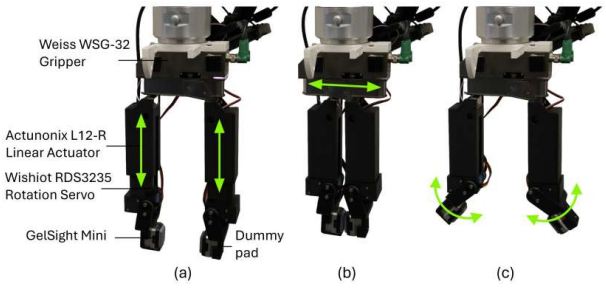
In-Hand Singulation and Scooping Manipulation with a 5 DOF Tactile Gripper

Yuhao Zhou[1], Pokuang Zhou[1], Shaoxiong Wang[2] and Yu She[1]
[1]School of Industrial Engineering, Purdue University
[2]CSAIL, MIT

1. Introduction

- The potential of in-hand manipulation using a **fewer Degrees of freedom gripper** remains less explored
- Previous work in human-like **dexterous manipulation** usually relies on high-DOF hand and intricate control strategies. In this work, we develop a **5-DOF gripper** and leveraging the visual-tactile sensor
- We present a model-based approach that utilizes tactile information to accomplish two tasks: **in-hand singulation** and **scooping manipulation**
- The results demonstrate the efficiency of the proposed approach, with a high success rate for spherical objects at high as **94.3%**, and a **100%** success rate for scooping and inserting credit cards

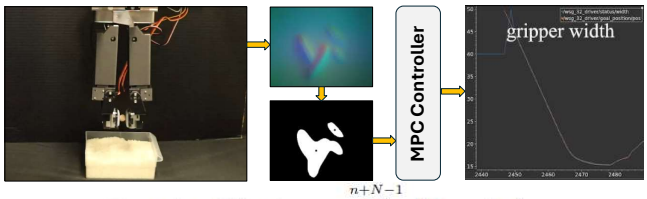
2. 5-DOF Tactile Gripper Design



3. Model-based Control

- **In-Hand Singulation**

[Tactile-reactivate MPC Controller] [Xu 2024]



$$J(\mathbf{y}_n, \mathbf{a}_n) = P\mathbf{e}_{n+N}^T \mathbf{Q}\mathbf{e}_{n+N} + \sum_{n+N-1} \mathbf{e}_k^T \mathbf{Q}\mathbf{e}_k + Q_a a_k^2$$

$$\mathbf{a}_n^* = \arg\min J(\mathbf{y}_n, \mathbf{a}_n)$$

Achieving stable grasping during dynamic in-hand manipulation

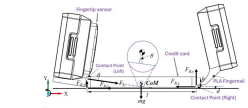
[Linear State Feedback Controller]

$$L = k_p \cdot p_{\text{stable}} + b$$

Achieving adaptability of singulation for various objects

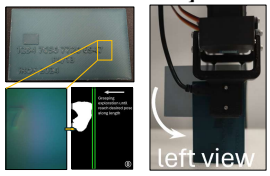
- **In-Hand Scooping**

[Grasp Maneuver Design]



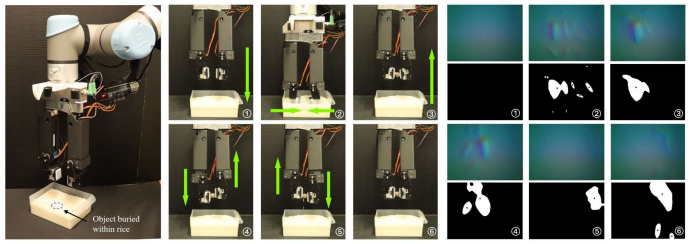
$$M_{\text{all}} = \frac{1}{2}[-(h-2d)F_{R,x} + lF_{R,y}] + \frac{1}{2}[hF_{B,x} - lF_{B,y}] + \frac{1}{2}[(l\tan\theta - h)F_L\cos\theta]$$

[Tactile Exploration for Precise Insertion]



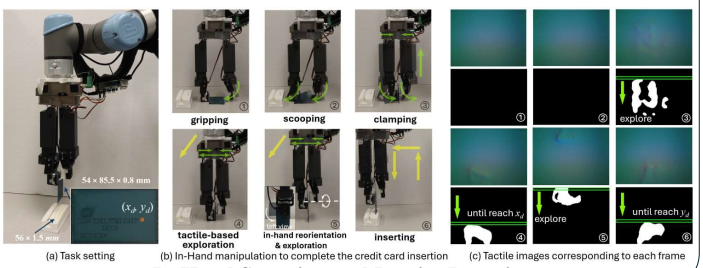
Achieving in-hand scooping manipulation with improved generalization capabilities taking advantage of the linear DOF

4. Experiment



(a) Task setting (b) In-Hand singulation manipulation to remove the rice (c) Tactile images corresponding to each frame

In-Hand Singulation

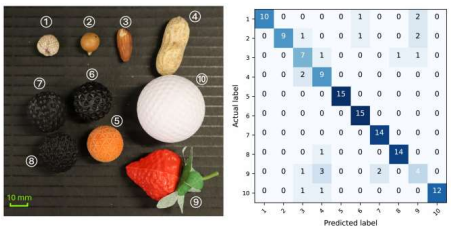


(a) Task setting (b) In-Hand manipulation to complete the credit card insertion (c) Tactile images corresponding to each frame

In-Hand Scooping and Precise Insertion

5. Result

Objects	Small		Nuts		Soft	Rigid			Large	
	Tree Seed 1	Tree Seed 2	Almond	Peanut	Soft Ball	PLA Ball 1	PLA Ball 2	PLA Ball 3	Artificial Strawberry	Golf Ball
success rate	13/15	13/15	10/15	11/15	15/15	15/15	14/15	15/15	9/15	14/15



6. Summary

We present a 5 DOF tactile gripper that:

- shows challenging in-hand manipulation tasks using model-based method, with a low DOF
- demonstrates leveraging the vision-based tactile sensor, our proposed gripper can complete skillful manipulation

References
Xu, Zhengtong, and Yu She. "LeTac-MPC: Learning Model Predictive Control for Tactile-reactive Grasping." IEEE Transactions on Robotics, 2024.