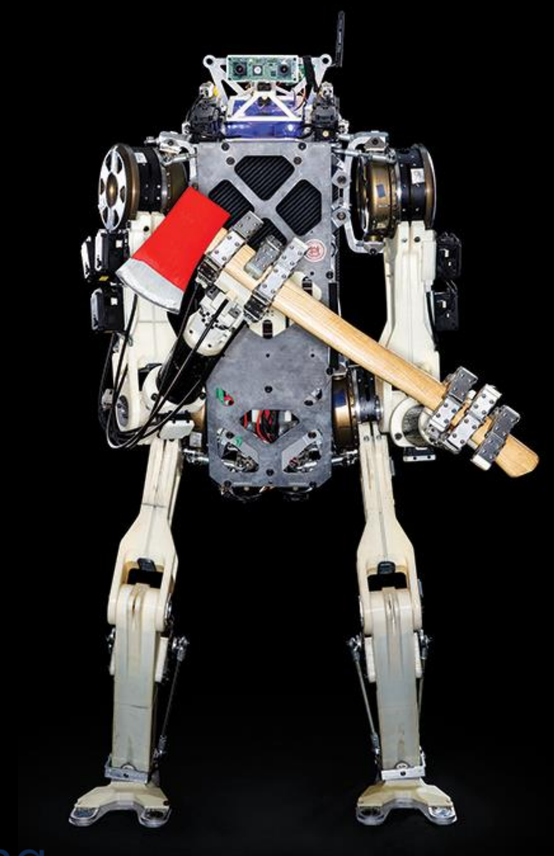
Dynamic Synchronization of Human Operator and Humanoid Robot via Bilateral Feedback Teleoperation.

Humanoids 2019

Workshop on Teleoperation of Humanoid Robots

João Ramos, PhD
Assistant Professor



ILLINOIS
Mechanical Science & Engineering
GRAINGER COLLEGE OF ENGINEERING

What is the problem?

https://sites.suffolk.edu: Fukushima Daiichi Nuclear Disaster

Source: *http://www.darpa.mil/program/darpa-robotics-challenge*

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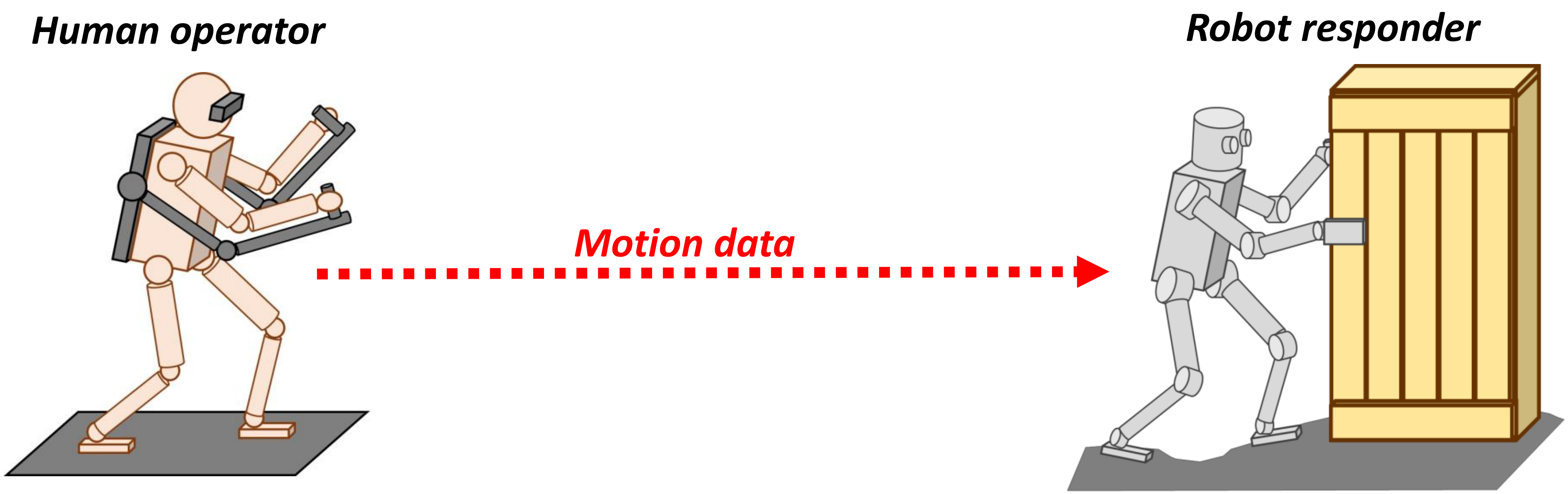
Maybe a human can help?



Human-controlled drone

[1]

[2]

[1] *From YouTube: Why Should you fly Freestyle at 800mW? | FPV - https://www.youtube.com/watch?v=bBb_kSO3vTo&feature=youtu.be*
[2] *https://www.ctvnews.ca – CTV News: Boy drone racing champ flying high*

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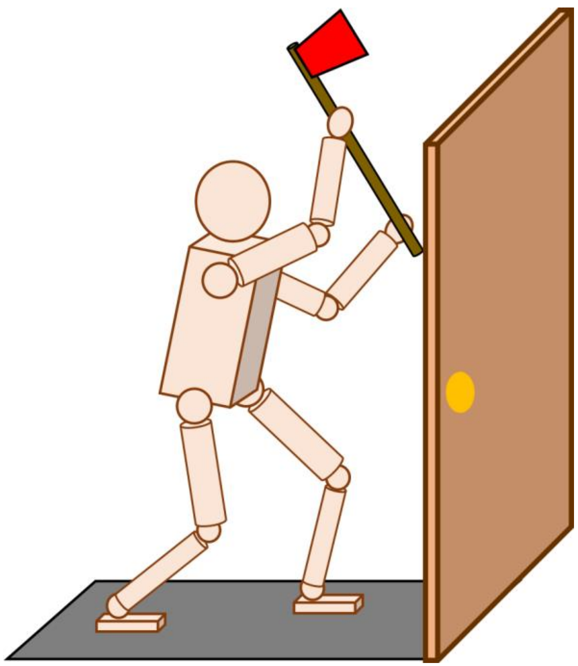
Dynamic whole-body interaction



[1]

[2]

[1] From YouTube: "S&D Sledge Technique, 6 lb Axe versus 8 lb Pig"
[2] Unknown source

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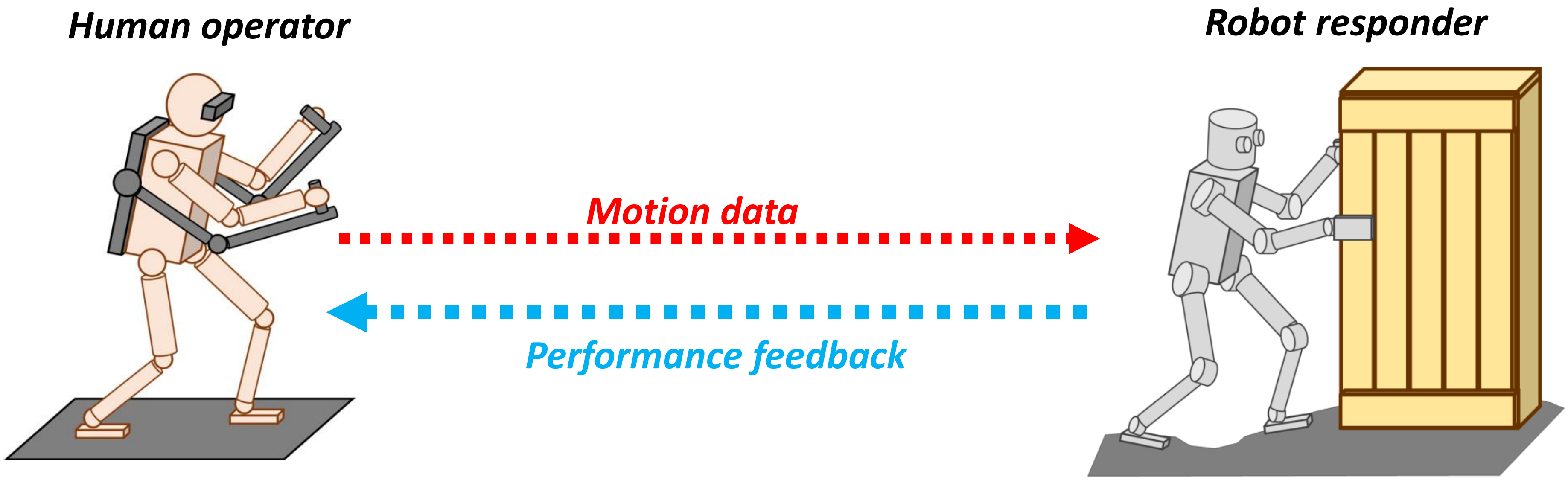
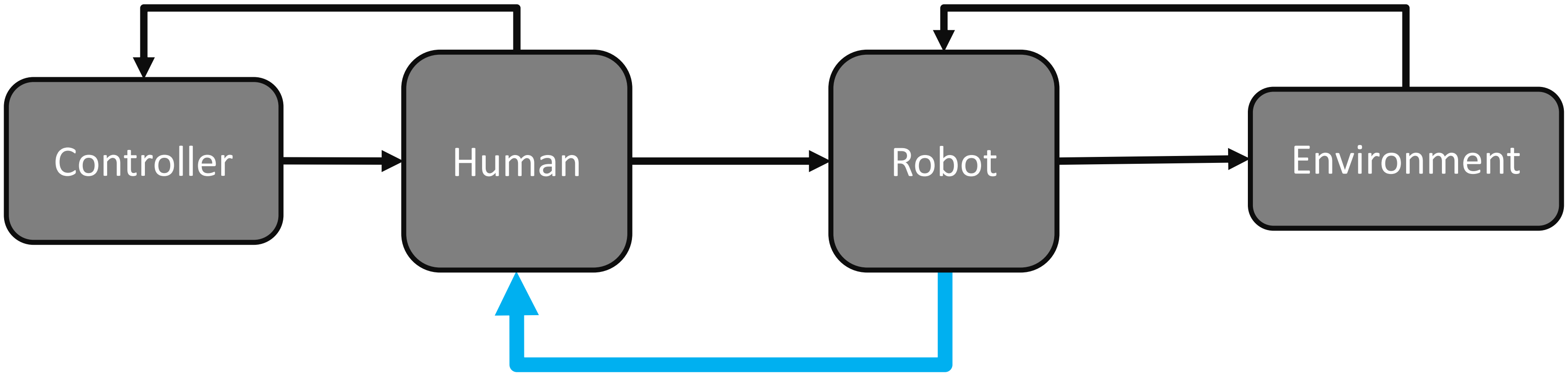
Whole-Body Teleoperation





Research hypothesis:

1- If we properly ***map*** human ***motion*** to the robot and;

2- If we provide the correct ***physical feedback*** to the operator;

A human operator can utilize ***motor intelligence*** to control the ***physical interactions*** between the robot and its environment.

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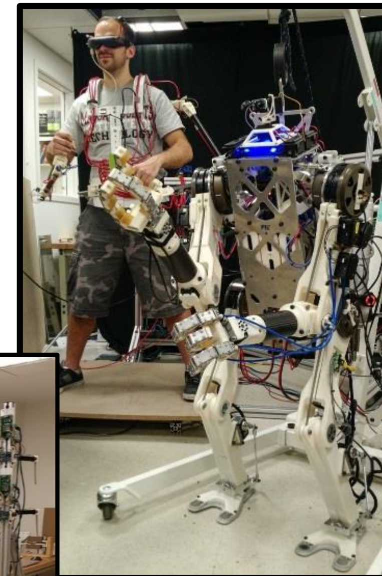
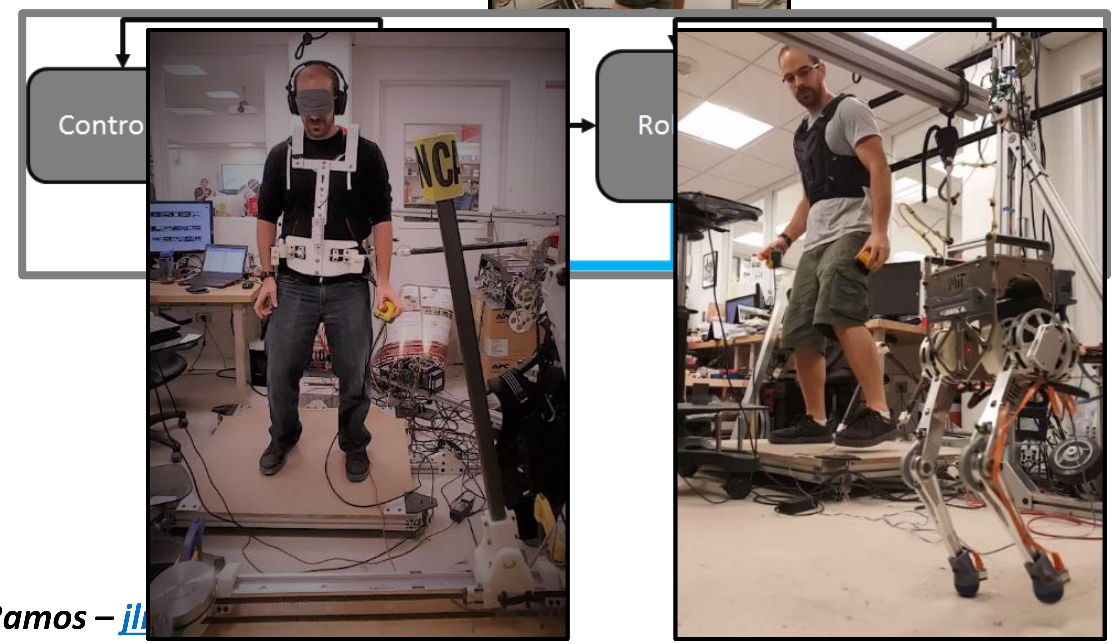
Talk outline:

- HERMES System: upper-body dynamic teleoperation
- Human-Machine Interface for whole-body feedback
- Bilateral feedback teleoperation for locomotion
- Application to two different systems
- Future work and research vision





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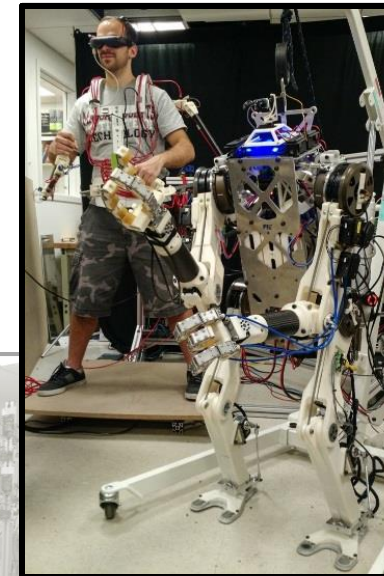

