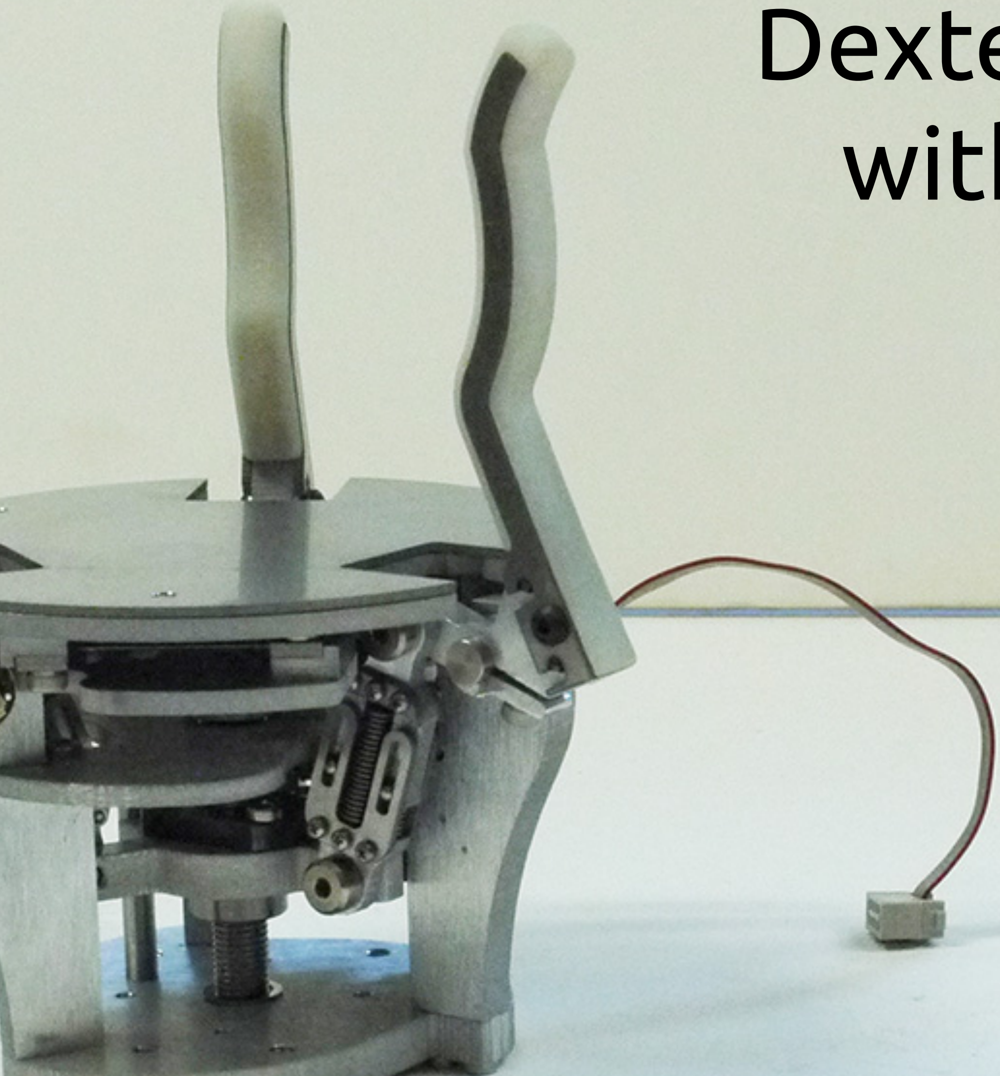
Dexterous Manipulation with External Forces

