Robust Grasping by Integrating Machine Learning with Physical Models

Zixi Liu[1], Alexandre Bayle[1], Robert D. Howe[1,2], Lucas Janson[1]

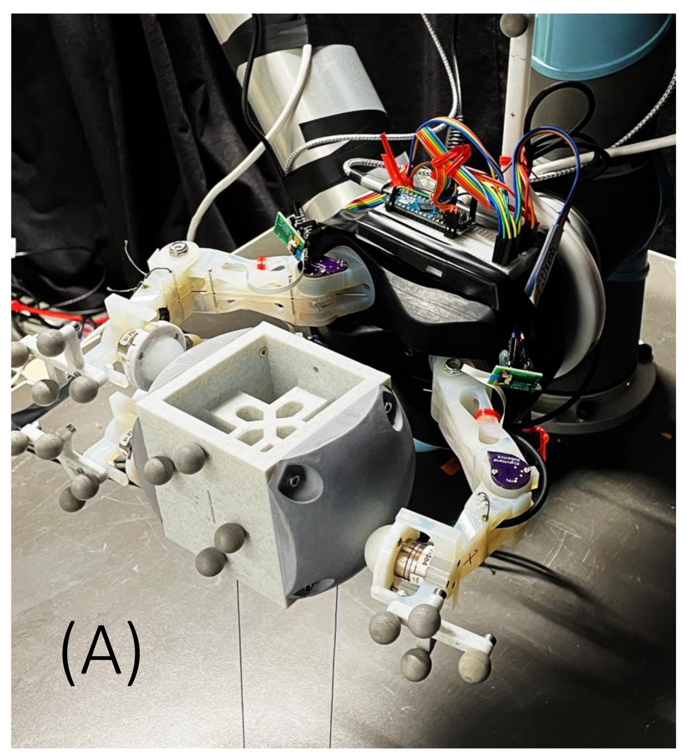
[1] Harvard University [2] RightHand Robotics, Inc.

http://biorobotics.harvard.edu/research.html

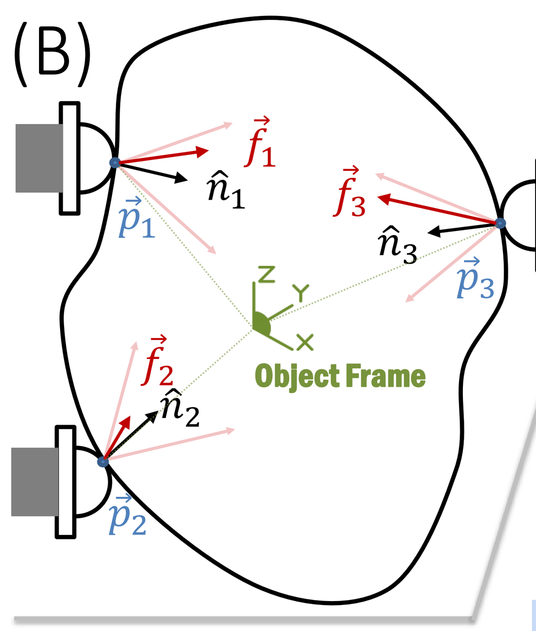
Abstract

Contact sensing is essential for reliable robotic grasping in unstructured environments, but existing methods have not been effective, and requirements for effective sensors are unknown. This project aims to establish the foundation for effective grasp stability prediction and control by developing new ways to integrate machine learning with physical sensor models. **Physical sensor models** will be characterized in grasping experiments and validated against **independent lab gold standard** measurements. Physical models based on mechanical principles (grasp analysis) will be augmented using **parametric and nonparametric machine learning methods**, allowing interpretability and generalizability. Analysis of these models will guide the creation of a new sensor suite that, together with the carefully-crafted models, will form the basis for reliable robotic grasping systems.

Highly Instrumented Robotic Hand



(A) The robot hand holding an object during an experiment.

