Data-Driven Control of a Soft Bioinspired Grasper

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Introduction

- Soft graspers have inherent advantages in handling fragile and deformable objects e.g. fruits, food, biological tissues
- However, even very deformable items like soft clays may require active force control to minimize deformation

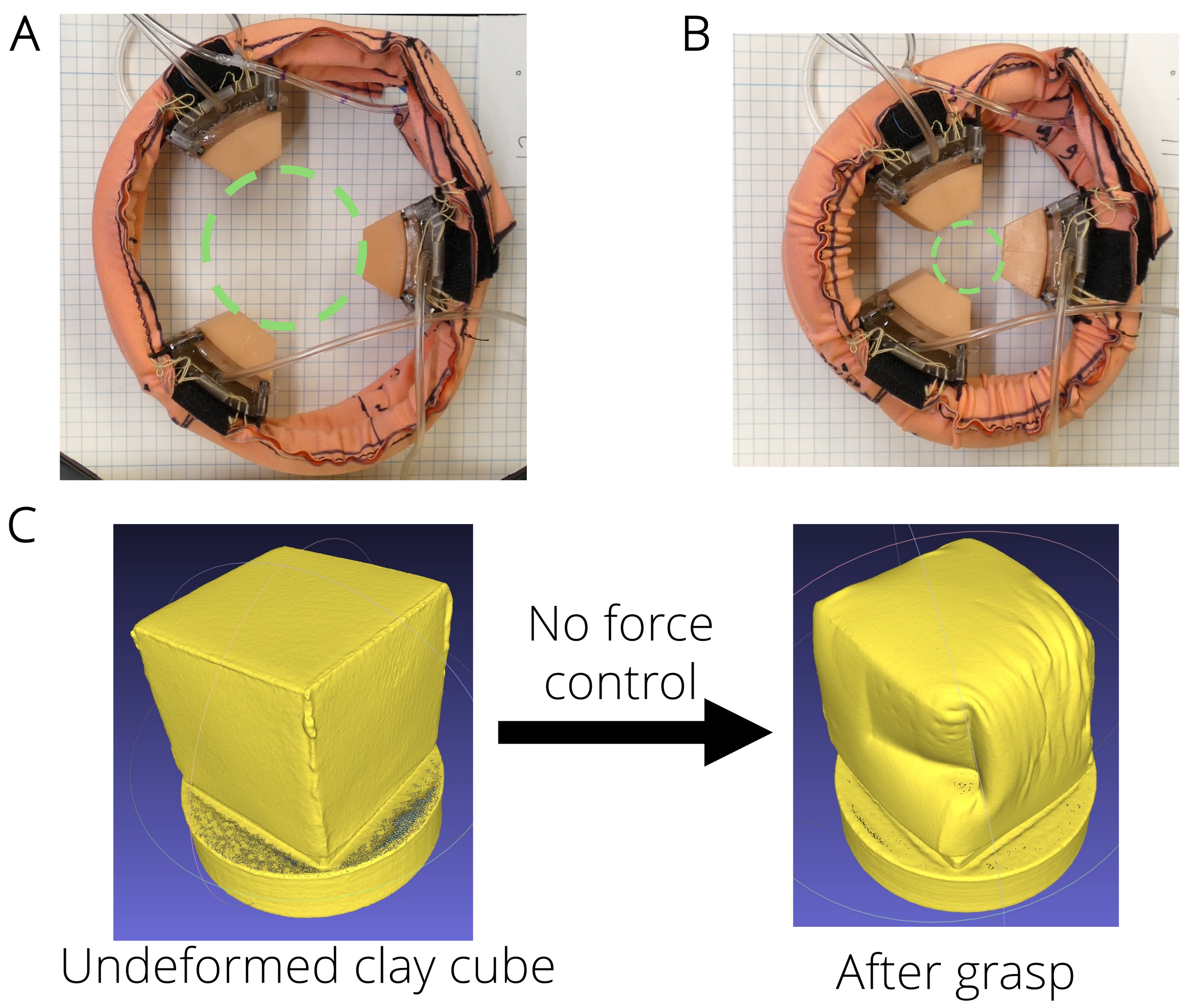

Fig. 1: Bio-inspired soft grasper with contact sensing via pneumatic jaws [1]. The grasper decreases the enclosed area when moving from the rest state (A) to the actuated state (B). Without force control, the grasper can impart significant deformations on very soft plastically deformable objects (C).