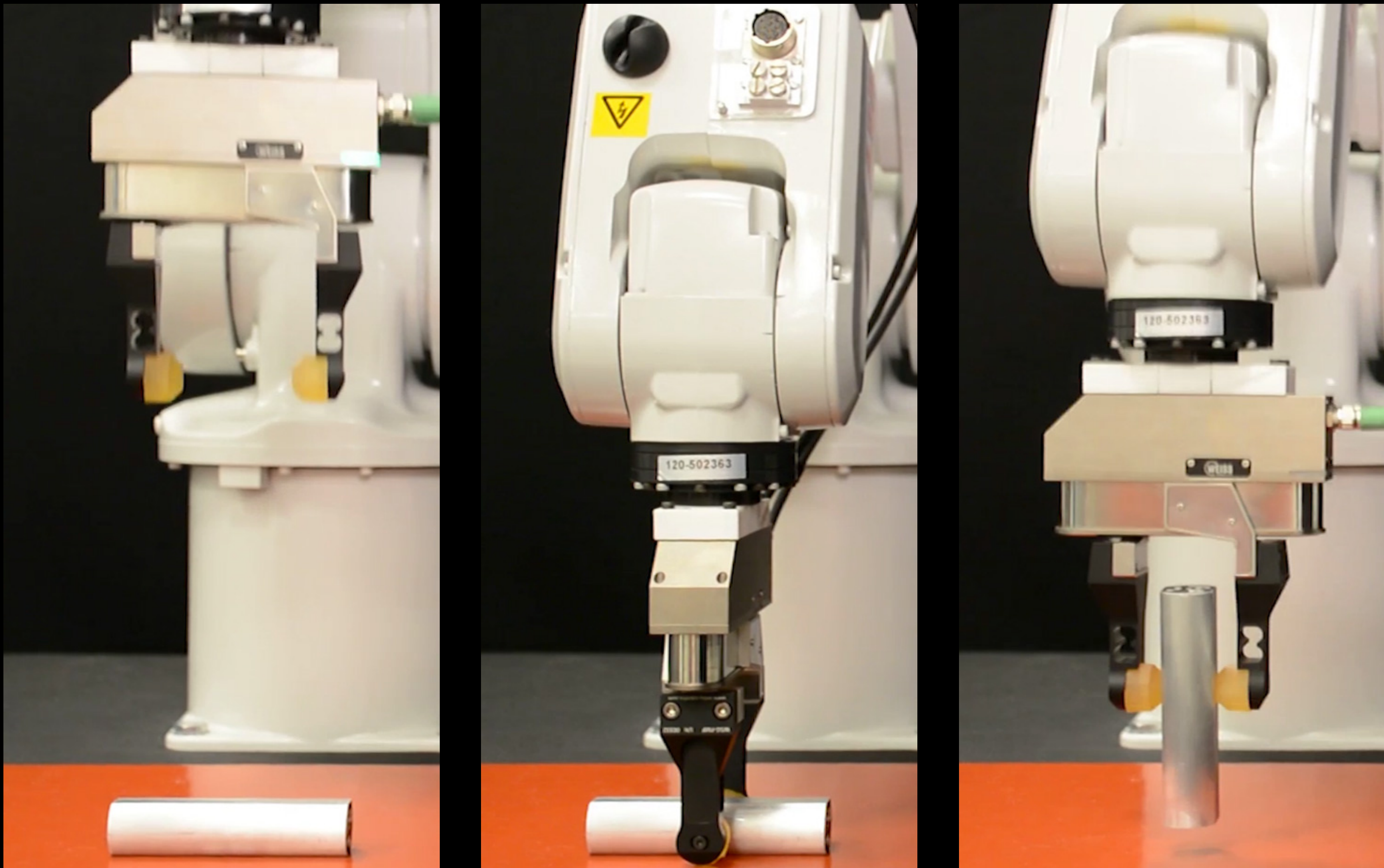


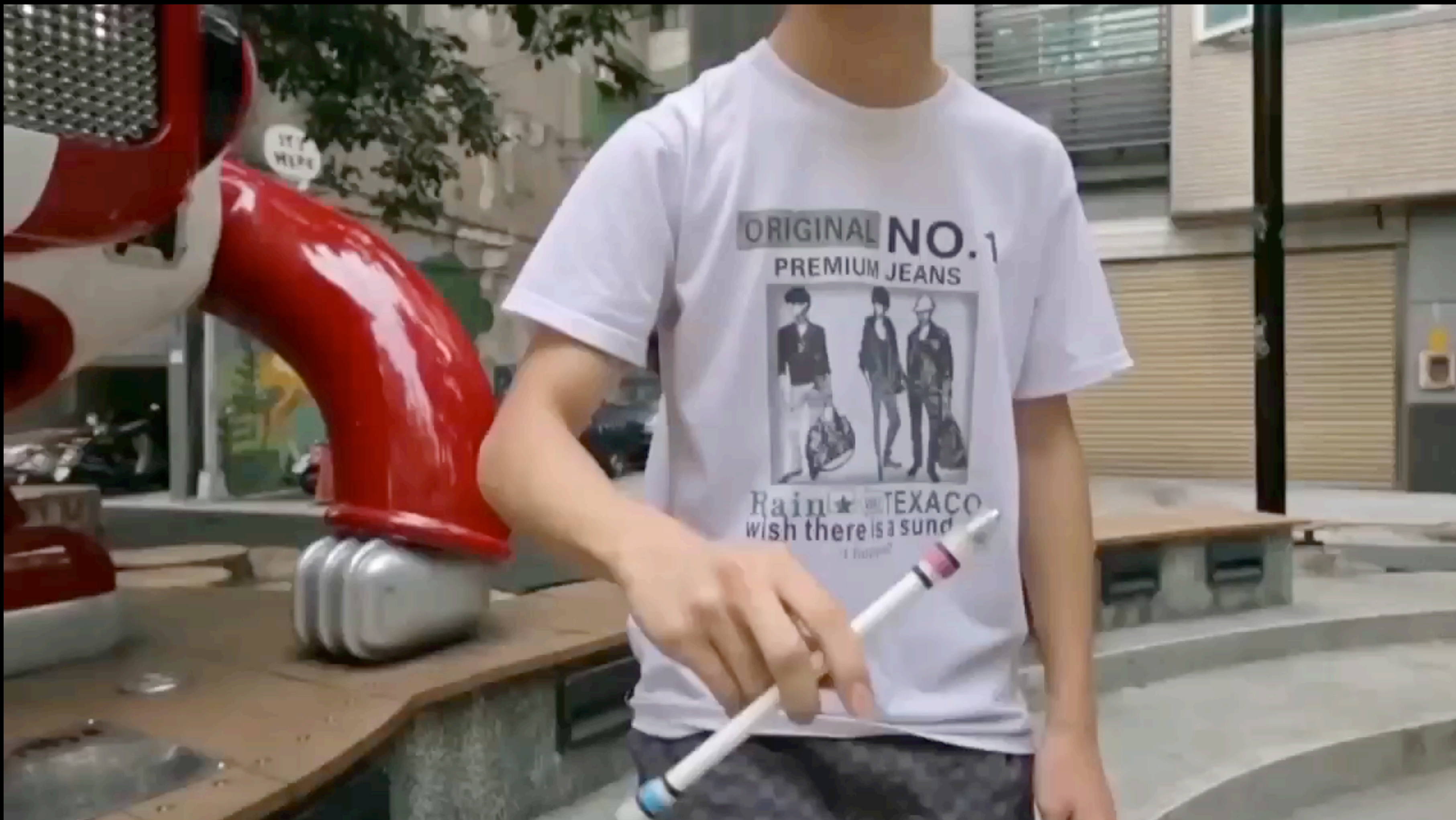
October 10, 2016
IROS – Workshop
Daejeon

