NRI: FND: Controllable Compliance: A New Robotic Arm for Contact-Rich Manipulation

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NRI Program Review

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rc robotics collaborative
The Helping Hands Lab
Northeastern University

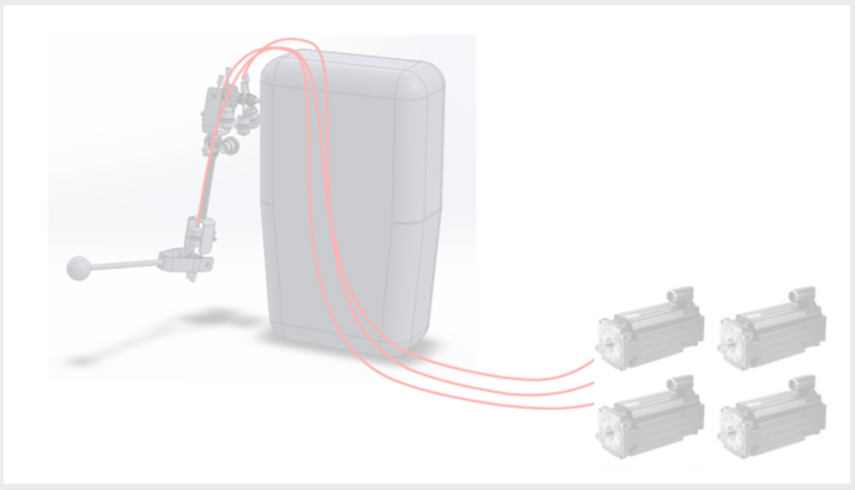
Key Principles

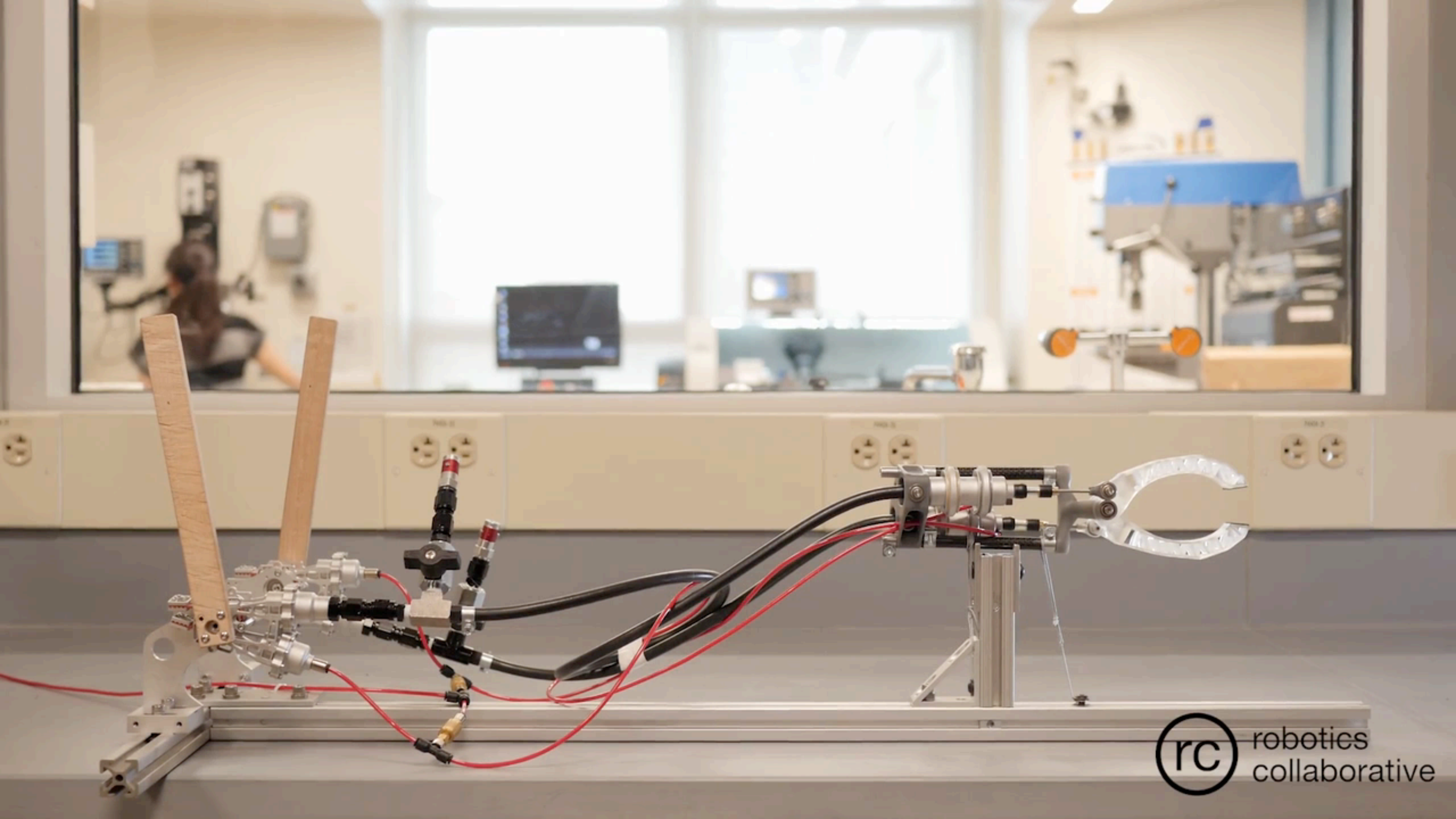
- Remote Direct Drive (RDD) actuation:
  - Use low-friction rolling diaphragm hydraulic transmission to ***remotely locate every motor in a robotic arm***
  - Greatly reduce the moving mass of the manipulator
  - Manipulator exhibits ideal 2nd-order dynamics…easy to model, ***learned results should have better transference***
- Controllable Compliance:
  - Using direct-drive motors and friction observers, easy to ***electronically tune joint compliance over 1000:1 range***

Two operating configurations

Passive mode:
- *puppeting, animatronics*
- remote manipulation
(medical, MRI, nuclear…)

Motorized mode:
- human-safe robots
- low impedance + dexterous
manipulation
- very light manipulators

