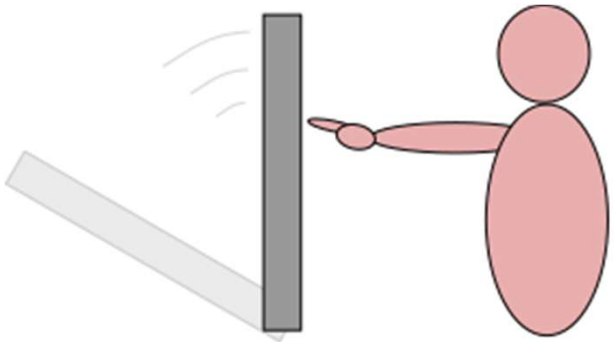
Hybrid Active-Passive Actuation For Human-Robot Collaboration and Rehabilitation

PI's: Peter Adamczyk, Michael Zinn, Kreg Gruben • *CMMI-1830516* • *NRI 2.0 2018*

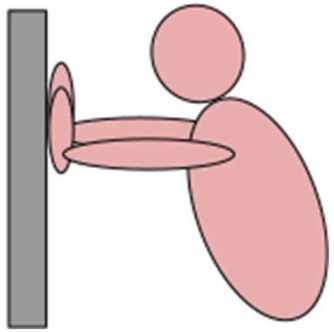
WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

Goal: Safe Human-Robot Interaction

- Limit Danger to People

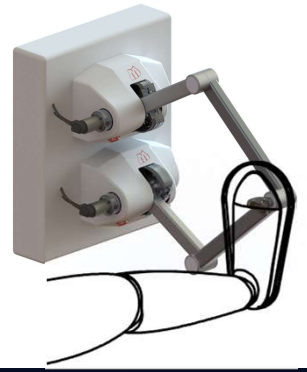


- But Be Stiff when Acted Upon



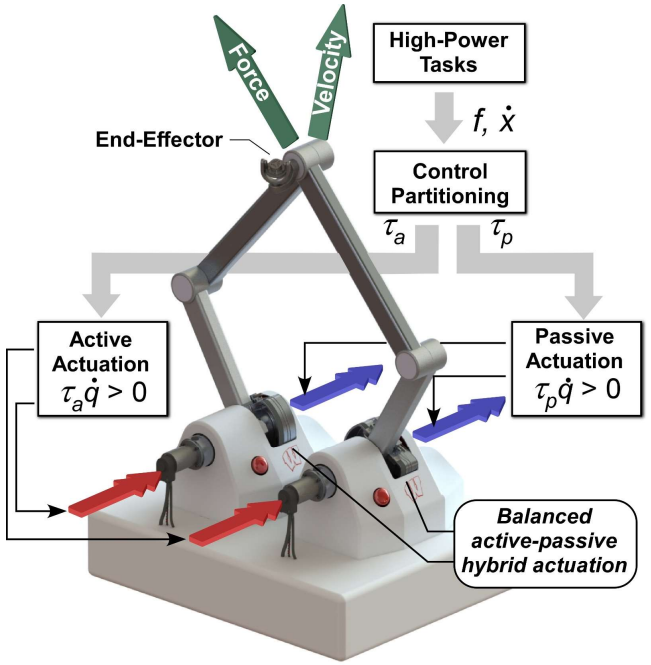
Question: How to do this with High Force capability?