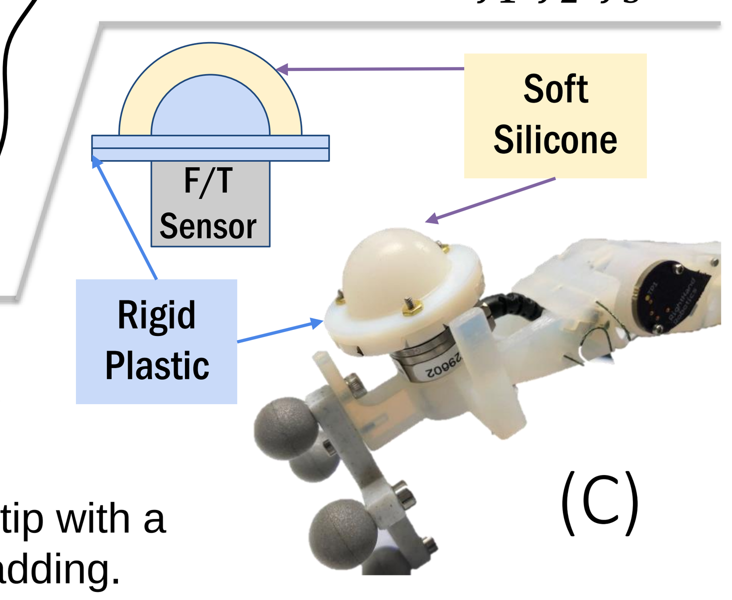


(B) 3 **grasp parameters** that determines grasp stability:

Contact locations: $\vec{p}_1, \vec{p}_2, \vec{p}_3$

Surface normal: $\hat{n}_1, \hat{n}_2, \hat{n}_3$

Contact forces: $\vec{f}_1, \vec{f}_2, \vec{f}_3$

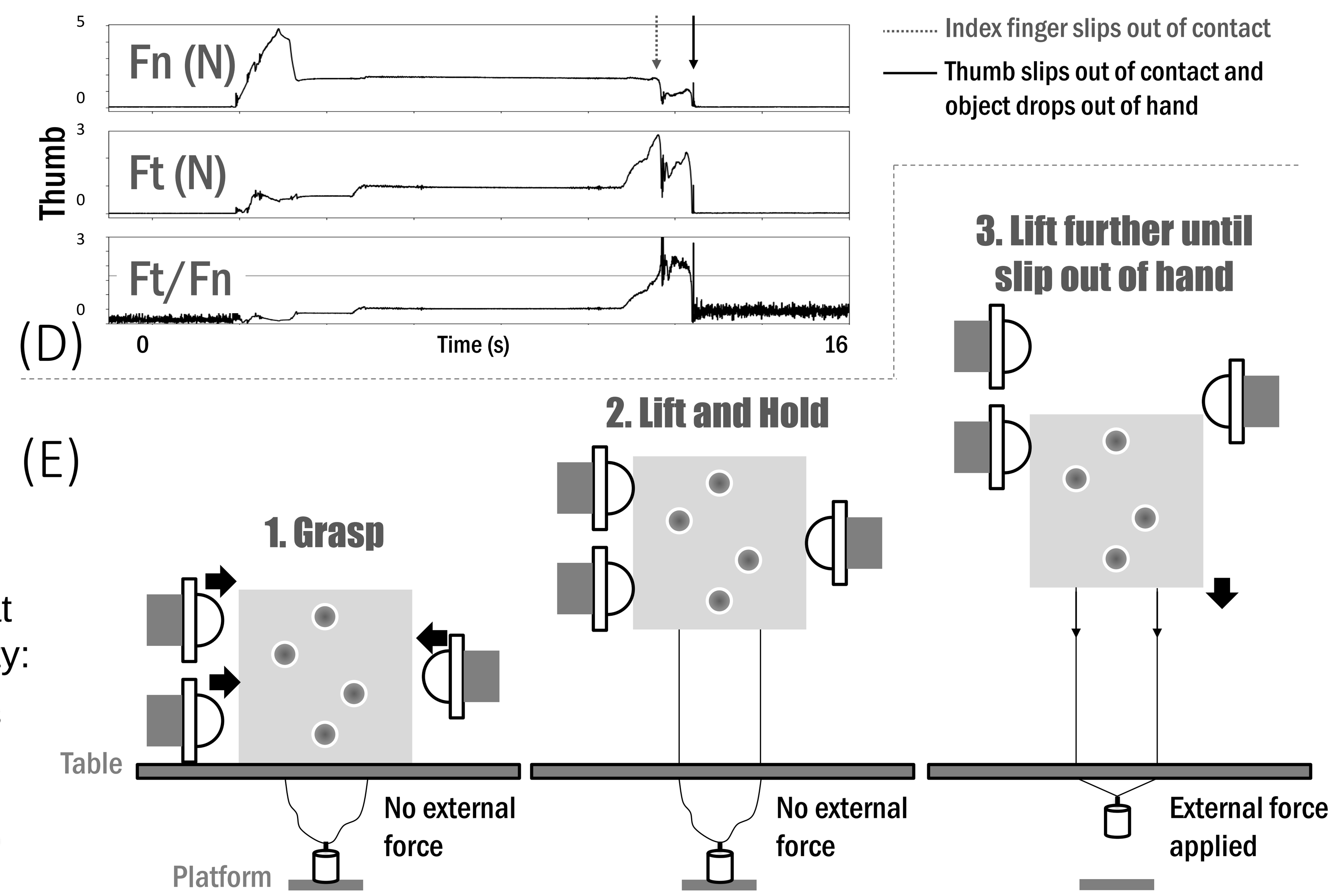


(C) The robot finger:

- high precision force/ torque sensor
- hemispherical fingertip with a 3mm soft silicone padding.

Grasp Parameters	In-Hand	Lab Gold-Standard
Contact Location	Optical tracker (Atracsys Fusion Track 500, resolution: 90 µm RMS) + geometry of fingertip & object	Joint angles (0.0219°/LSB) + kinematic models (±5 mm)
Surface Normal	Optical Tracker + geometry of fingertip & object	Contact location (fingertip frame) + fingertip geometry + kinematics
Contact Force/Torque	Force Torque sensor (ATI Nano17, resolution: 1/160N, 1/32Nmm)	(same as in-hand)