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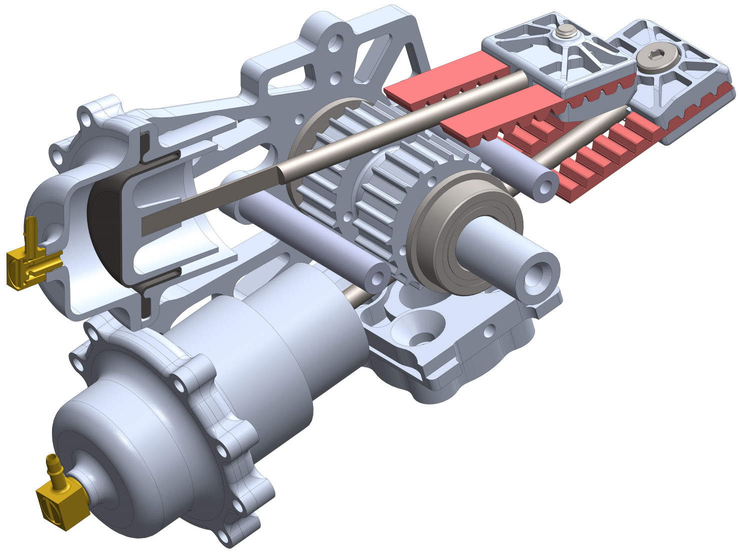
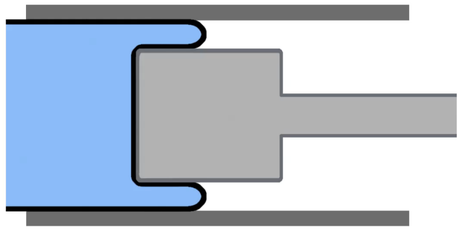
Passive Hydrostatic Transmission

- Hydraulic cylinders connected 1-to-1
- Passive hydrostatic transmission using rolling diaphragms
  - *- Continuous seal → no fluid leakage*
  - *- No sliding seals → nearly-zero static friction*
- Rotary-motion and linear-stroke versions





rolling-diaphragm seal, no rubbing or sliding

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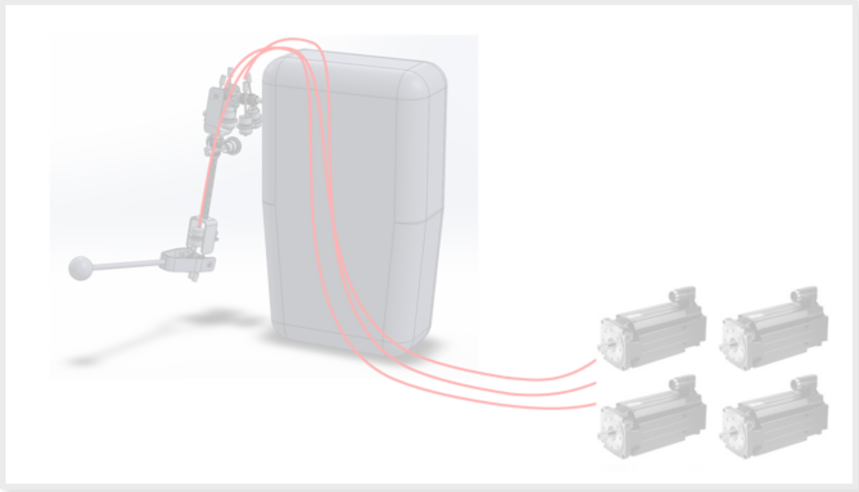

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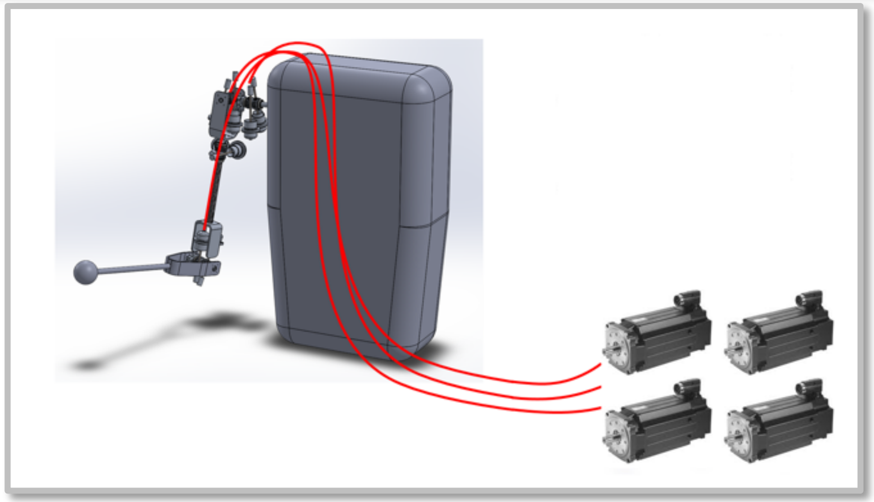