Motivation: Leg Rehabilitation



Focus 1: Balanced Hybrid Active-Passive Actuation

Safe • Strong • High-Performance

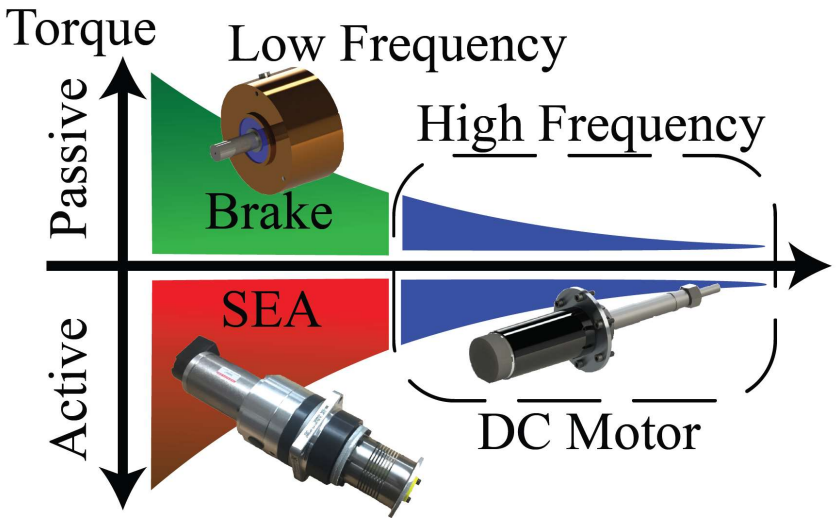


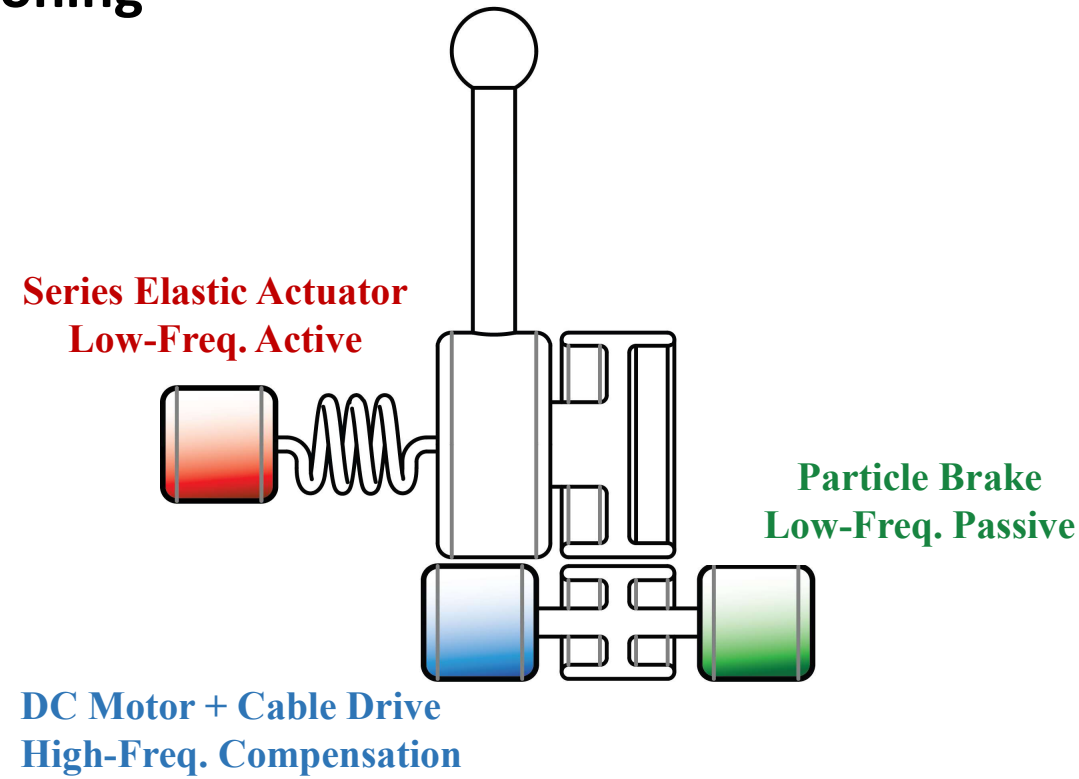
Objectives:

- Low Active Output Impedance
  - Won't whack you with high inertia.
- High Passive Output Impedance
  - Hold stiffly when you push on it.
- High Force Bandwidth
  - Render accurate haptic fields.