Grasp—Lift and Hold—Slip: Experiment Setup

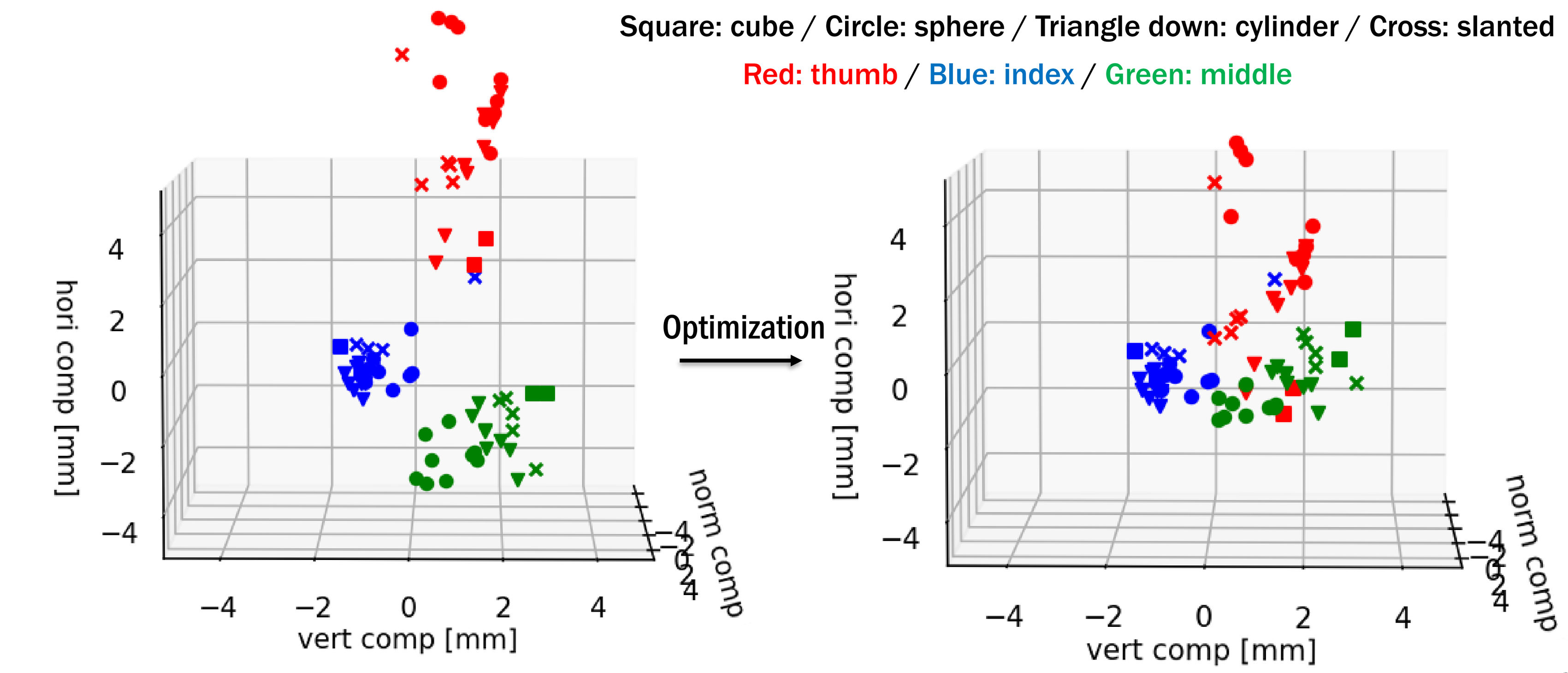


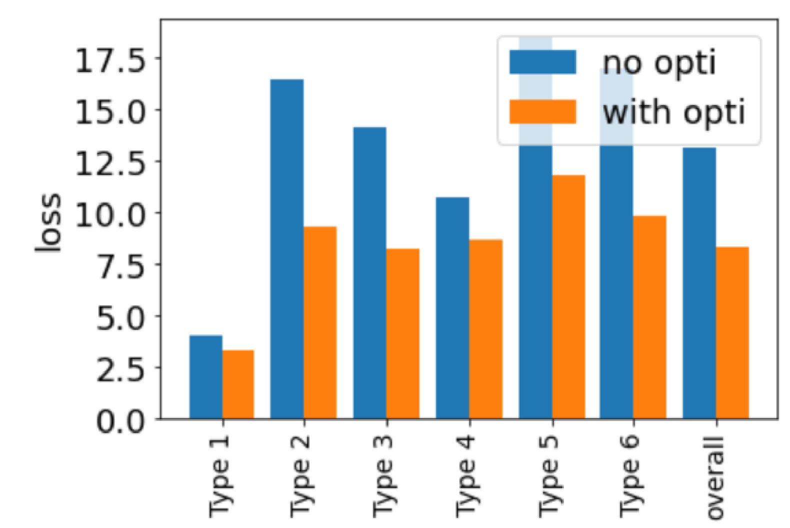
(D) A demonstration of the sensor data: normal, tangential forces and the ratio of the two on the thumb in one experiment.

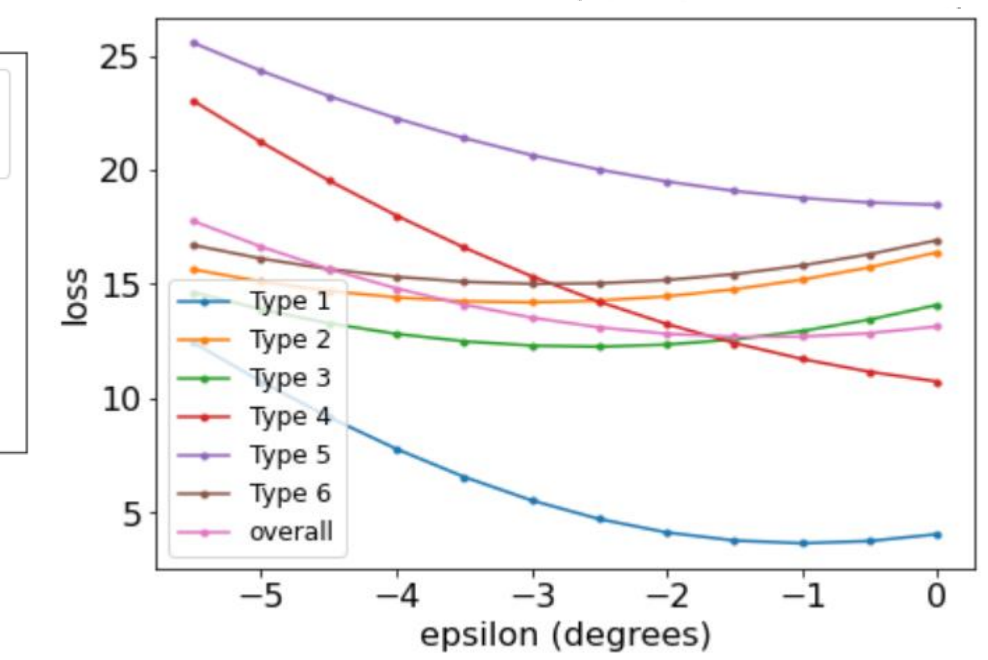
(E) **The experiment process**: 1. Grasping the object, 2. lifts and holds the object in air, 3. continues to lift the object until external force is activated and pulls the object, causing it to slip out of the robot hand.

