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Learning to Visually Observe, Plan, and Control Compliant Robot In-Hand Manipulation

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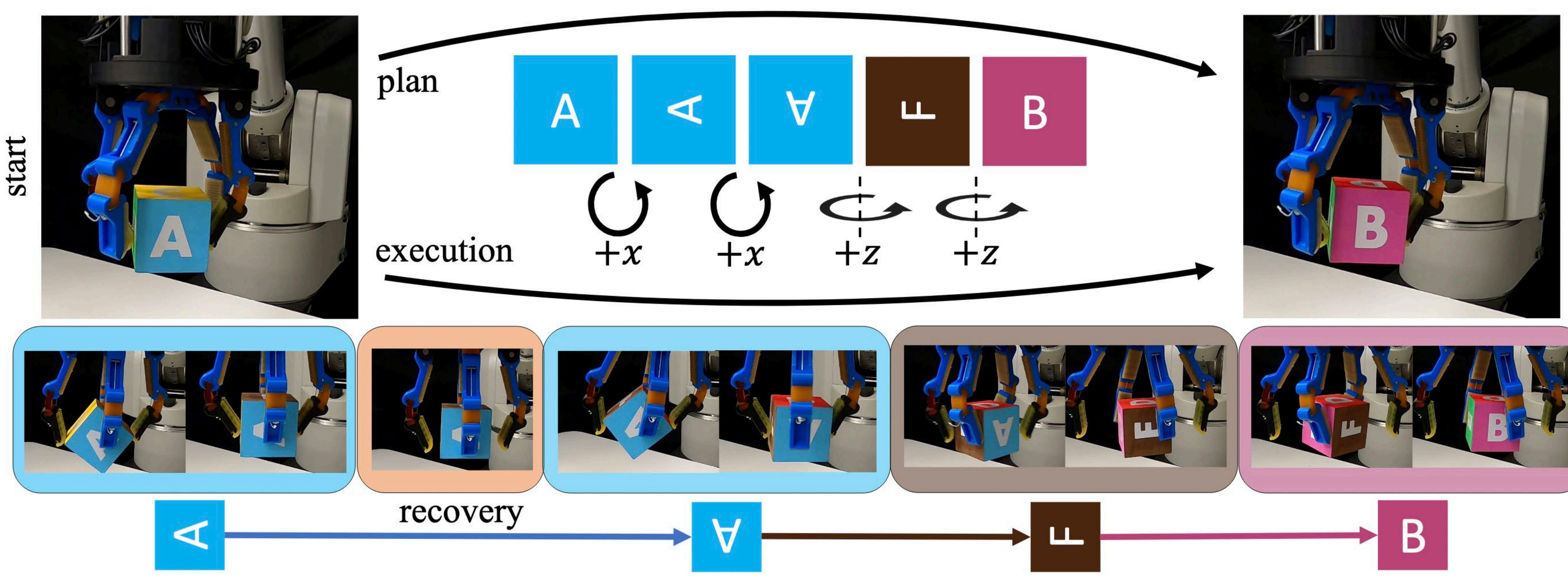
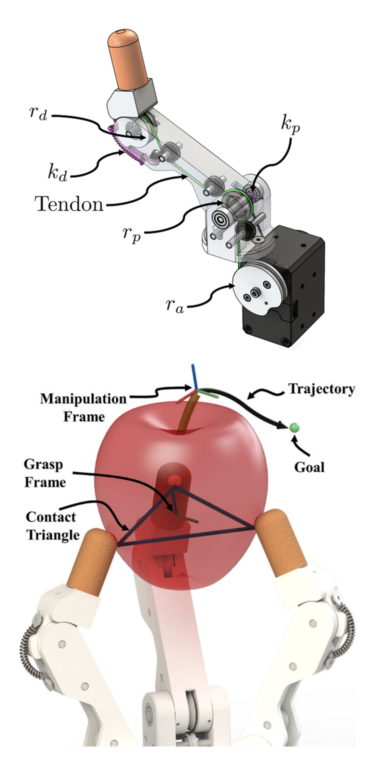
Background

- Humans often leverage *in-hand manipulation* to reorient and/or reposition objects with respect to the hand frame.
- This action has been particularly difficult for a robot, as it requires a group of serial-link manipulators to work in proper unison with one another to complete a task.
- *Uncertainty* in models and/or sensor readings often lead to task failure and we can overcome this uncertainty with compliance, which introduces questions regarding precise control of the robot.
  - *Fixed-contact manipulation* is possible through energy-based modeling of the hand-object system with online adaptation.
  - *Fluid-contact manipulation* (i.e. finger gaiting) can be achieved by combining fixed contact models with multi-modal planning, which can also be achieved online through a visual feedback framework.