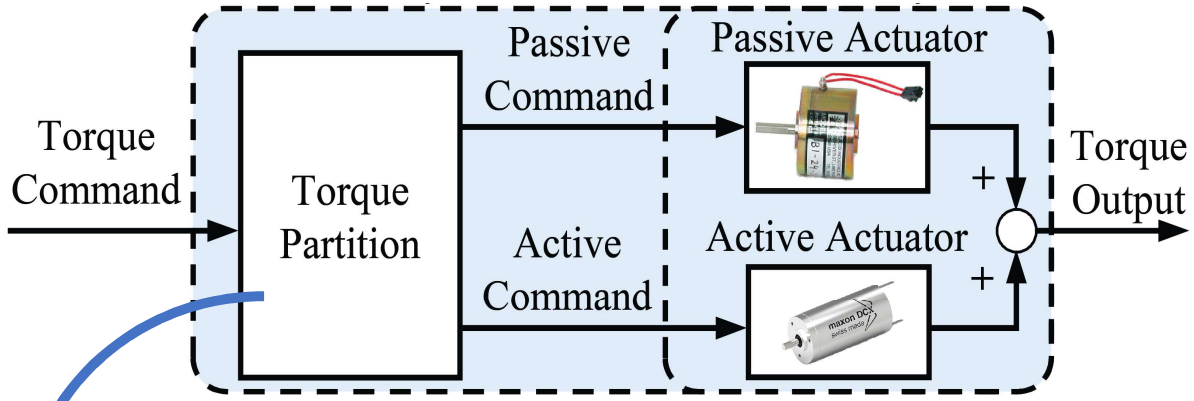
Approach

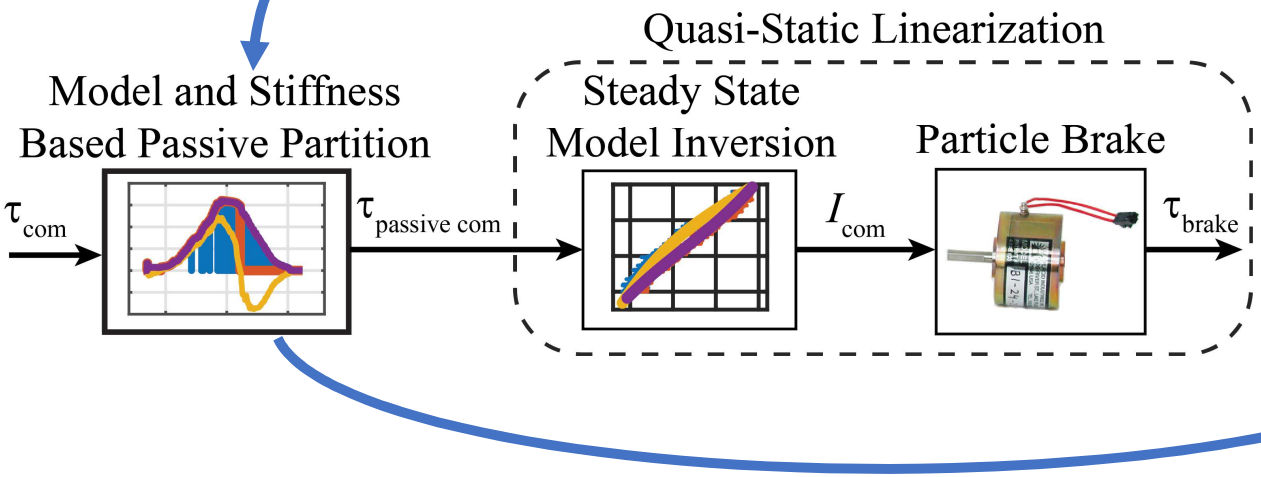
Multiple Actuators – Torque Partitioning