Alberto Rodriguez

Massachusetts Institute of Technology

MCube Lab


120-502363
120-502363


ORIGINAL NO.1
PREMIUM JEANS
Rain TEXACO

Intrinsic vs. Extrinsic Dexterity

Extrinsic Dexterity

Exploit Robot Environment

Regrasping Objects Using
Extrinsic Dexterity

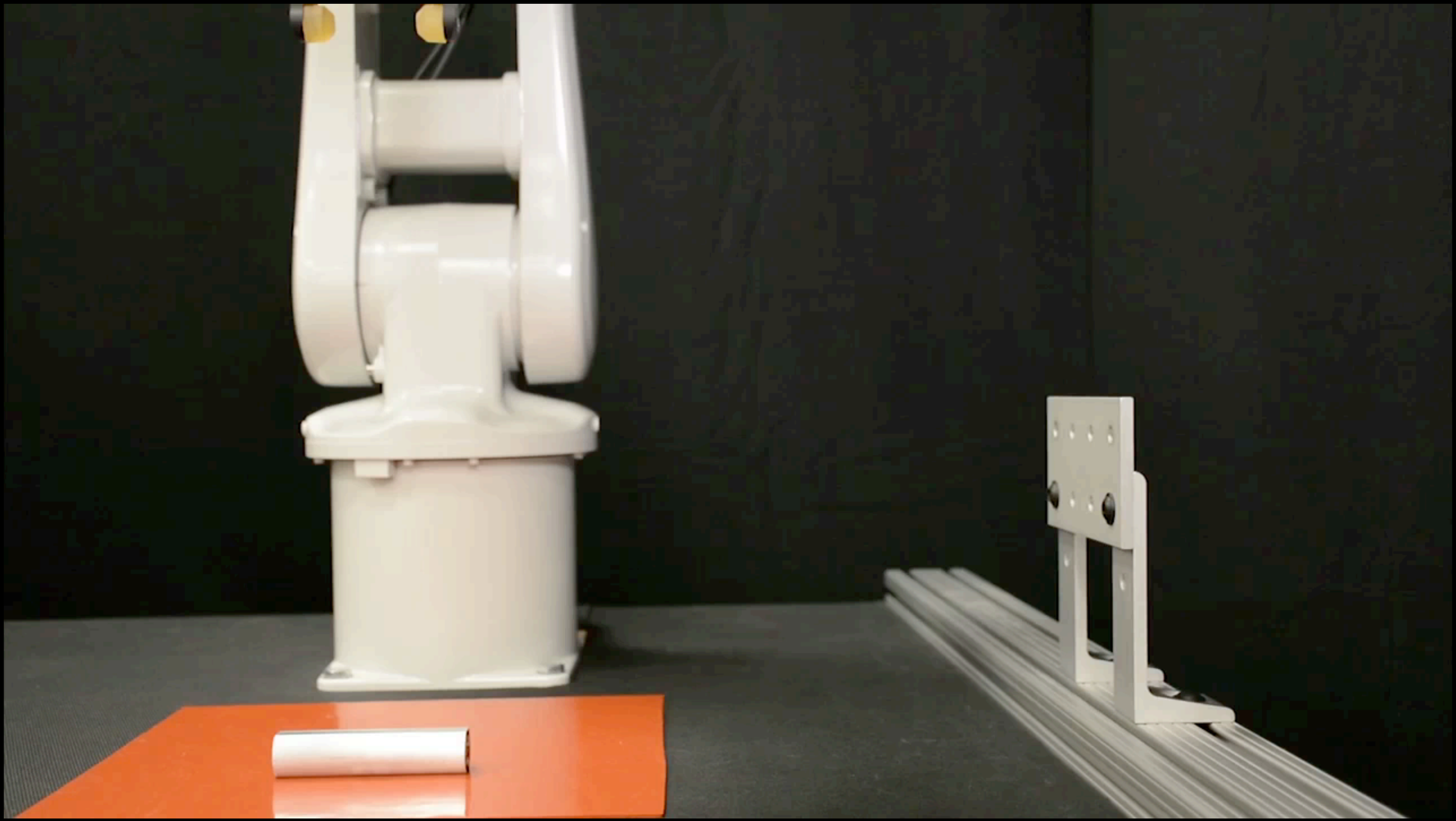
Carnegie Mellon
THE ROBOTICS INSTITUTE

MITMECHE

[Nikhil Chavan-Dafle et al., “Extrinsic Dexterity: In-Hand Manipulation with External Forces”, ICRA 2014]

Extrinsic Dexterity

Controlled Pushes against the Environment



High accuracy – High force – High speed – Large Workspace

Extrinsic Dexterity

Controlled Pushes against the Environment

How to … plan these motions?

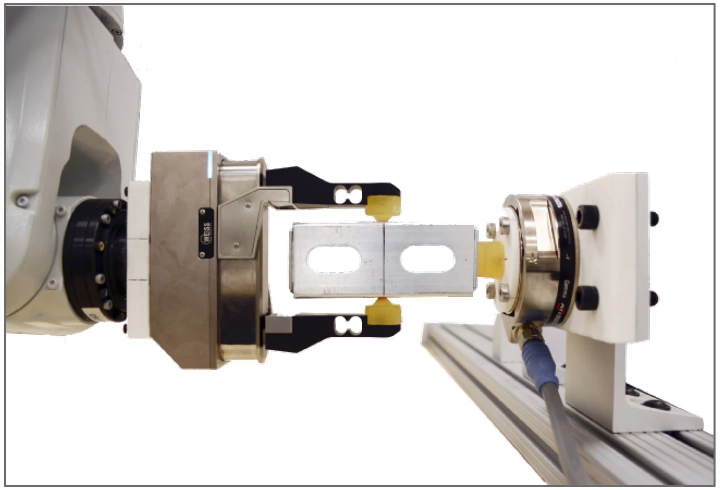
… monitor their execution?

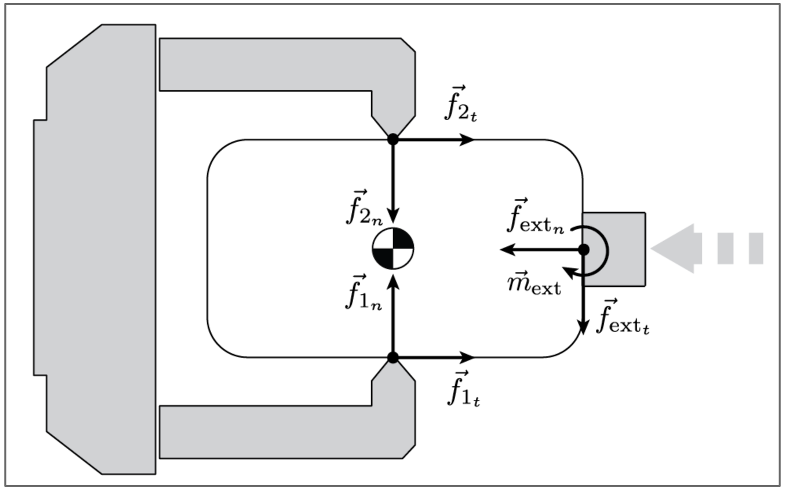
… make them reliable?

… make them fast?

