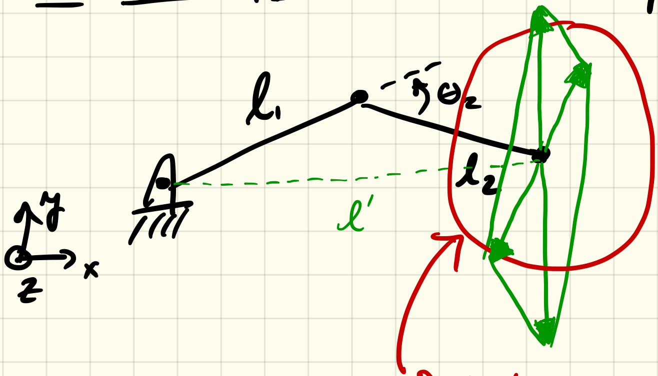
Lecture 33 - Design Considerations 2

- Workspace
  - Manipulability
- Redundant Manipulators
- Actuator Considerations
  - (Types & Transmissions)
  - Lecture by videos

Not all Workspace is created equal:



$$J = \begin{bmatrix} -l_1 s_1 - l_2 s_{12} & -l_2 s_{12} \\ l_1 c_1 + l_2 c_{12} & l_2 c_{12} \end{bmatrix}$$

$$\det(J) = l_1 l_2 s_2$$

Manipulability: $w = |\det(J)| = \sqrt{\det(JJ^T)}$

- Depends on configuration
- Consider all velocities $\sum_{i=1}^{n} |\dot{\theta}_i| \leq 1$

$\text{Vol}\,\lozenge \approx w$

Design Criteria

Maximize Averge case performance

$$\text{maximize} \iiint_{\Omega} w \, dV$$

integrate over desired workspace

Maximize worst-case performance

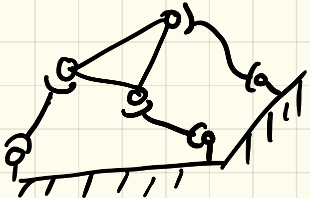
$$\text{maximize} \min_{\Omega} w$$

minimum over desired workspace

Structures w/ Closed Kinematic loops

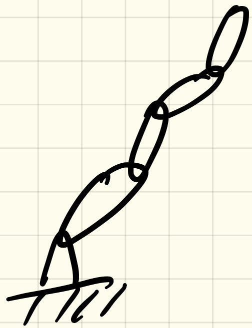
Closed Chain

- Redundant constraints
  (Redundant Load paths)
- Improved stiffness
- Challeging Fwd Kin
- Easy Inverse Kin