Goal: Track arbitrary contact pressure trajectories during grasping of rigid and deformable objects using optimal control techniques

Methods

- Soft graspers exhibit behaviors that are hard to analytically model e.g. non-linear material properties, hysteresis, deformable contact etc.
- We use a data-driven approach to get the dynamics of the grasper so we can apply optimal control techniques.

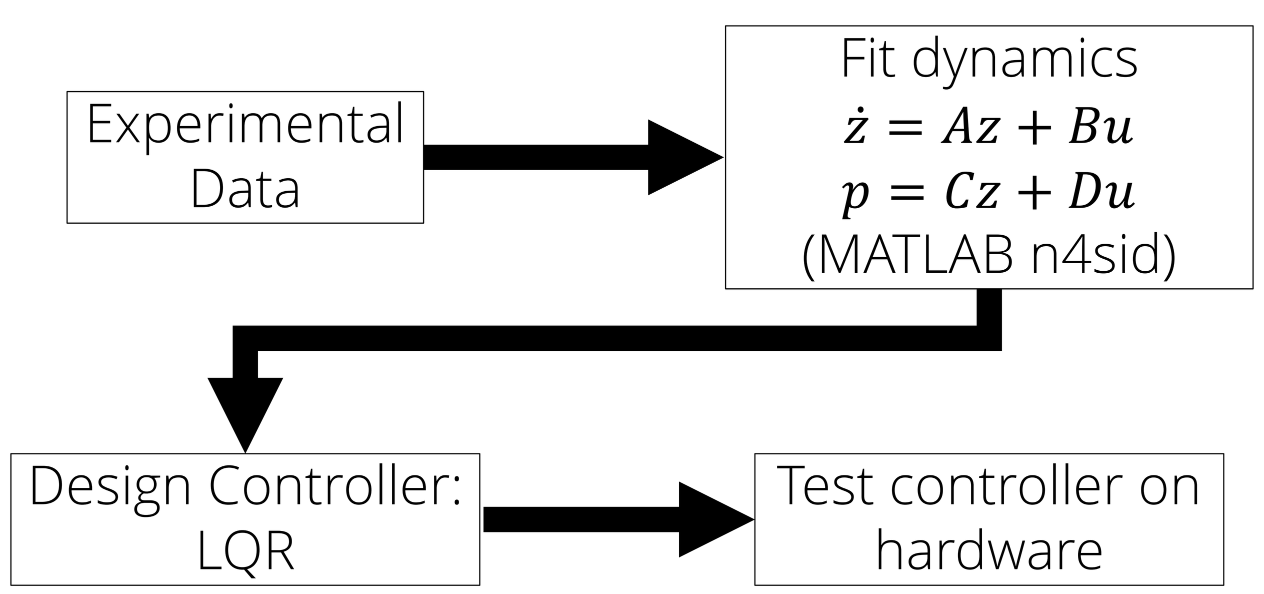

Fig. 2: Flow chart for controller development

Methods

Observables:

$p \in \mathbb{R}^{3\times 1}$

$$p = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \end{bmatrix}$$

Controls:

$u \in \mathbb{R}^{3\times 1}$

$$u = \begin{bmatrix} x \\ y \\ P_c \end{bmatrix}$$

Random step changes in controls

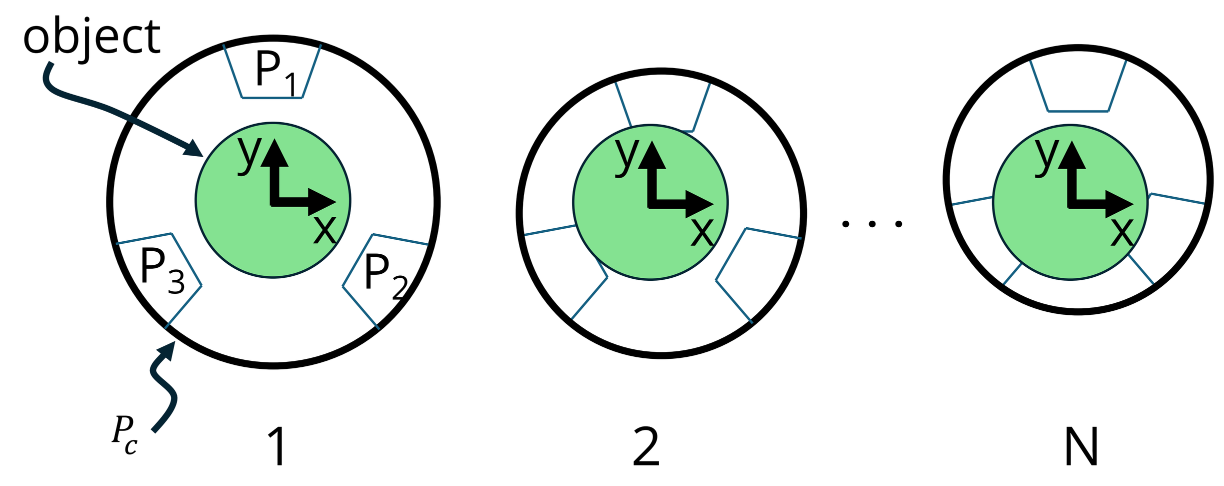

Fig. 3: Experimental setup to gather data for fitting using random step changes in controls on a fixed cylinder (N = 58). Data was gathered at a sampling rate of 16 Hz.

Results

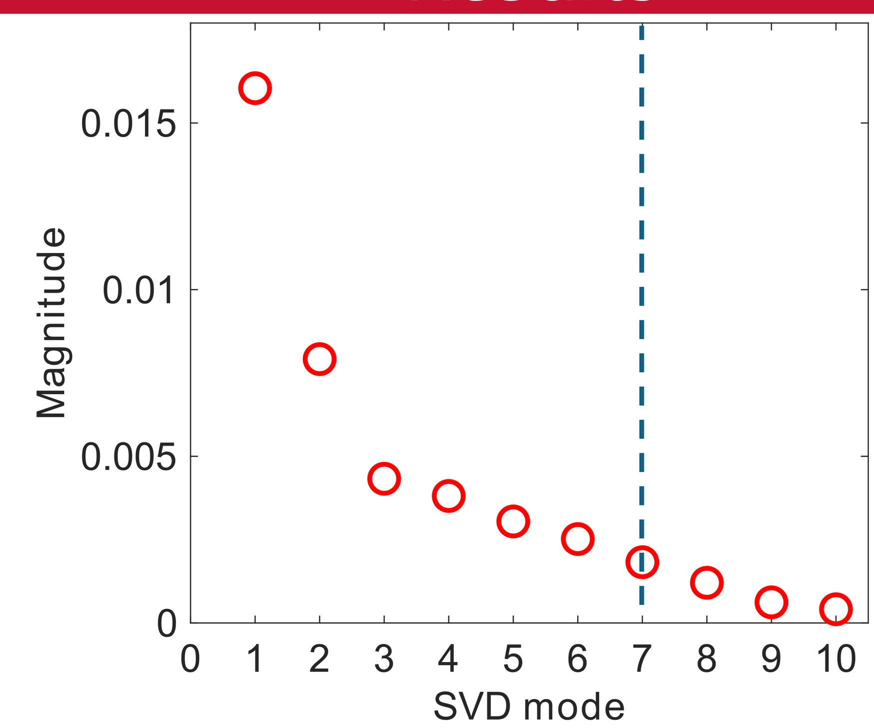

Fig. 4: Magnitude of the SVD modes of the Hankel matrix. 7 modes were chosen to represent the lifted state, z.