Prehensile Pushing

Problem Description

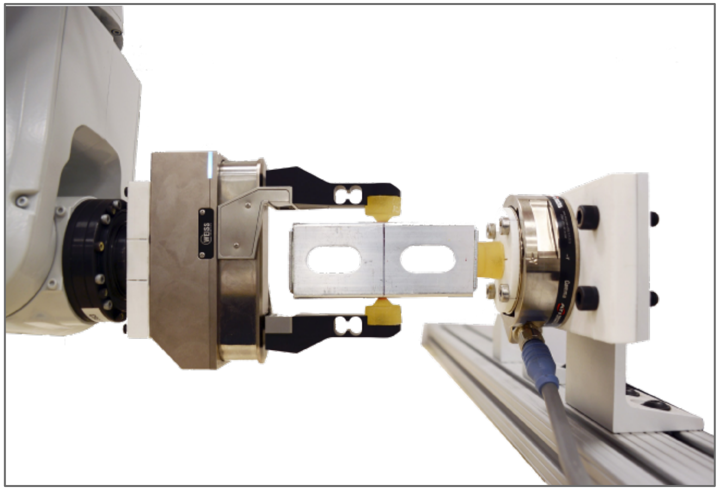


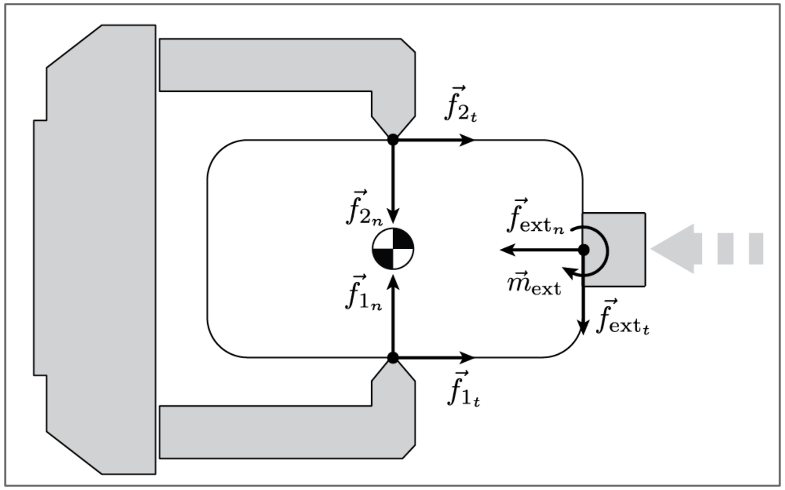


Plan arm motions to “move the environment”

Prehensile Pushing

Problem Description





Given:

- ✓ **Shape** and **mass** of object.
- ✓ **Kinematics** of gripper.
- ✓ **Location** of contacts.
- ✓ **Friction** coefficients.
- ✓ **Gripping** forces.
- ✓ **Pushing** force.

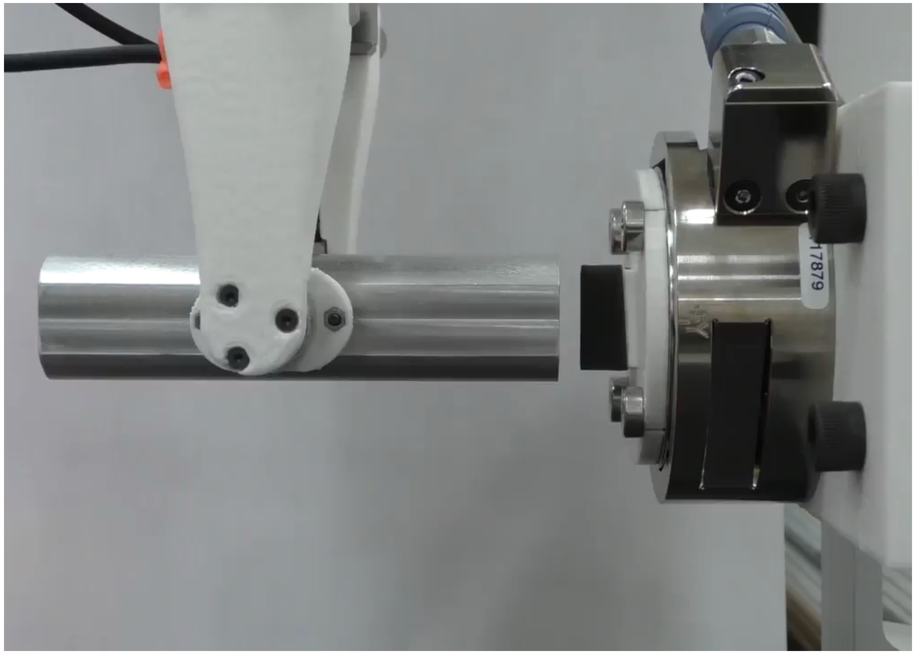
Find motion and forces applied to the object.

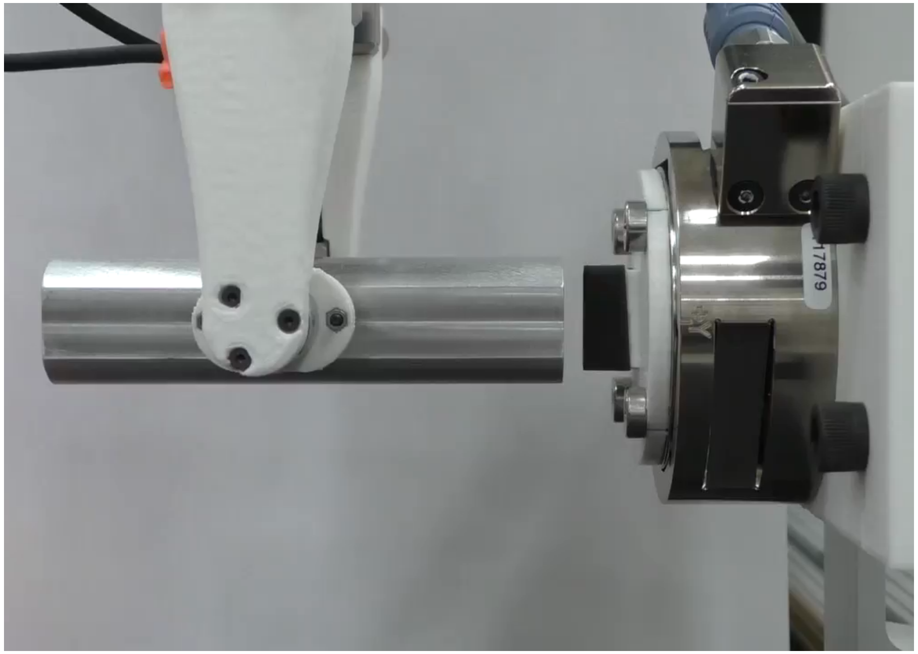
Prehensile Pushing

Main Challenges

1 - Need to model reliability

Sensitivity to kinematics, gripping force, and pushing velocity.