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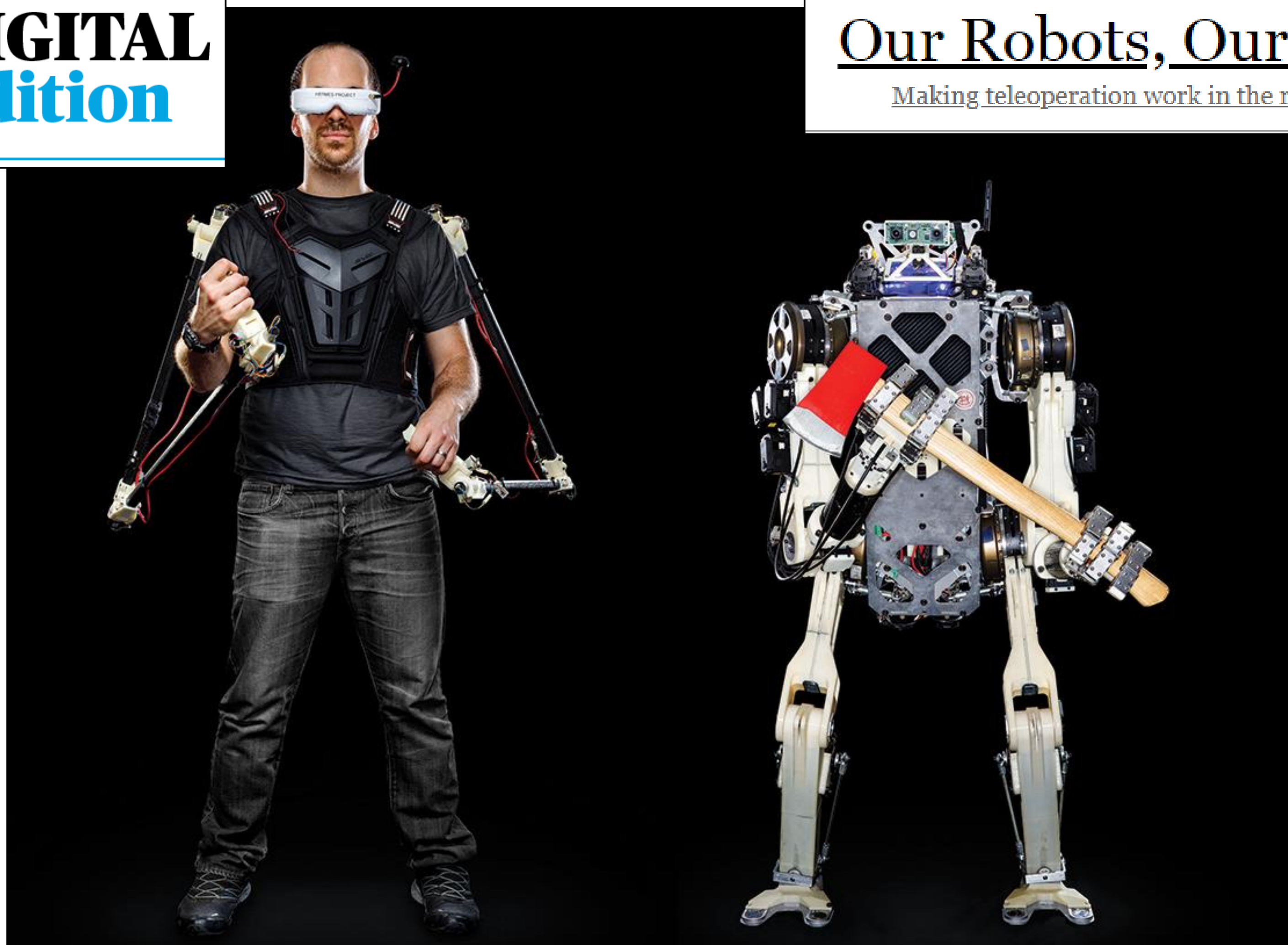
The HERMES System

IEEE SPECTRUM
The DIGITAL Edition

Our Robots, Ourselves
Making teleoperation work in the real world



Picture by Bob O'Connor

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Motion Mapping

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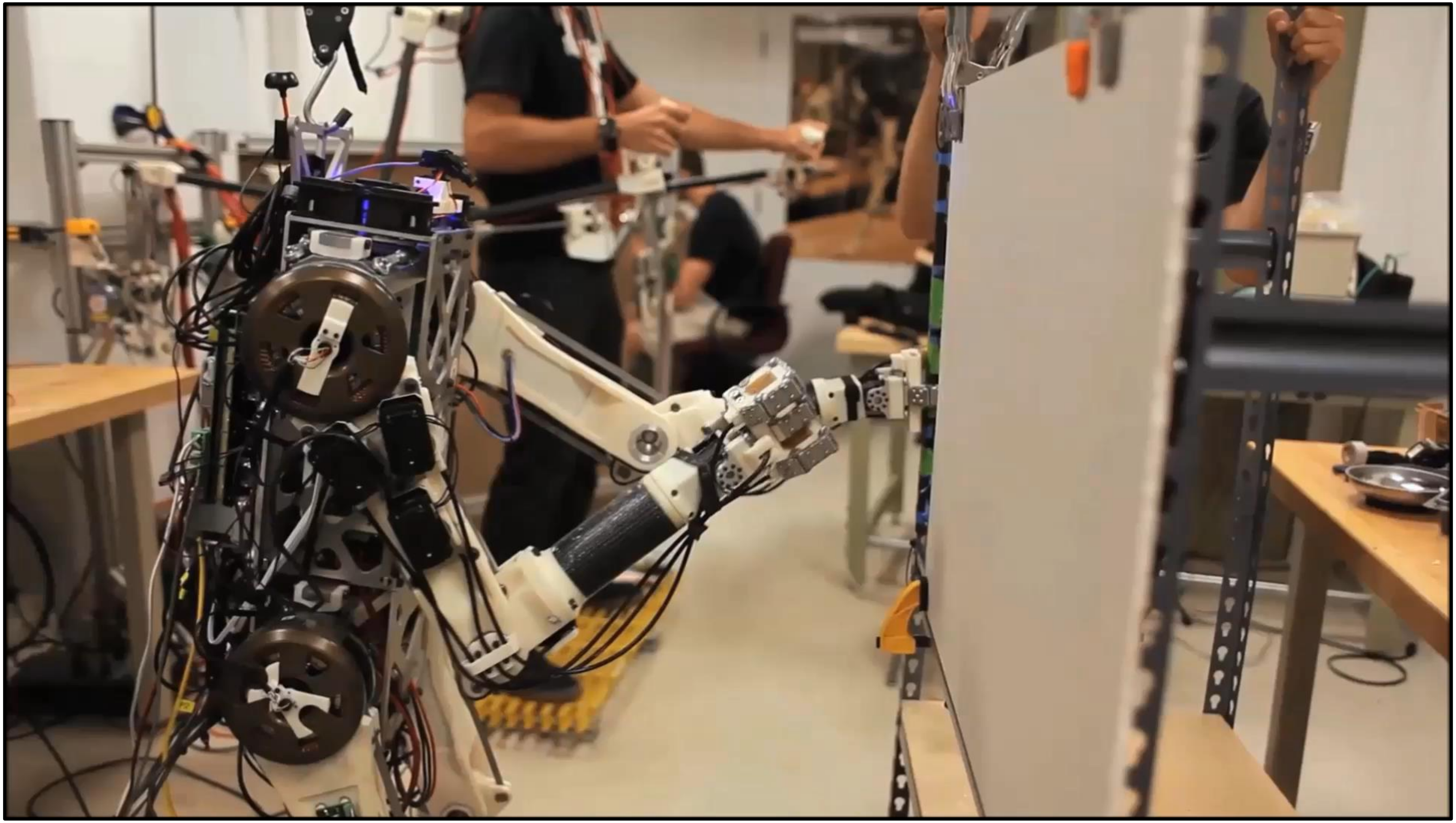
Manipulation

Dexterous manipulation

Human-level ***perception***

Power Manipulation



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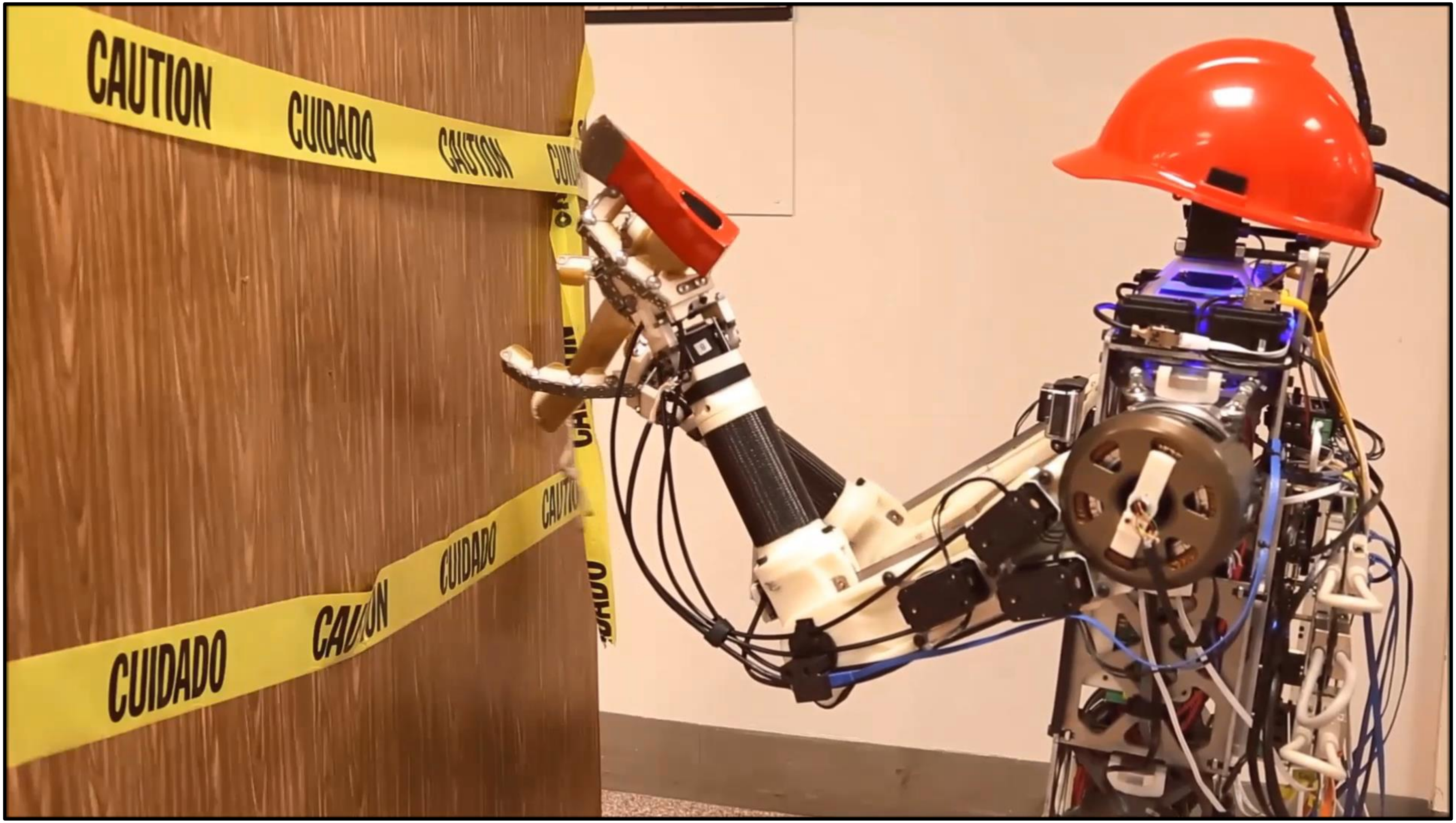
Power Manipulation



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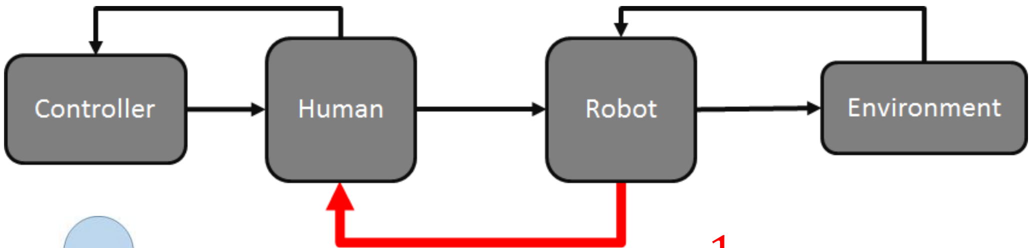
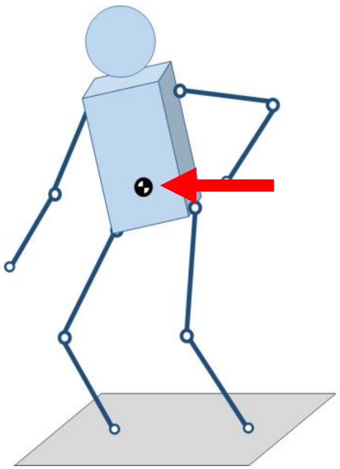
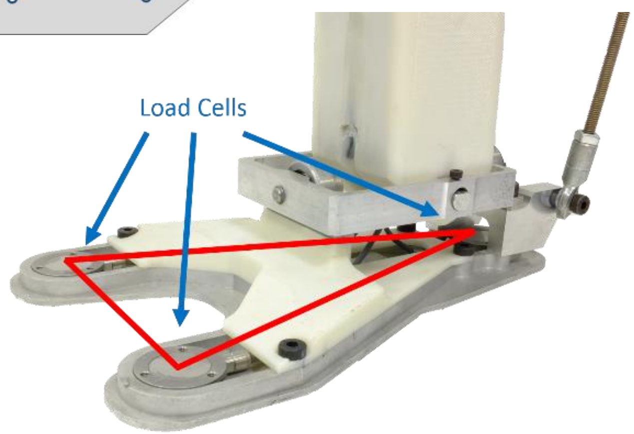
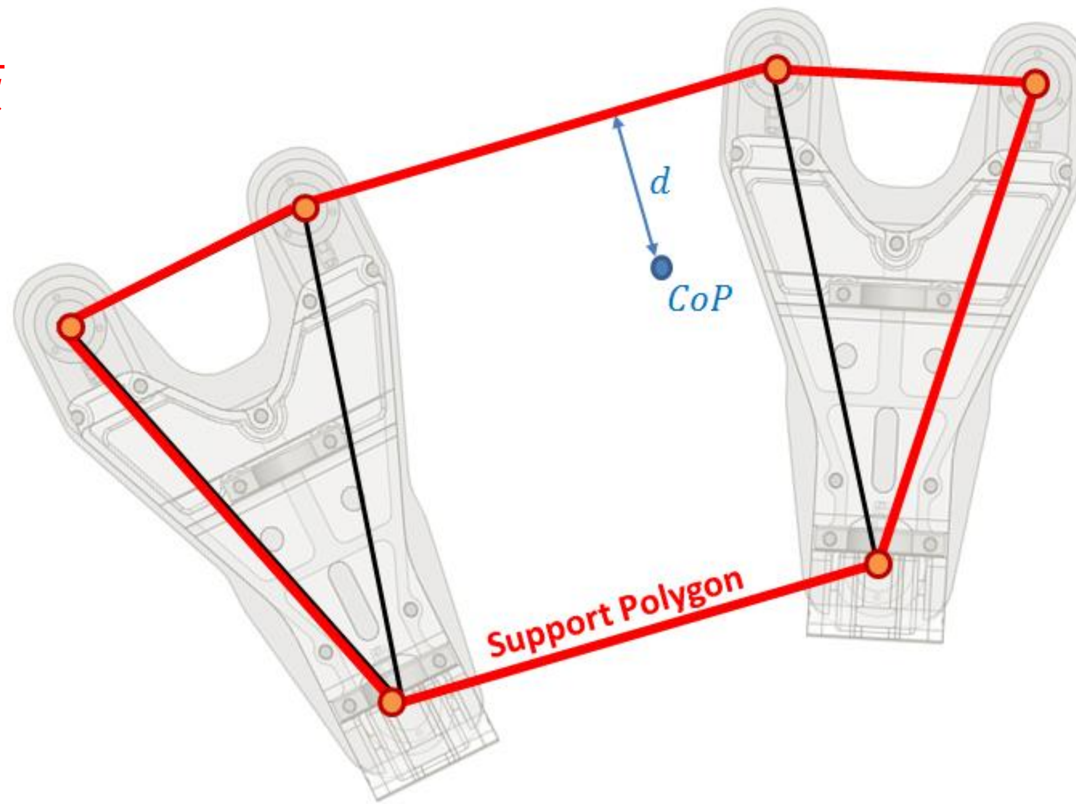
Quasi-static Balance Feedback Strategy