Fixed-Contact Manipulation



- Mechanically compliant mechanisms can be modeled as an energy minimization problem with constraints:

$$\mathcal{T} = (|p_1 - p_2|_2, |p_2 - p_3|_2, |p_3 - p_1|_2) \in \mathbb{R}^3 \quad (1)$$

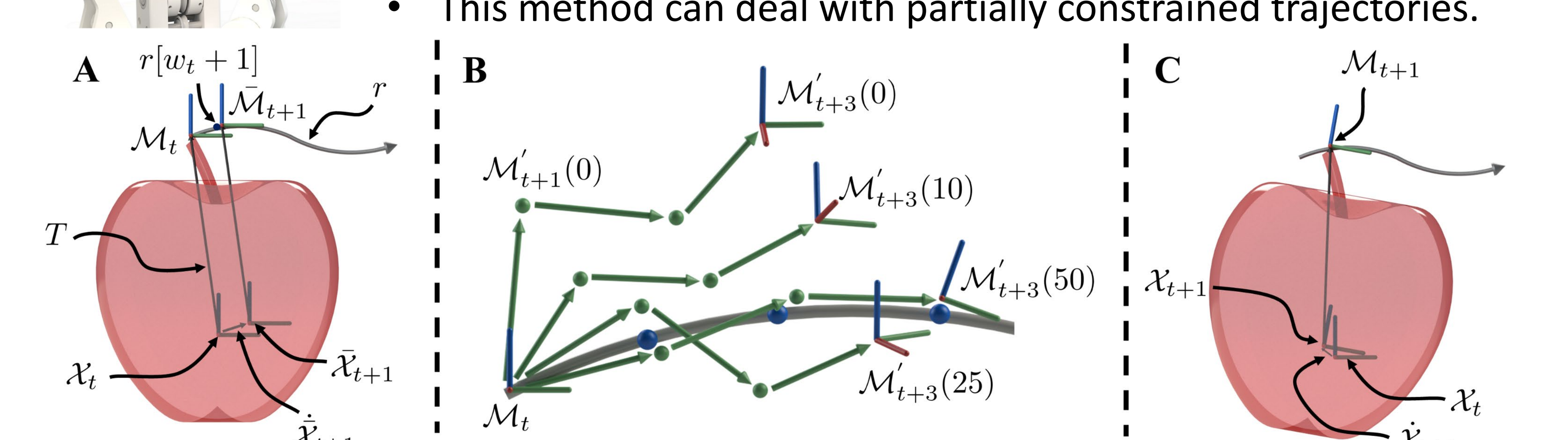
$$r_a \dot{q}_a = r_p \dot{q}_p + r_d \dot{q}_d \quad (2)$$

