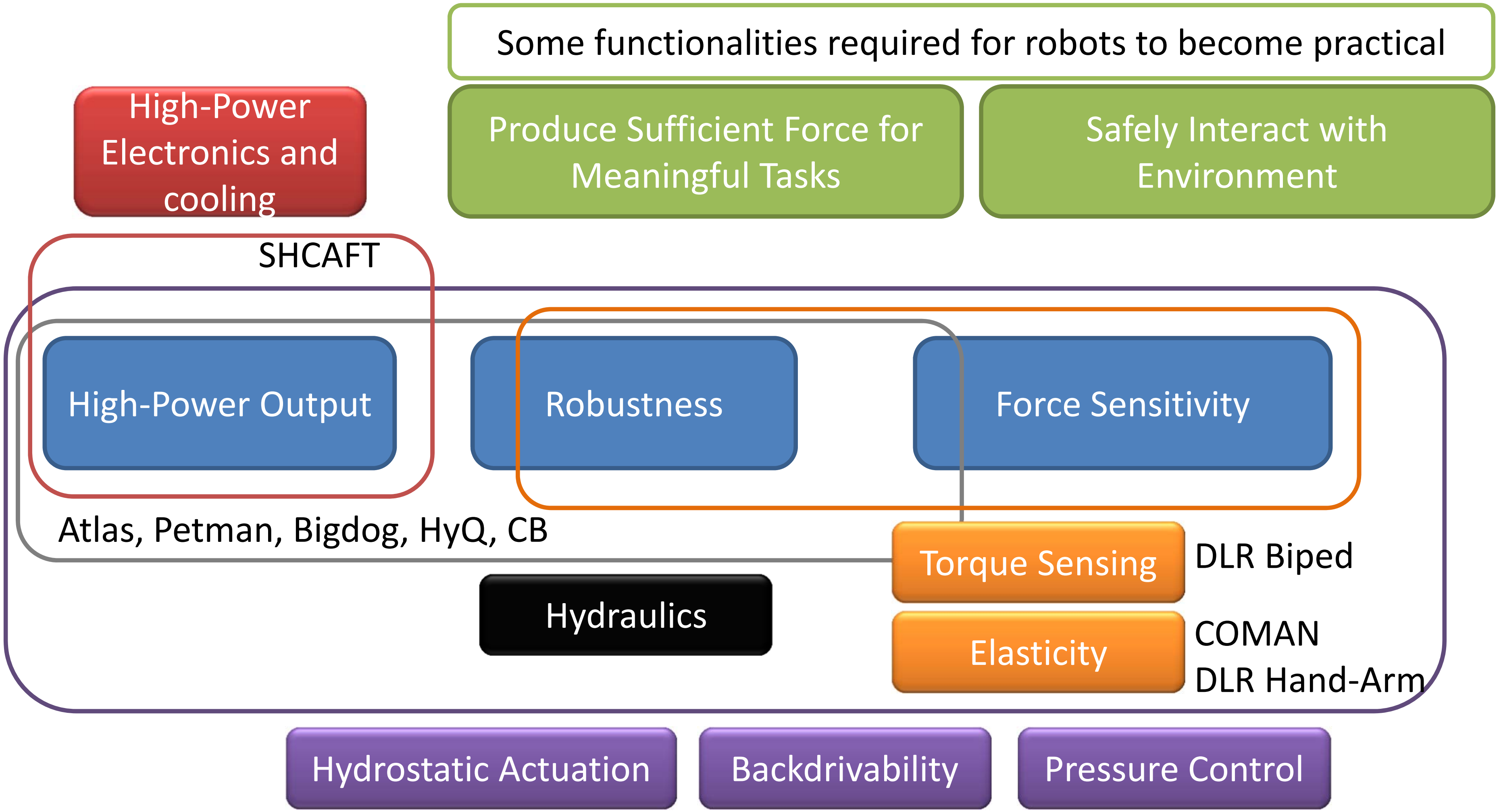
Design of Robust and Force Sensitive Hydraulic Actuator for Humanoid Robot Systems

Hiroshi Kaminaga,

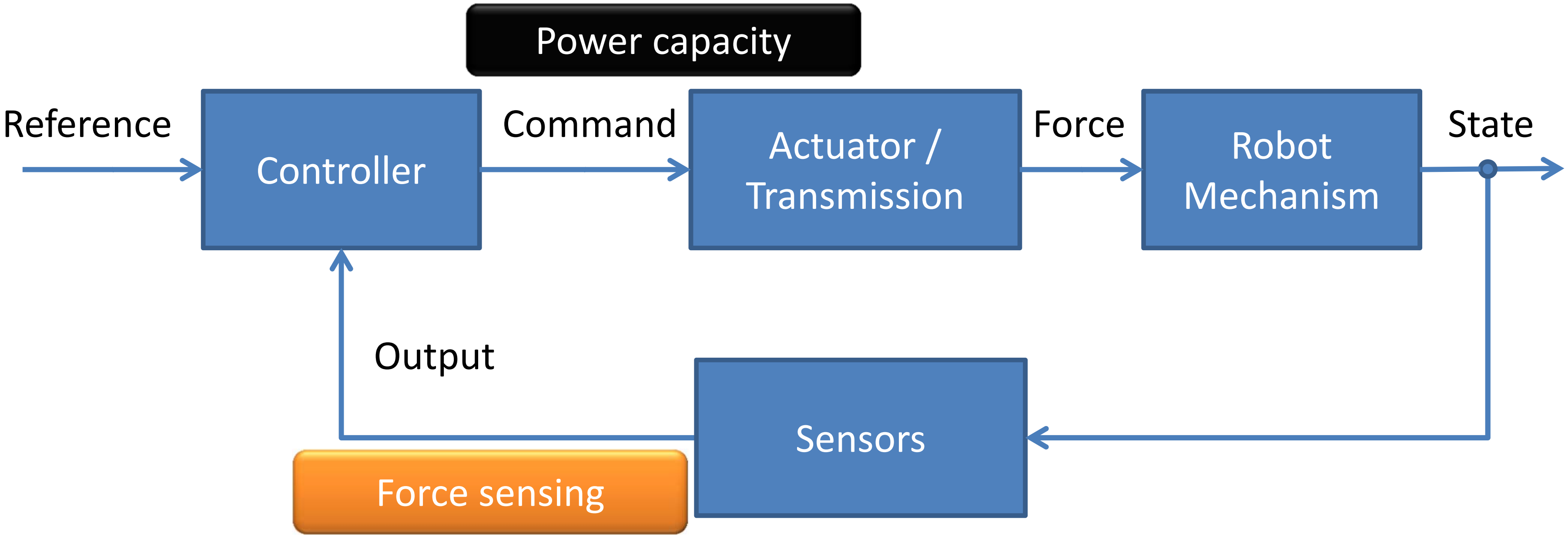
The University of Tokyo

Motivation


Some functionalities required for robots to become practical
High-Power Electronics and cooling
Produce Sufficient Force for Meaningful Tasks
Safely Interact with Environment
SHCAFT
High-Power Output
Robustness
Force Sensitivity
Atlas, Petman, Bigdog, HyQ, CB
Torque Sensing
DLR Biped
Hydraulics
Elasticity
COMAN
DLR Hand-Arm
Hydrostatic Actuation
Backdrivability
Pressure Control