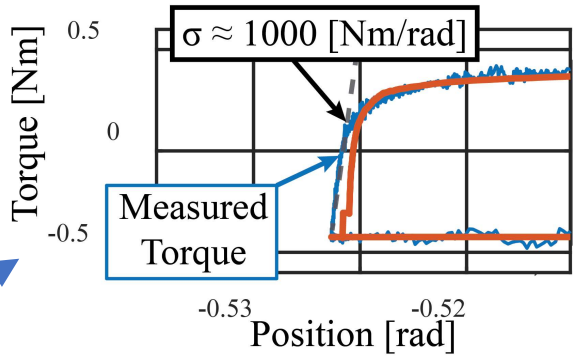
Approach





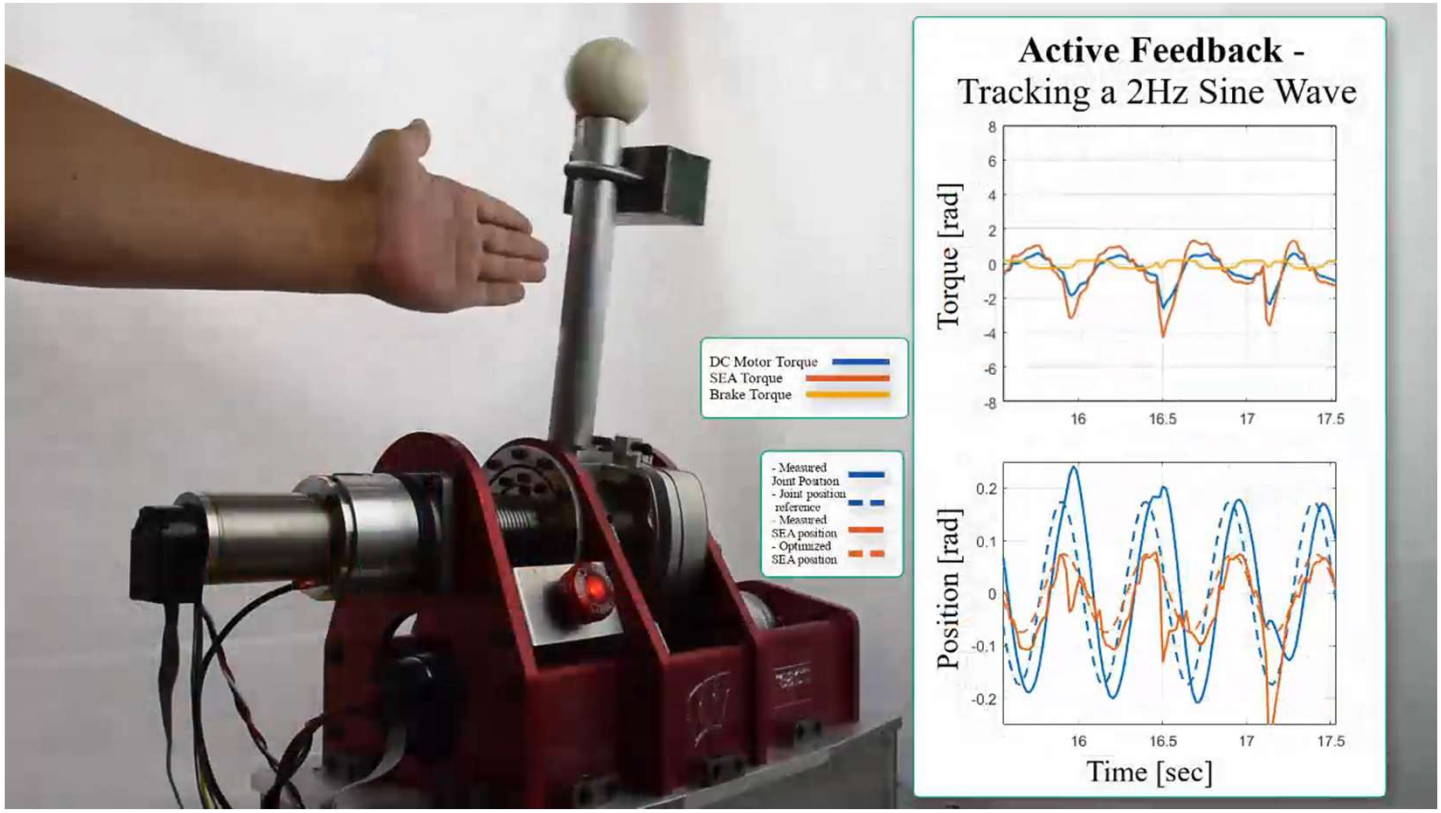
Dahl friction model

Stiffness + Hysteresis



Achievements: Partitioned Control

Improved Trajectory Tracking

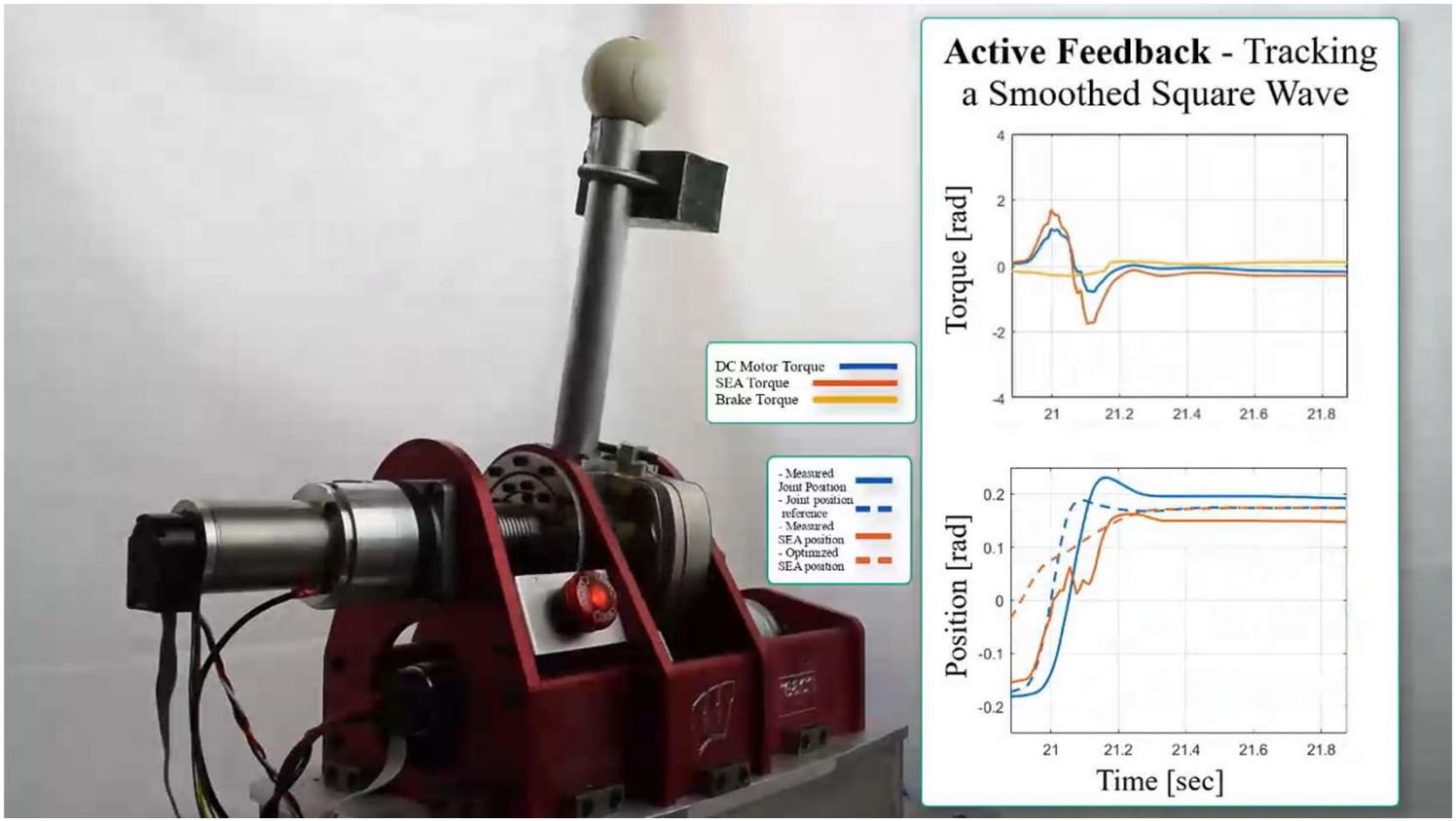


Benchtop Demonstrator

Dills et al, ICRA/RA-L 2021

Achievements: Partitioned Control

Improved Servoing

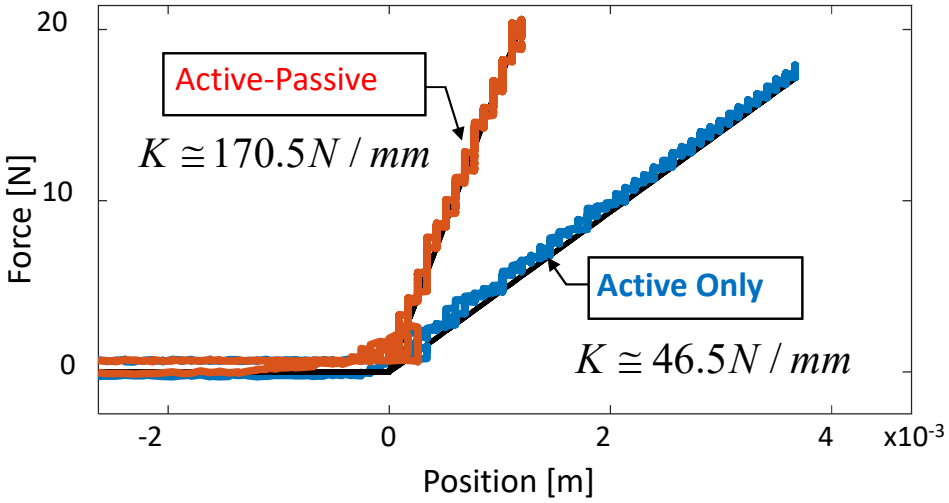


Benchtop Demonstrator

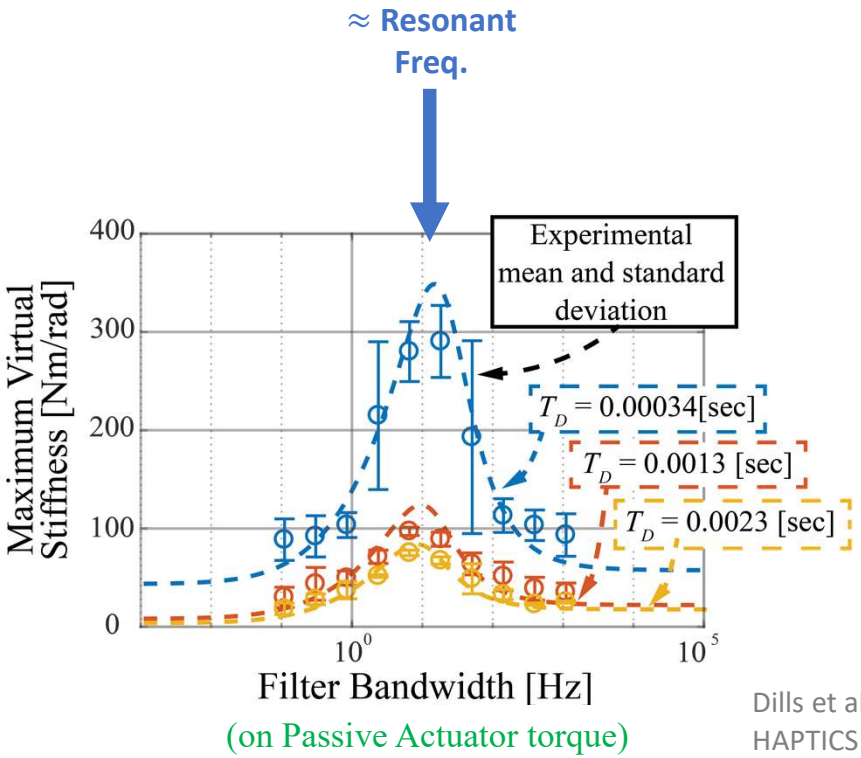