Open Chain

- Easy Fwd Kin
- Challenging Inv. Kin

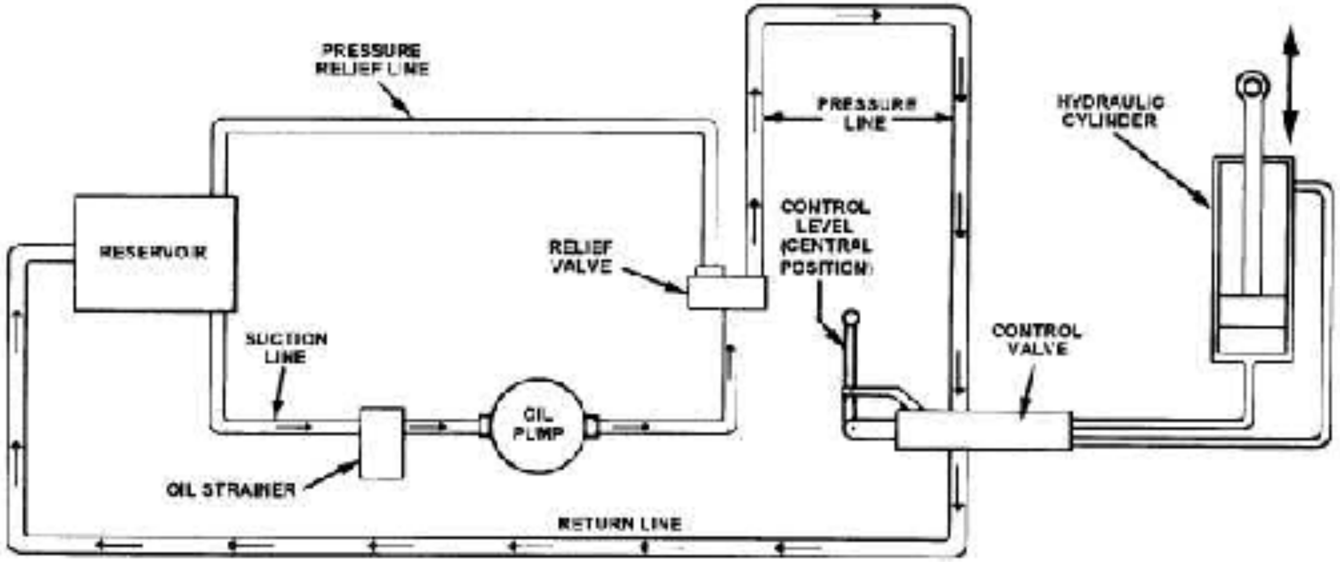


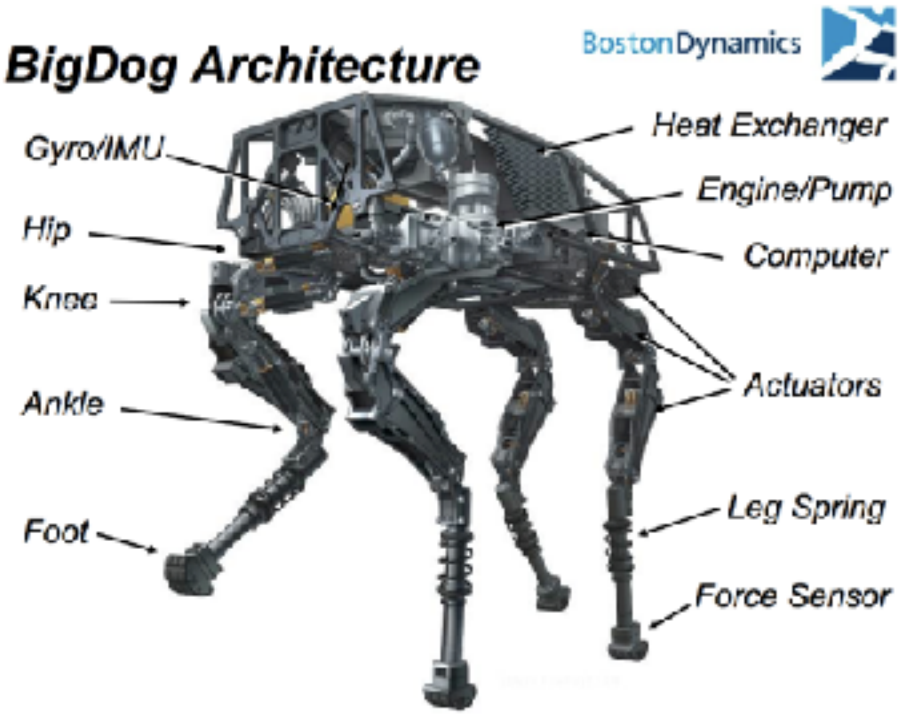
Actuator Selection - A quick overview then lots of robot videos.

- Type
  - Hydraulic (Strong, energetically inefficent)
  - Pneumatic (less strong, more compliant)
  - DC Electric Motors (Industrial Manips)
  - Many more!

- Transmission (Amplification & Relocation of Force)
  - Direct Drive (No transmission)
  - Cable Drives / timing belts / gearboxes
  - Series elasticity / parallel elasticity
  - Many More!

Hydraulics





Hydraulic actuators are suitable for high-force applications. A great deal of supporting Infrastructure is needed for hydraulics.

Hydraulics - Wildcat

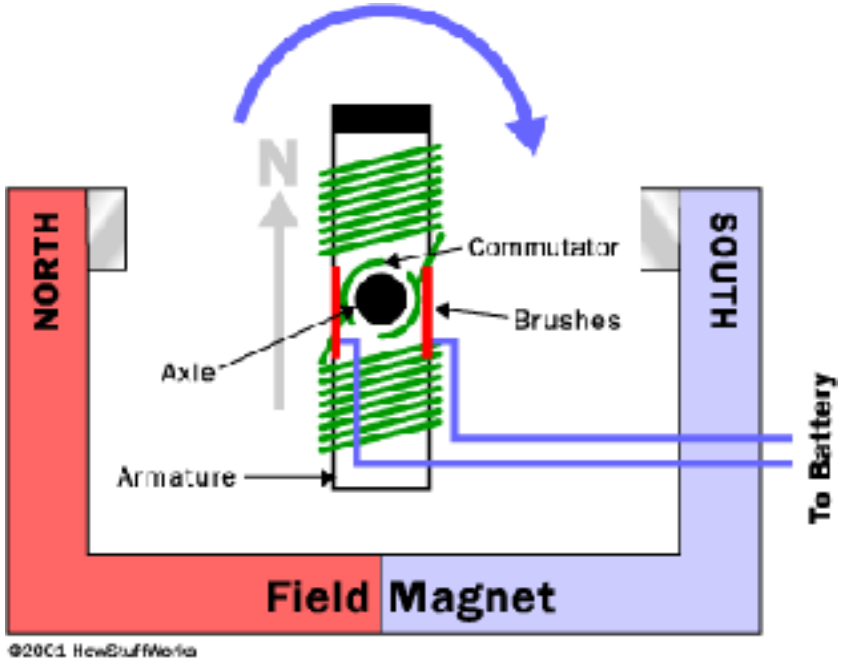
https://www.youtube.com/watch?v=wE3fmFTtP9g