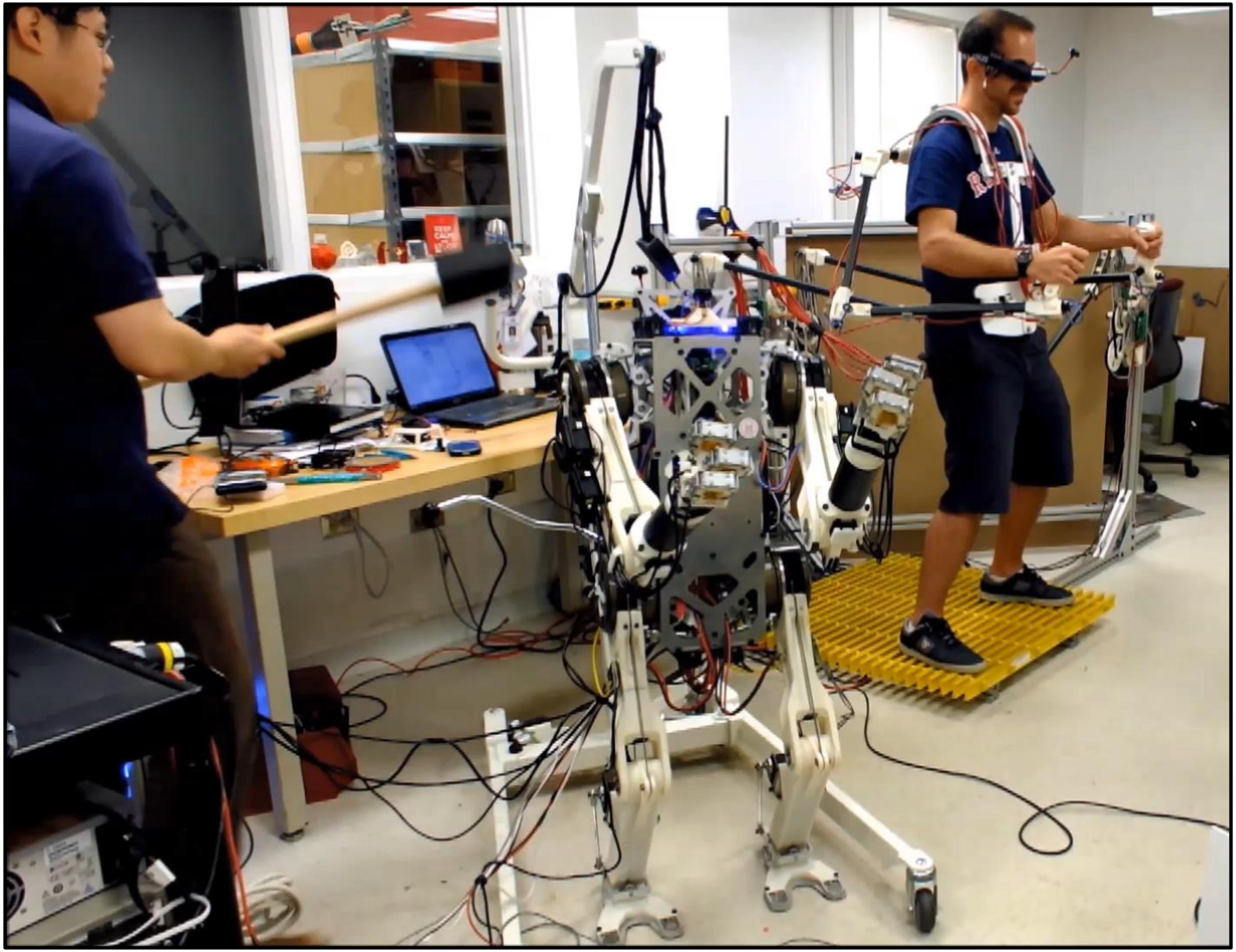
$$F_{feedback} = -K\frac{1}{d}$$







Balance Feedback



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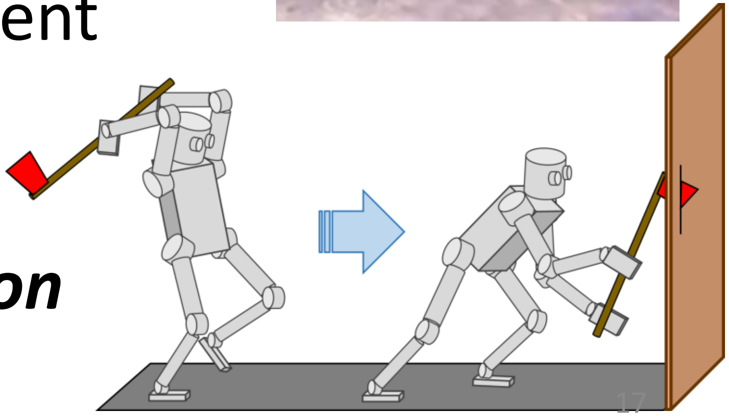
Lessons learned with HERMES

- Teleoperation of ***fast motions***
- ***Large*** feedback forces
- Humanoid design for ***dynamic interactions***

- Regulate ***balance*** and foot placement while ***applying forces***
- Feedback must consider ***locomotion dynamics***



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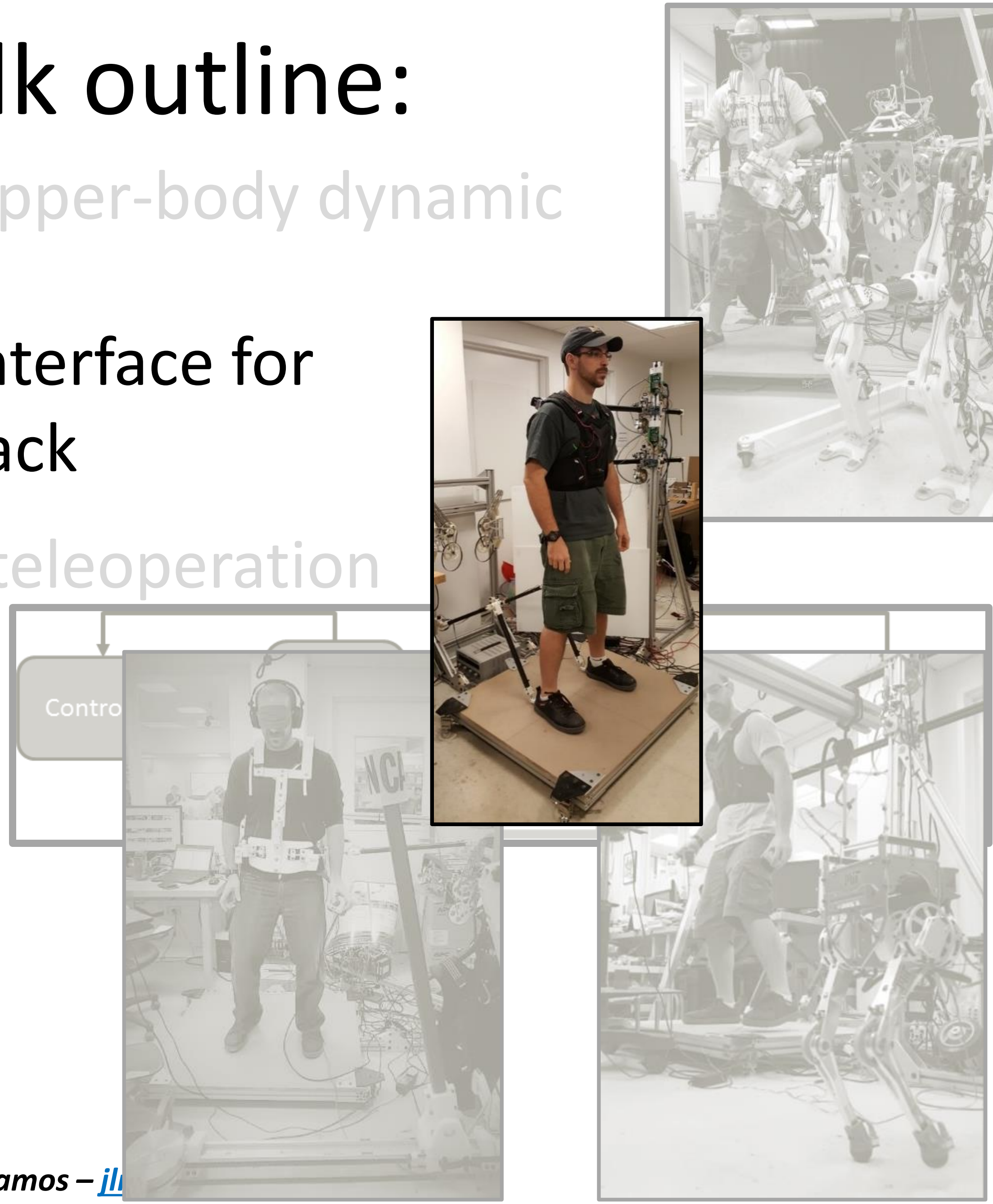
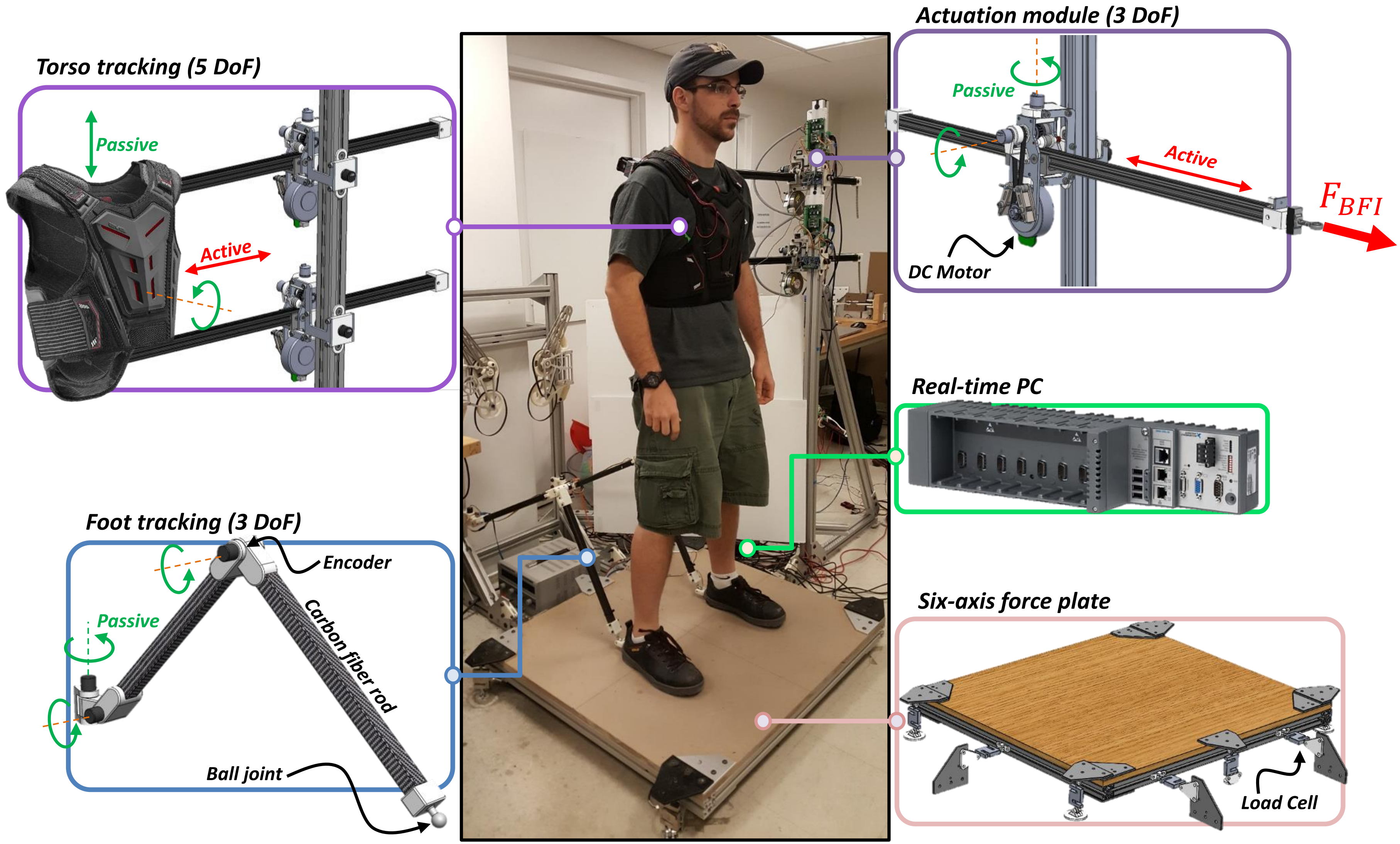


Balance Feedback Interface (BFI):



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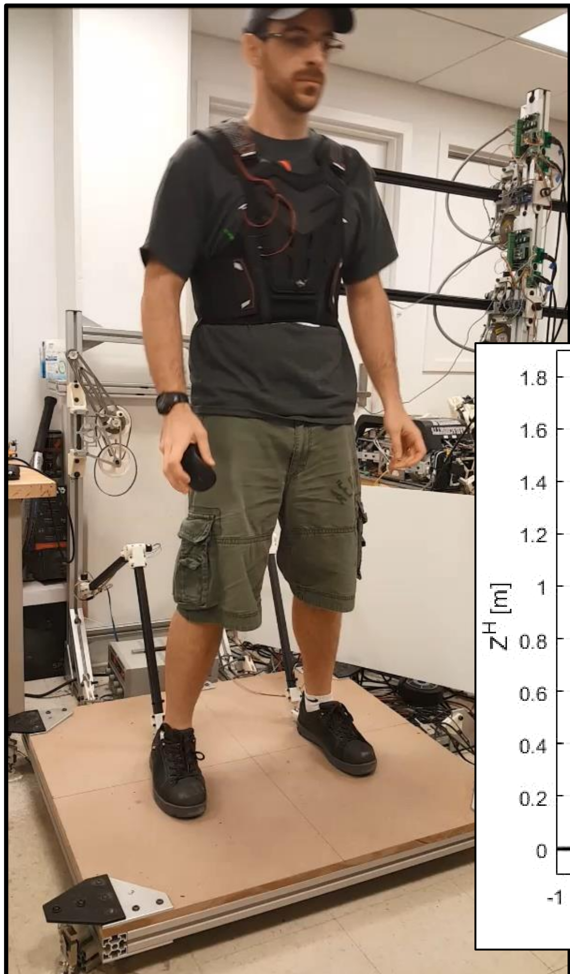
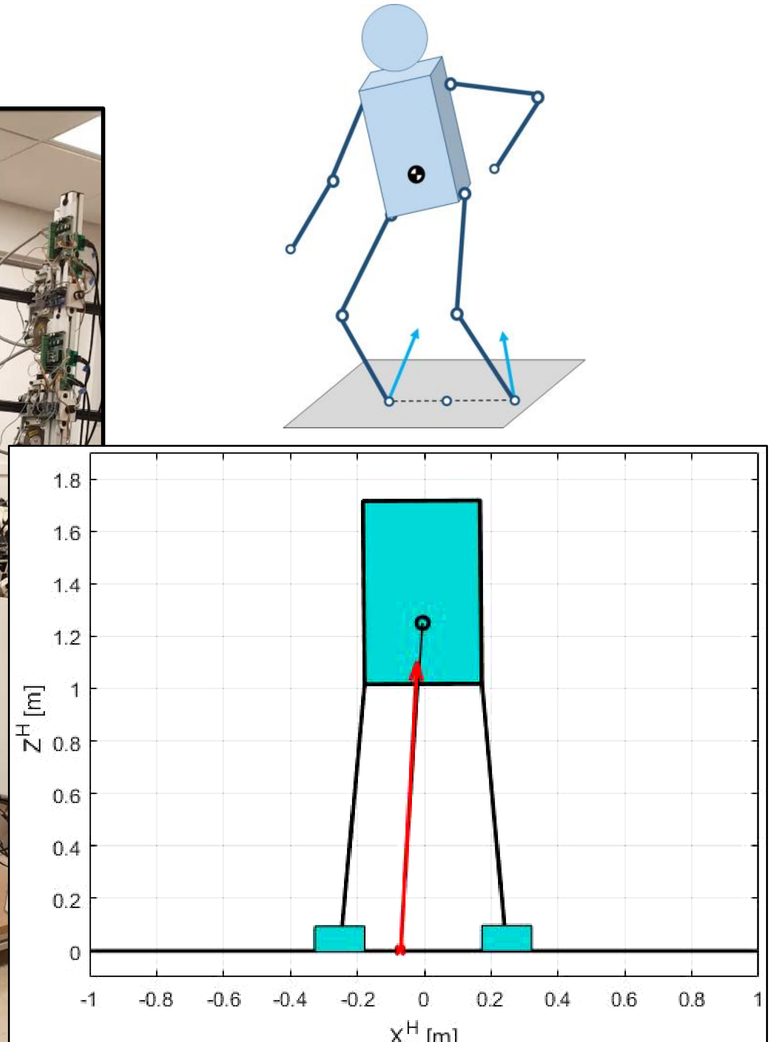
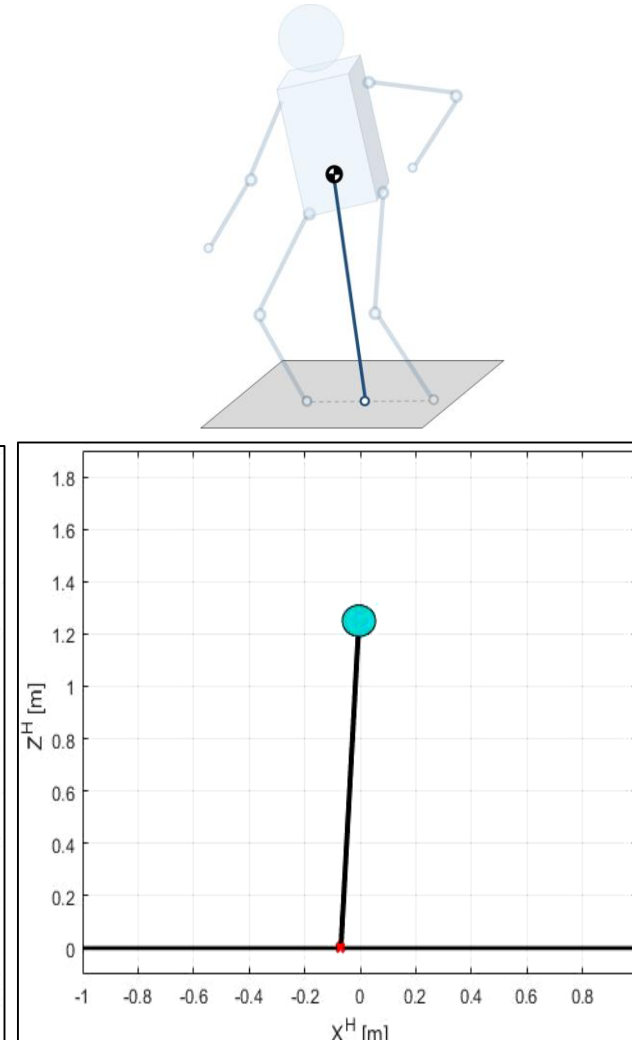
Human Reduced Model