Dills et al, ICRA/RA-L 2021

Achievements: Partitioned Control

Stiffer Virtual Walls …



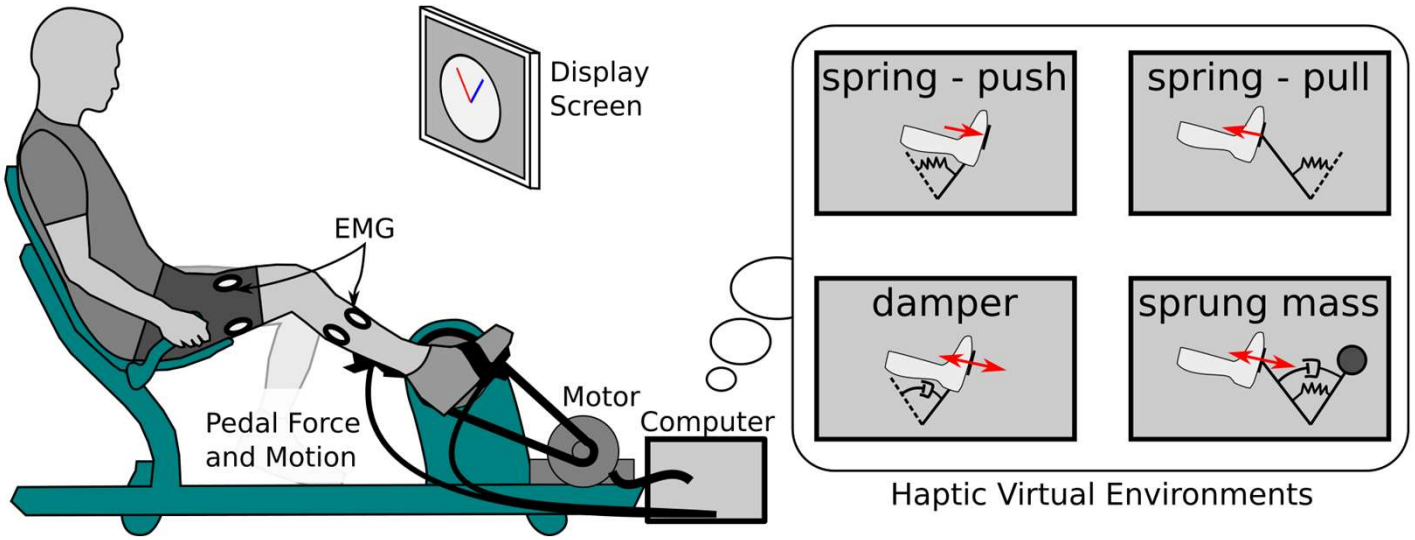
… with Theoretical Explanation



(on Passive Actuator torque)

Dills et al, HAPTICS 2022

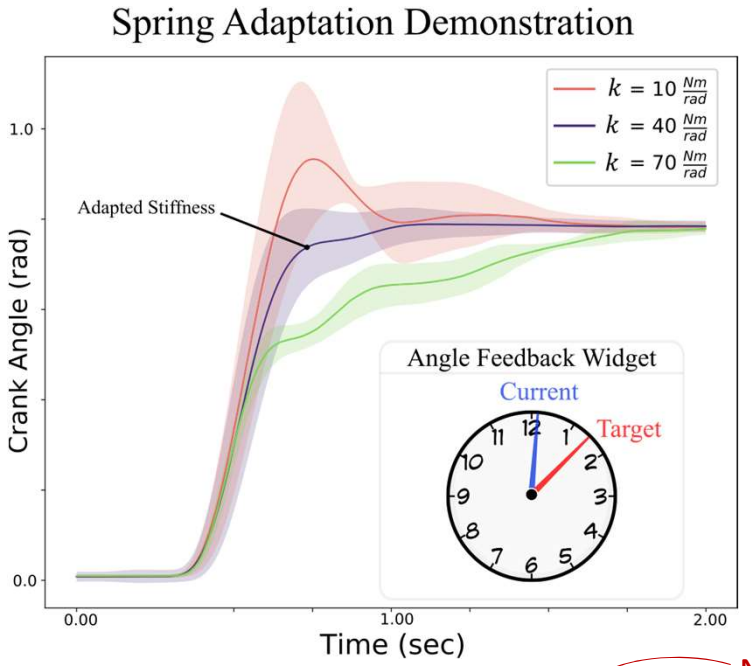
Focus 2: Haptic Experiments in the Leg



Challenge: Using Haptic Robots to study human motor adaptation and motor learning

NOTTABIKE

Neuromotor Optimization Testbed for Training in Atypical Behavior-Inducing Kinetic Environments



