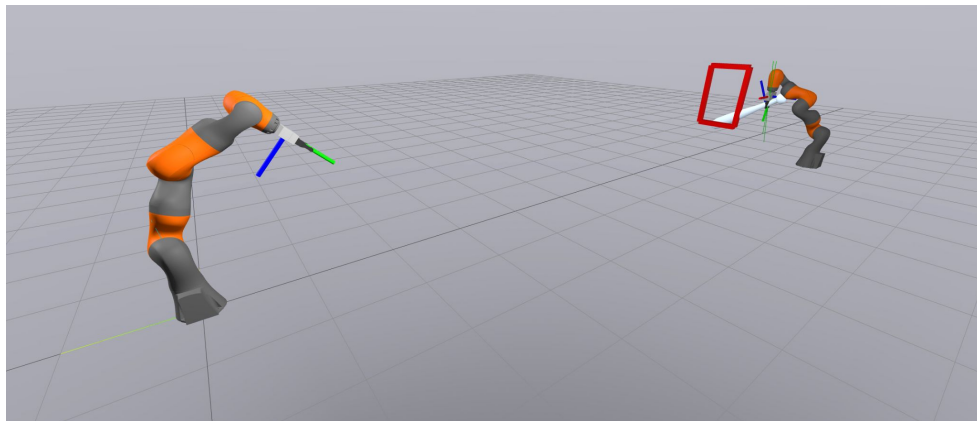


# BatterBot: A Case Study in Trajectory Optimization for Nonprehensile Manipulation

Felix Huang, Stephen Hong, Yajvan Ravan

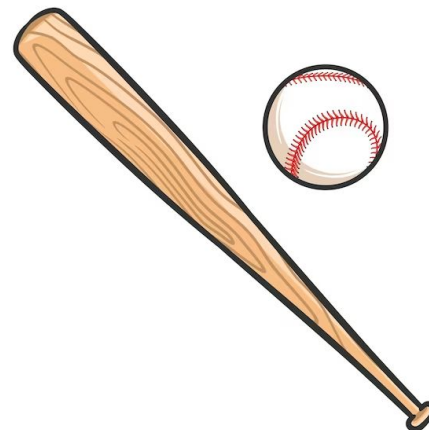
# Why Baseball?

- Classic (& *Favorite*) Sport
- Interesting Manipulation Tasks
  - Pitching
  - Batting
- Limited literature on nonprehensile manipulation for dynamic aerial objects
  - *Nonprehensile* = when an object is not in grasp for entirety of the task



# Simulation Setup

- Models from Drake and TurboSquid

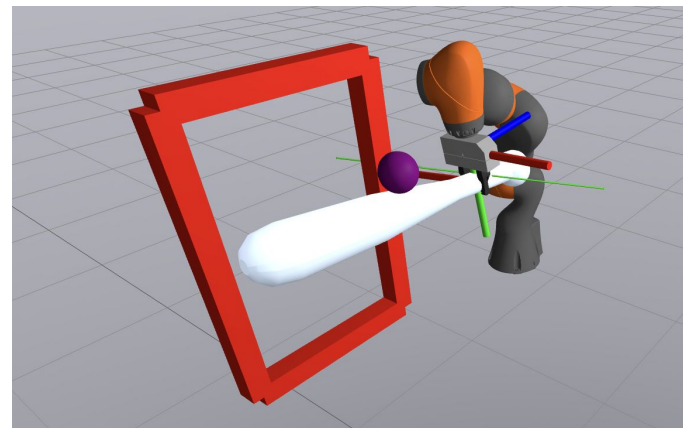
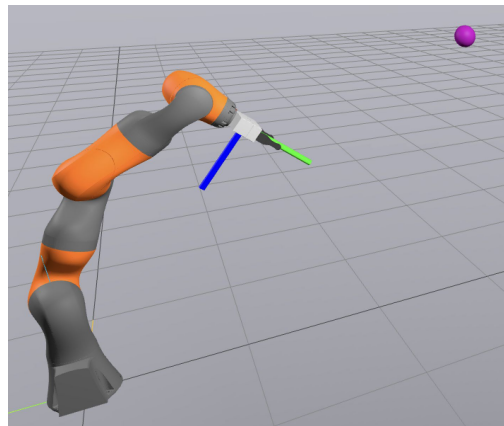
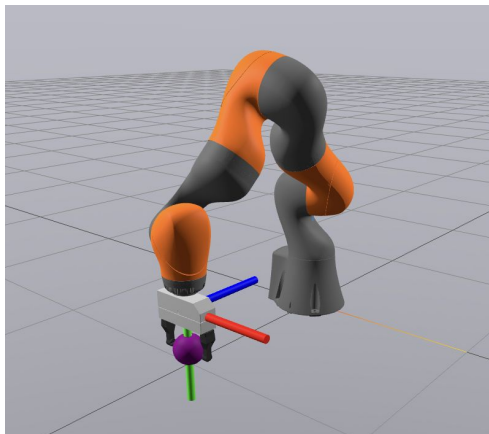