Force Controller

Force sensitive robots = robots that can react to force with high sensitivity

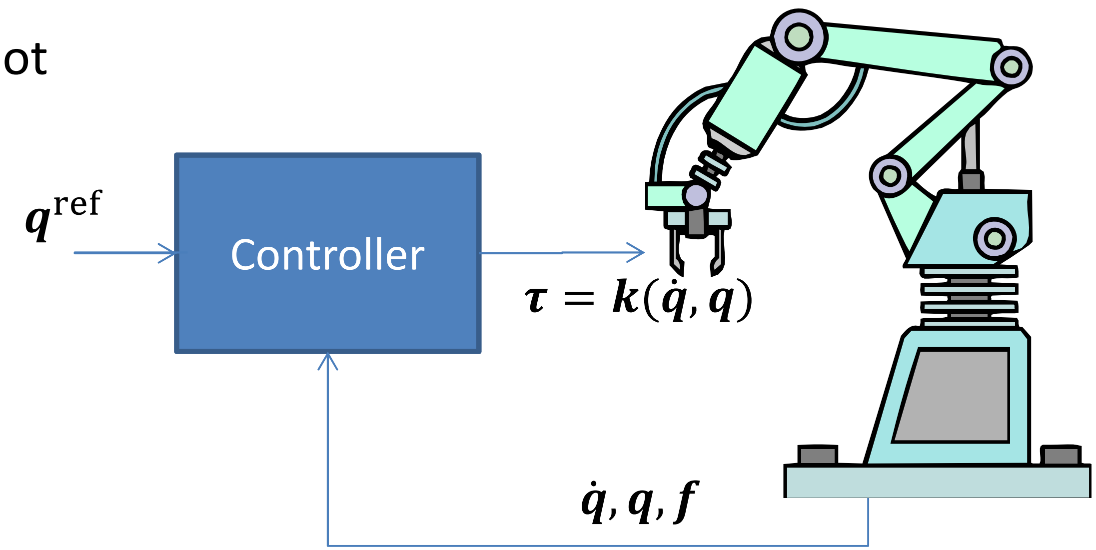


Are they equivalent?

Rigid body equation of motion with feedback

$$M(q)\ddot{q} + \boldsymbol{c}(\dot{\boldsymbol{q}}, \boldsymbol{q}) + \boldsymbol{g}(\boldsymbol{q}) = \boldsymbol{\tau} + J^T \boldsymbol{f}$$
$$\boldsymbol{\tau} = \boldsymbol{k}(\dot{\boldsymbol{q}}, \boldsymbol{q}, \boldsymbol{q}^{\text{ref}})$$

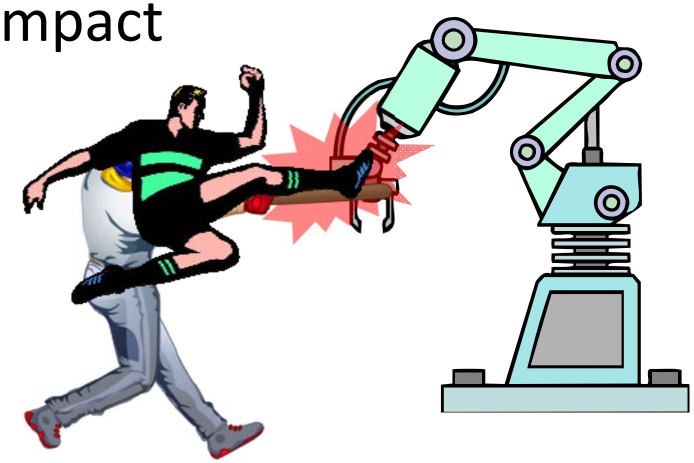
Real robot



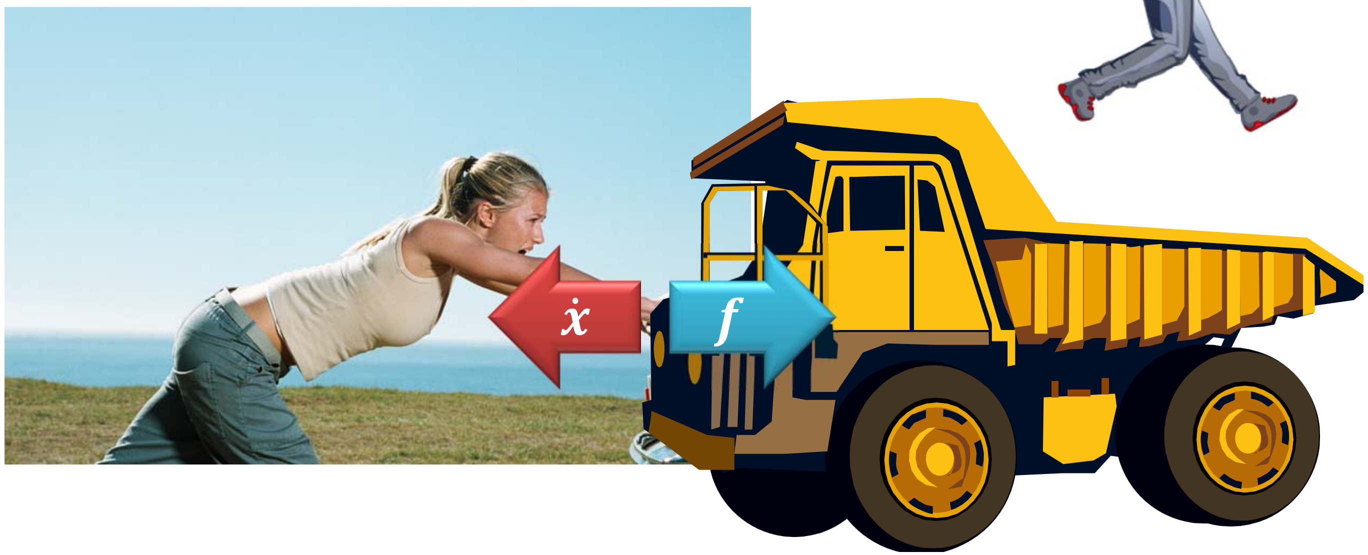
Joint wise high-gain feedback ⟵ Reject disturbance, model error and dynamics of the robot mechatronics