Negative!

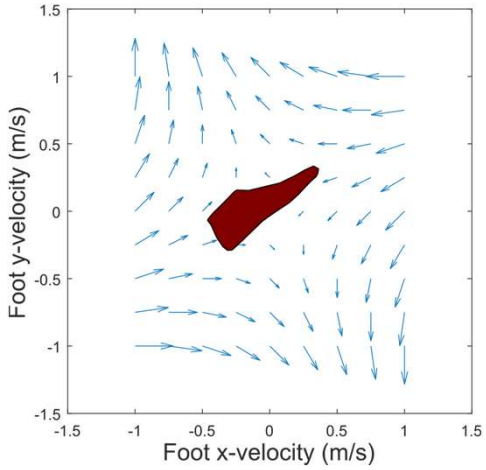
Current Challenge: "Half-Reversed Cycling": $\alpha = \frac{\tau_L - \tau_R}{I}$

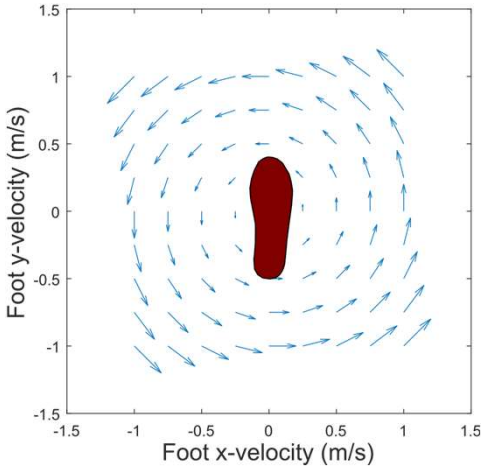
Dawson-Elli & Adamczyk, 2020 IEEE TNSRE

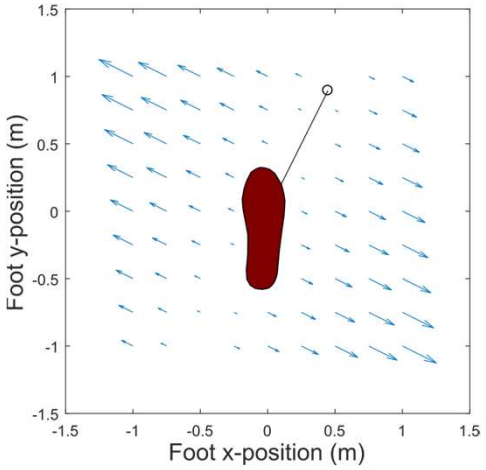
Focus 3: 2D Haptic Leg Robot

- Provide 2D Haptic Force Fields
  - High Forces: Leg Interaction and Rehab
  - Safety: Active-Passive Hybrid Actuation