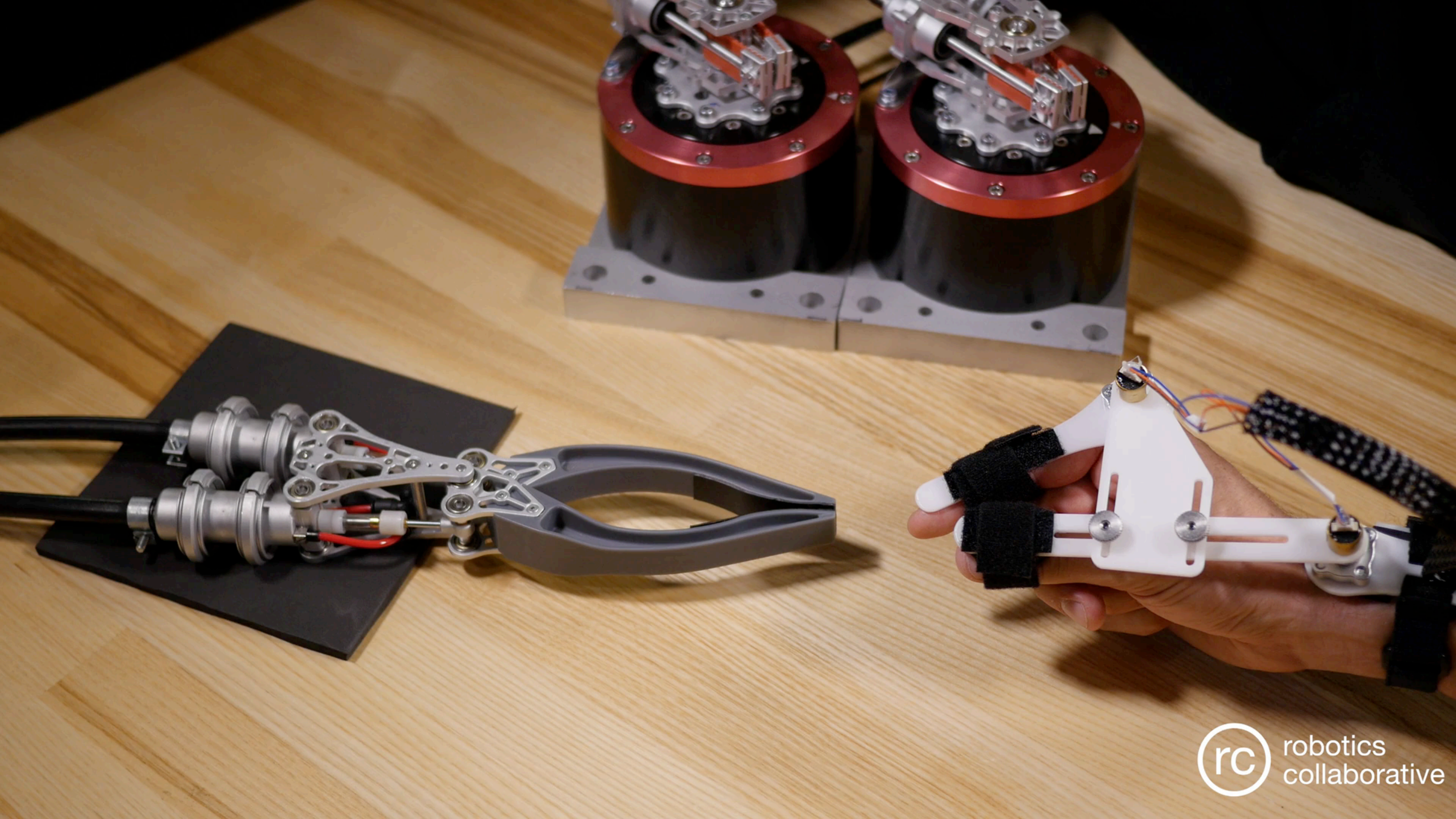
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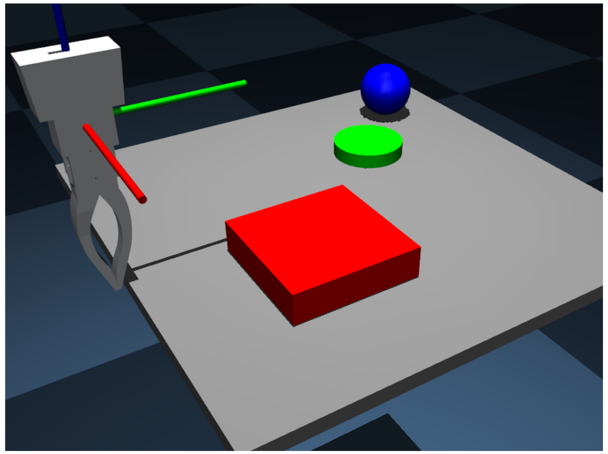
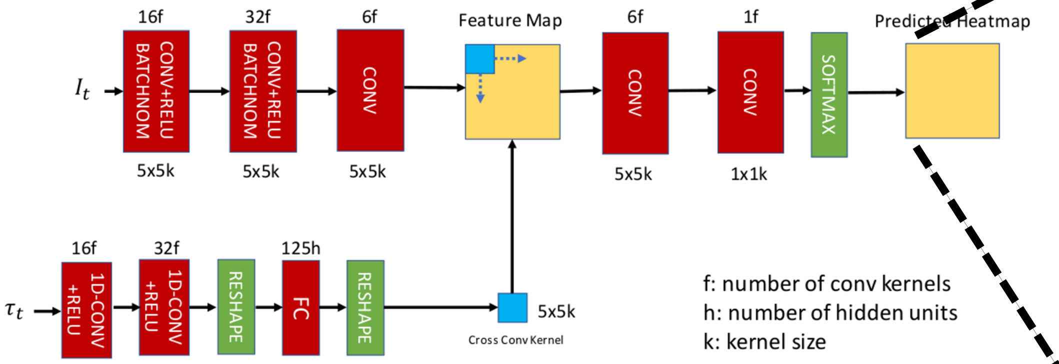
Key Properties

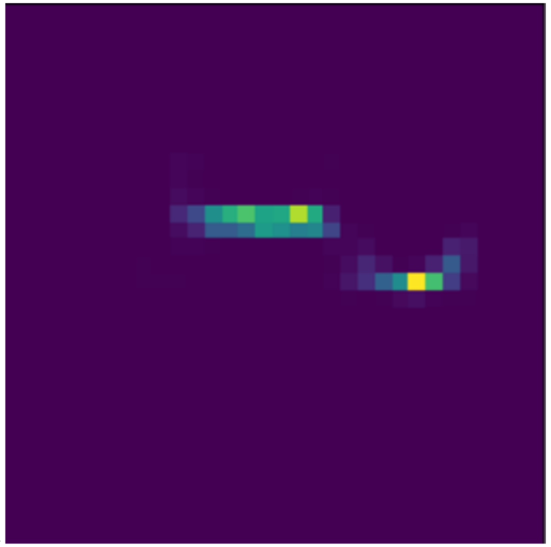
- Remote direct drive (RDD) actuation:
  - Extremely low moving mass, minimizes reaction torques and minimizes energy transfer when colliding with environment
  - Gearbox-free operation greatly reduces actuator friction, improving force sensitivity (i.e. inherent haptic perception)
  - ***Fully-backdrivable***
- Hydraulics used only as transmission:
  - Fluid pressure provides excellent direct measure of external torques
  - Easy to route hoses for many serial DOFs