$$q^* = argmin \sum_i E(q) \, s.t. (1), (2)$$

where,

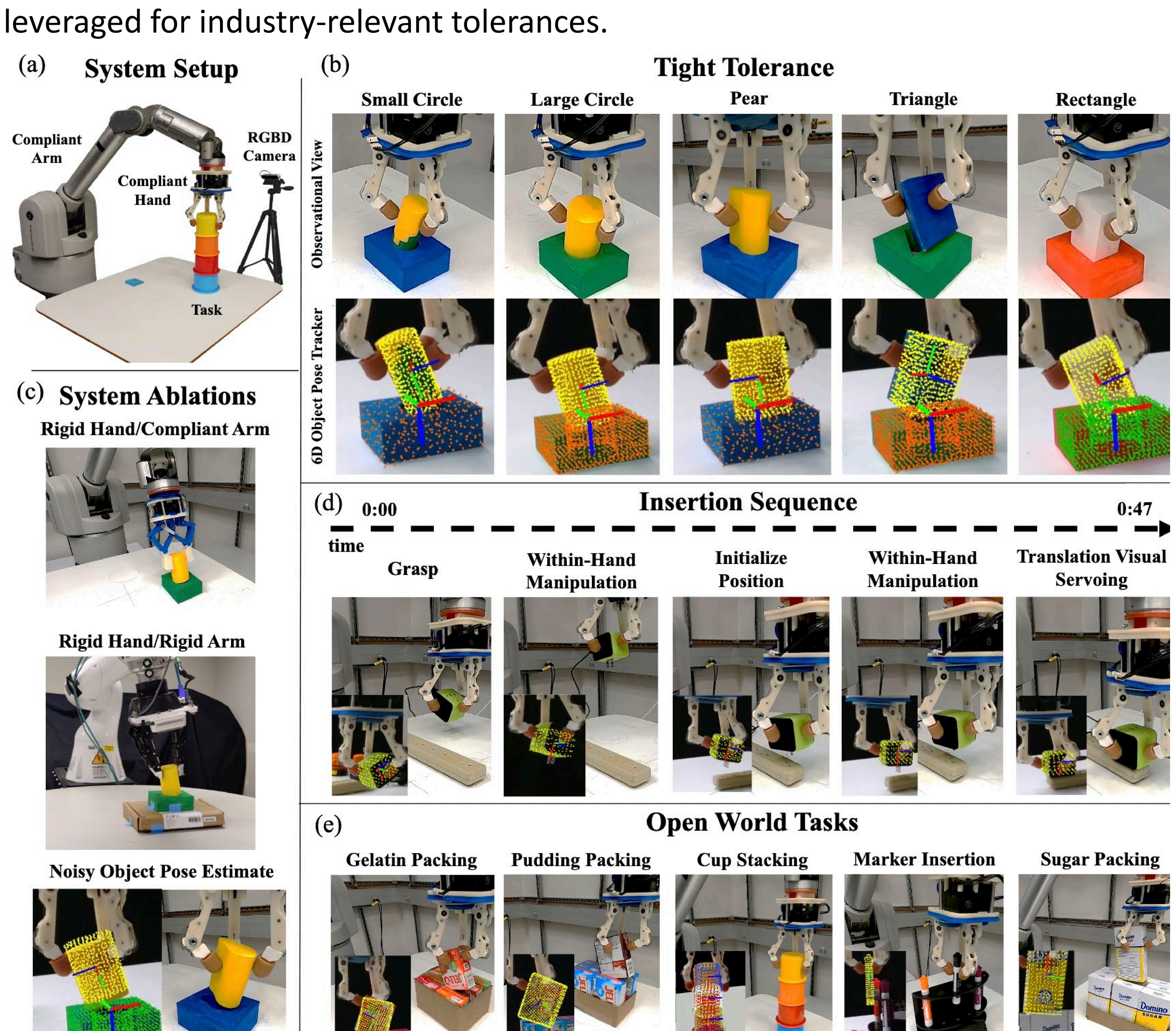
$$E(q) = \frac{1}{2}(k_p q_p^2 + k_d q_d^2)$$

- Using this model and while continually updating parameter estimates online, trajectories can be planned via a fast Model Predictive Control (MPC) importance sampling-based framework.
- This method can deal with partially constrained trajectories.