Core components of locomotion



Linear Inverted Pendulum

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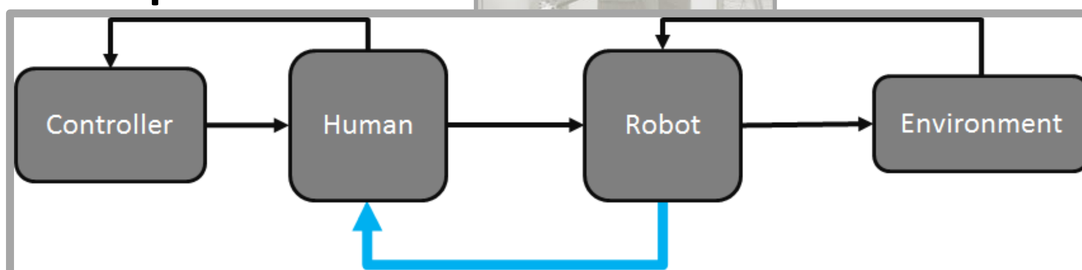
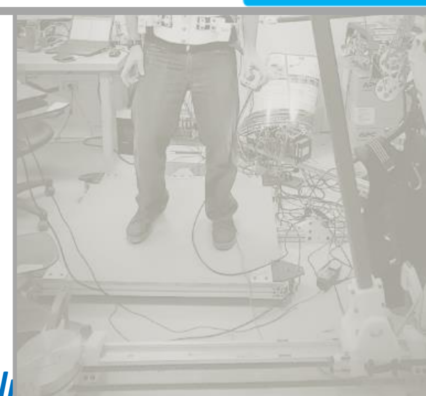
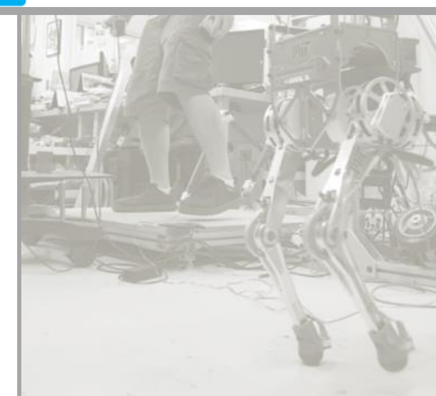
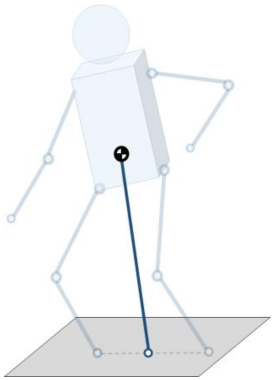
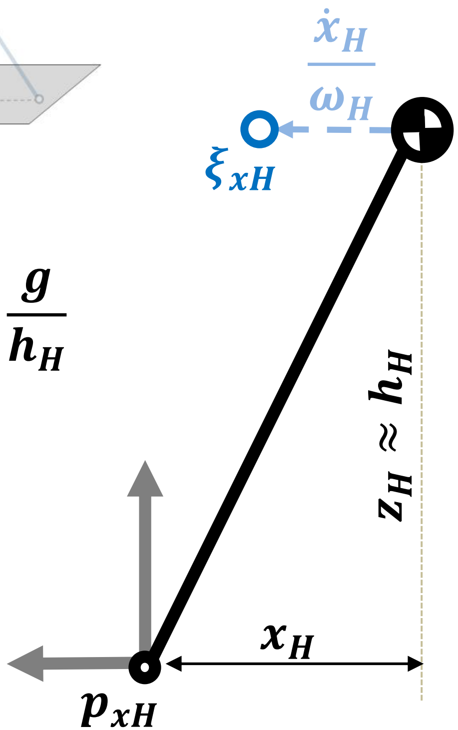






The Linear Pendulum Dynamics





$$\omega_H^2 = \frac{g}{h_H}$$

$$\ddot{x}_H = \omega_H^2 (x_H - p_{xH})$$

$$\begin{bmatrix} \dot{\zeta}_{xH} \\ \dot{\xi}_{xH} \end{bmatrix} = \begin{bmatrix} -\omega_H & 0 \\ 0 & +\omega_H \end{bmatrix} \begin{bmatrix} \zeta_{xH} \\ \xi_{xH} \end{bmatrix} + \begin{bmatrix} +\omega_H \\ -\omega_H \end{bmatrix} p_{xH}$$

Convergent Component of Motion (CCM):

$$\zeta_{xH} = x_H - \frac{\dot{x}_H}{\omega_H}$$

Divergent Component of Motion (DCM):

$$\xi_{xH} = x_H + \frac{\dot{x}_H}{\omega_H}$$

T. Takenaka, T. Matsumoto, and T. Yoshiike, *"Real-time motion generation and control for biped robot-1st report: Walking gait pattern generation,"* in *Proc. IEEE/RSJ Int. Conf. Intell. Robots Syst.*, 2009, pp. 1084–1091.

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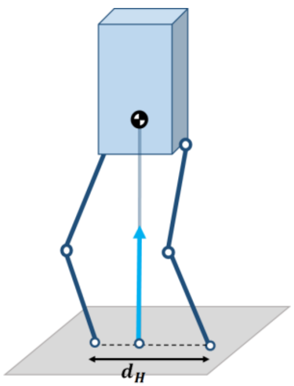
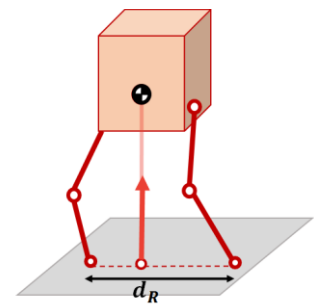
Core idea for bilateral feedback teleoperation

1- To achieve kinematic similarity between human and robot DCM:



$$\frac{\xi_{xH}(t)}{d_H} = \frac{\xi_{xR}(t)}{d_R}$$



2- We impose the similar evolution of DCM:

$$\frac{\dot{\xi}_{xH}(t)}{\omega_H d_H} = \frac{\dot{\xi}_{xR}(t)}{\omega_R d_R} \Rightarrow \boxed{\frac{p_{xH}(t)}{d_H} = \frac{p_{xR}(t)}{d_R}}$$

From human to robot

$$\boxed{F_{xR} = \frac{m_R d_R \omega_R^2}{m_H d_H \omega_H^2} F_{xH}}$$

From robot to human

$$\boxed{F_{BFI} = m_H d_H \omega_H^2 \left(\frac{\dot{x}_R}{d_R \omega_R} - \frac{\dot{x}_H}{d_H \omega_H} \right)}$$

J. Ramos and S. Kim, "Humanoid Dynamic Synchronization Through Whole-Body Bilateral Feedback Teleoperation," in *IEEE Transactions on Robotics*, 2018

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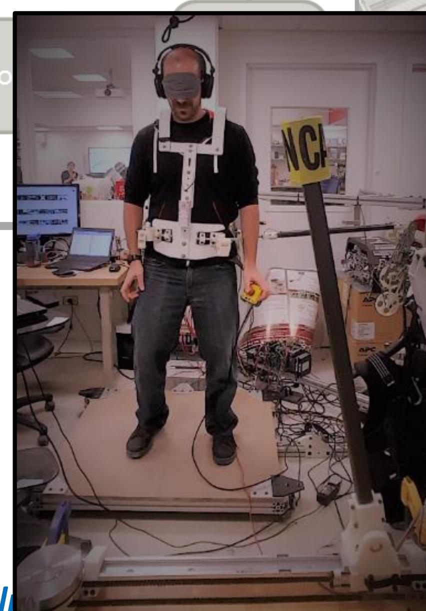
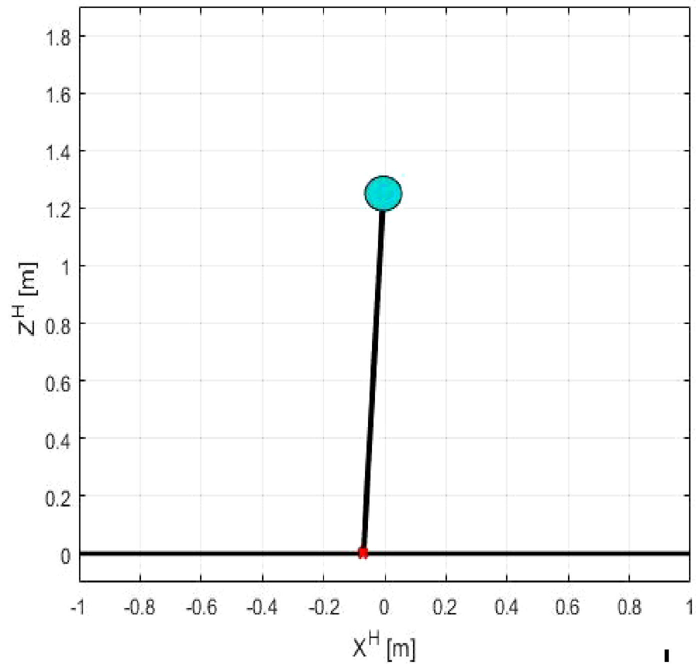
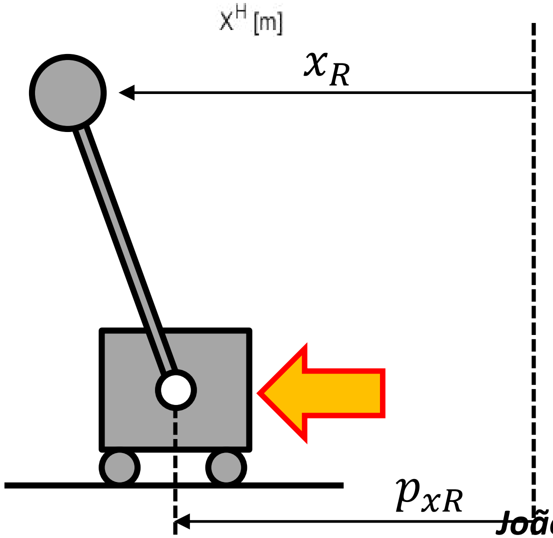
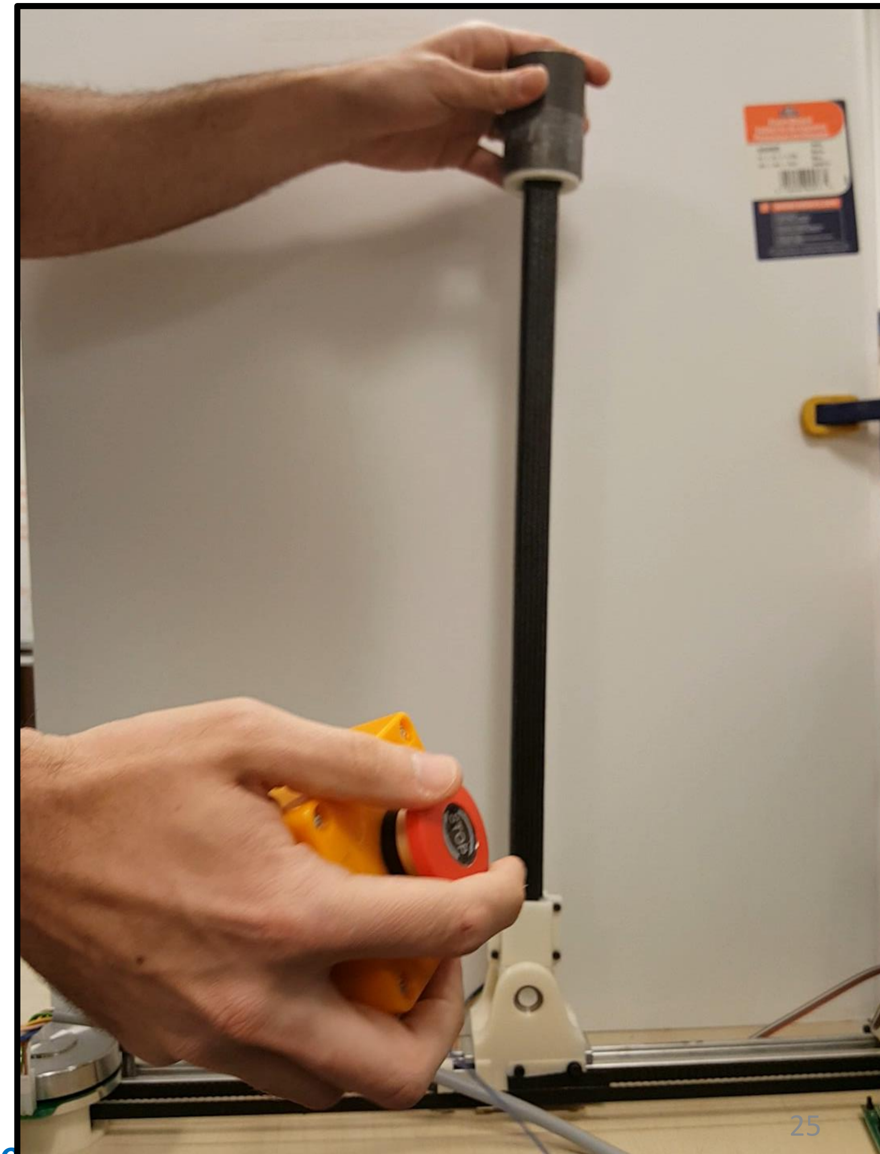