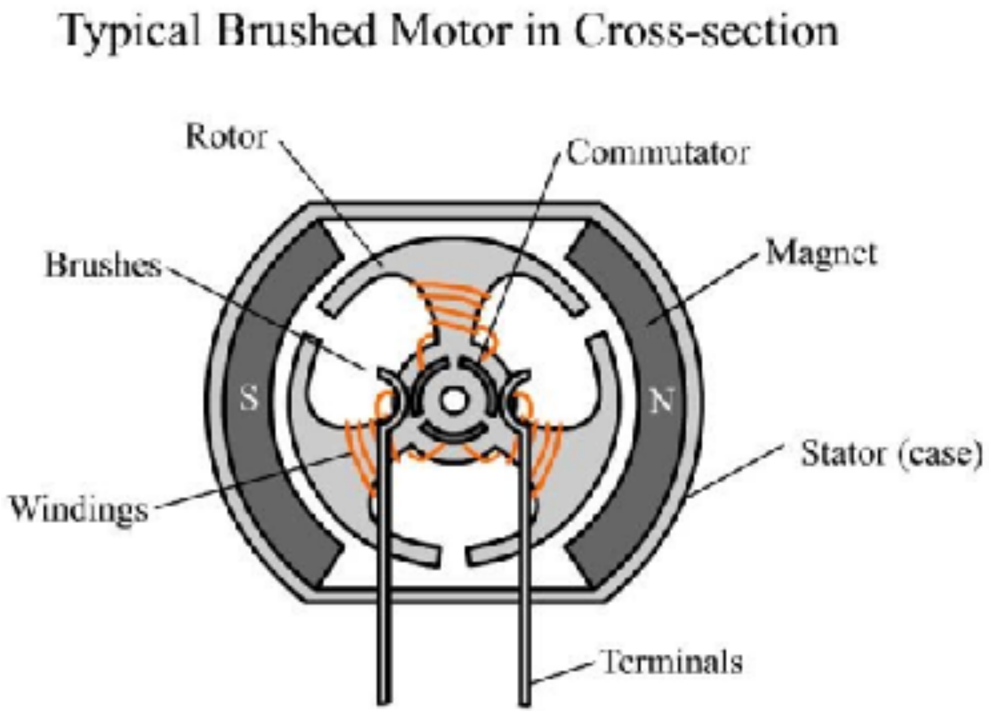
Pneumatics – FESTO robotics

Pneumatic actuators are suitable for low-force
Applications that require intrinsic compliance

https://www.youtube.com/watch?v=54u3H69tcgM

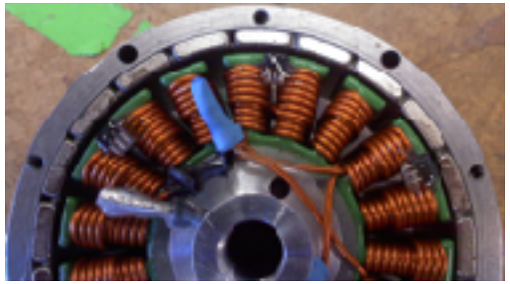
DC Electric Motors - Brushed

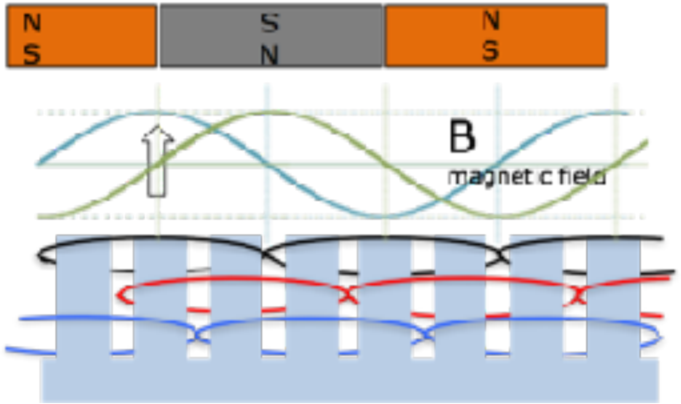


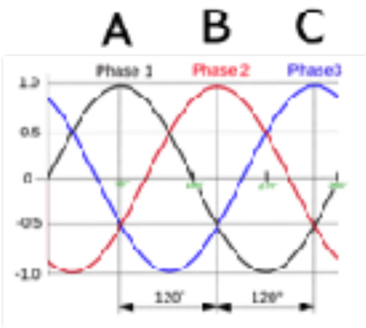


Brushed DC Electric Motors Use Mechanical Design To Switch Polarity of the Electromagnet