- Goal: 2D Motor Learning Challenges

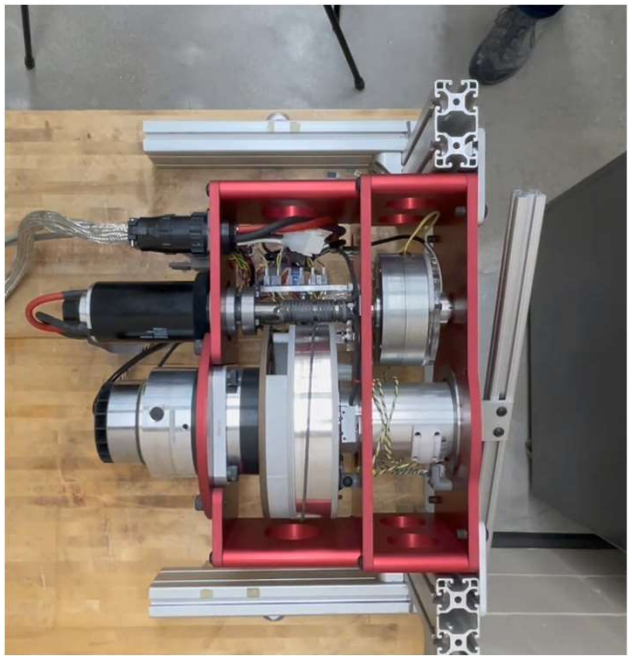






High-Performance Active-Passive Actuators

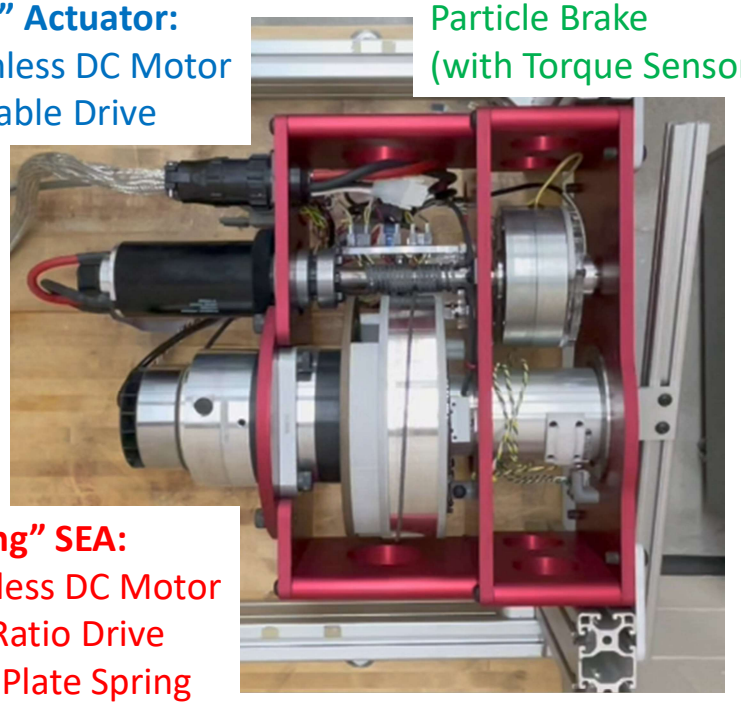
- 100 Nm capacity



Virtual Wall Demo

“Fast” Actuator:
Brushless DC Motor
9:1 Cable Drive

“Passive” Actuator:
Particle Brake
(with Torque Sensor)