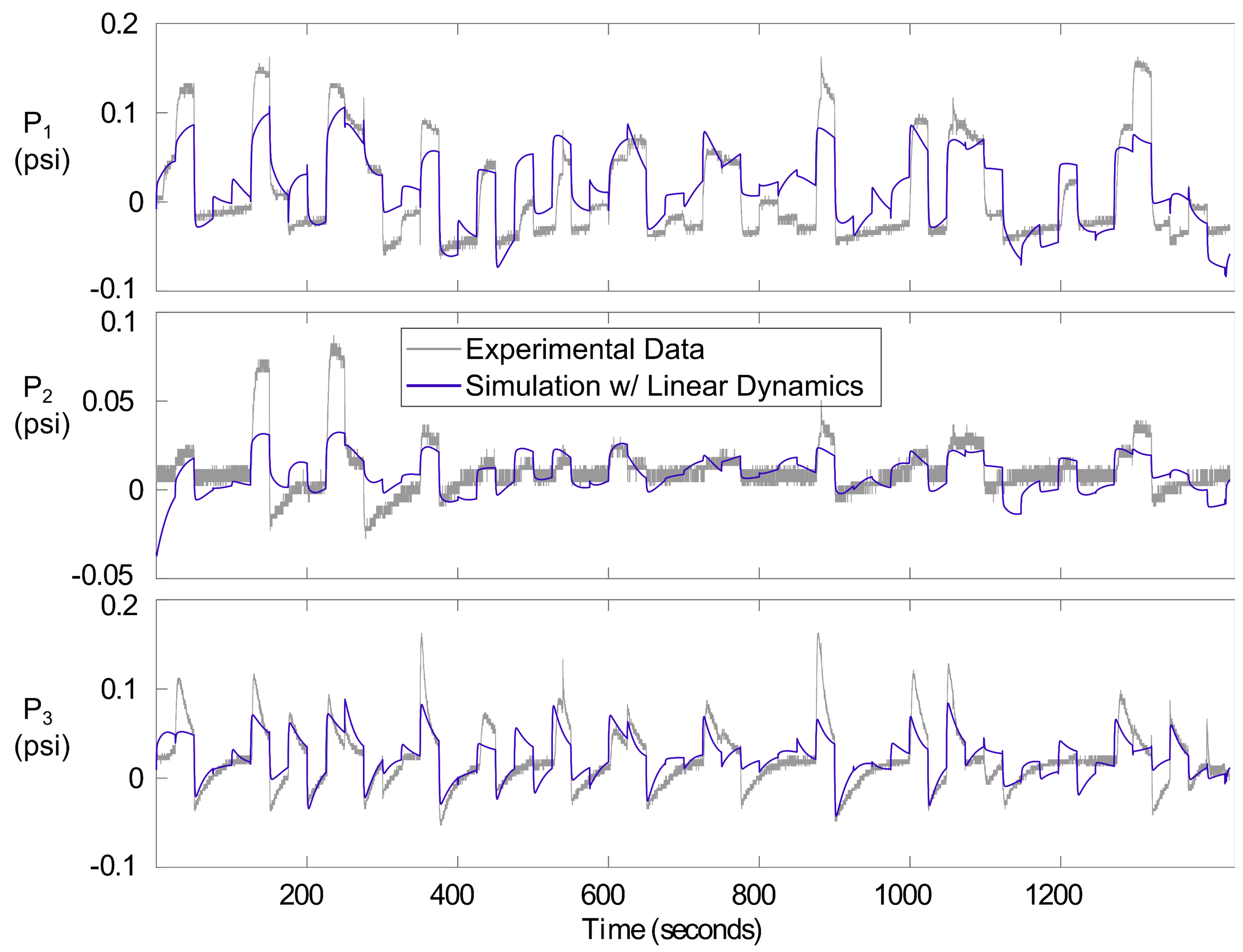

Fig. 5: Contact jaw pressures from random perturbations of the grasper position (x, y) and control pressure (P_c). The simulated response from the linear dynamics is shown in blue.