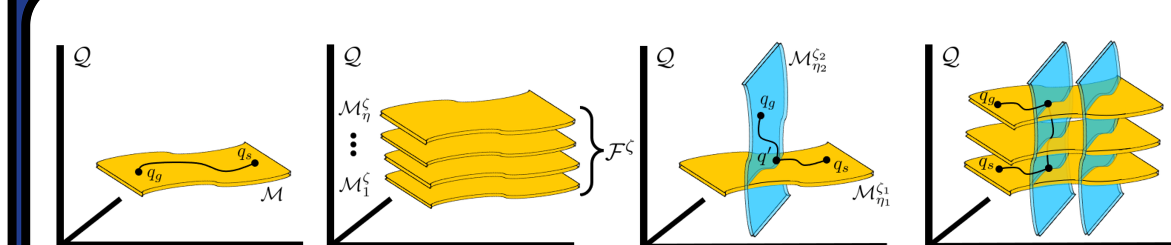


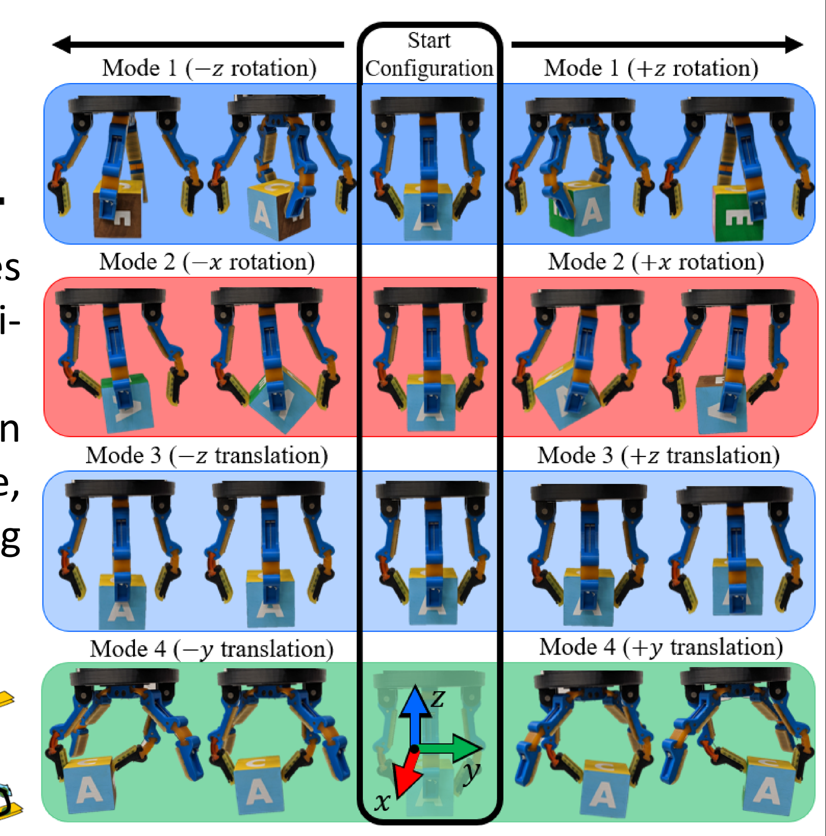
Compliance-Leveraged Assembly

- By tracking the object's pose via a RGBD-based 6D Pose Object Tracker (se(3)-tracknet), we are able to complete tight tolerance (<0.25mm) insertion tasks without tactile data or joint encoders on the hand, with relatively simple planning.
- We show the extent to which compliance in either the hand/arm/object can be leveraged for industry-relevant tolerances.