Examples of difficult force control

Impact



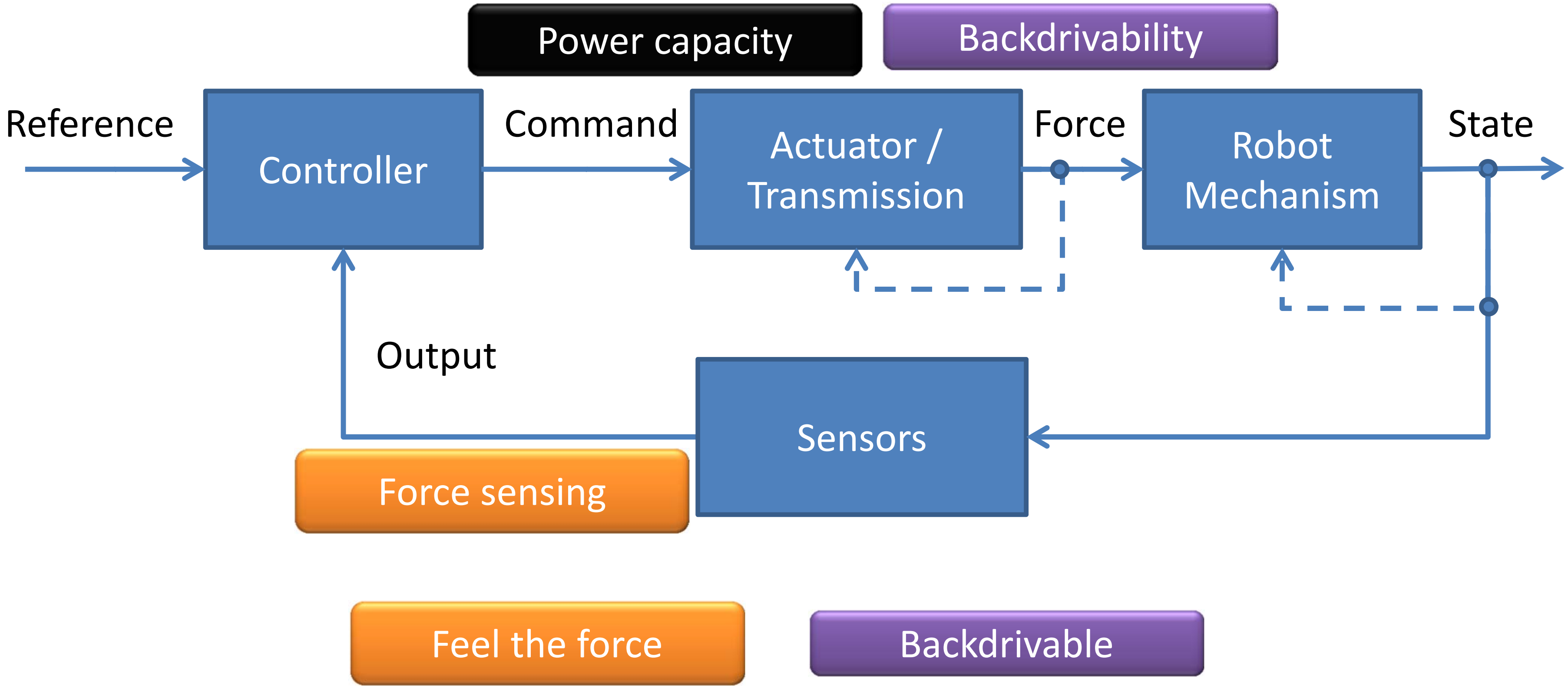
Negative Work



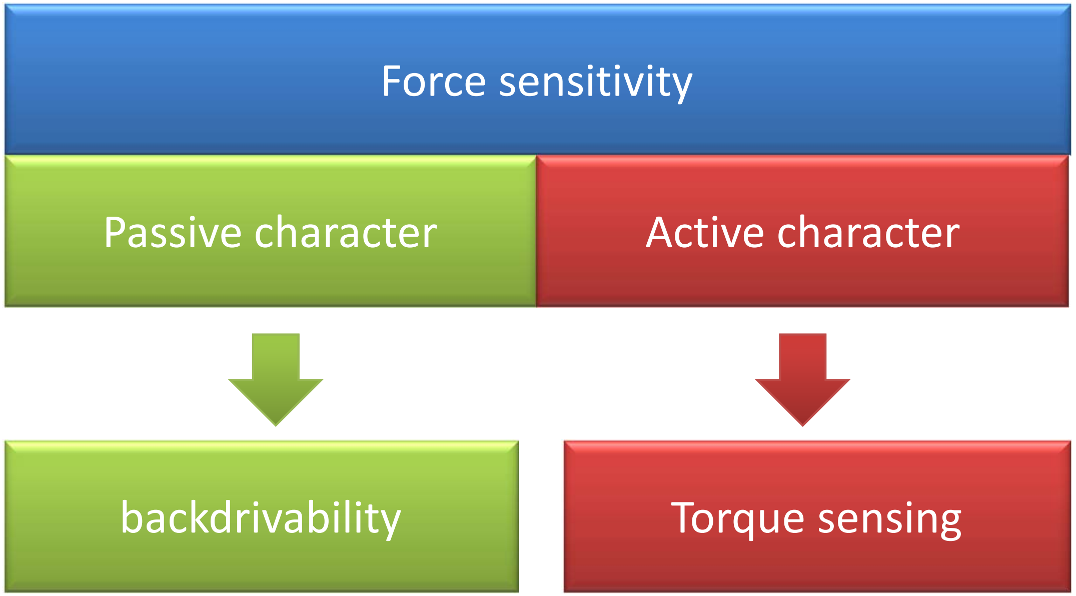
Force measurement based admittance control

Force Controller

Force sensitive robots = robots that can react to force with high sensitivity



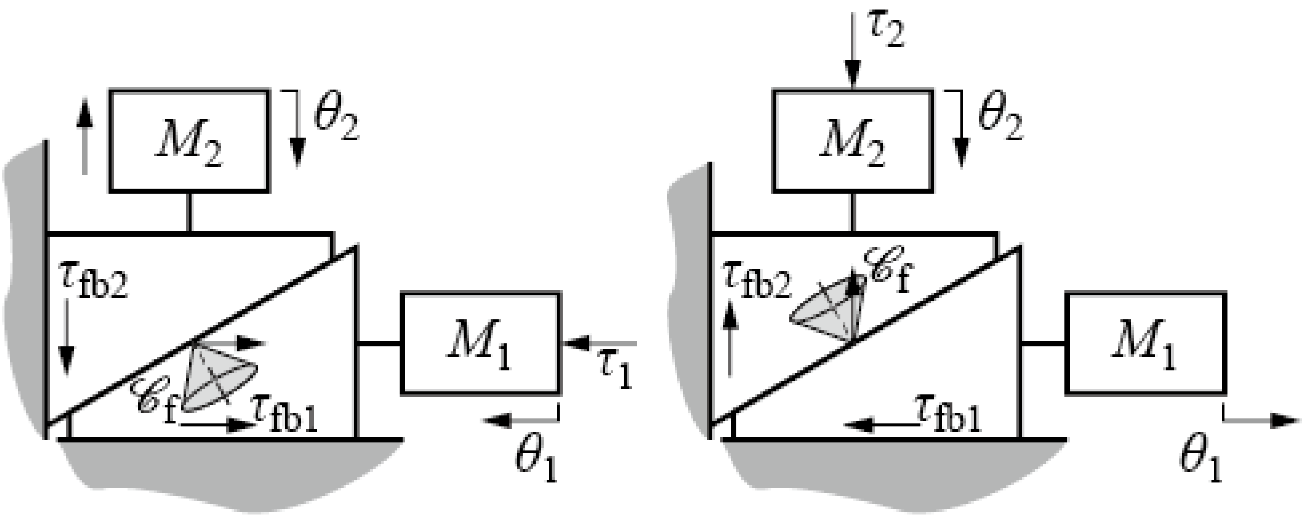
Force sensitivity, force measurement, and backdrivability



SEA
[Pratt et al. 1995]
EHA
[Humanioids2007]

Backdrivability

Actuator can be driven from output axis



(a) Normal Actuation (b) Non-Backdrivable System

Electro-Hydrostatic Actuator

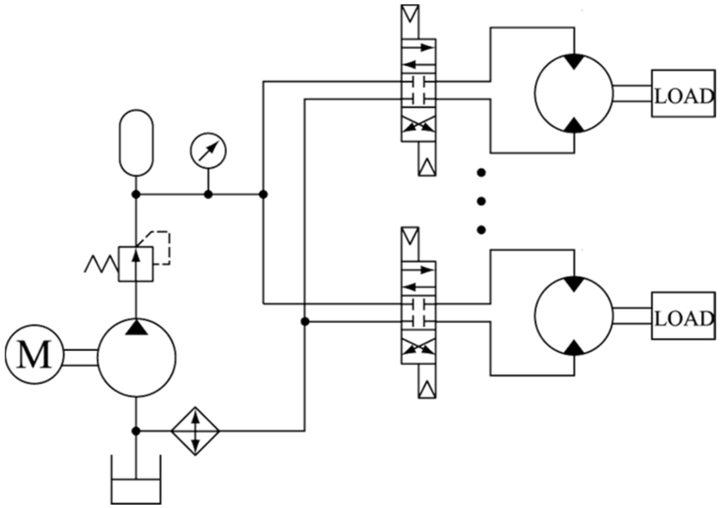
- Displacement control type hydraulics
- Hydraulics as gears