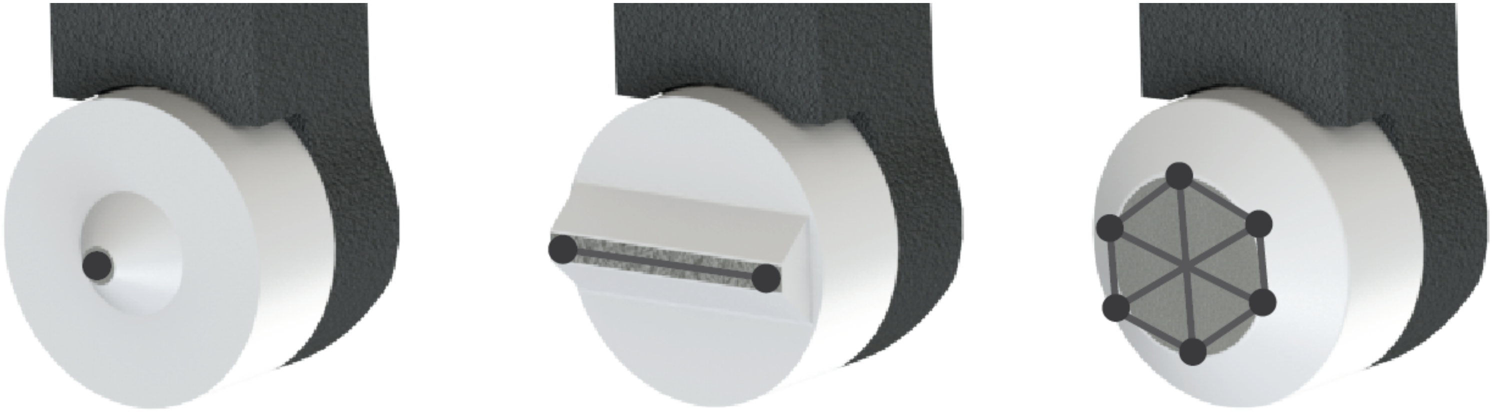


Prehensile Pushing

Main Challenges

2 - Need to model complex contacts

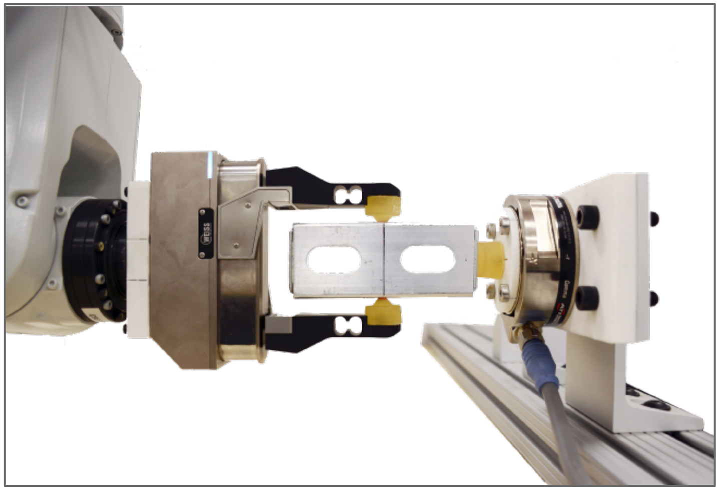
In order to exploit them

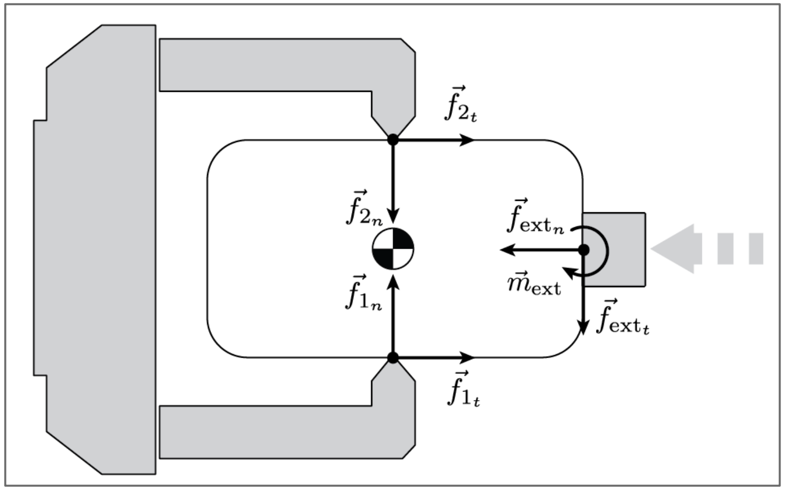


- ✓ **Kinematic** constraints from different contact geometries.
- ✓ **Linear** and **rotational** friction.
- ✓ **Computationally** tractable.

Prehensile Pushing

Problem Formulation





Find a trajectory of **forces** and **motions** that respects

- ✓ **Newtonian** mechanics.
- ✓ **Rigid** body.
- ✓ **Unilaterality** of contact.
- ✓ **Friction** laws/principles.
- ✓ **Complex** contacts.
- ✓ Motion of the **pusher**.