# System Design

Grasp

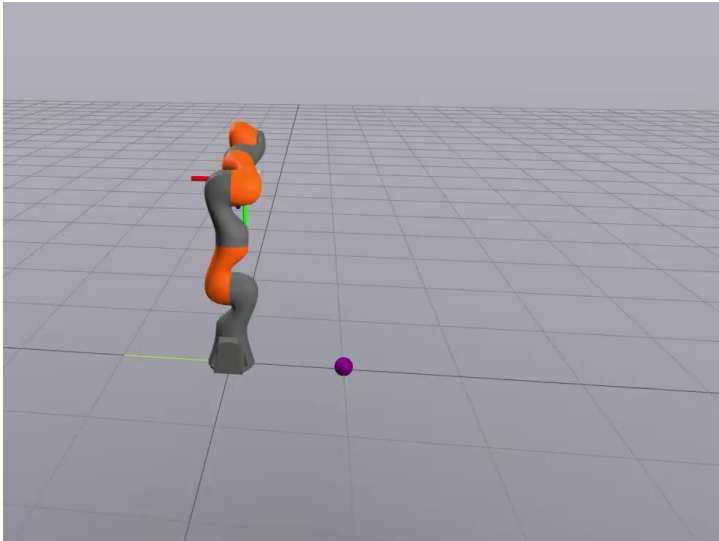
Pitch

HIT!