The Cart-Pole System

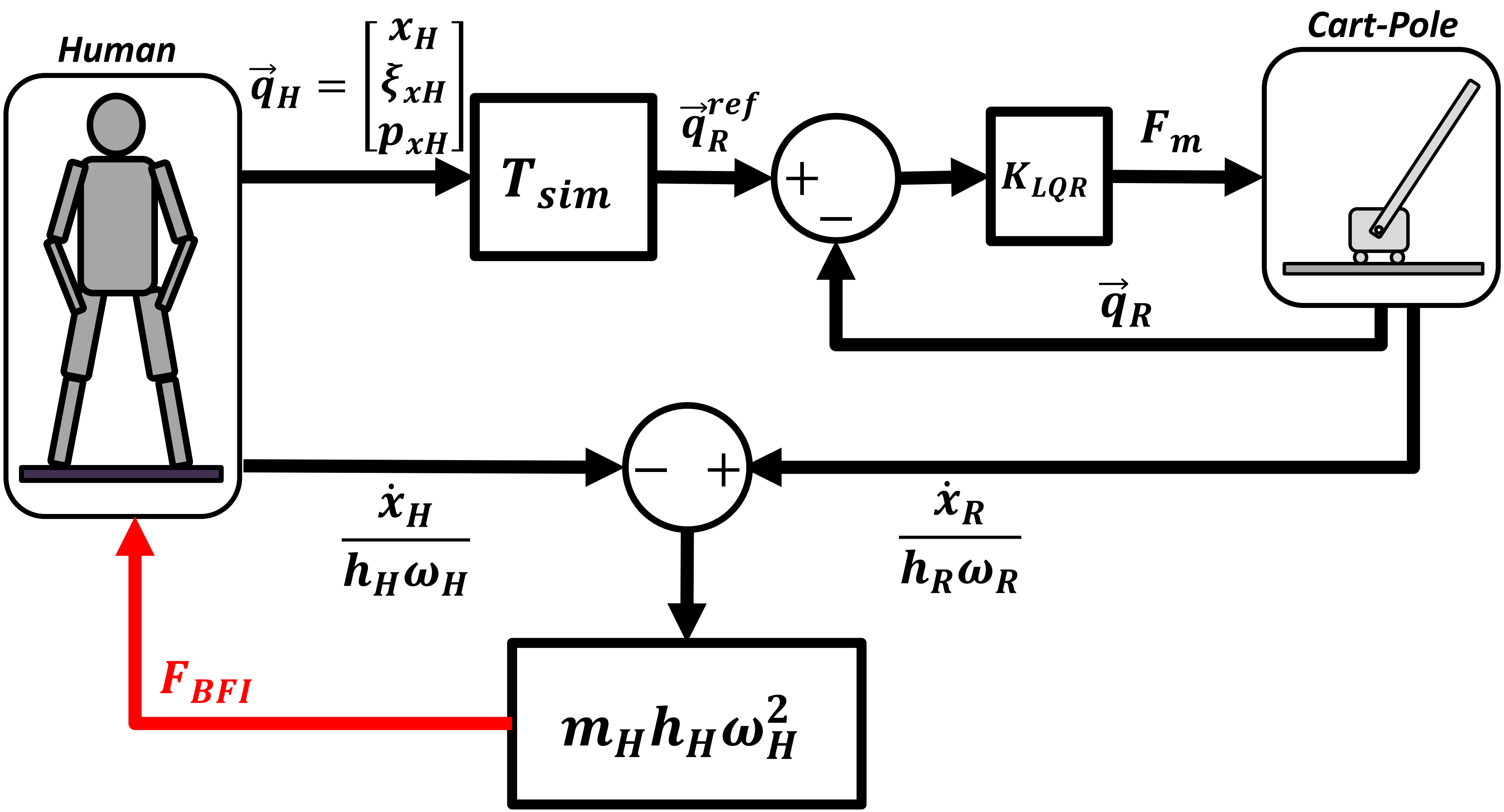
From human motion:





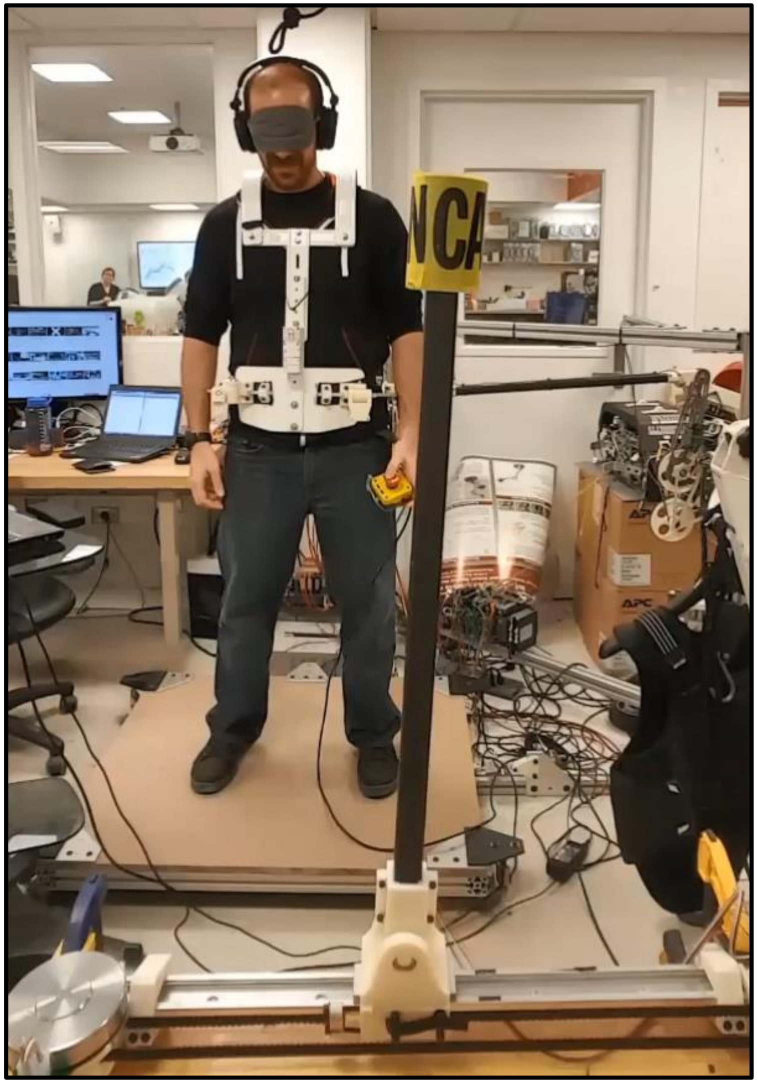


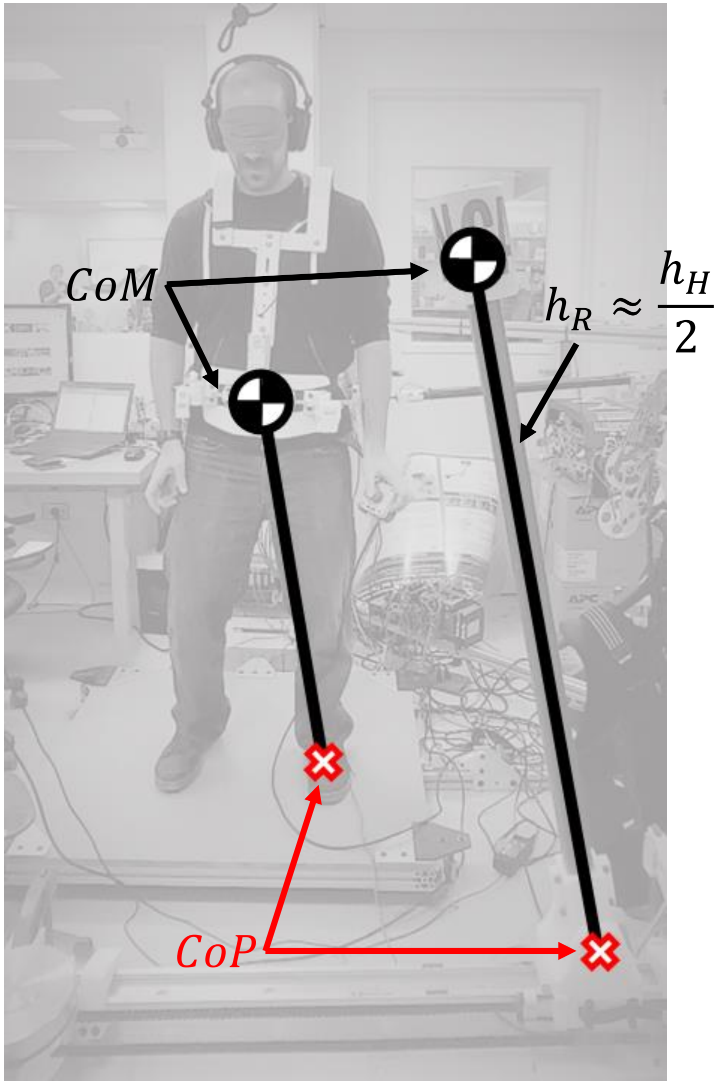
Teleoperation of the Cart-Pole



Teleoperation of the Cart-Pole

J. Ramos and S. Kim, "*Dynamic Bilateral Teleoperation of the Cart-Pole: A Study Toward the Synchronization of Human Operator and Legged Robot*," RA-L, 2018





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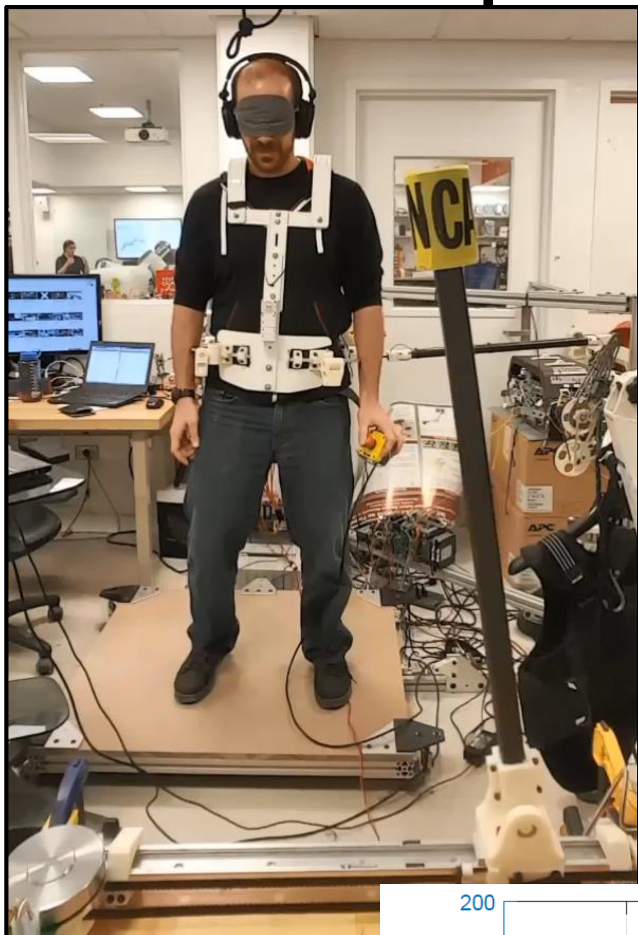