[Nikhil Chavan-Dafle et al., "Prehensile Pushing: In-Hand Manipulation with Push Primitives", IROS 2015]

Prehensile Pushing

Problem Formulation

- ✓ **Newtonian** mechanics.

$$\overline{\mathbf{G}} \cdot \overline{\mathbf{\Lambda}} + \vec{w} = \mathbf{M} \cdot \vec{a}_{\text{obj}}$$

- ✓ **Unilaterality** of contact.

$$a_n \cdot \lambda_n = 0, \;\; a_n \geq 0, \;\; \lambda_n \geq 0$$

- ✓ **Rigid** body and **motion of the pusher**.

$$\vec{a} = \mathbf{G}^{\top} \cdot \vec{a}_{\text{obj}} - \mathbf{J} \cdot \ddot{\vec{\theta}}$$

- ✓ **Complex** contacts.

$$\sum_{j=1\ldots k} \lambda_{n_j} = \text{Gripping force}$$

$$\vec{a_j} = \vec{a}_1 + \frac{\vec{a}_2 - \vec{a_1}}{\text{dist}(p_2, p_1)} \text{dist}(p_j, p_1)$$

- ✓ Coulomb **friction**.

$$[\mu\lambda_n - \boldsymbol{e}^{\top}\boldsymbol{\beta}]\xi = 0, \quad \mu\lambda_n - \boldsymbol{e}^{\top}\boldsymbol{\beta} \geq 0, \quad \xi \geq 0$$

$$[\xi\boldsymbol{e} + \boldsymbol{D}^{\top}\vec{a}_{\text{obj}}]^{\top}\boldsymbol{\beta} = 0, \quad \xi\boldsymbol{e} + D^{\top}\vec{a}_{\text{obj}} \geq 0, \quad \boldsymbol{\beta} \geq 0$$

[Nikhil Chavan-Dafle et al., "Prehensile Pushing: In-Hand Manipulation with Push Primitives", IROS 2015]

Prehensile Pushing

Problem Formulation

Problem formulation based on many **assumptions**:

- ✓ Uniform, isotropic, and deterministic Coulomb friction.
- ✓ Maximum power dissipation.
- ✓ Quasi-dynamic interaction.
- ✓ Rigid contact.
- ✓ Perfect knowledge of geometries and inertias.

How usable is the model?

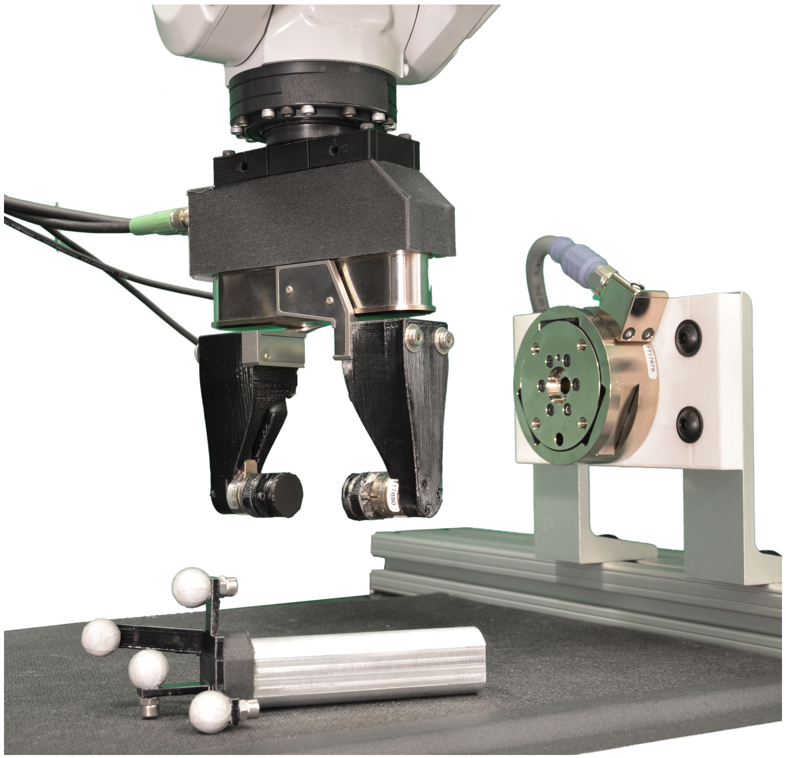
Prehensile Pushing

We need model validation

Prehensile Pushing

Validation

Automated Experimental Setup



Capture:

- ✓ **Motion** of robot and object.
- ✓ **Forces**/**torques** at all contacts.

Variations in:

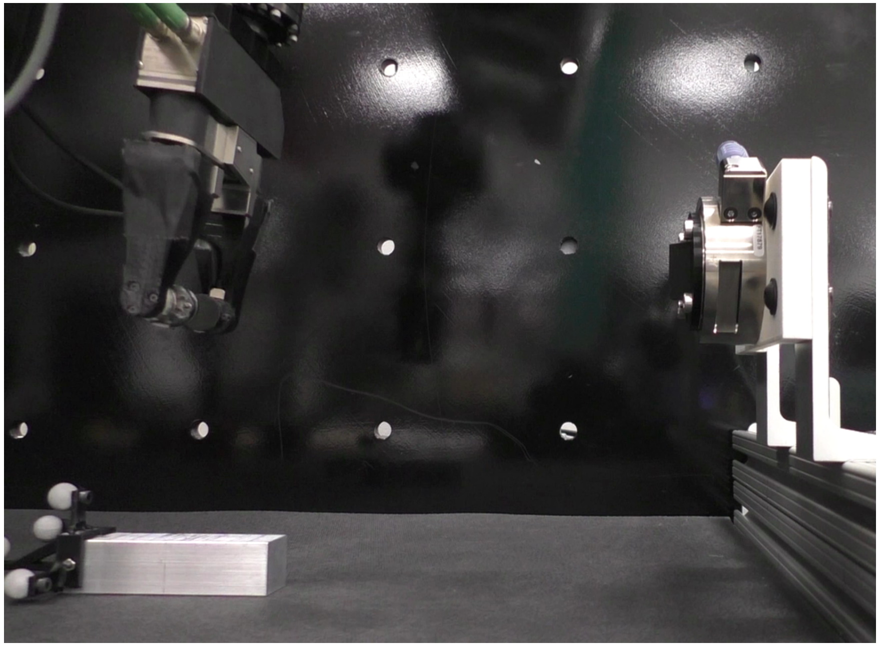
- ✓ Contact **geometry**.
- ✓ Gripping **force**.
- ✓ Pusher **motion**.