DC Electric Motors - Brushless

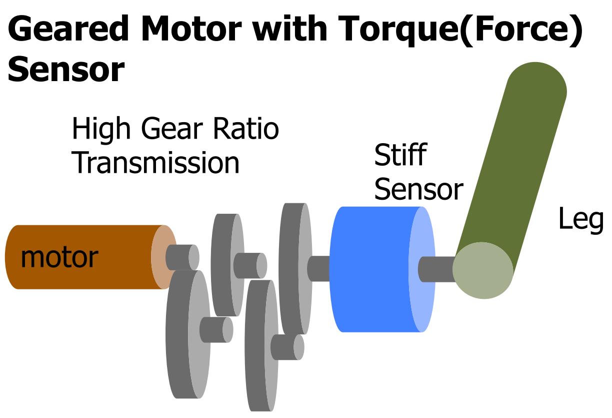


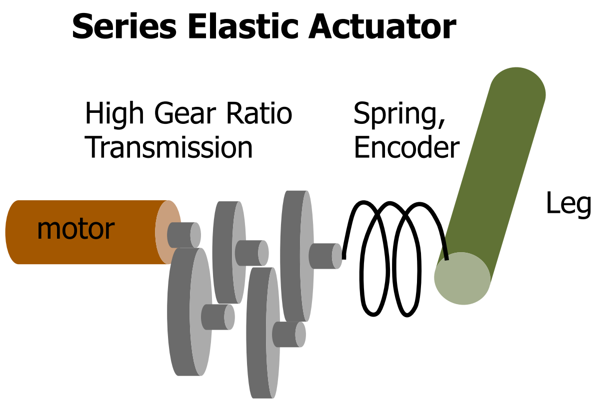


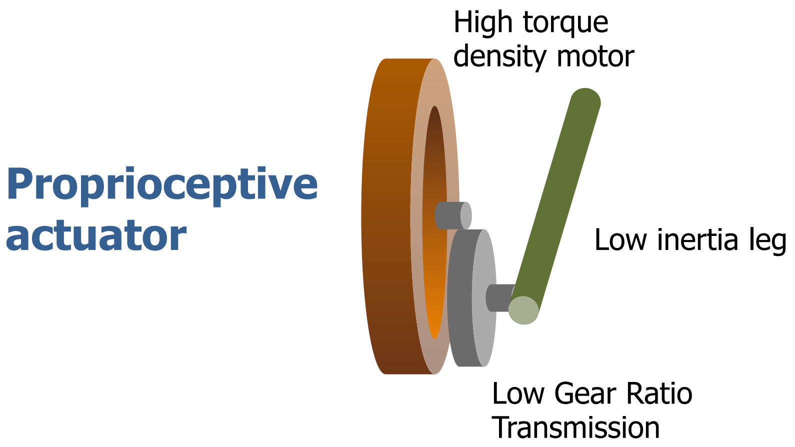


Brushless DC Electric Motors Use Control Electronics
To Vary Polarity of the Electromagnet

Actuator Paradigms







Paradigm	Bandwidth	Impact Robust
Traditional	~5 Hz	No
Series Elastic	~15 Hz	Yes
Proprioceptive	~100 Hz	Yes

High Gear Ratio Transmission – The Harmonic Drive

<u>Three Components:</u>
Wave Generator
Flex Spline
Circular Spline

https://www.youtube.com/watch?v=bzRh672peNk

Harmonic gearboxes are a solid option for systems that
Need low-backlash, require a high reduction, and can avoid impacts