2-DOF gripper

Localization Using Tactile Data





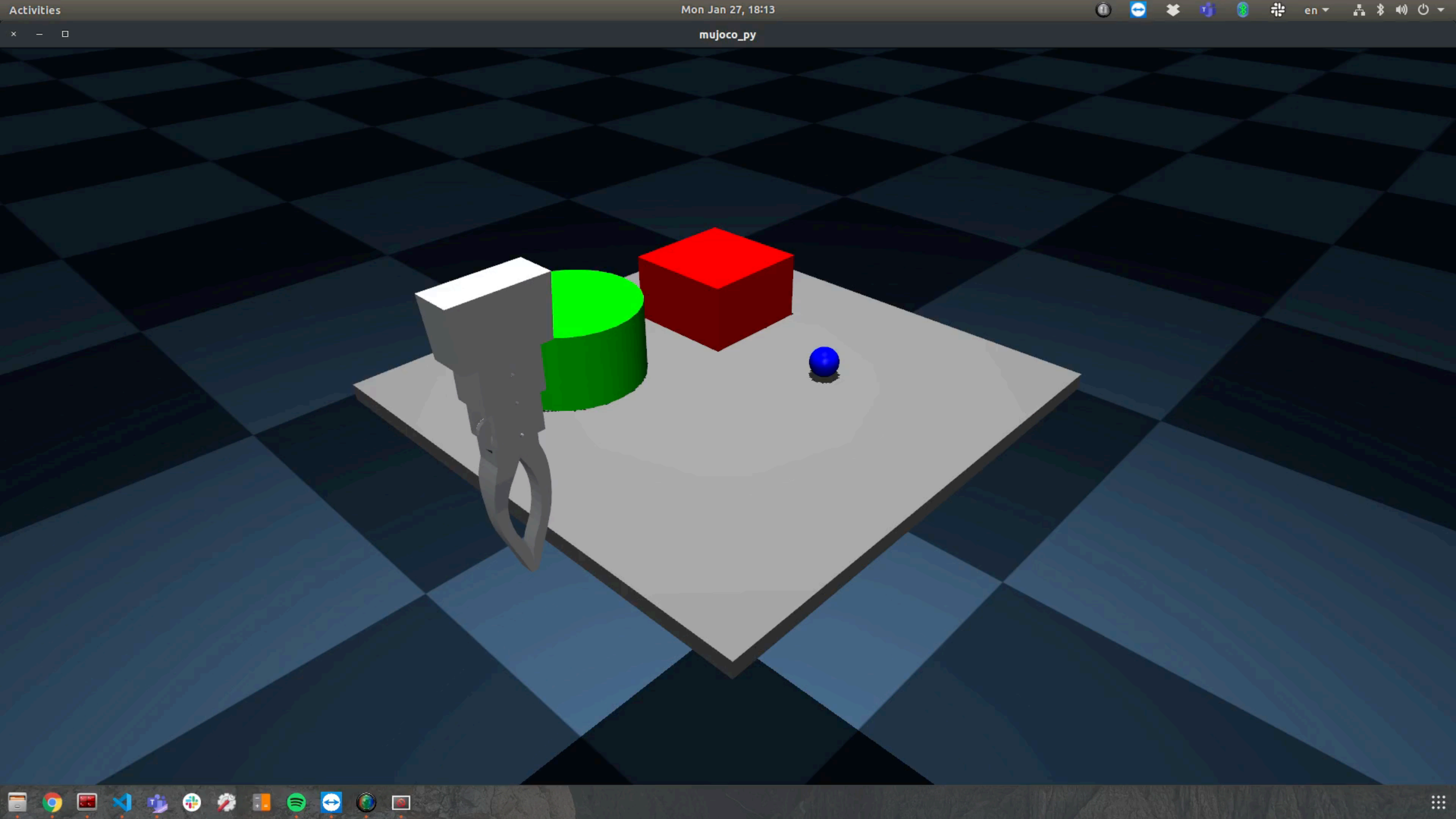


occupancy probability map

<u>Problem:</u>

Localize finger tip using:

- *Initial single coarse depth image*
- *Continuous finger force measurement*


Activities
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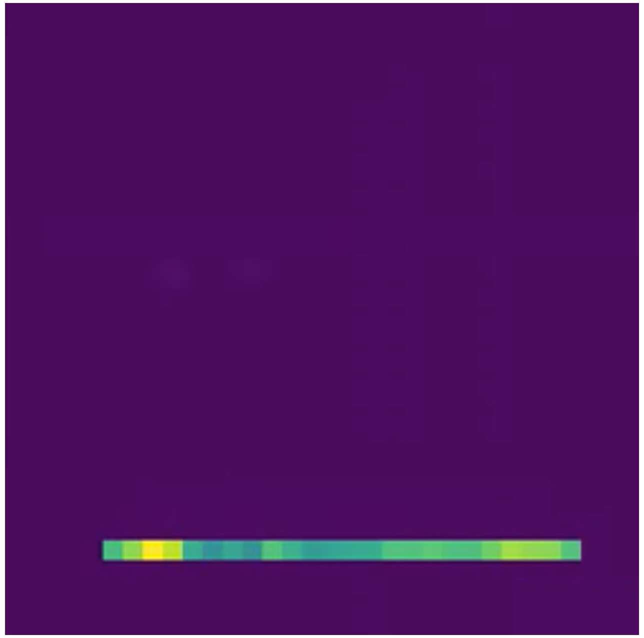
Localization Using Tactile Data