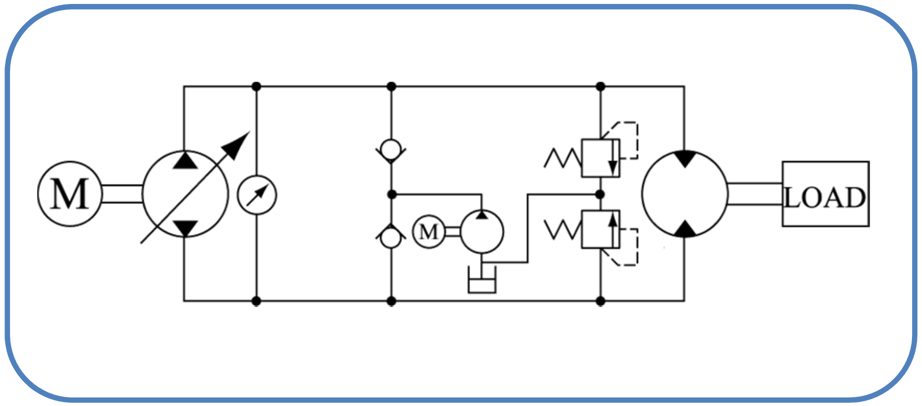
Low friction in speed reduction

No valve friction

Force estimation with pressure sensors

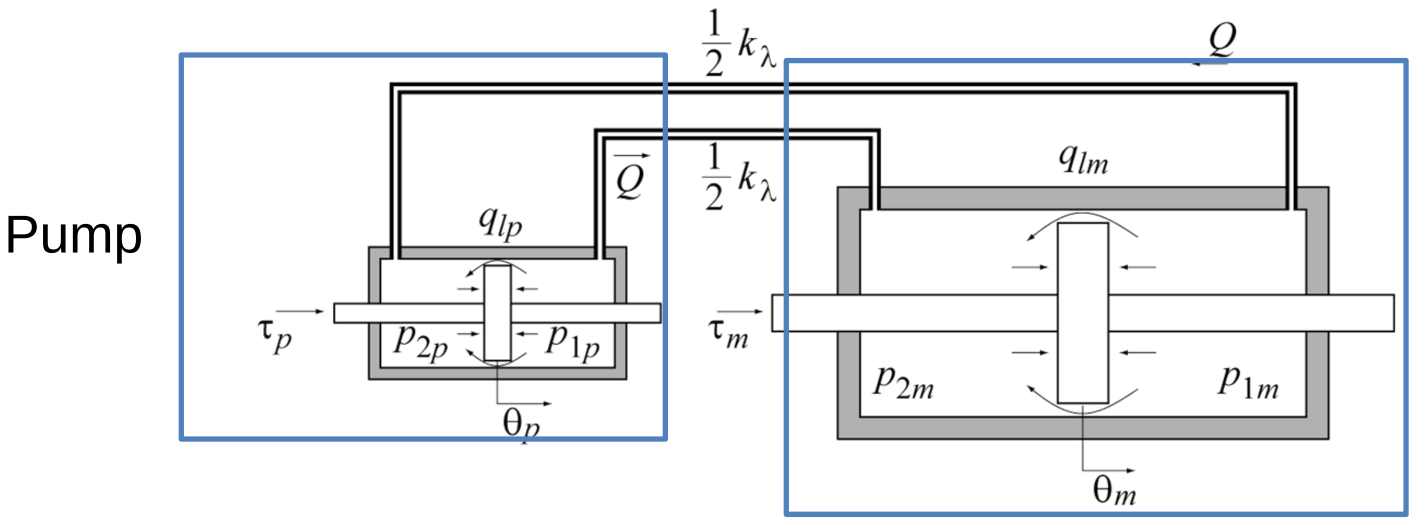
Whole actuator become backdrivable





Model of EHAs

[ICRA 2009]



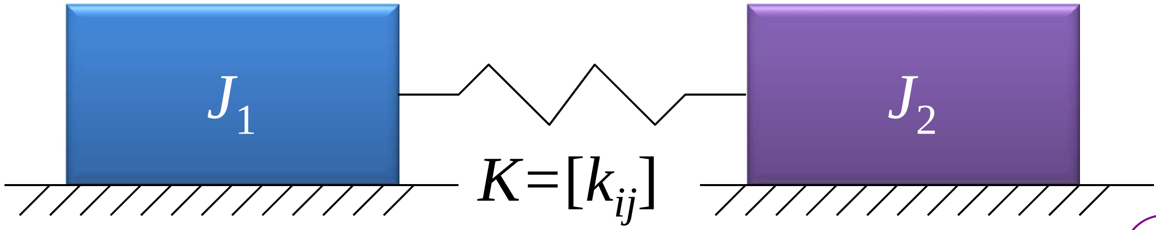
$$\begin{cases} J_1\ddot{\theta}_1 = -k_{13}(k_{11}\dot{\theta}_1 - k_{12}\dot{\theta}_2) - \tau_{1\mathrm{f}} + \tau_1 \\ J_2\ddot{\theta}_2 = -k_{23}(k_{21}\dot{\theta}_2 - k_{22}\dot{\theta}_1) - \tau_{2\mathrm{f}} + \tau_2 \end{cases}$$

Subscript 1: pump side

Subscript 2 : output side

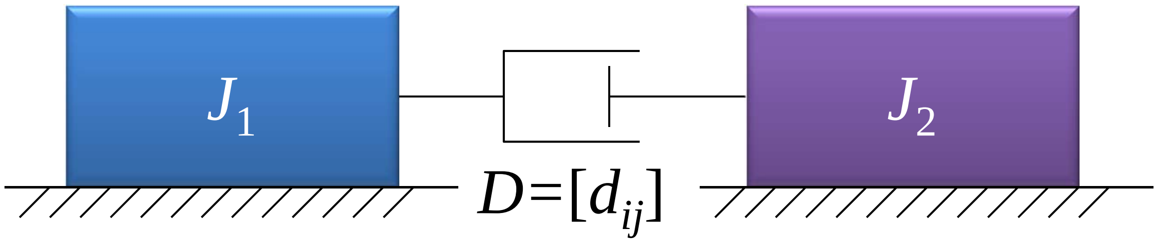
Abstract Model of Backdrivable Actuators

- Series Elastic Actuator



- Electro-Hydrostatic Actuators

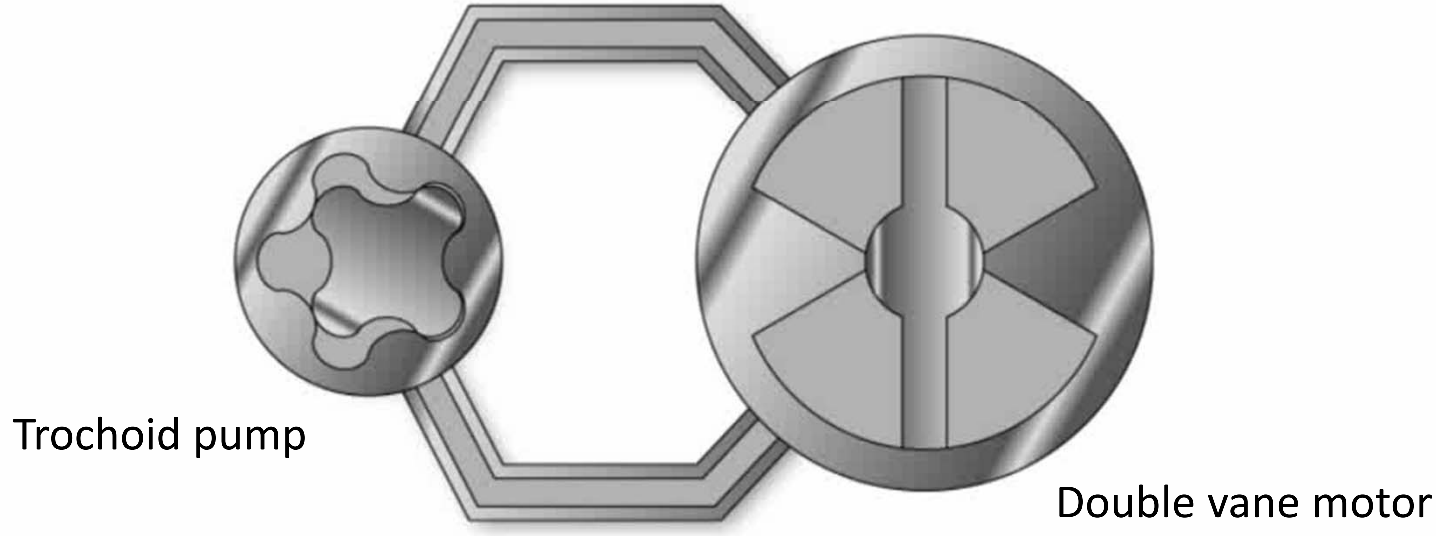
[ICRA2010]