Improved Hybrid Grasp Parameter Estimation

- Pure end-to-end black-box machine learning and pure physics-based methodologies in the literature have unsatisfactory performance when it comes to high-accuracy grasp stability prediction
- Keeping the same inputs: joint angles and forces/torques ATI measurements
- Relaxing physics-based approach thanks to ML thus improving grasp parameter estimation by allowing noise-induced error terms on the physical measurements
- Gold-standard grasp parameters, necessary for this ML-based improvement, are obtained with the optical tracker. In the next figures, we observe a direct improvement of the grasp parameter estimation across experiments on different object/material combinations. After the optimization process, we see that losses consistently shrink towards 0

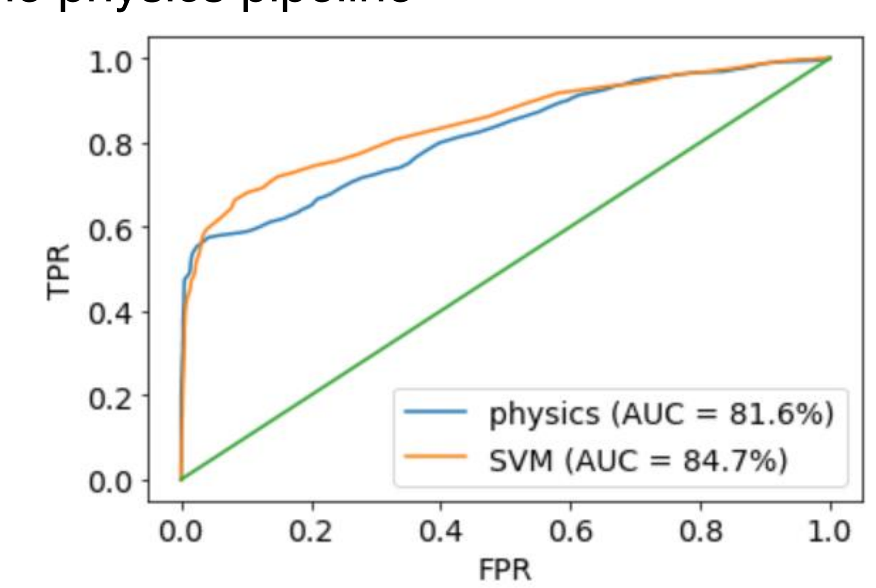






Improving Physics and ML Grasping

- Improving grasp parameter estimation is one step towards the actual goal of grasp stability prediction
- We are developing a hybrid approach that starts from physics, but intelligently relaxes it with ML to make it flexible enough to account for imperfections in the physics while still maintaining the sample complexity/generalizability benefits of low-complexity learning.
- By using gold-standard sensors in the fitting procedure, we can optimally tune the hybrid approach to match the physics as closely as possible at every step in the physics pipeline
- We plot the ROC curves for the physics and ML models
- Hybrid is a work-in-progress with more parameters to add and tune



2022 NRI & FRR Principal Investigators' Meeting
April 19-21, 2022

Award ID#: 1924984