initial depth image



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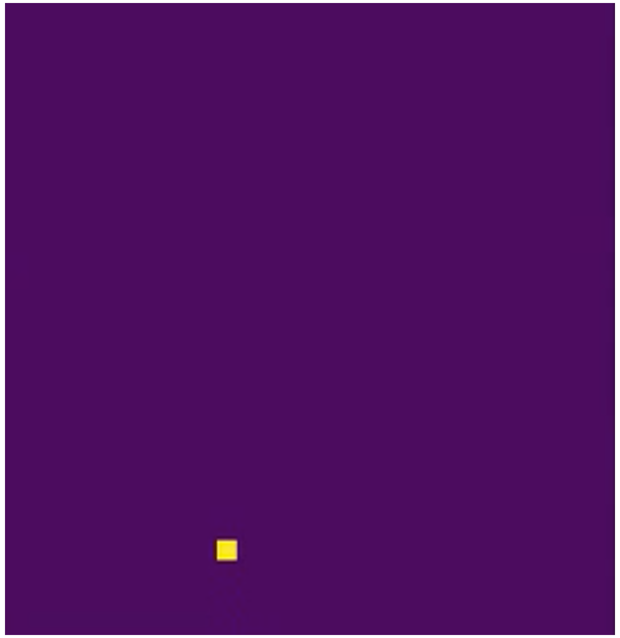
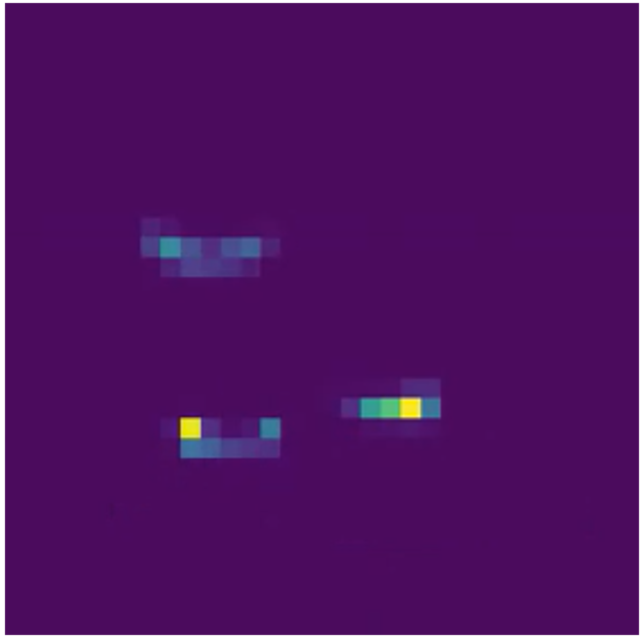


ground truth

Localization Using Tactile Data

initial depth image



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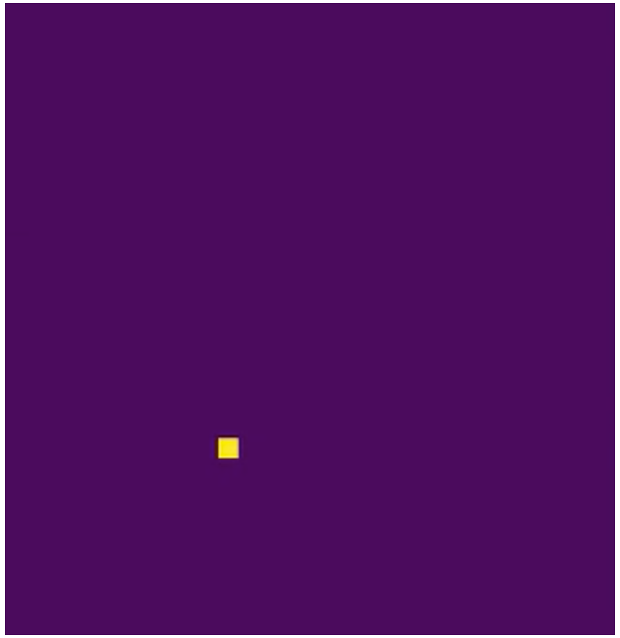

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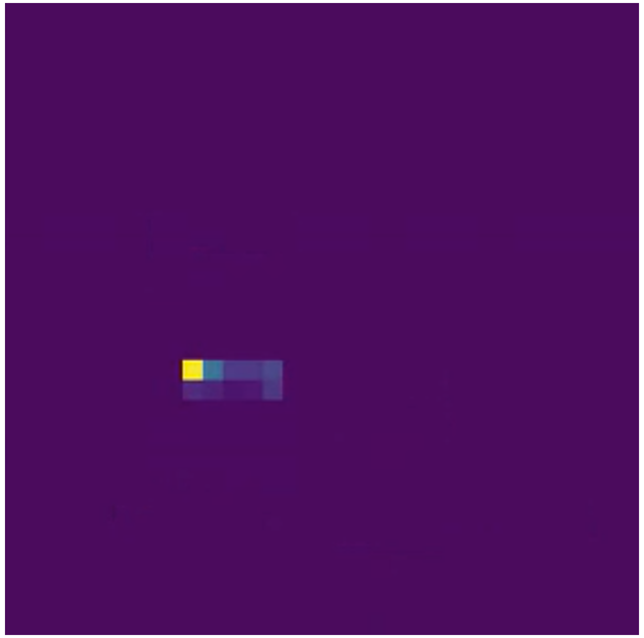

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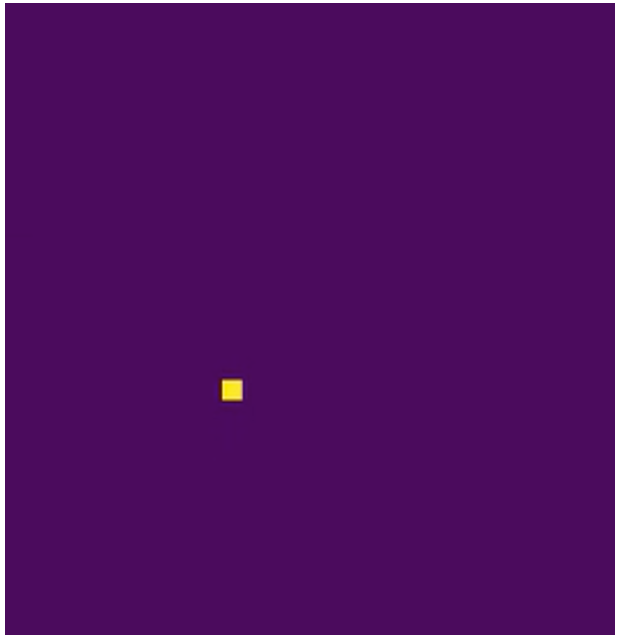