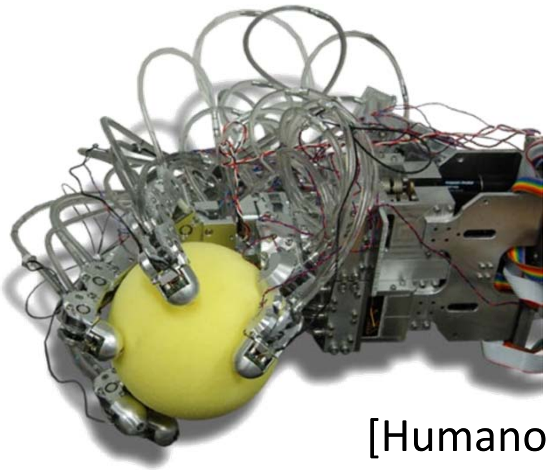
Dynamics decoupling

Series damping actuator [Chew et al. 2004]

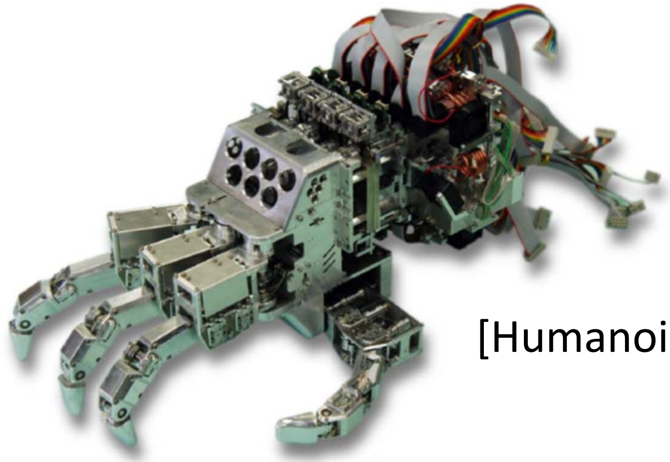
How EHAs work



Previous Studies on EHA

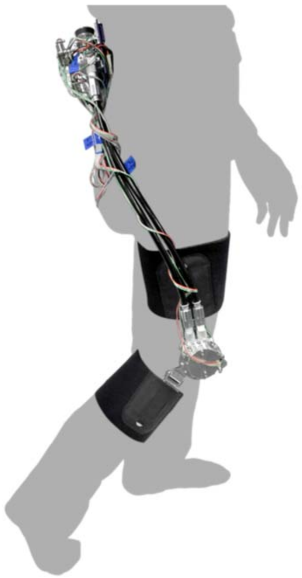


[Humanoids2007]



[Humanoids2009]

[ICRA2009]



[IROS2011]

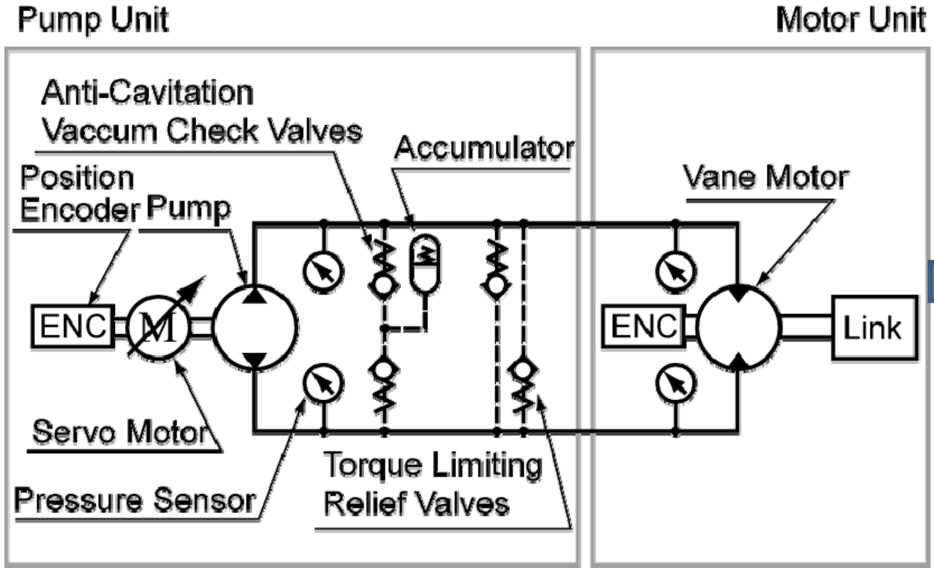
[IROS2013]