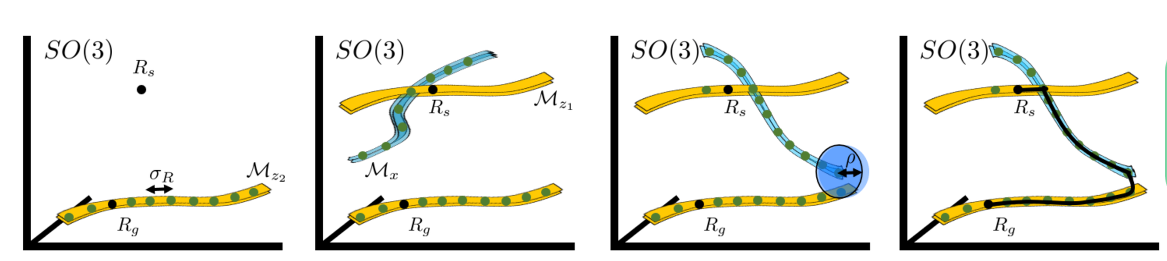


Multi-Modal Planning

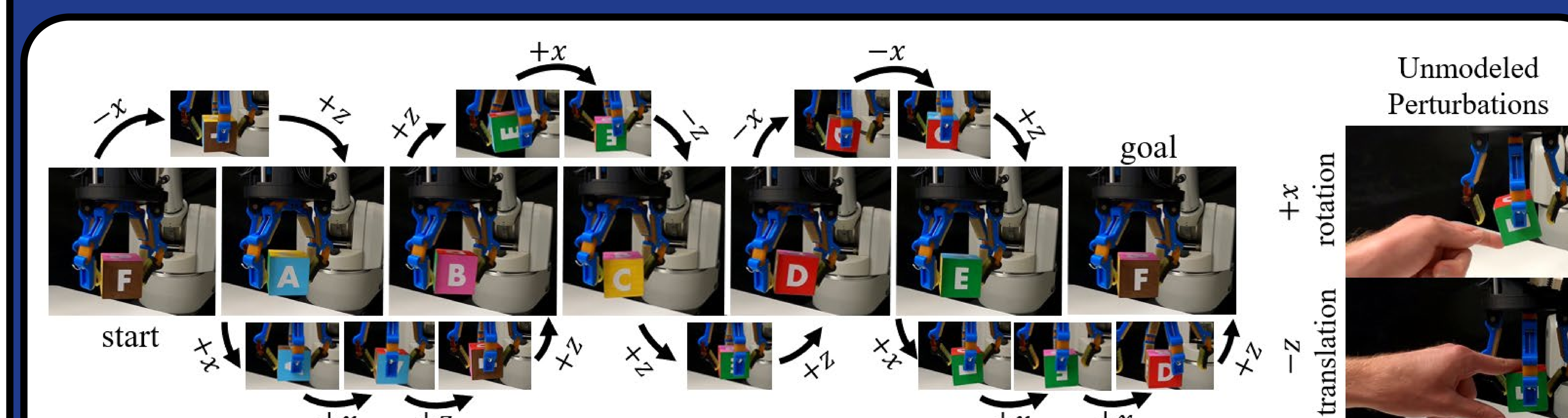


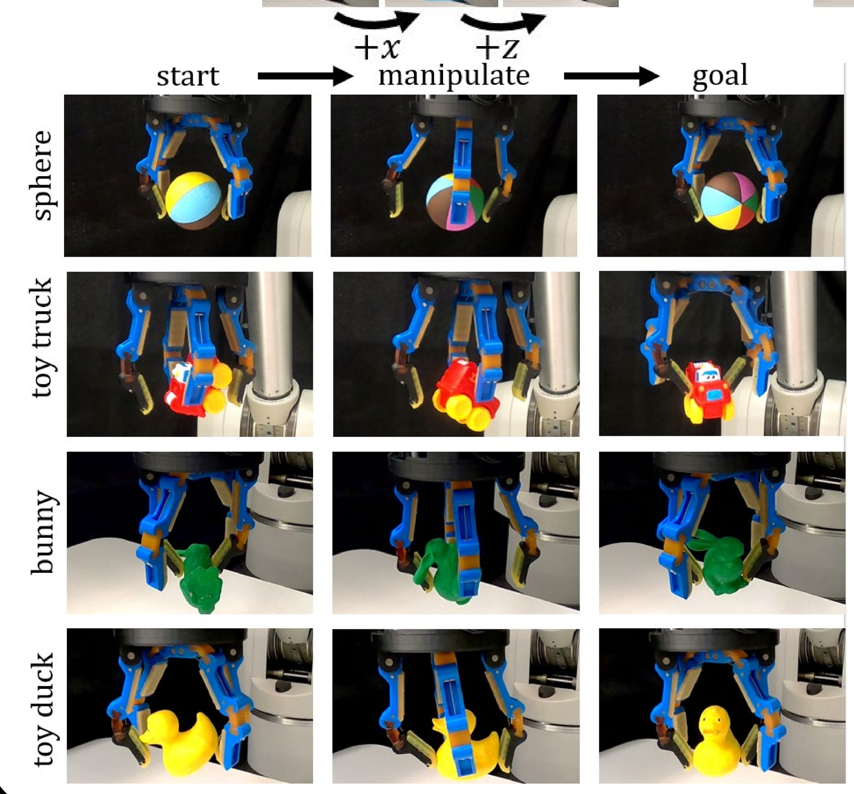


- Transitioning between different manifolds usually requires a near zero transfer configuration volume, making multi-modal planning difficult for rigid systems.
- For compliant systems, conversely, this transfer region can be inflated due to the system's passively adaptive nature, which further allows us to accelerate finger gait planning for complete, online *SO(3)* control.



Compliance-Leveraged Finger Gaiting





- We are able to run our multi-modal planning and control solution online for:
  - Long-horizon (multiple) trajectory goals
  - Manipulation with unmodeled perturbations
  - Different convex and non-convex objects
- Manipulation of convex objects was completed 5/5 times with $\pm 5°$ axis precision.
- One of the first works in the literature to do complete *SO(3)* finger gaiting *against gravity.*
- *In the future,* I will focus on aspects of this problem that include theoretically quantifying the inflated volume of the transfer region and developing more complete whole-hand caging manipulation models.

Acknowledgements and Contact

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