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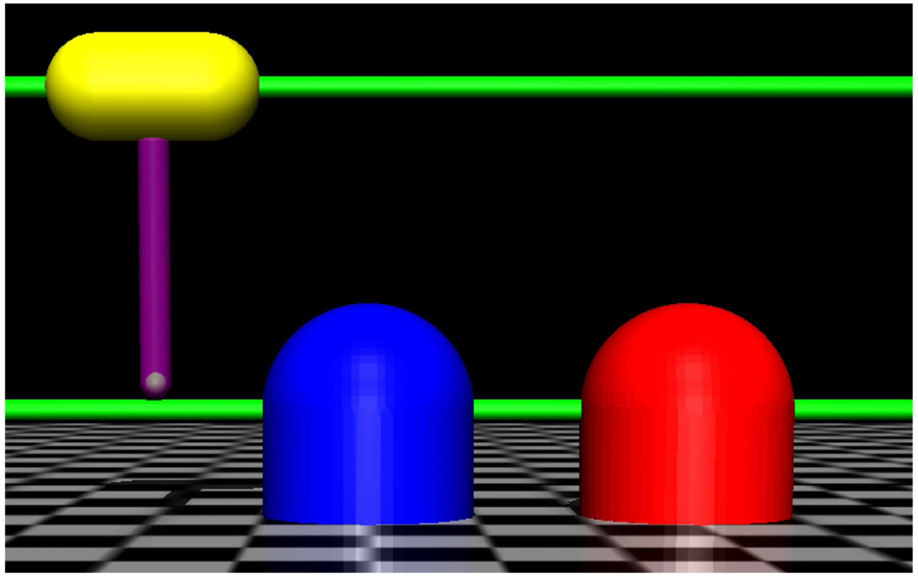
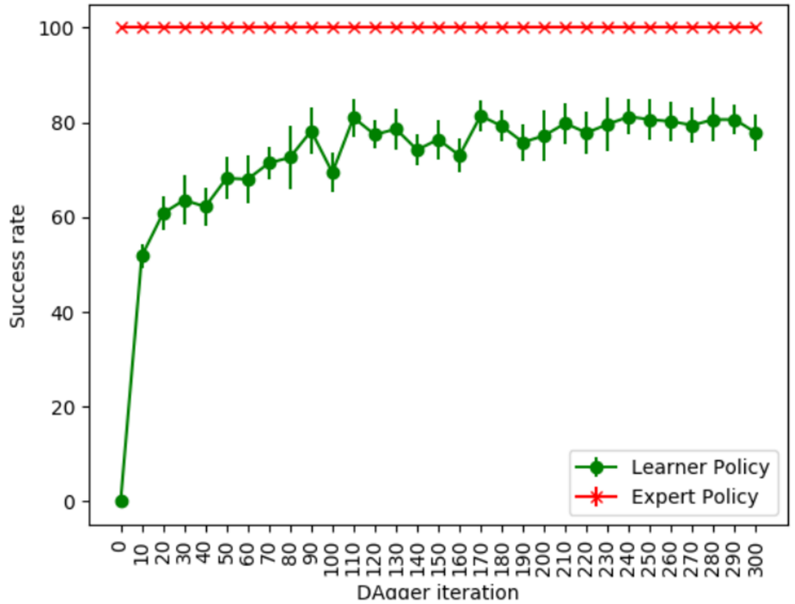
Force Feedback "Terrain Following"