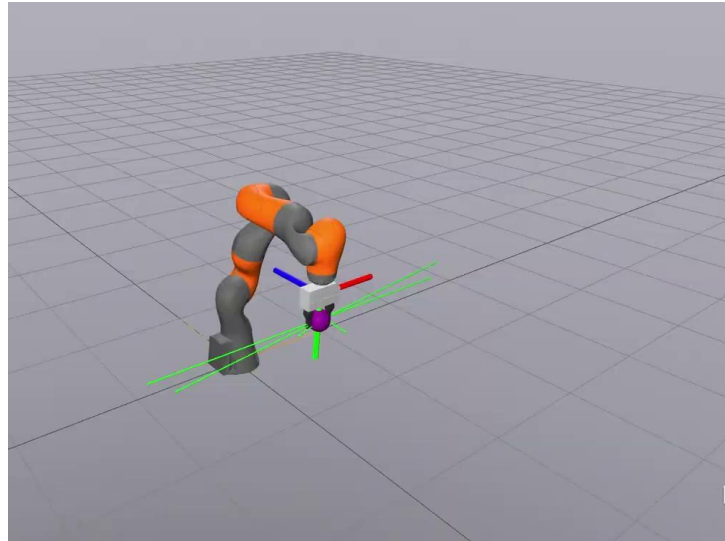


# Pitching

**Picking**

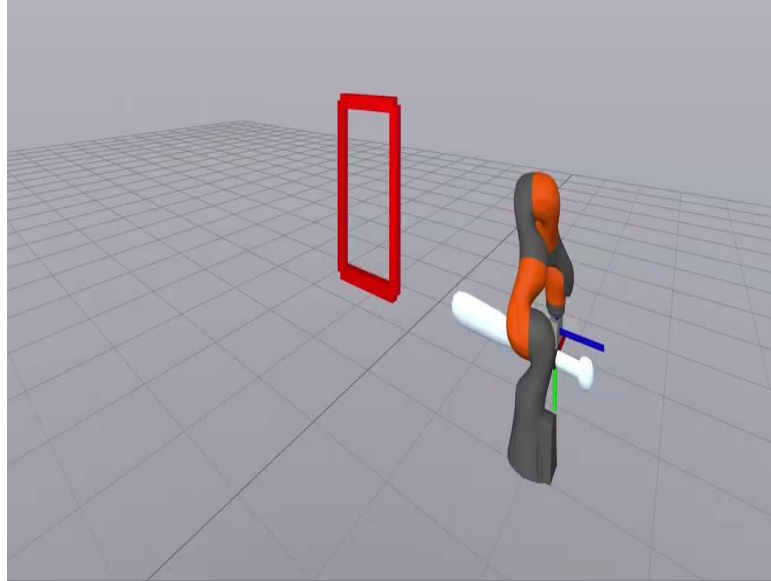


**Throwing**



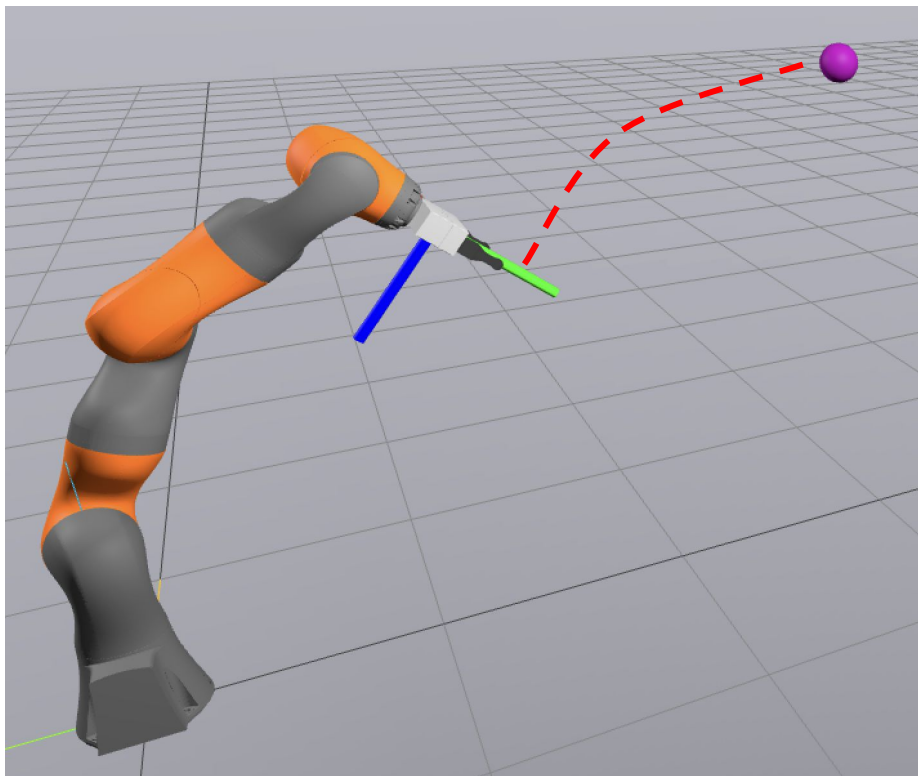
# Batting

## Hitting



**Example of a  
bunt**

# Trajectory Optimization



## Inverse Kinematics:

$$\min_{q_{PrePick}} |q_{PrePick} - q_{Initial}|_2^2$$

subject to  $X_{PrePick} = f_{kin}(q_{PrePick})$

## Kinematic Trajectory Optimization:

$$X_{initial}^{Gripper} = X_{PickDone}^{Gripper}$$

$$p_{Throw}^{Gripper} = p_d$$

$$R_{Throw}^{Gripper}(\theta) = \arccos\left(\frac{-\hat{k} * \vec{V}_d}{|V_d|}\right)$$