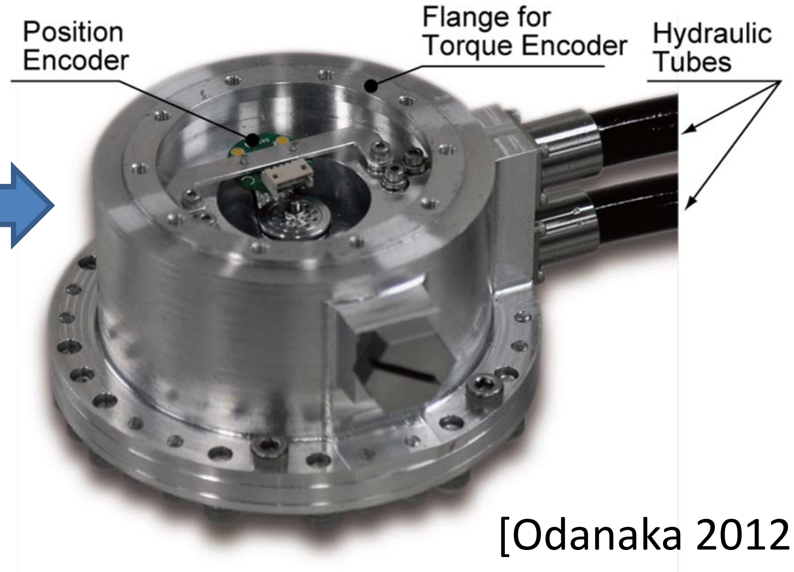
Backdrivability

Scalability

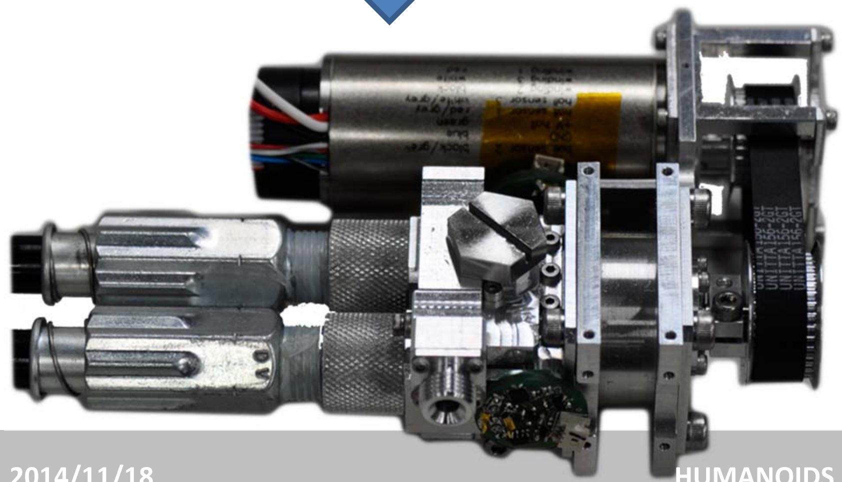
System Integration

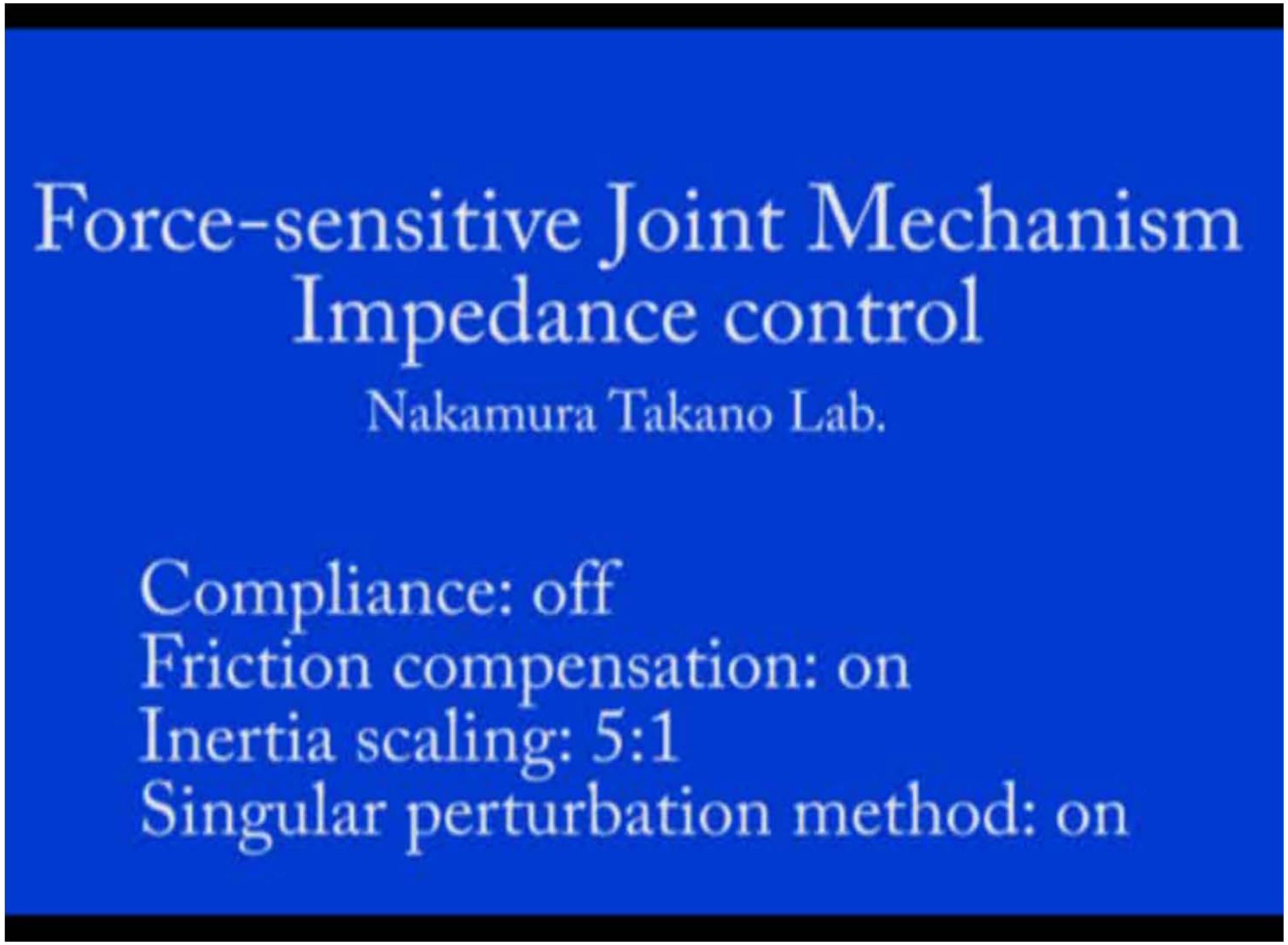
Recent Design of Rotary EHA



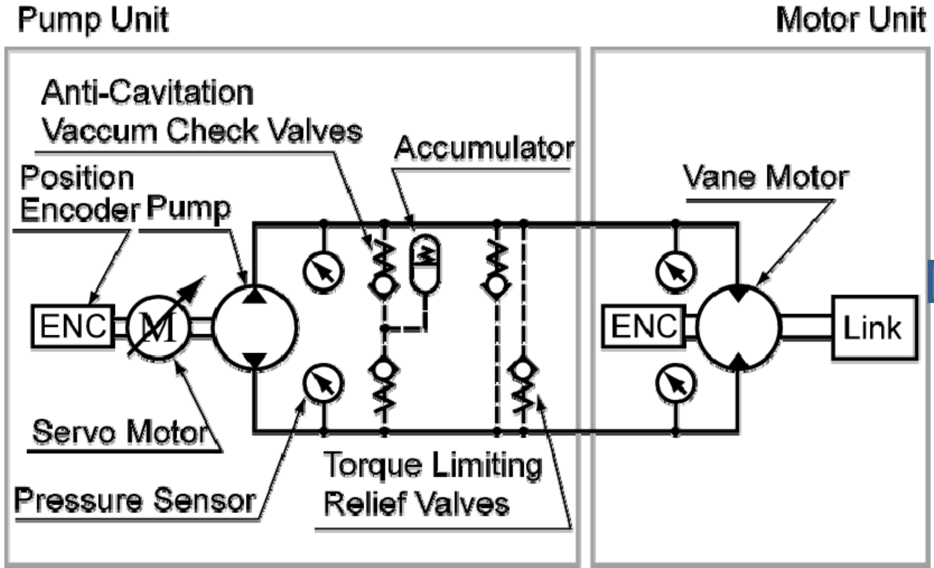


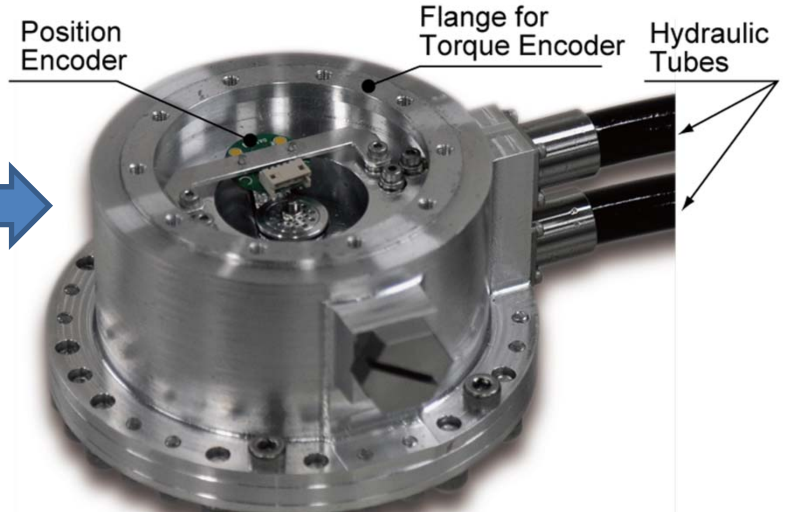
[Odanaka 2012]