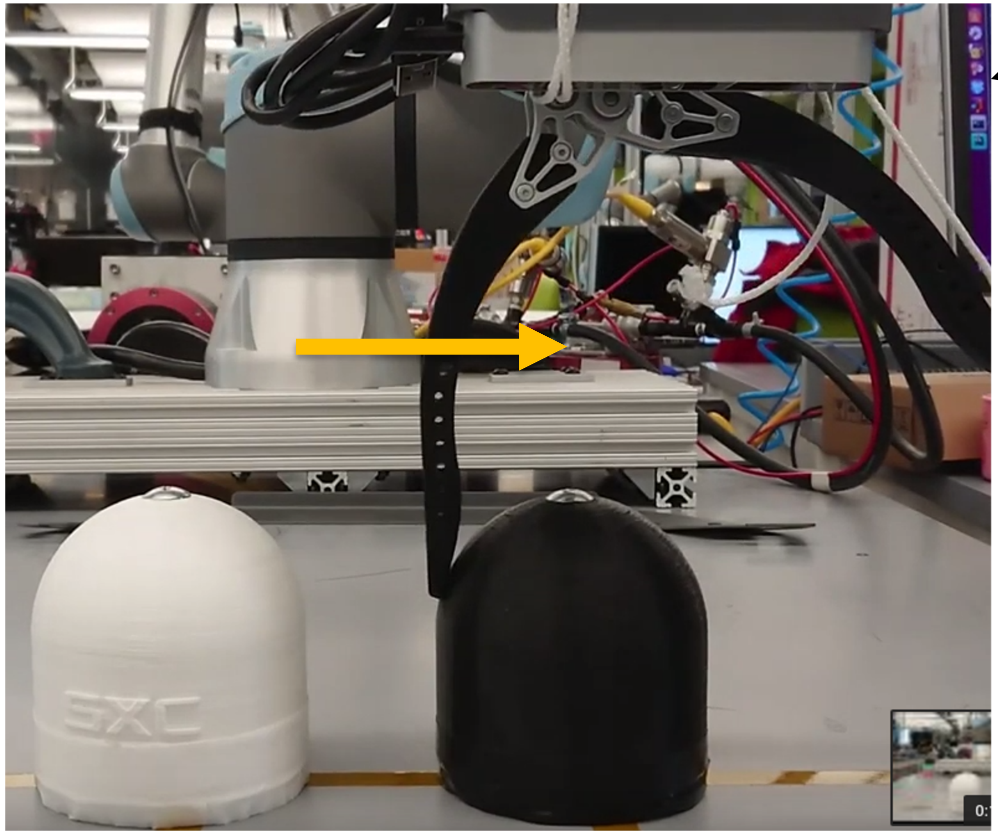


<u>Problem:</u>

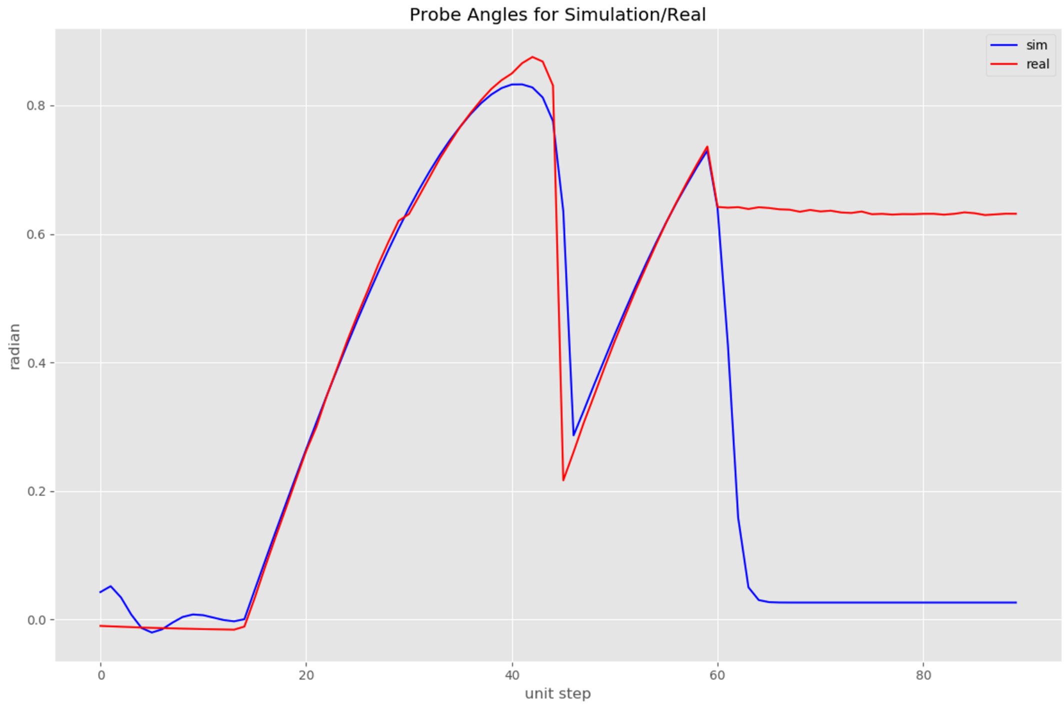
Push the red bump to the right without moving the blue bump

- **Force feedback only** (no vision)
- DAgger active learning

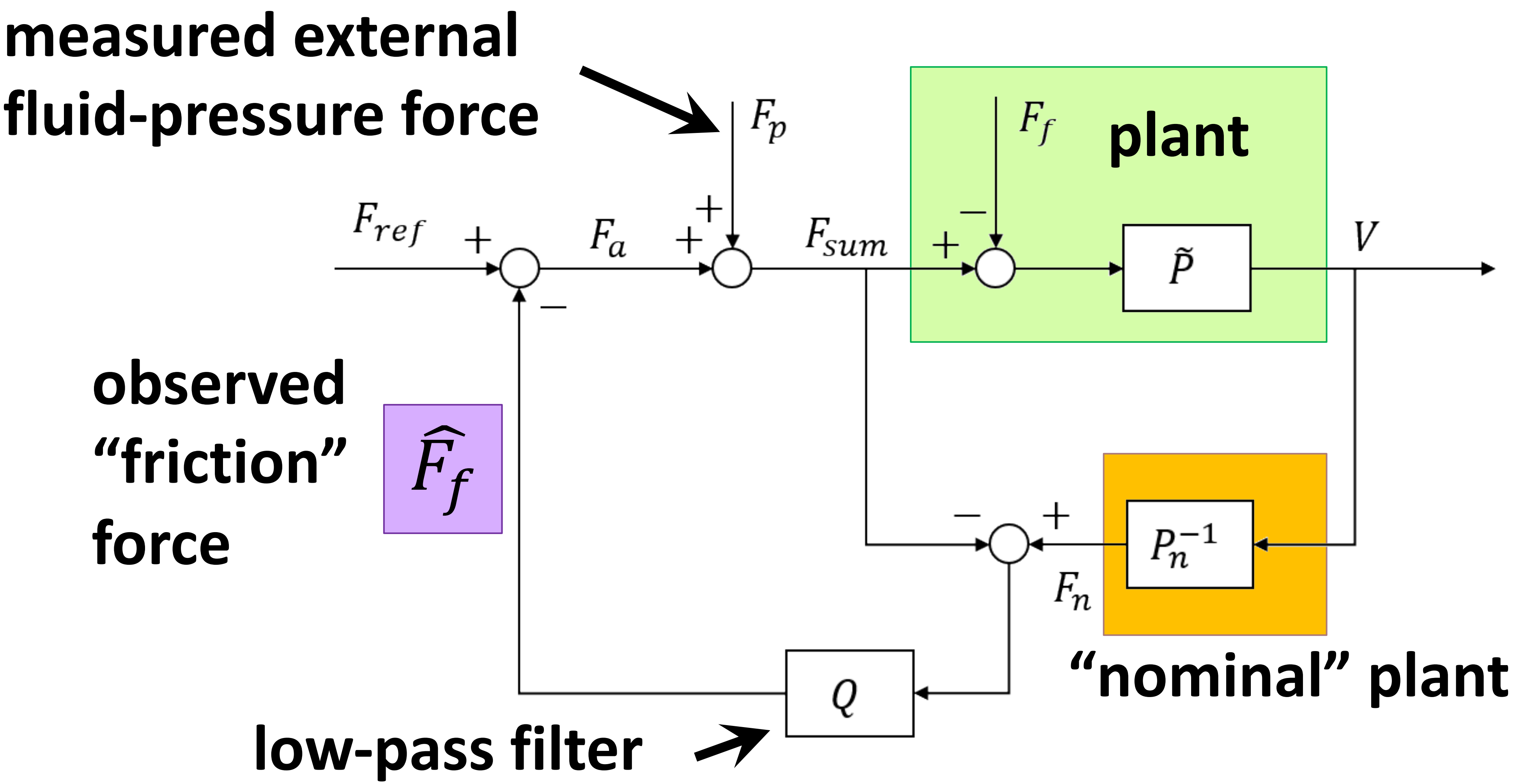
Force Feedback "Terrain Following"



2-DOF gripper attached to UR-5 robot arm, swipes finger left-to-right



Force Feedback and Tunable Stiffness



Simple PD Motor Control

Unit Behaviors

- Very low stiffness operation:
  - Localization
  - Terrain mapping
  - ***Future: "Tactile SLAM"***
- Adaptive stiffness:
  - Behavior switching
  - Future: online adaptation of stiffness for complex and coordinated tasks (e.g. grasping delicate objects in sand)