Managing-Low Bandwidth Interactions with Force Sensing

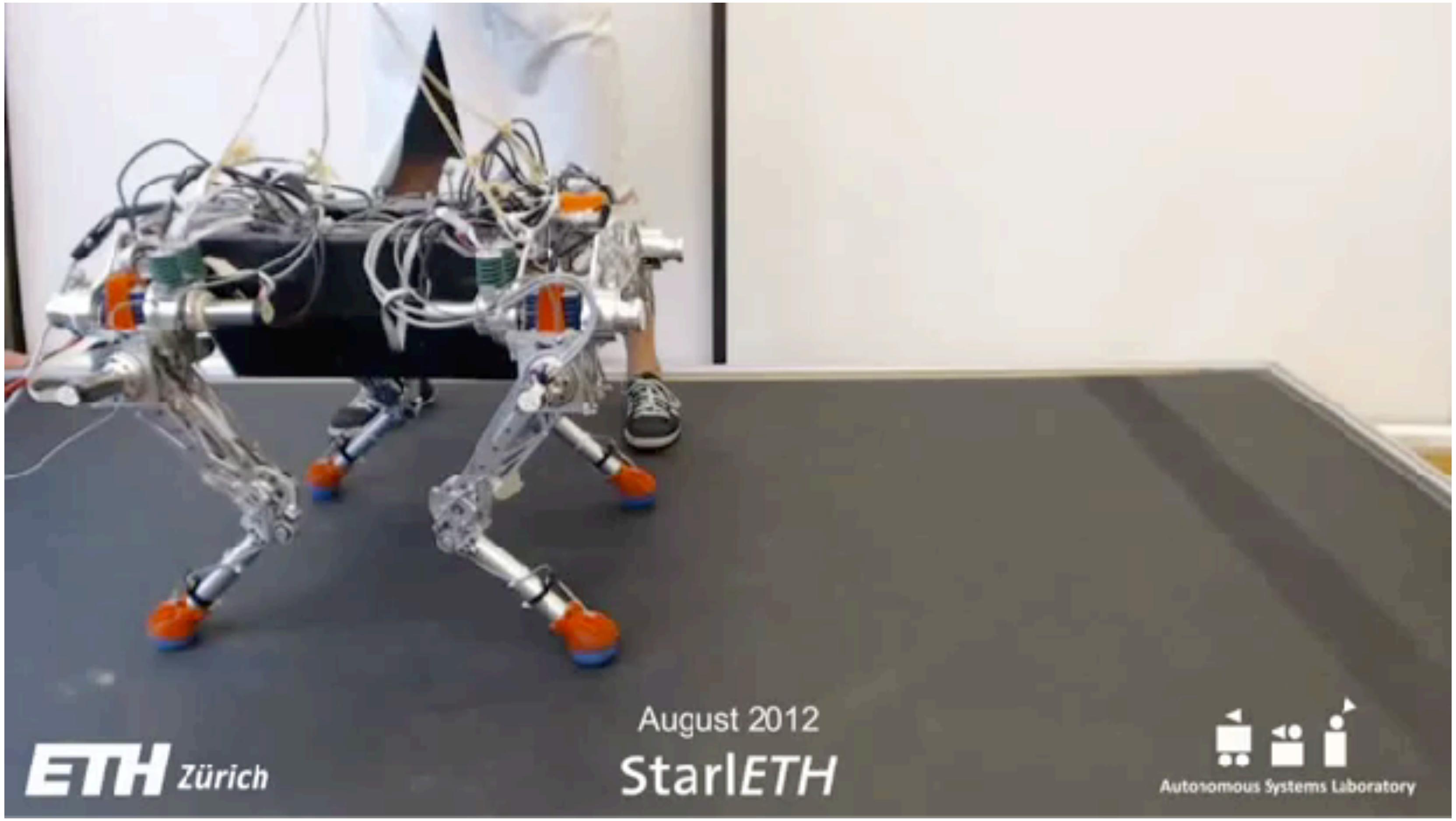
Although harmonic gearboxes have limited back drivability
Added control can be used to enable low-bandwidth interactions

Series Elastic Actuators

https://www.youtube.com/watch?v=nw_PRZeiNs8

Series compliance can protect fragile transmission components from Impacts. It can also be used for efficient energy storage.