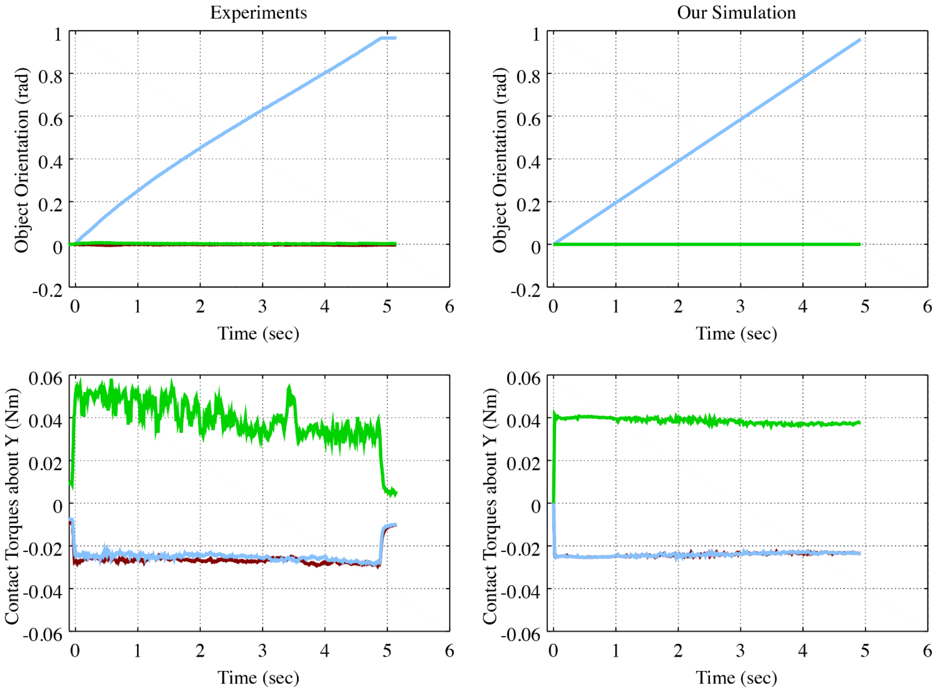
[Roman Kolbert et al., "Experimental Validation of Contact Dynamics for In-Hand Manipulation", ISER 2016]

Prehensile Pushing

Validation

Experiment: Pivoting Push



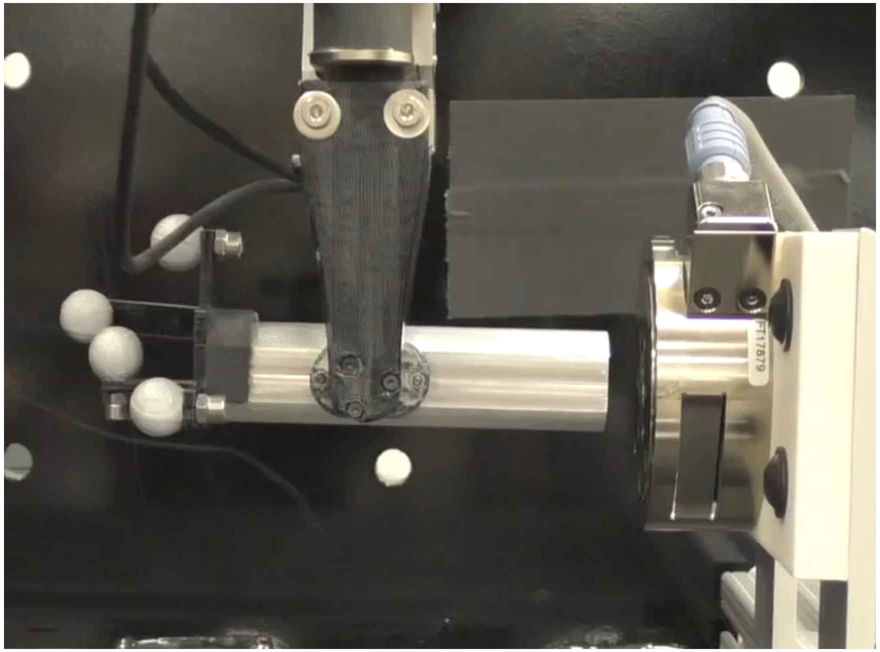


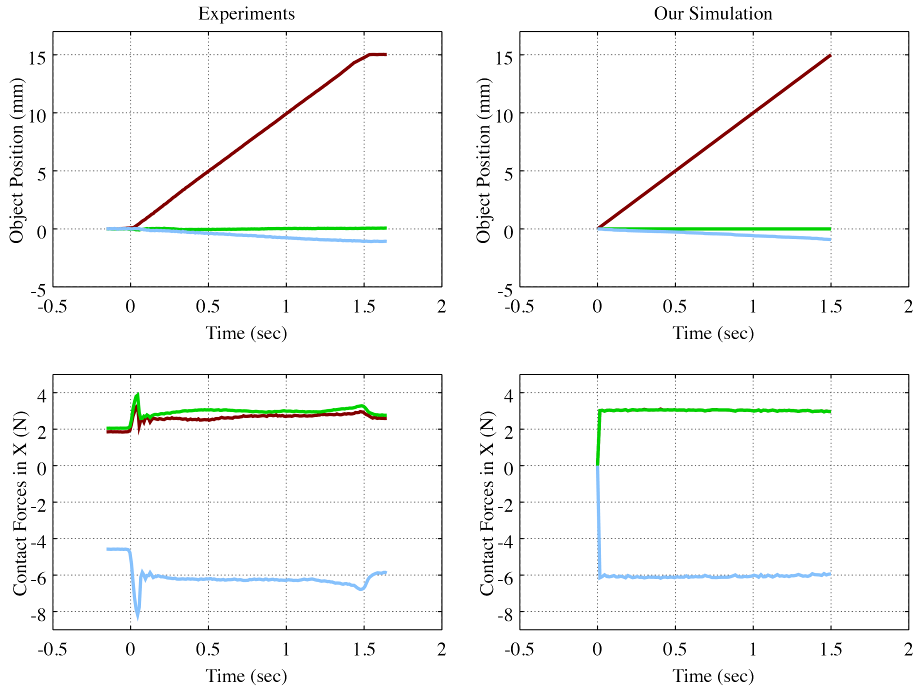
[Roman Kolbert et al., "Experimental Validation of Contact Dynamics for In-Hand Manipulation", ISER 2016]