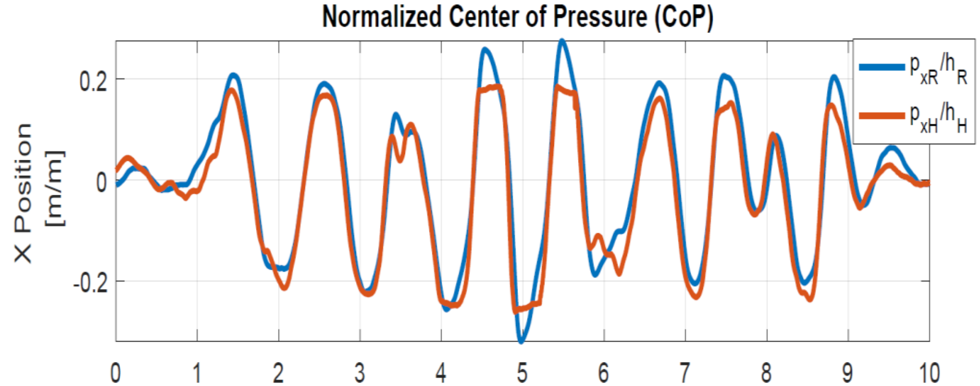

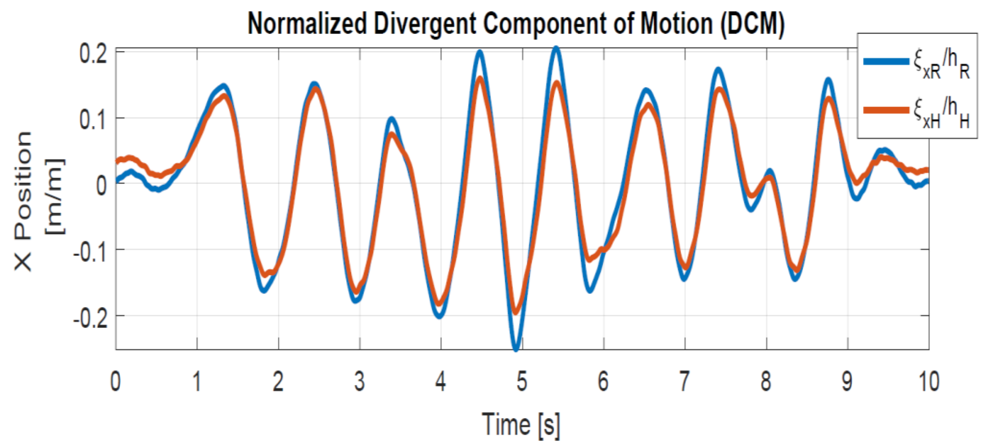

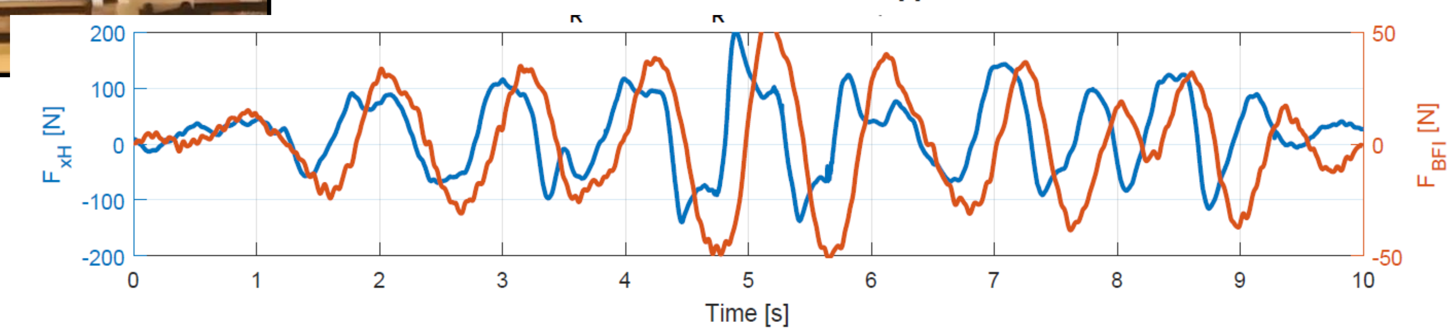

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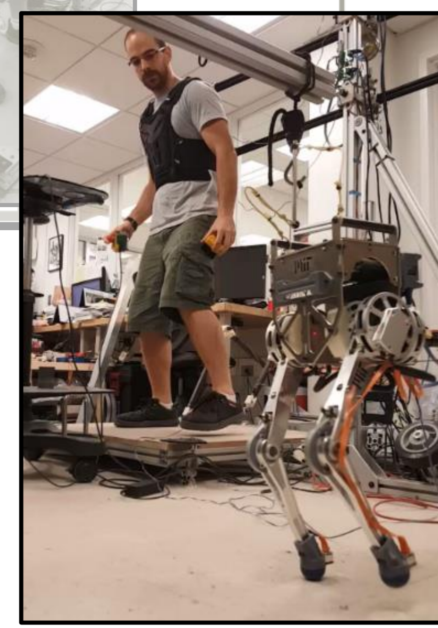
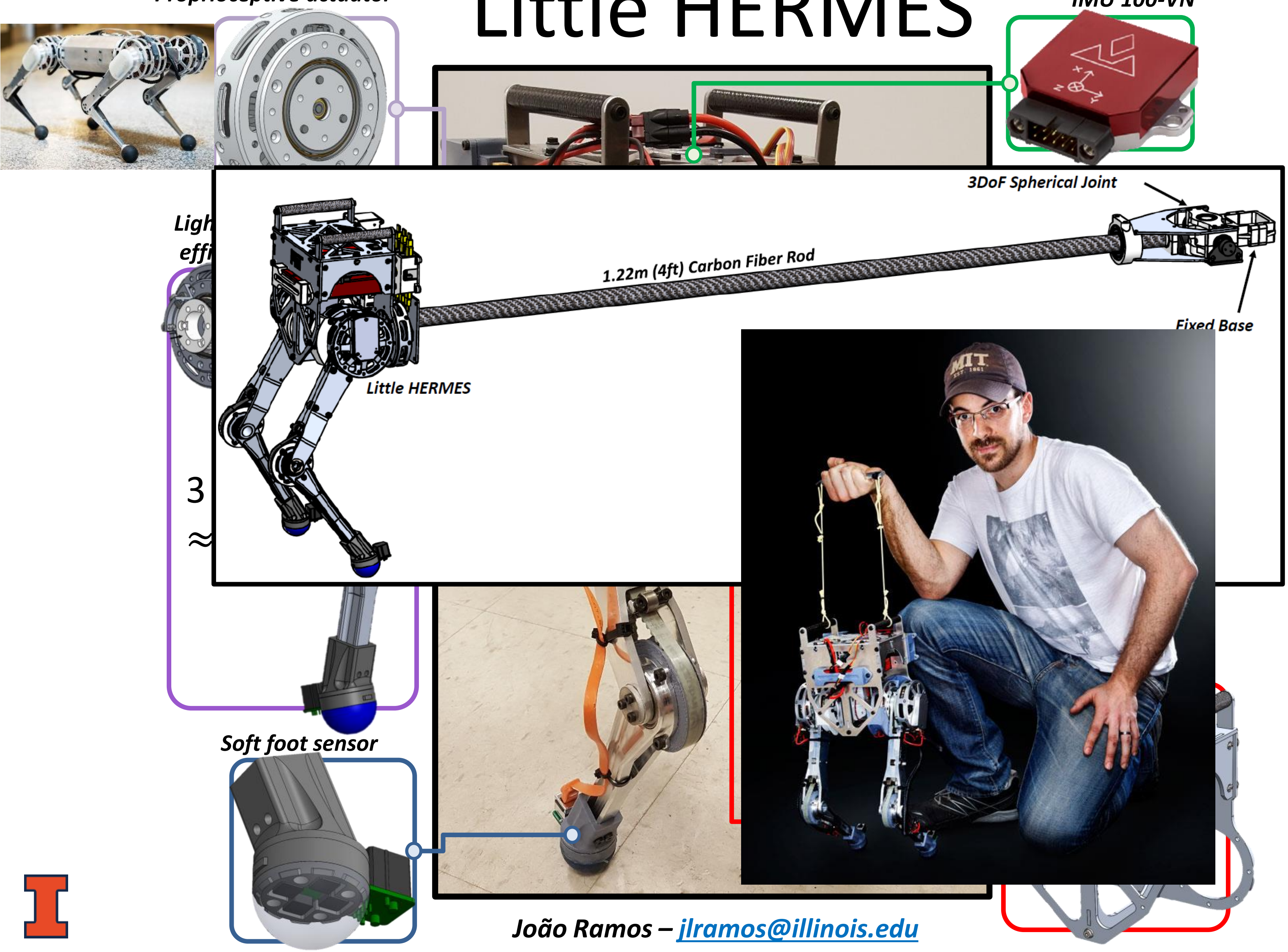
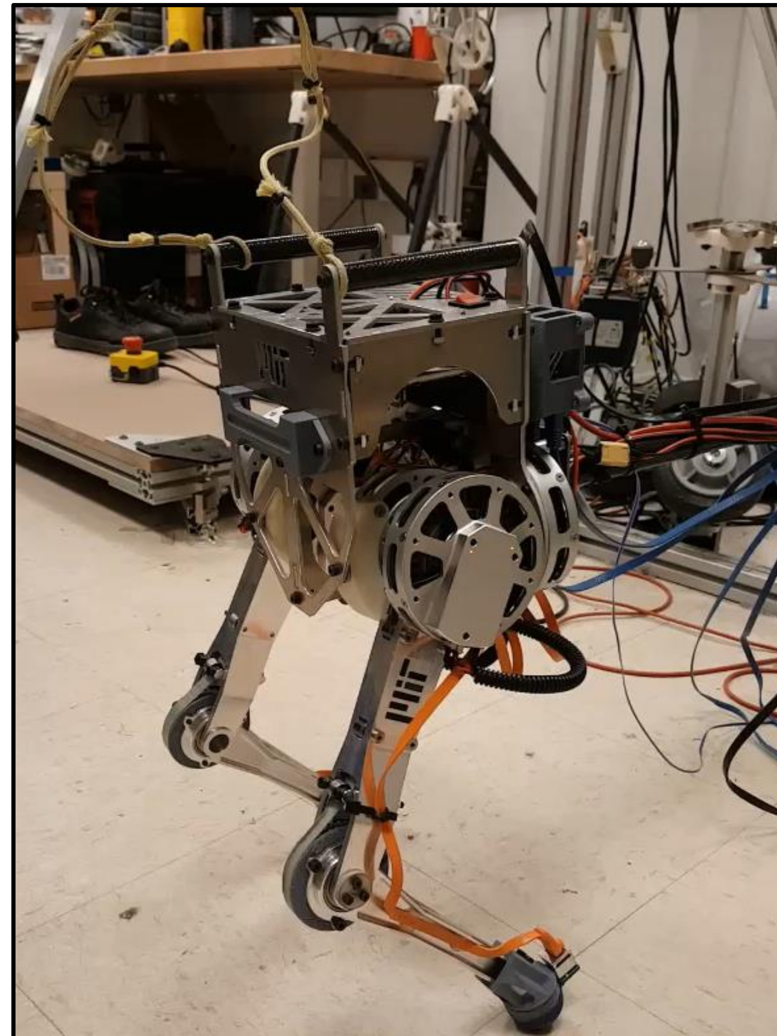


Little HERMES

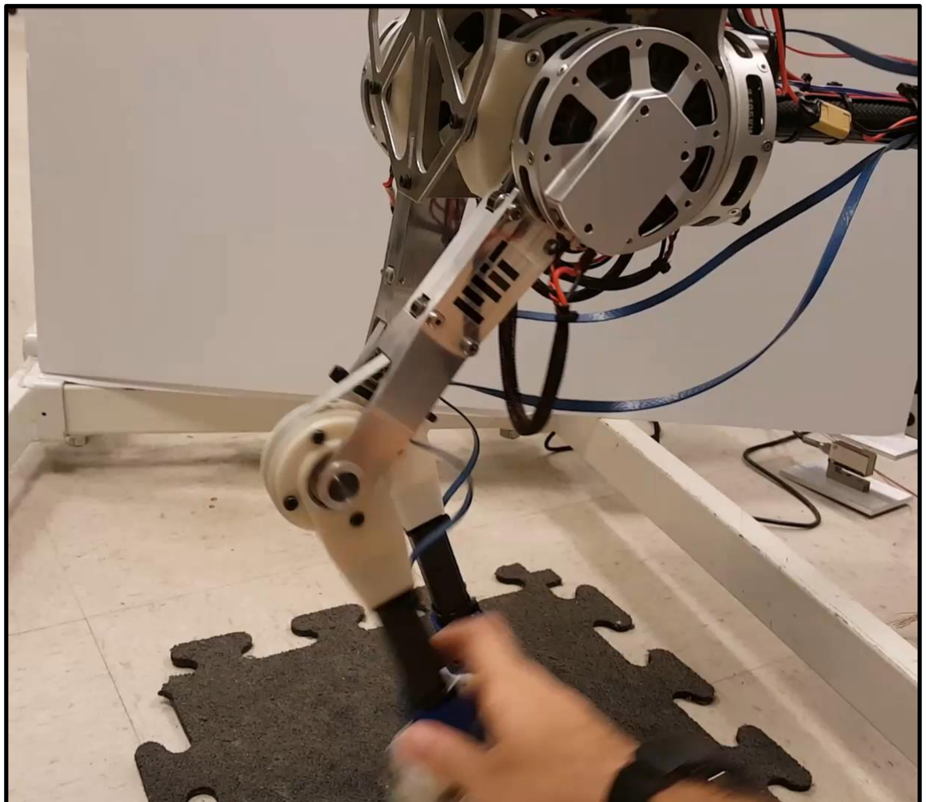


Designed for force control

Force control



Backdrivable: robot off



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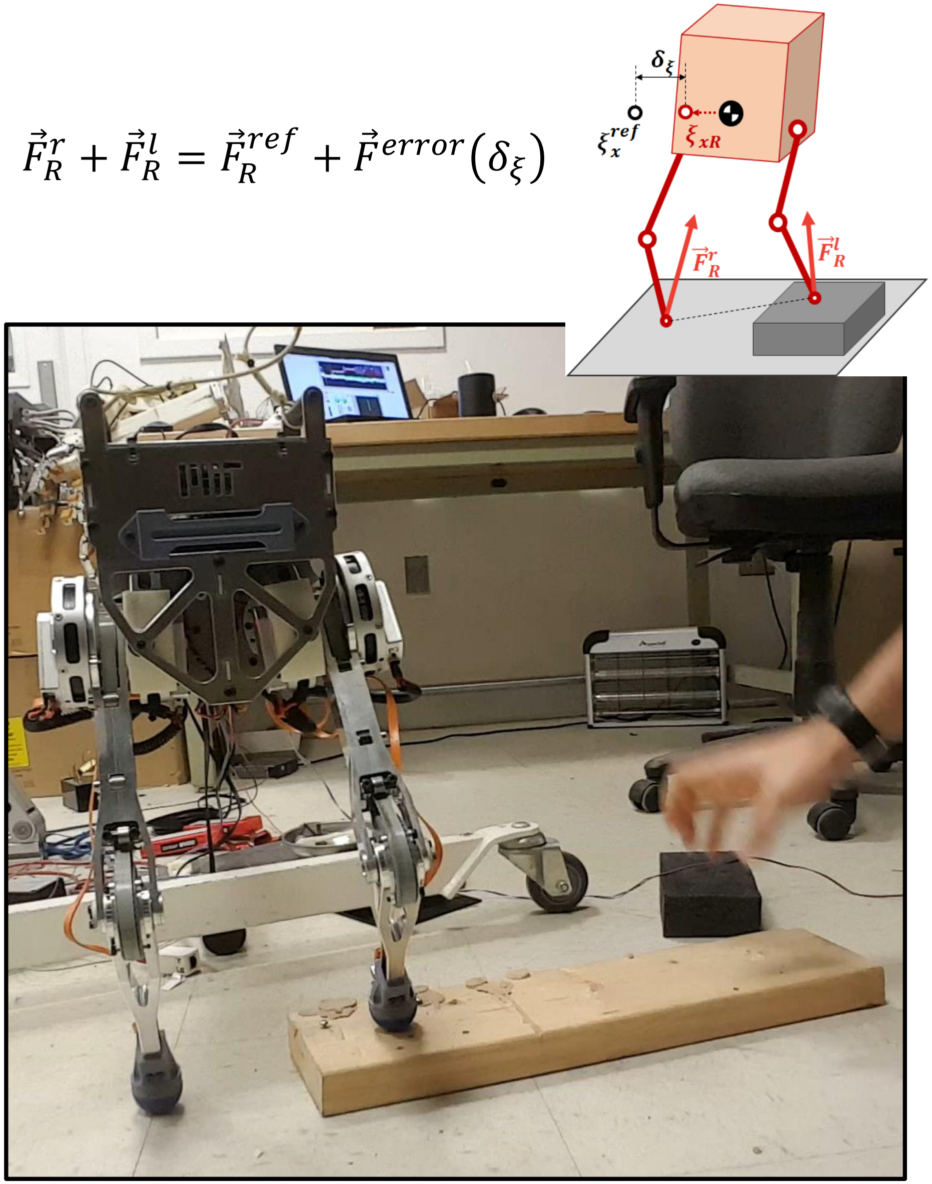
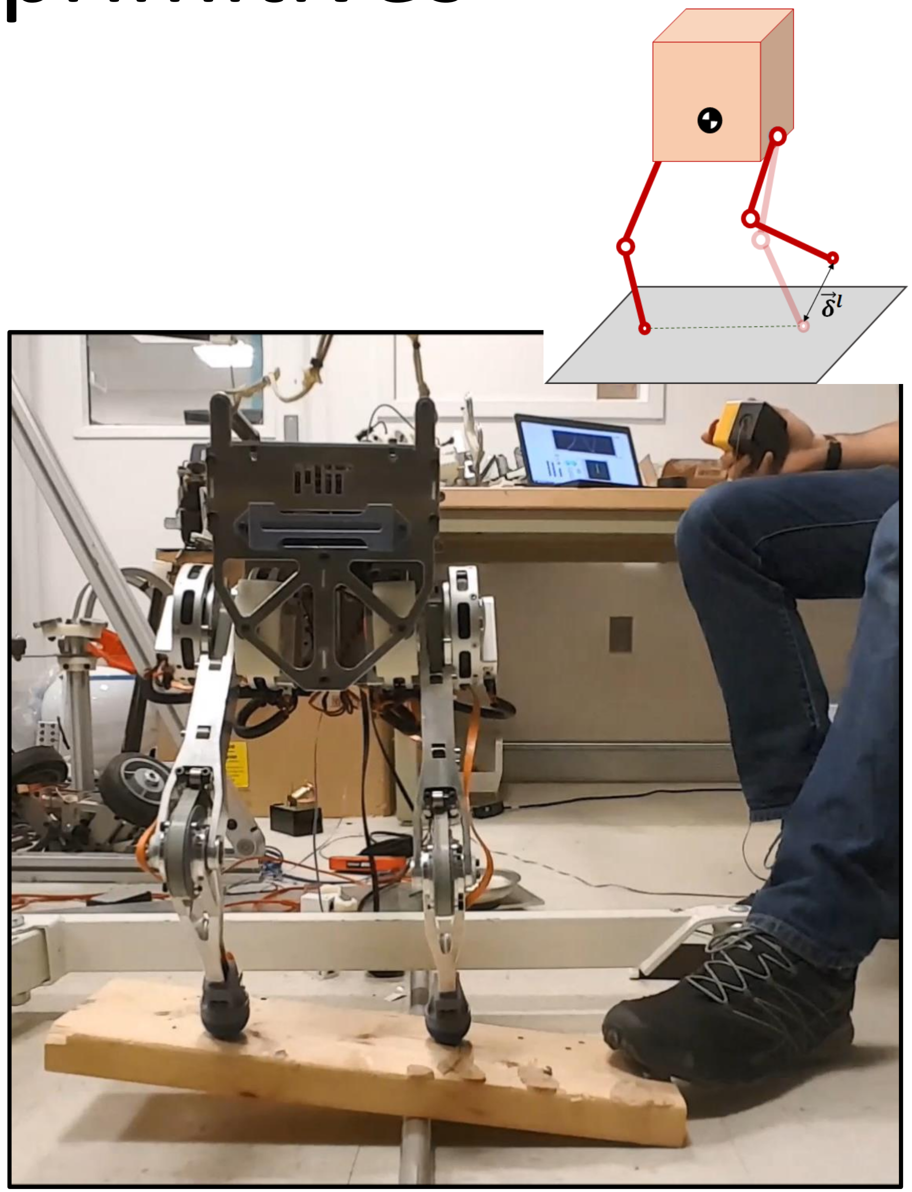
Controller primitives

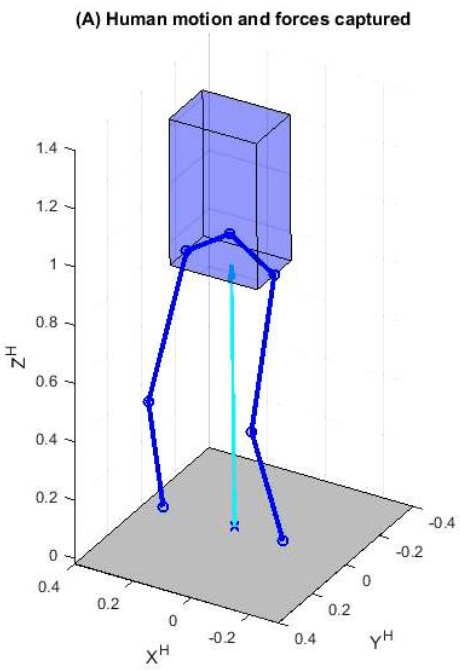
$$\vec{F}_R^r + \vec{F}_R^l = \vec{F}_R^{ref} + \vec{F}^{error}(\delta_\xi)$$





Dynamic similarity of the simple model

Dynamically similar



Capture human locomotion data.

J. Ramos and S. Kim, "Humanoid Dynamic Synchronization Through Whole-Body Bilateral Feedback Teleoperation," in *IEEE Transactions on Robotics*, 2018.