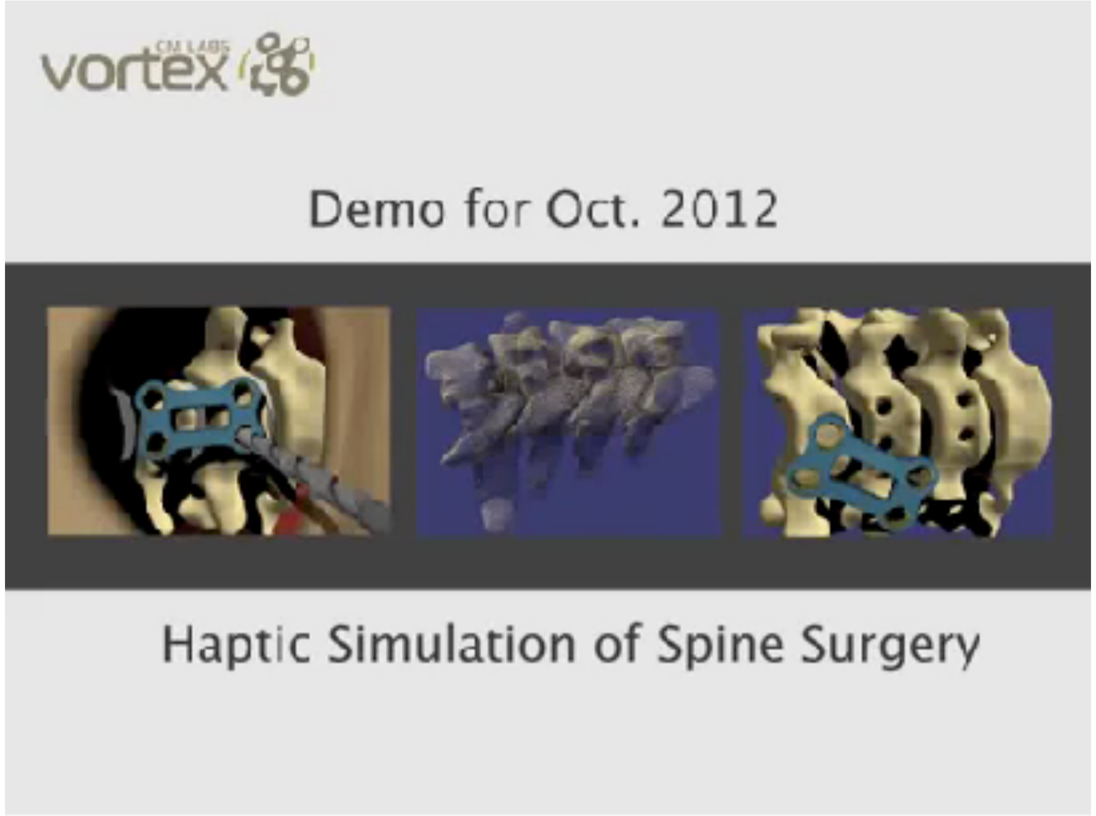
Series Elastic Actuators



https://www.youtube.com/watch?v=7F6GRFPkdp0

Transparent Transmissions - Haptics

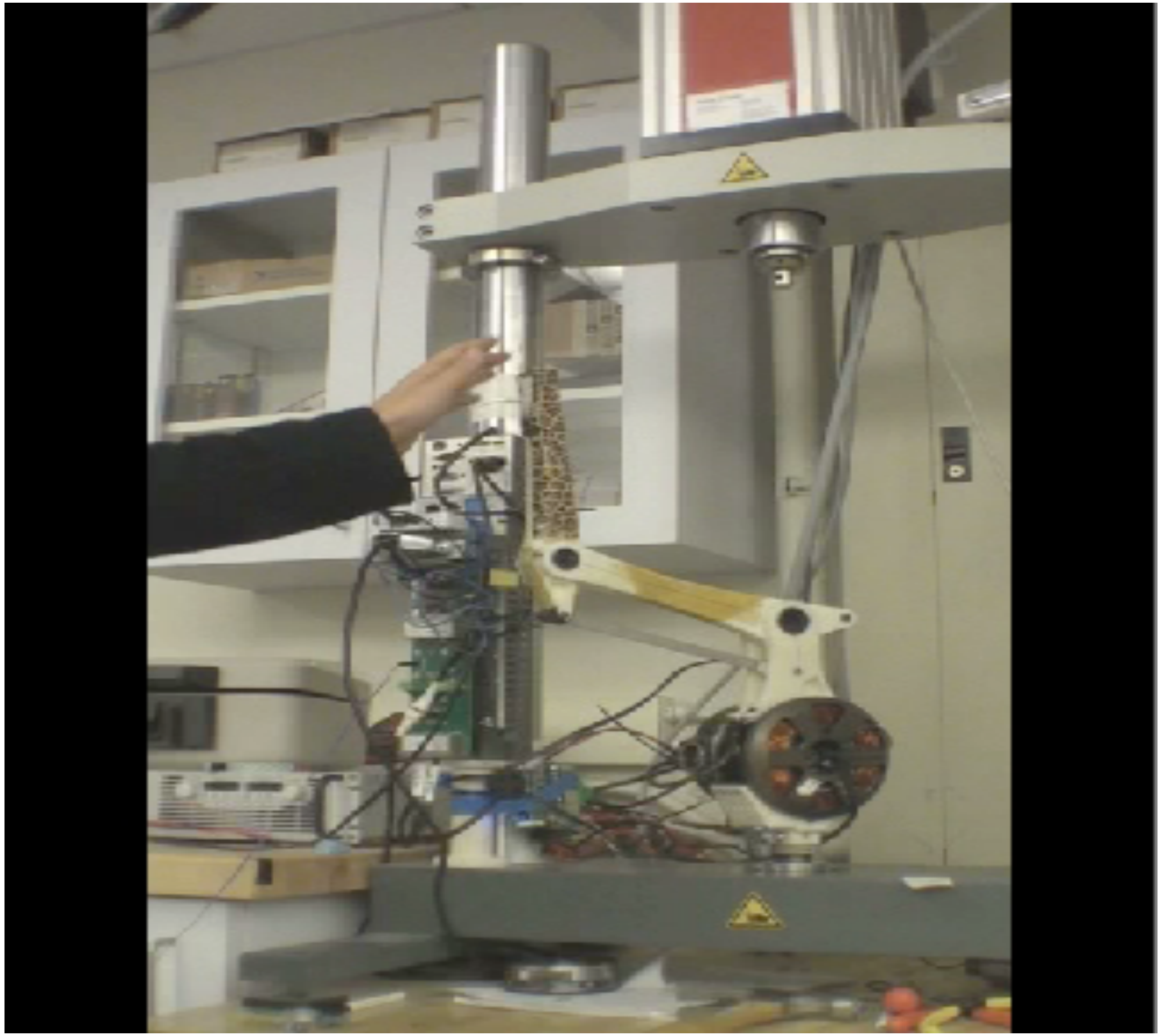
Phantom – Haptic display device
Kenneth Salisbury