Prehensile Pushing

Validation

Experiment: Linear Push





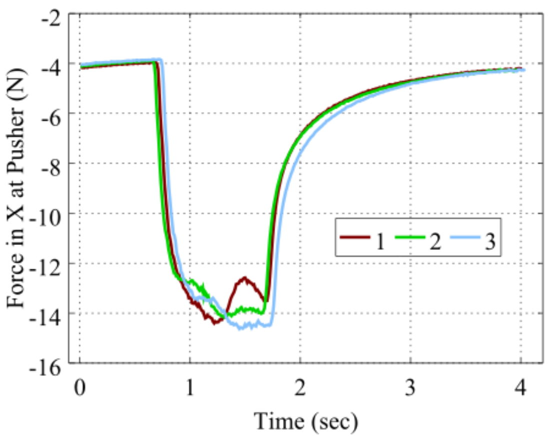
[Roman Kolbert et al., "Experimental Validation of Contact Dynamics for In-Hand Manipulation", ISER 2016]

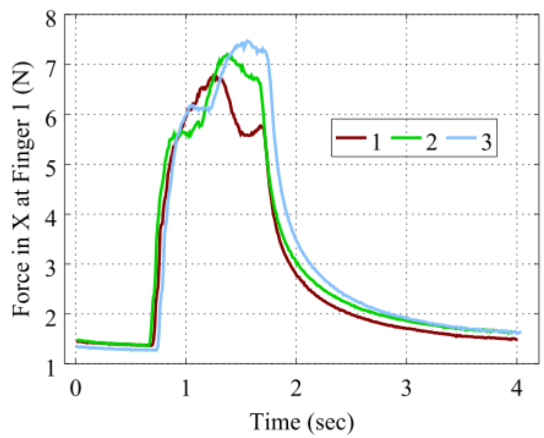
Prehensile Pushing

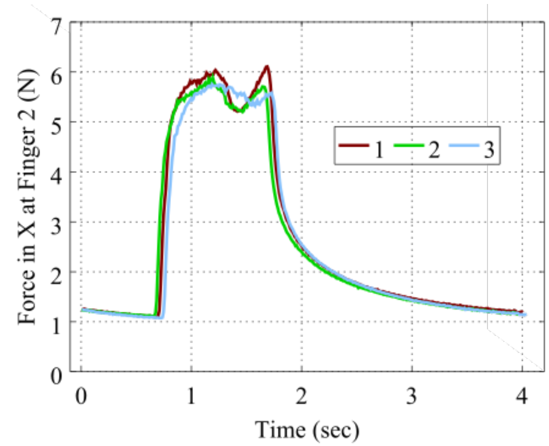
Challenges

Variability

During experiments with same initial conditions.

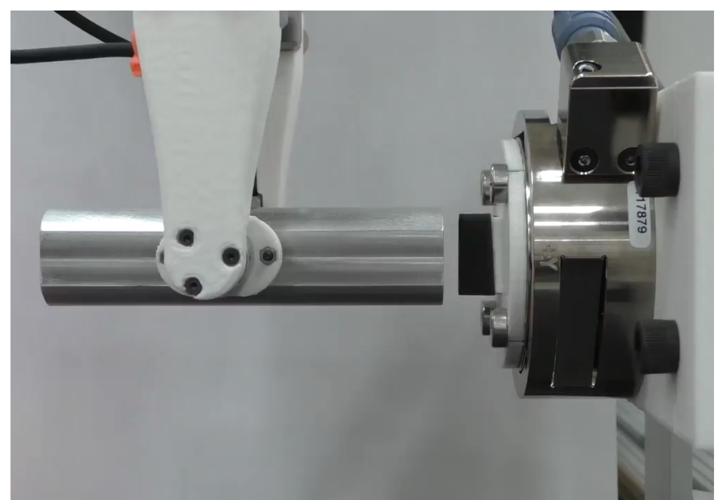




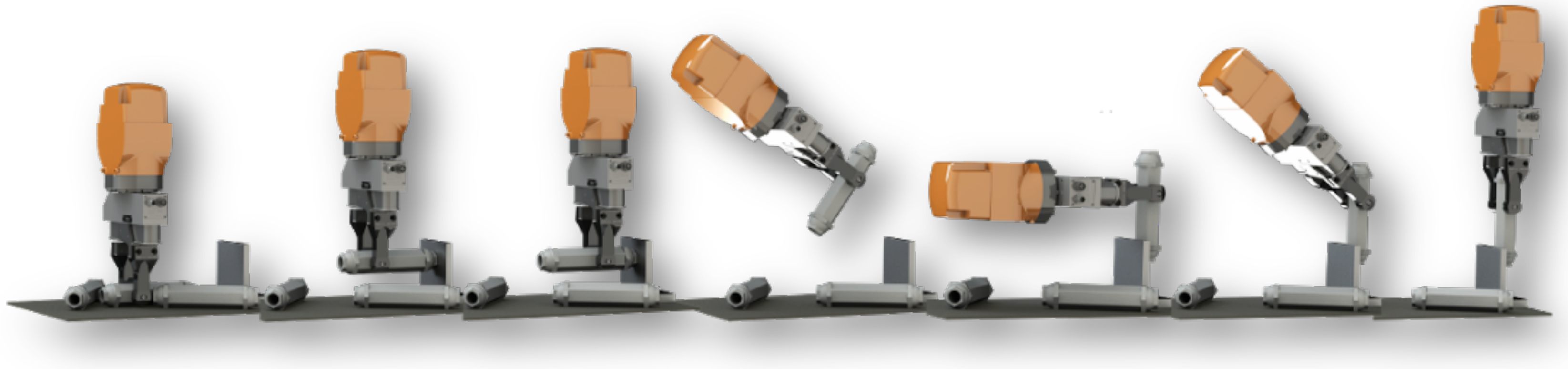


Stability

Some pushes are still inherently unstable and difficult to control.



Summary



- ✓ **Extrinsic dexterity** - specially for simple gripers.
- ✓ Good approximation to **contact dynamics**.
- ✓ **Evaluate** and **reinforce** with data when possible.
- ✓ Close the loop!

Massachusetts Institute of Technology

MCube Lab