Force-sensitive Joint Mechanism
Impedance control
Nakamura Takano Lab.
Compliance: off
Friction compensation: on
Inertia scaling: 5:1
Singular perturbation method: on

Recent Design of Rotary EHA





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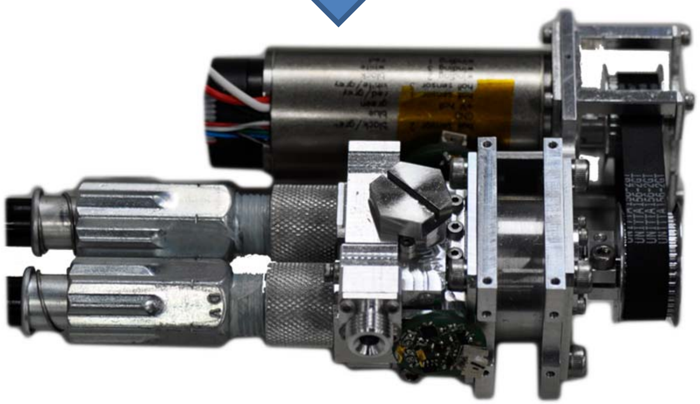
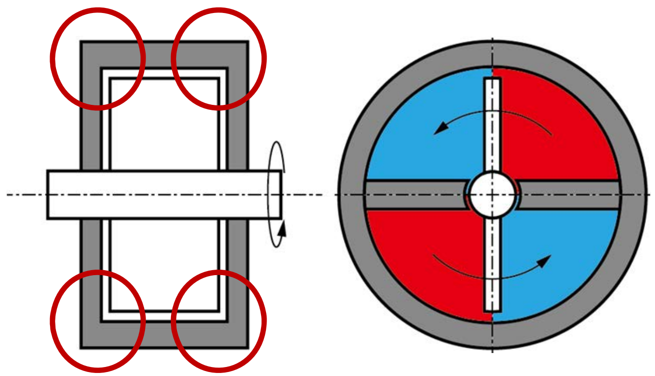
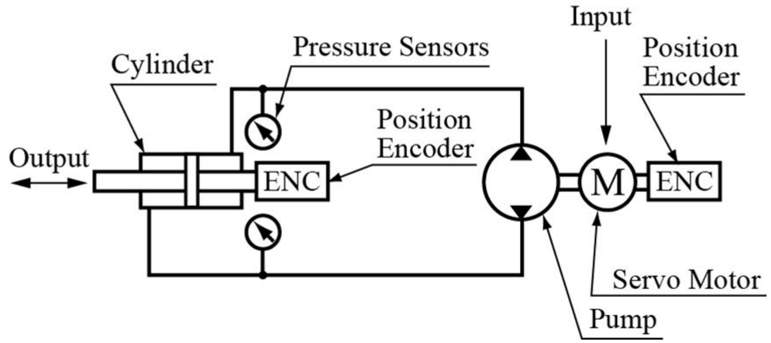
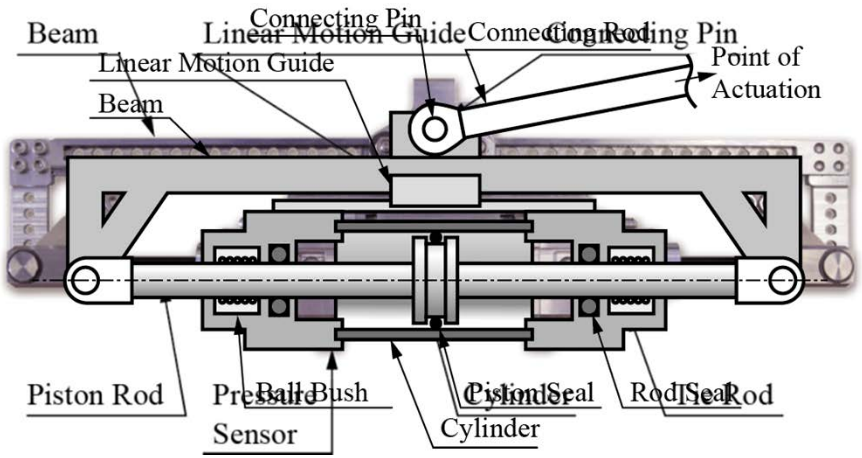