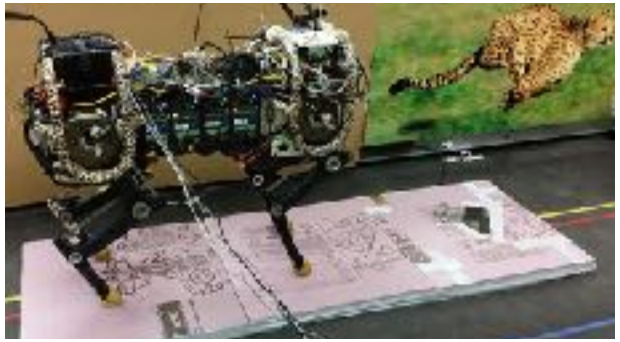
Low impedance transmissions simplify force control and enable rendering of virtual environments.

https://www.youtube.com/watch?v=_luhn7TLfWU

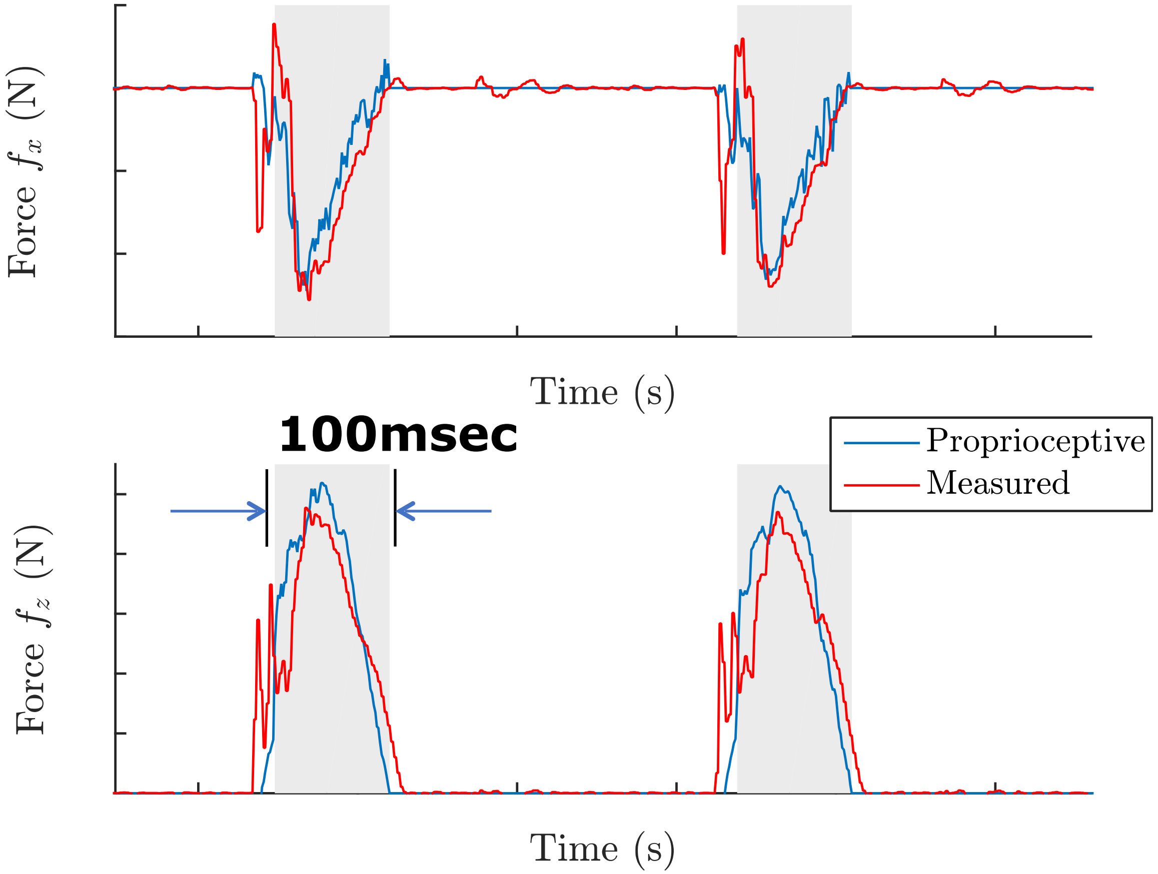
Transparent Transmissions – Acting like a spring