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  - Localization
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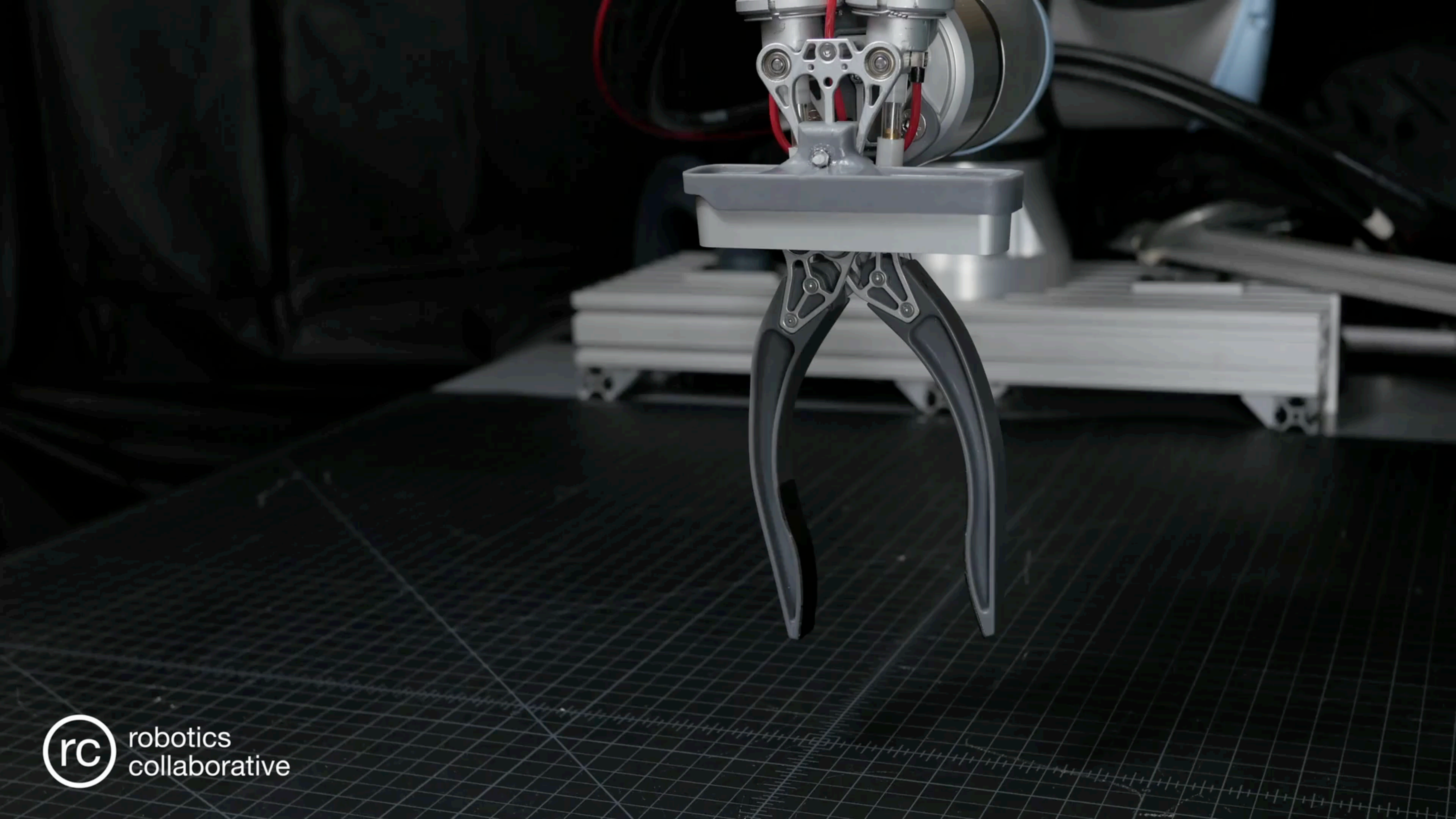
  - **High speed reflexes**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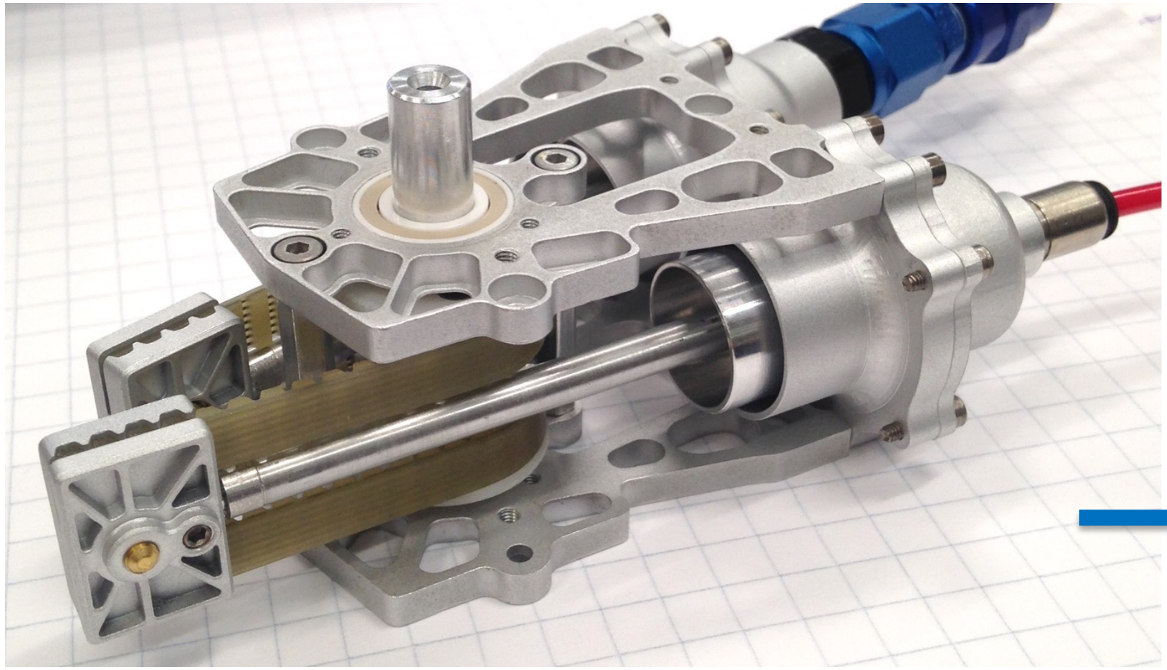
Ongoing work: Low-Cost Actuators



Traditional CNC-machined metal rolling-diaphragm actuators ($$$)

3D-printed actuators with selective fiber reinforcement ($)

Takeaways

- ***Zero*** electronics/sensing/actuation in the arm
- 100% remotized electric direct-drive actuation
- 3D-printable versions of electro-hydraulic actuators
- RNN/LSTM/imitation machine learning architectures for dynamic supervisory force-aware control
- Developing modular behaviors:
  - ***Haptic localization***
  - ***Force-reflexes***
  - ***Tactile surface mapping***