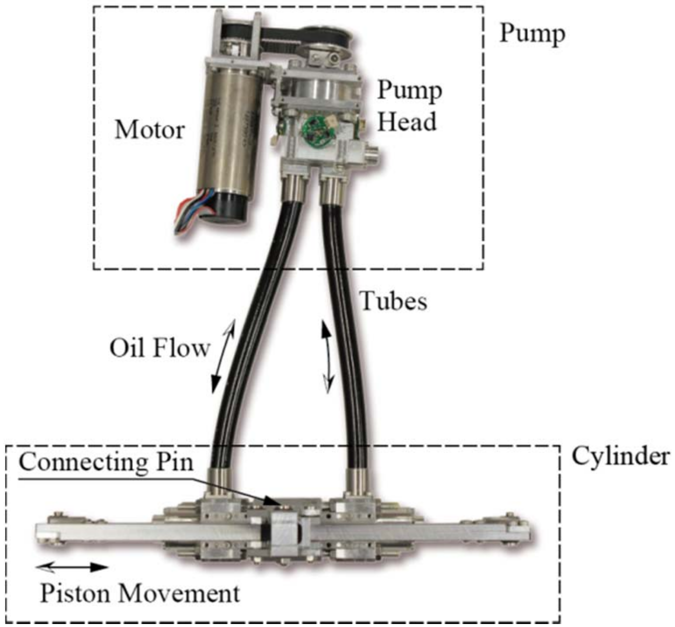


Linear EHA

To be presented Nov. 20





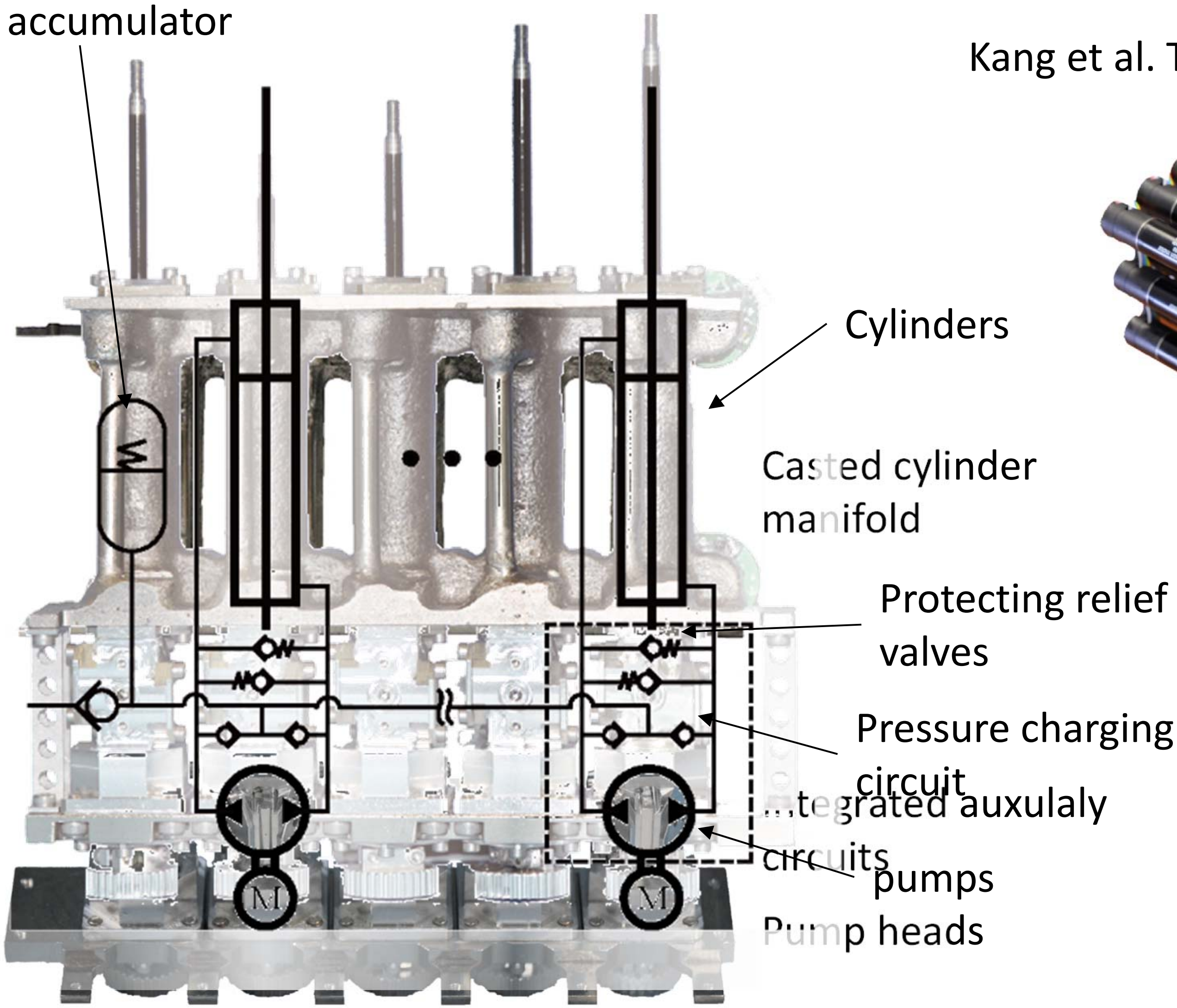


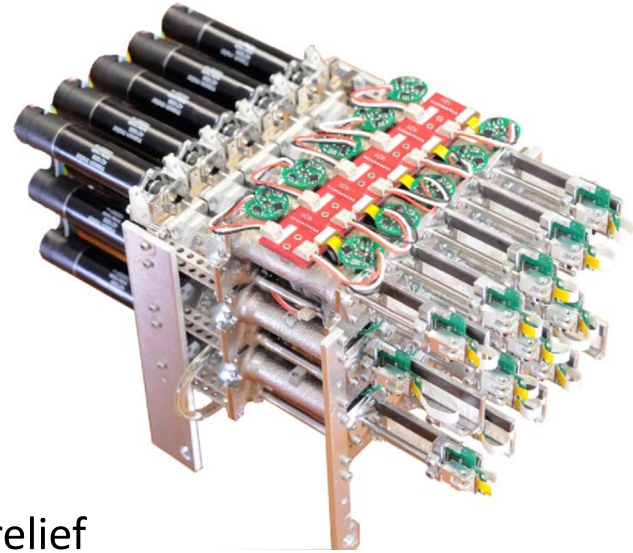
Item	Value
Max. Force	1500N
Max. Speed	0.27m/s
Pos. Control BW	>2Hz
Stroke	50mm
Weight (Pump+Cyl.)	0.35+0.44kg

Related work: S. Alfayad et al. 2011

Cluster of small EHAs

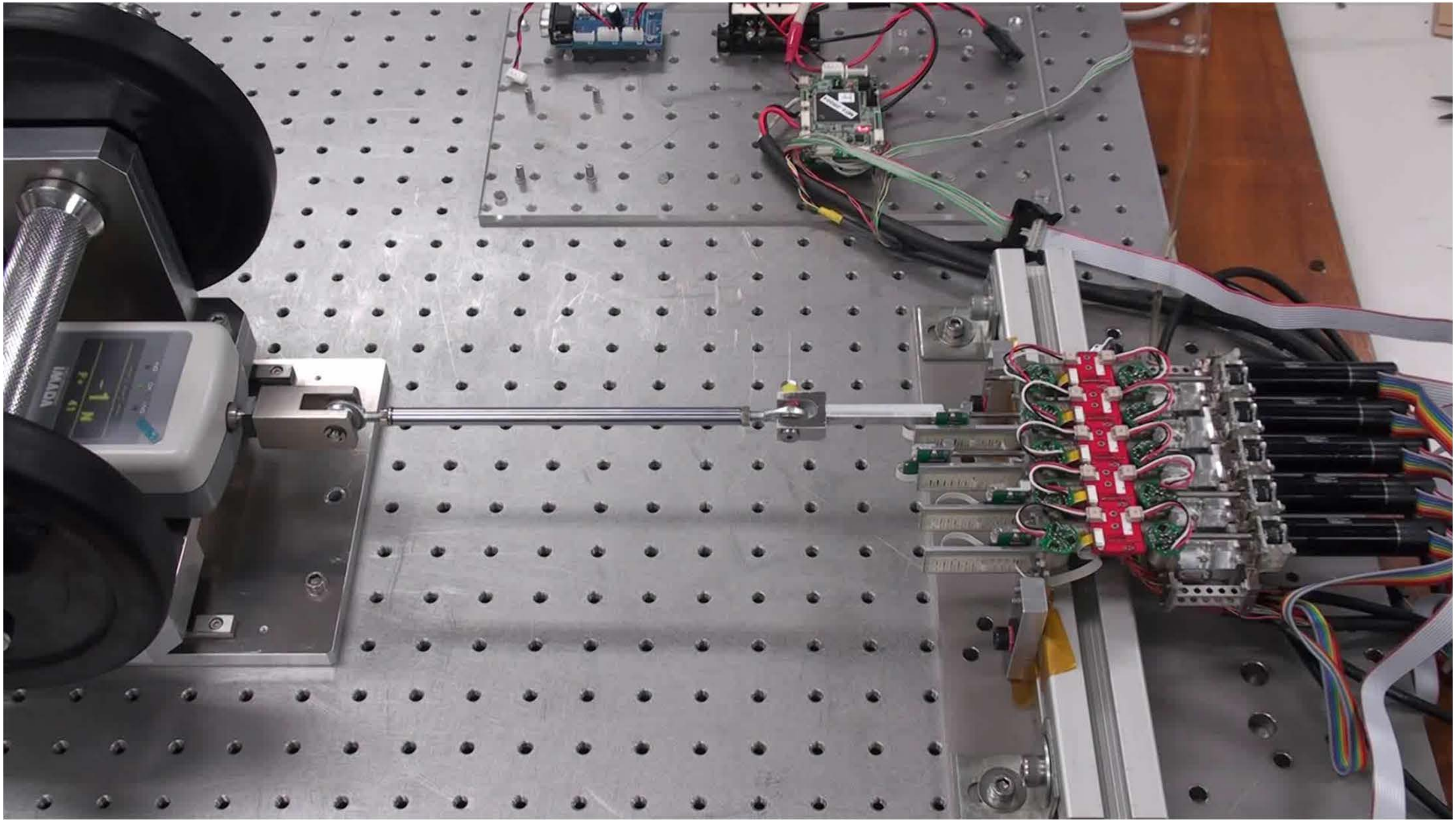
Kang et al. To be presented Nov. 19





Linear EHA Frequency Response Test

Cluset EHA Frequency Response Test



A Robot Hand Driven by Hydraulic Cluster Actuators

Treratanakulwong et al., 2014

Wire Driven Underactuated Hand

Treratanakulwong et al. (ICRA2014)

11 Dof Tendon Driven Hand with 12 active tendons

Coupling mechanism for fingertip pinching

Carpal tunnel mechanism with no sliding contact between the tendons and structure

Hand in Action

Friction Compensation

Force Control of EHA

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Hiroshi Kaminaga, Assistant Prof.
The University of Tokyo
kaminaga@ynl.t.u-tokyo.ac.jp