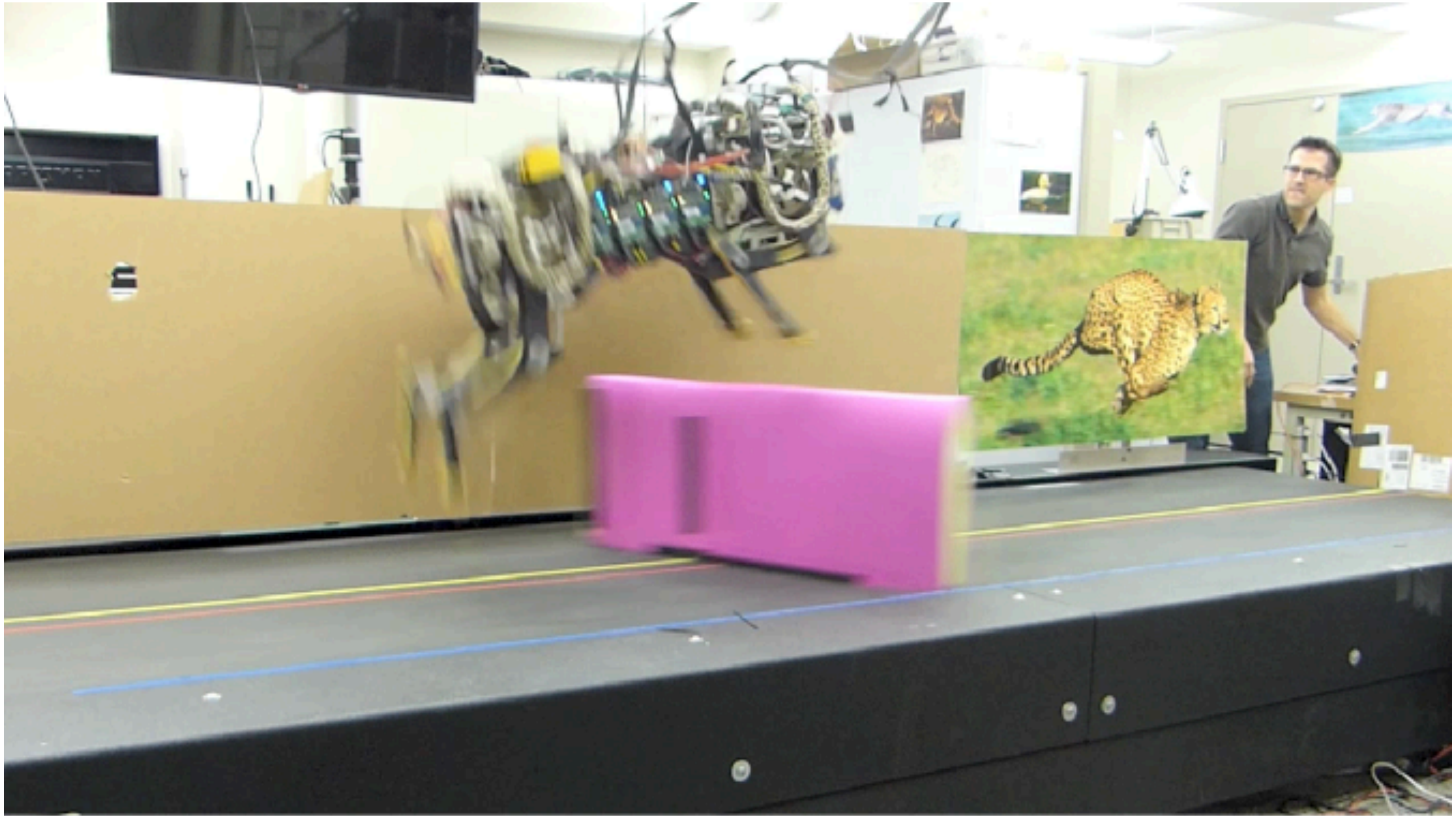
Contact force control after impact :500N within 100ms



$$\tau = J^T f$$



Rapid Force Production



https://www.youtube.com/watch?v=_luhn7TLfWU