****Operator controlling a simulated robot.***

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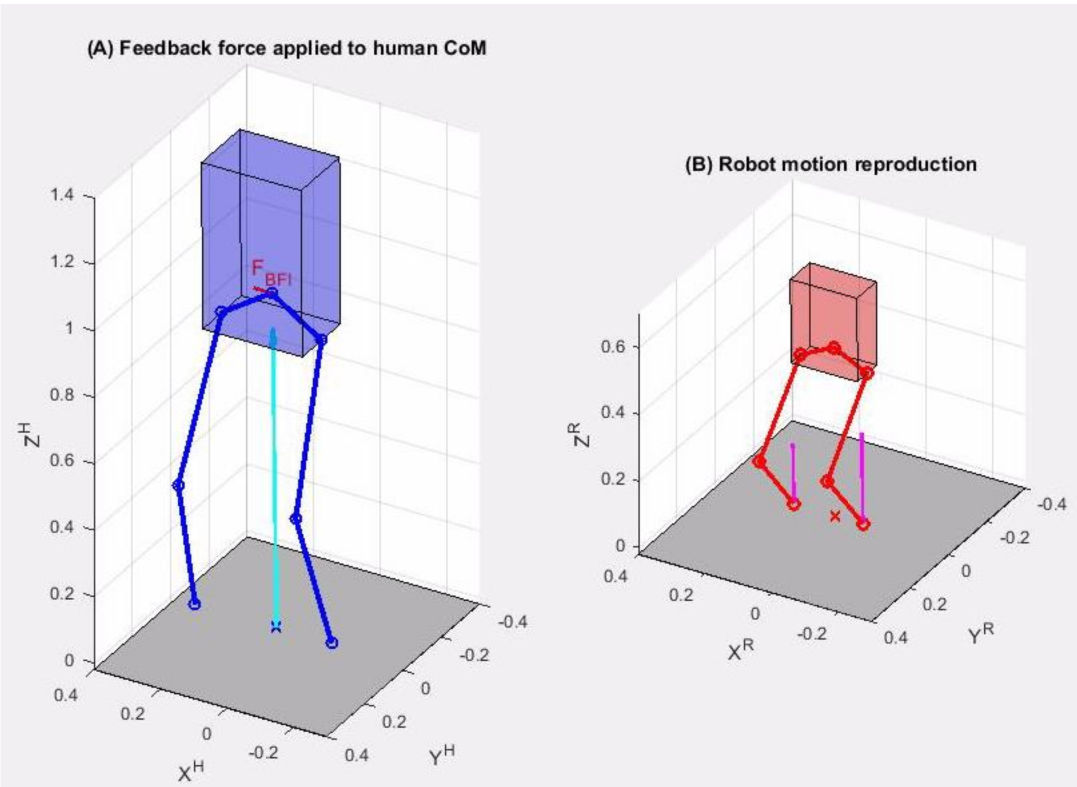
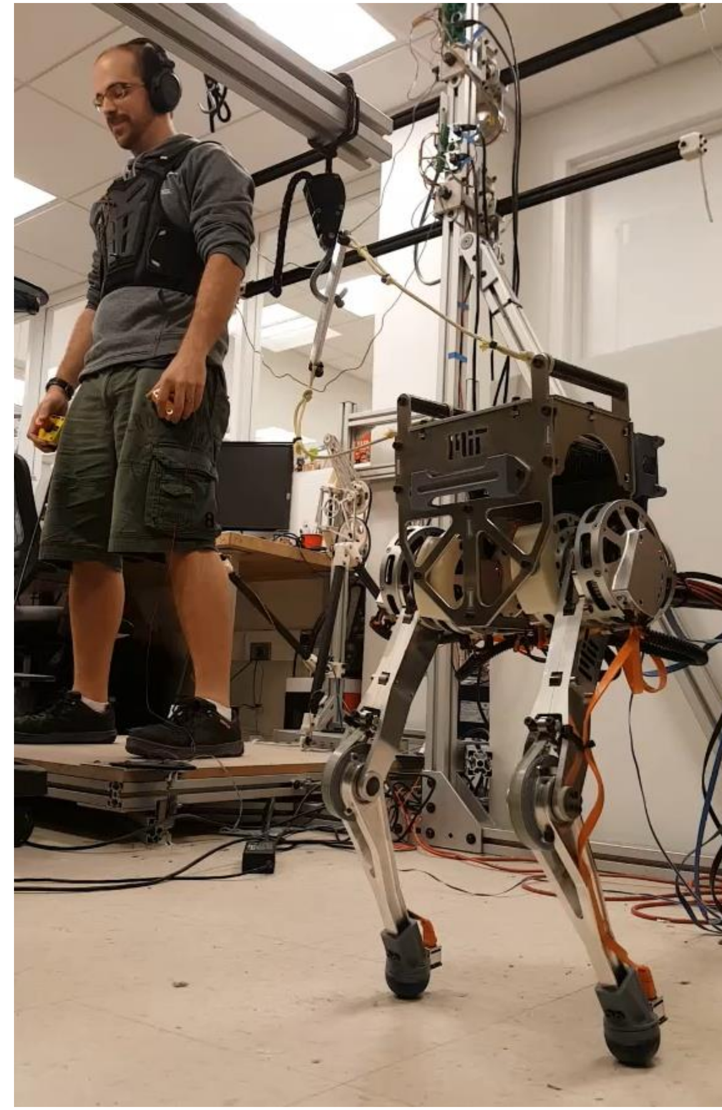
The feedback force

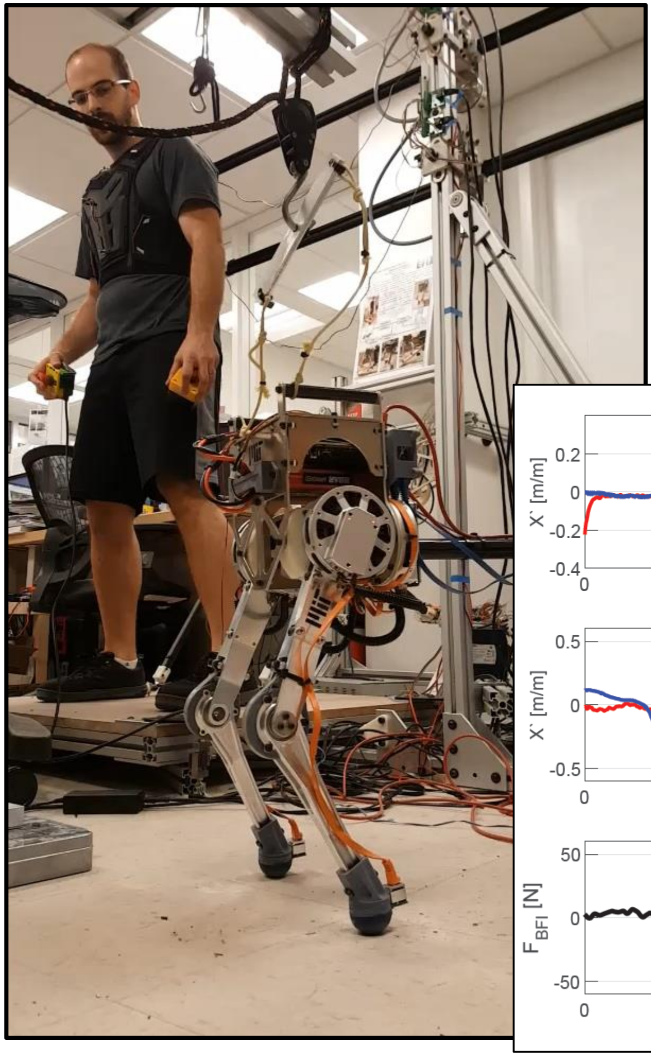


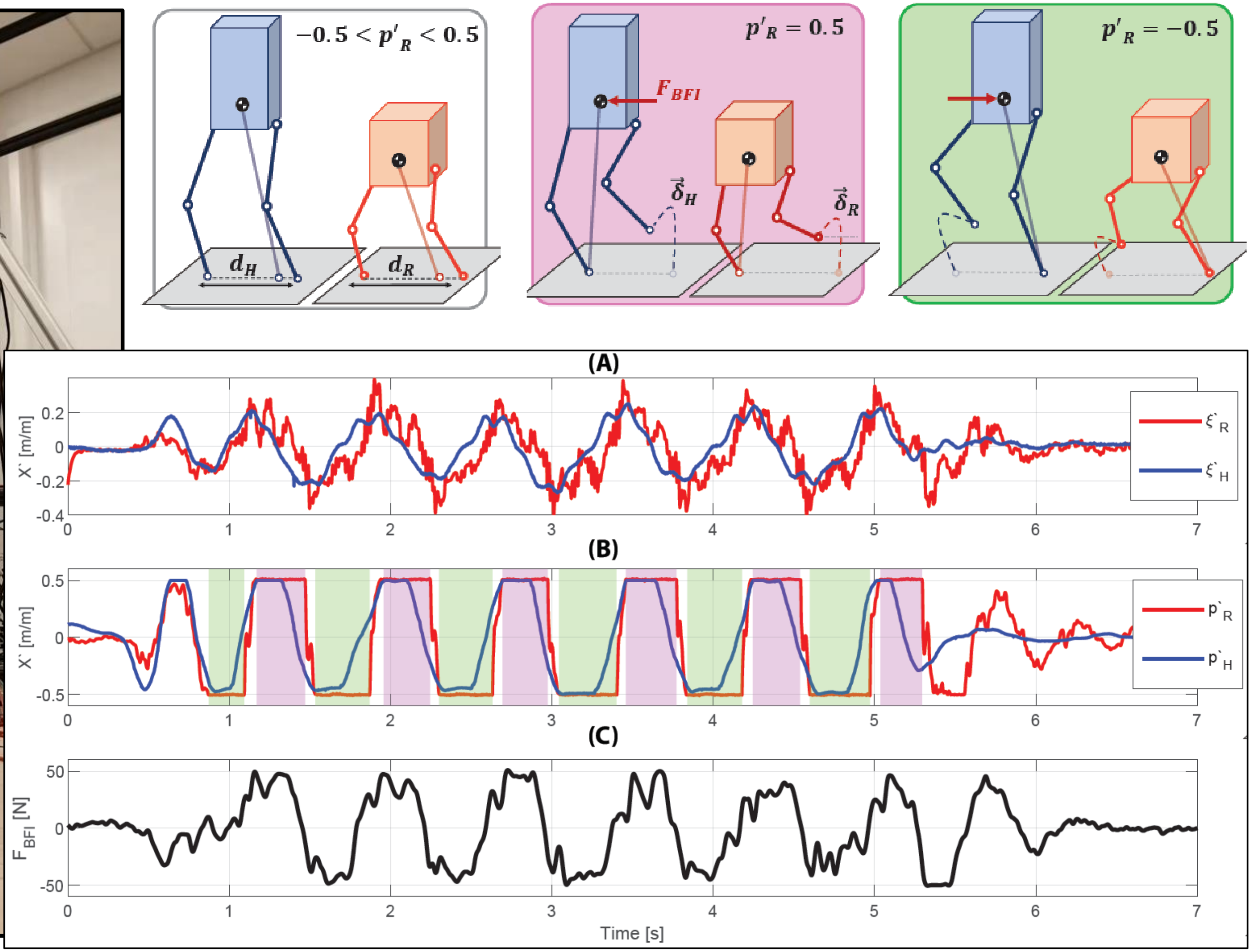


The feedback force F_{BFI} applied to the operator is proportional to the relative motion velocity between human and robot:

$$F_{BFI} = m_H d_H \omega_H^2 \left(\frac{\dot{x}_R}{d_R \omega_R} - \frac{\dot{x}_H}{d_H \omega_H} \right)$$