$$R_{Throw}^{Gripper}(axis) = \left(\frac{-\hat{k} \times \vec{V}_d}{|V_d|}\right)$$

$$p_{PreThrow}^{Gripper} = p_d - T/100 * V_d$$

$$R_{PreThrow}^{Gripper} = R_{Throw}^{Gripper}$$

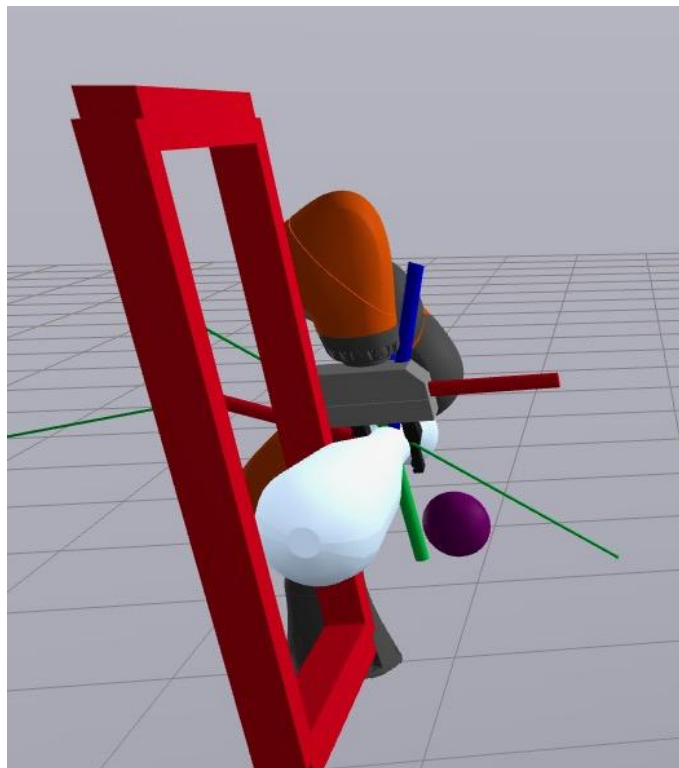
## Position Constraints

## Velocity Constraints

$$v_{Gripper}^W = v_d$$



# Results



Pitch Distance	1 m	2 m	4 m	8 m
Position Constraints Only	0.12m	0.20m	0.33 m	0.76m
Velocity Constraints	0.074m	0.16m	0.25 m	0.57m
% Strikes	100	100	90	60

TABLE I

AVERAGE ERROR FOR 10 TOSSES (5 M/S USING TWO DIFFERENT METHODS OF KINEMATIC TRAJECTORY OPTIMIZATION)

Bat Swing Velocity	0.5 m/s	1 m/s	2 m/s	4 m/s
Position Constraints Only	0.031m	0.077m	0.11 m	0.19m
Velocity Constraints	0.001m	0.0042m	0.013 m	0.022m
% Hits (1 m Pitch)	30	20	40	40

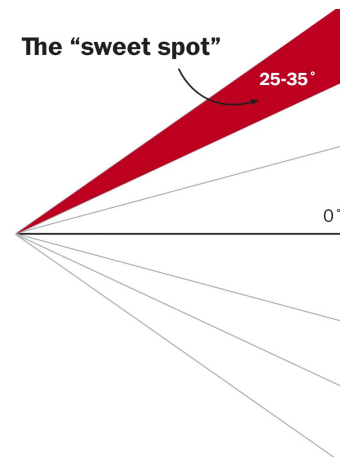
TABLE II

AVERAGE ERROR FOR 10 BAT SWINGS USING TWO DIFFERENT METHODS OF KINEMATIC TRAJECTORY OPTIMIZATION

*\*As of this morning, Hit/Strike rate (up to 4m) is now 100%*

# Limitations

- Use of privileged information
  - Awareness of pitch trajectory
  - Implement perception algorithm
- Physics Modeling



# Future Work

- Visual pose estimation
- Explore dynamics of friction
- Test trajectory optimization framework for other tasks

**Thank You!**