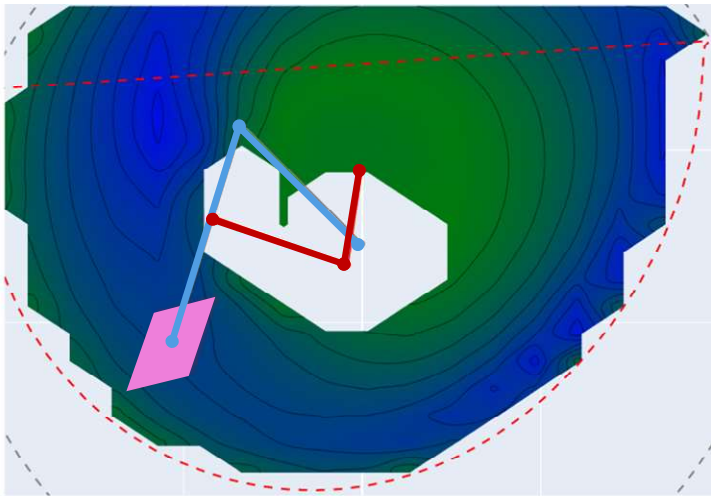


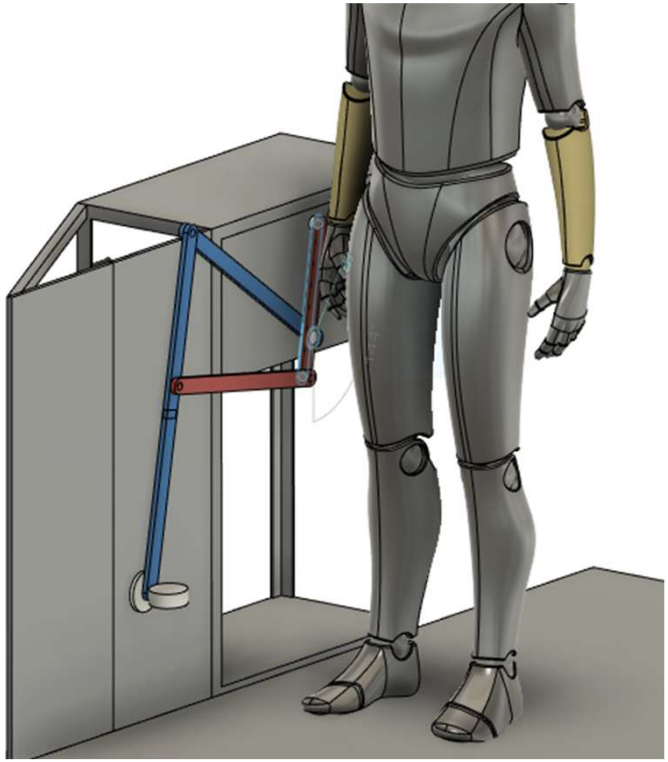
“Strong” SEA:
Brushless DC Motor
High-Ratio Drive
Spiral Plate Spring

Work in Progress

“Pedipulandum” Design for Haptic Leg Interaction

- Match Force and Workspace
  - Empirical model of human leg capacity
  - Optimized robot geometry/layout
  - Left/right reconfigurable





Work in Progress

Broader Impacts

- Rehabilitation
- Control Theory
- Handheld Haptic Demonstrator
  - Miniature active-passive actuator
    - DC Motor + particle brake
  - Trigger, click, washboard demos

  - Ready to demonstrate at expositions and public science days.

Products

- Publications Supported
  - C. Parthiban, P. Dills, I. Fufuengsin, N. Colonnese, P. Agarwal, and M. Zinn, “A Balanced Hybrid Active-Passive Actuation Approach for High-Performance Haptics,” in 2019 IEEE World Haptics Conference (WHC), 2019, pp. 283–288.
  - P. Dills, N. Colonnese, P. Agarwal, and M. Zinn, “A Hybrid Active-Passive Actuation and Control Approach for Kinesthetic Handheld Haptics,” in 2020 IEEE Haptics Symposium (HAPTICS), 2020, pp. 690–697.
  - A. R. Dawson-Elli and P. G. Adamczyk, “Design and Validation of a Lower-Limb Haptic Rehabilitation Robot,” IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 28, no. 7, pp. 1584–1594, Jul. 2020, doi: 10.1109/TNSRE.2020.3000735.
  - P. Dills, A. Dawson-Elli, K. Gruben, P. Adamczyk, and M. Zinn, “An Investigation of a Balanced Hybrid Active-Passive Actuator for Physical Human-Robot Interaction,” IEEE Robotics and Automation Letters, vol. 6, no. 3, pp. 5849–5856, Jul. 2021, doi: 10.1109/LRA.2021.3064497.
  - P. Dills, A. Dawson-Elli, K. Gruben, P. Adamczyk, and M. Zinn, “Stability and Rendering Limitations of a Parallel Hybrid Active-Passive Haptic Interface,” in 2020 IEEE Haptics Symposium (HAPTICS), 2020, forthcoming.
- Technical Conference Contributions
  - Dawson-Elli et al. 2019 International Society of Biomechanics
  - Parthiban et al. 2019 World Haptics (see paper above)
  - Dills et al. 2020 Haptics Symposium (see paper above)
  - Dills et al. 2021 ICRA (see RA-L paper above)
  - Dawson-Elli et al. 2021 American Society of Biomechanics
  - Dawson-Elli et al. 2021 IREK12 MRS Research Day
  - Gabardi et al. 2021 World Haptics
  - Dills et al. 2022 Haptics Symposium (see paper above)
- Students
  - Patrick Dills
  - Alex Dawson-Elli
  - Stephanie Hernandez

ACKNOWLEDGMENTS

- National Science Foundation
  - NRI 2.0 (CMMI-1830516)
- Preliminary work:
  - UL1TR000427 to UW ICTR from NIH/NCATS
  - 2 P2C HD065690-06A1 to NCSRR from NIH
  - Oculus Research
  - University of Wisconsin Vice Chancellor for Research and Graduate Education.

WISCONSIN
UNIVERSITY OF WISCONSIN–MADISON