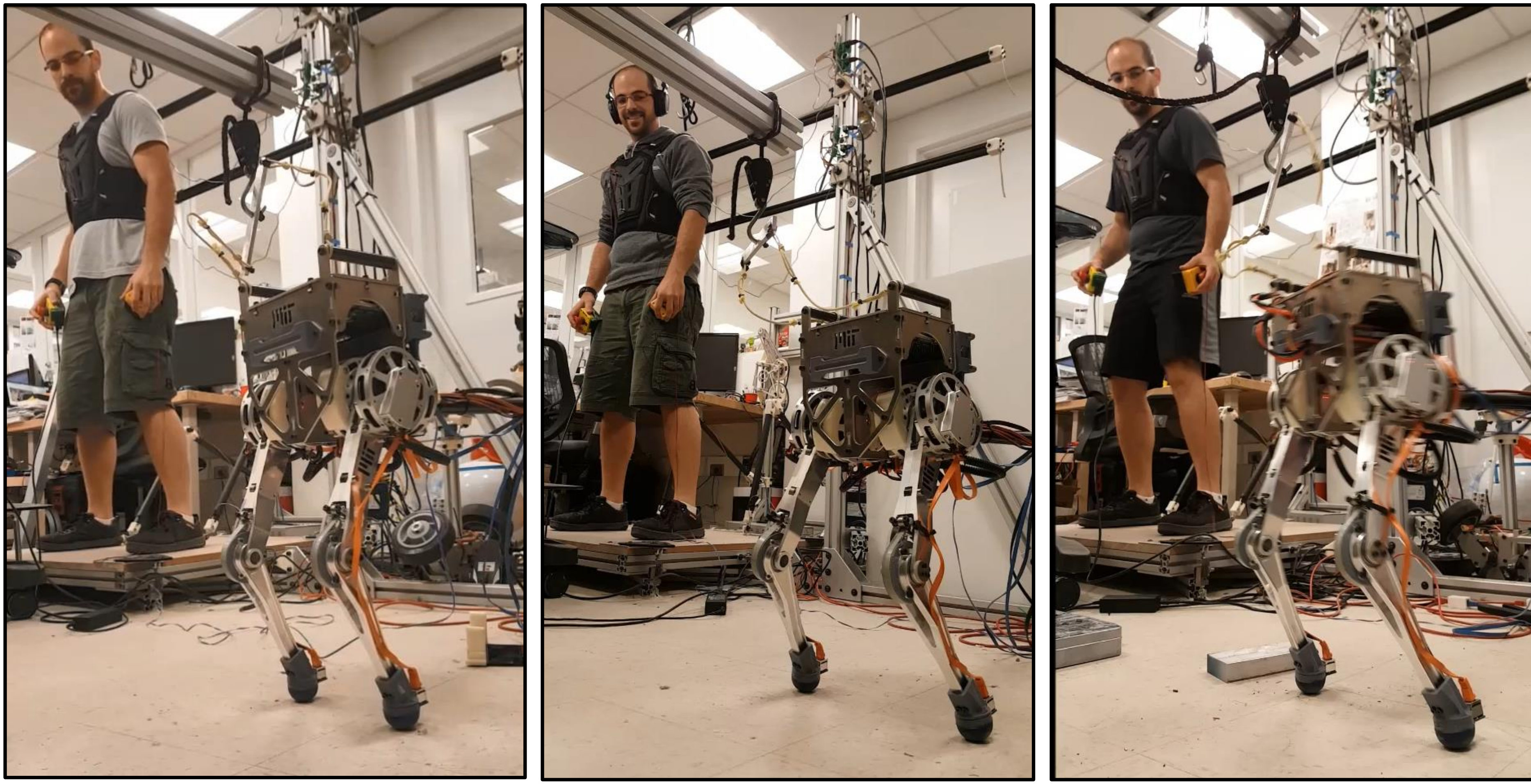
Synchronized dynamic stepping



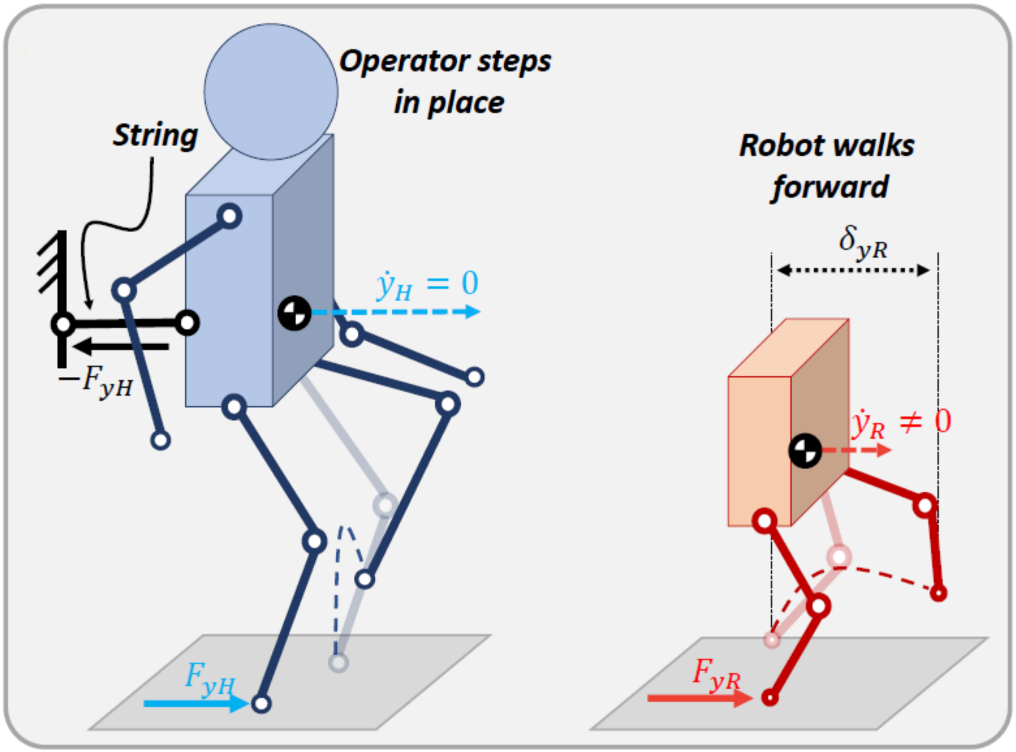


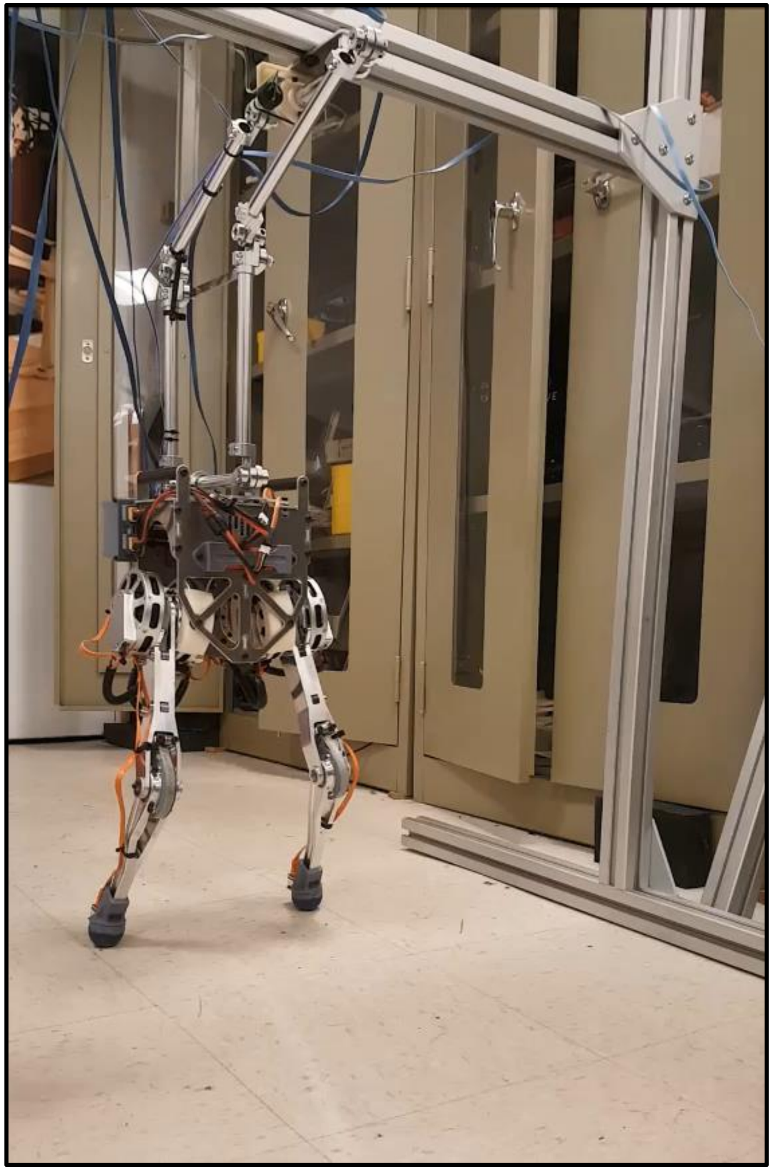
J. Ramos and S. Kim, "Dynamic locomotion synchronization of bipedal robot and human operator via bilateral feedback teleoperation," *Science Robotics*, 2019

Dynamic Teleoperation



Extend to locomotion





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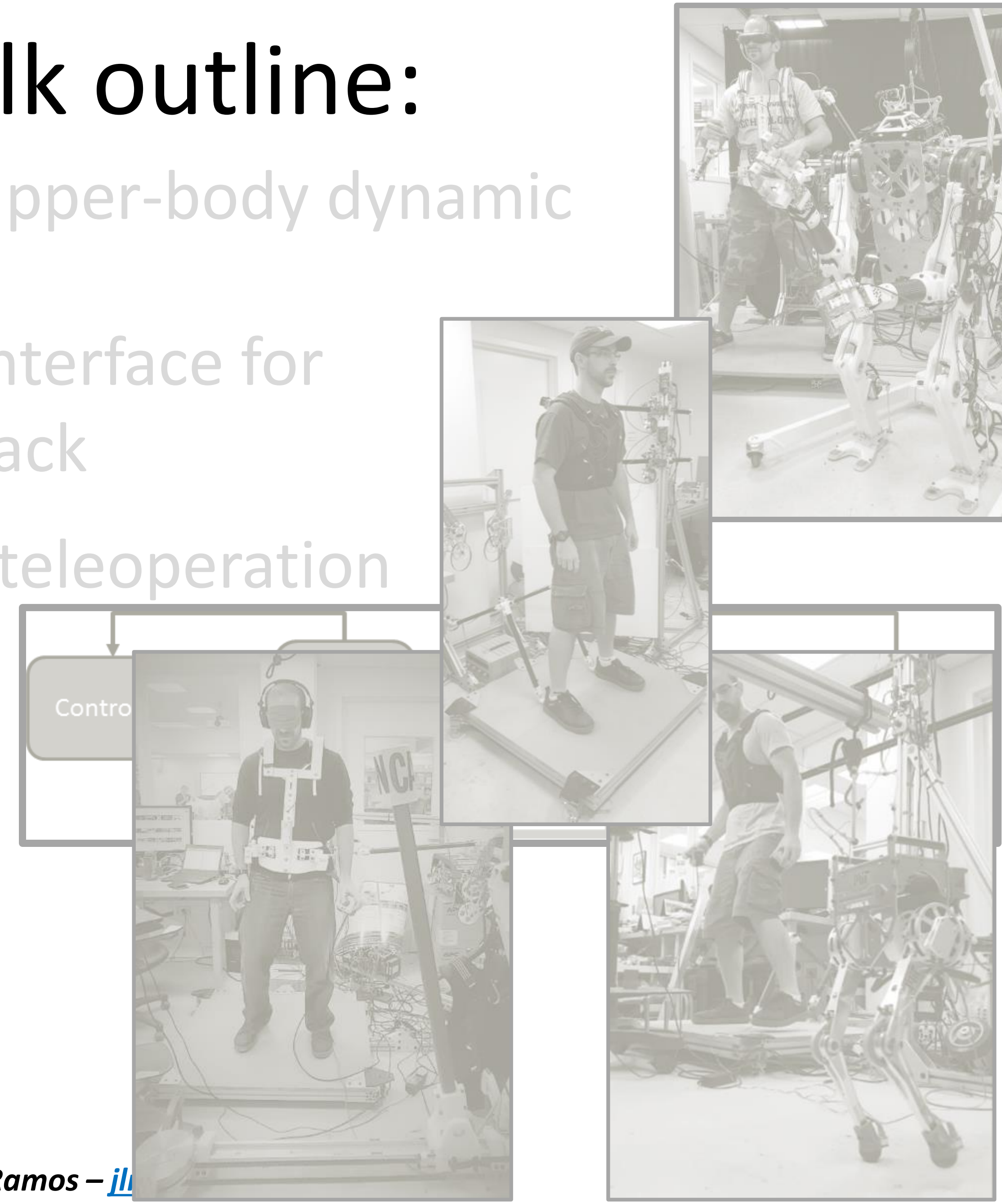
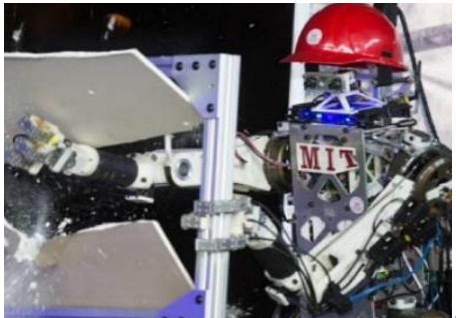
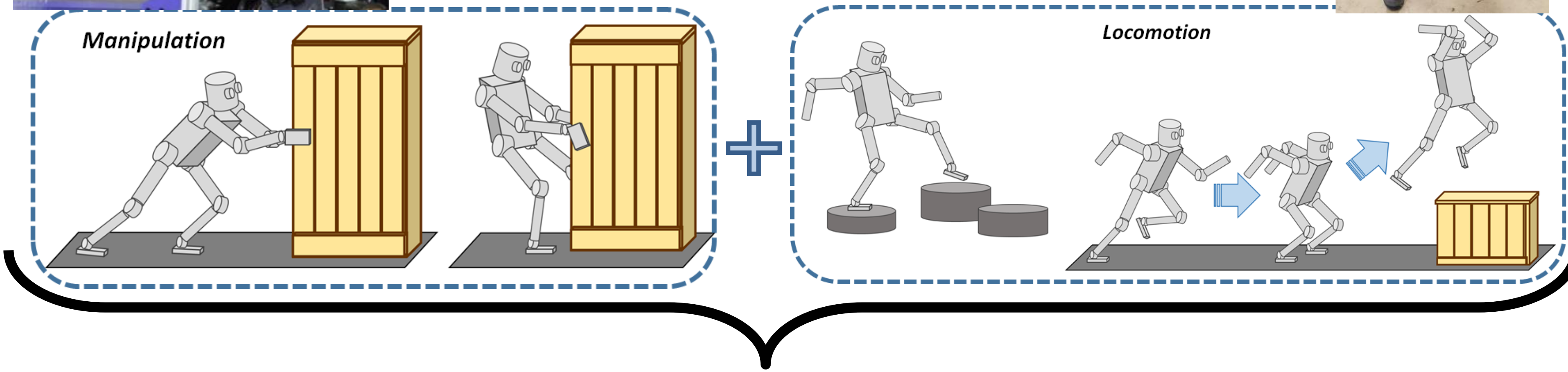


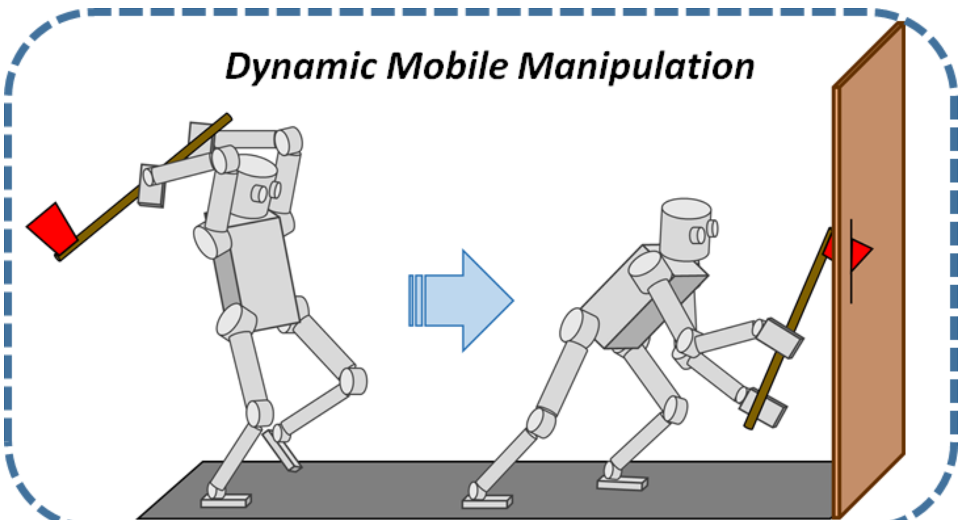
Where do we go form here?

- Can ***autonomous*** controllers improve performance?
- Can the ***robot*** to ***learn*** from the operator?
- Can the ***human practice*** to improve the synergy?
- Can we make a more ***immersive*** interface?
- Can the robot ***anticipate*** human motion?

Next steps

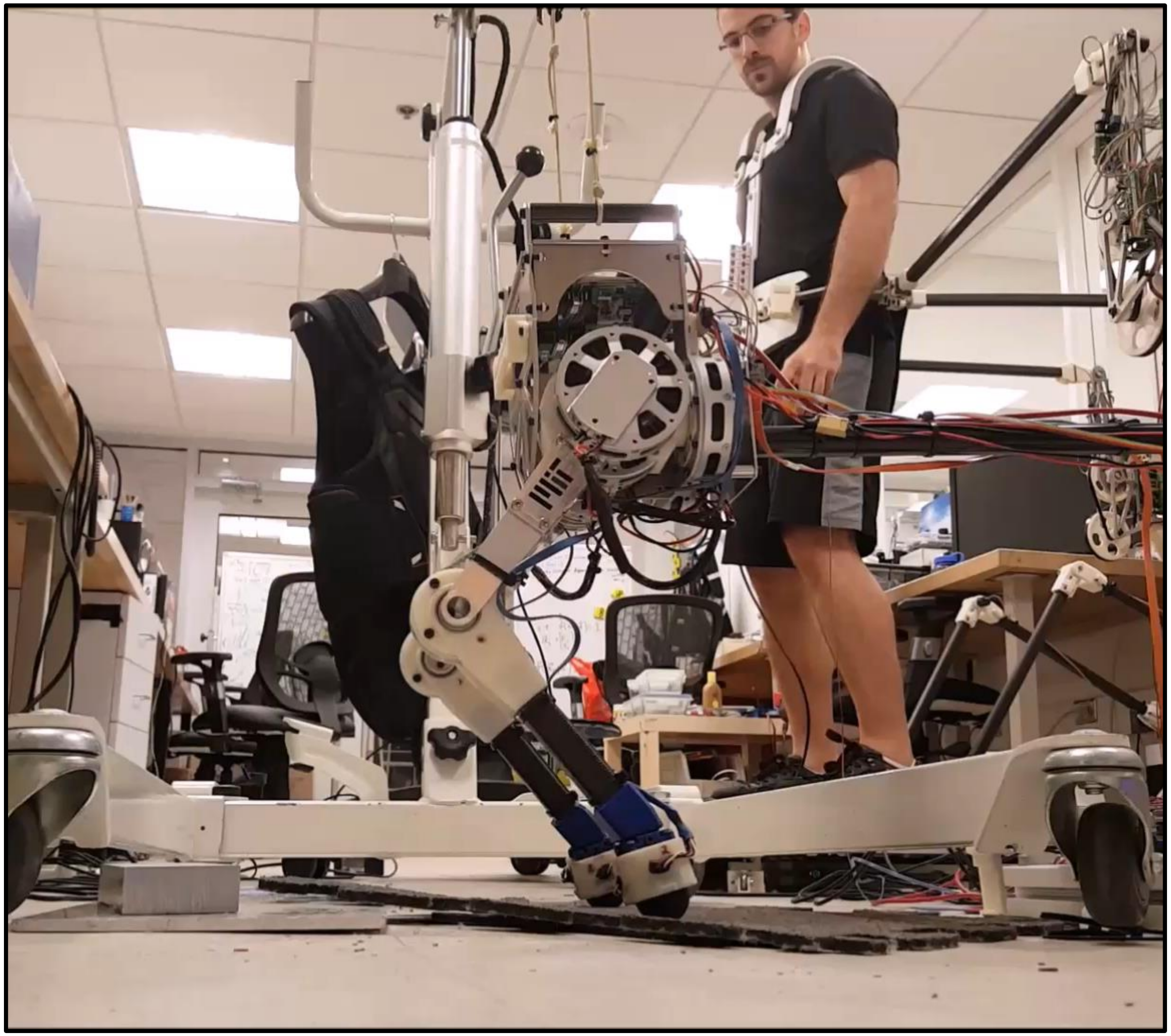






Highly dynamic motions
Whole-body coordination
Balance regulation
Momentum regulation
Large forces
Impacts

Questions?



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"The greatest teacher, failure is."

Master Yoda

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