Results

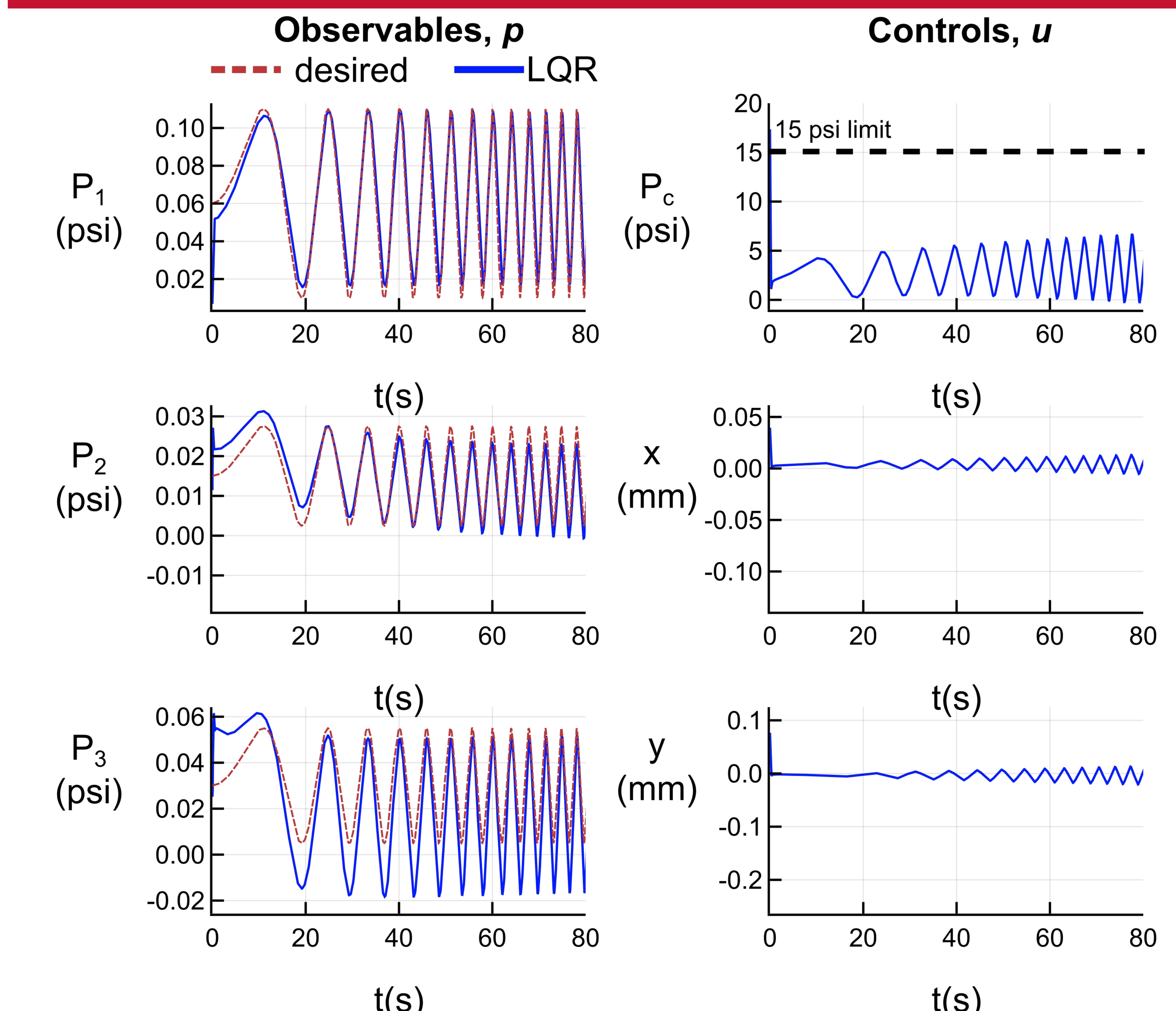

Fig. 6: Comparison of desired contact pressures and the simulated response with LQR. The stage cost corresponding to jaw 1's pressure was given more weight to facilitate closer tracking of that trajectory.

Discussion

- The linear dynamics does not fully capture the experimental data
- From the LQR simulation, P_c has a larger influence on the contact pressure compared to the x and y controls
  - It may not be possible to individually track contact pressures on all three jaws

Future Work

- Further refine the dynamics regression model:
  i. Parse the data and regression such that the dynamics model is fit solely to when the grasper experiences contact
  ii. Perform cross validation on tracking error vs quantity of time delays embedded
  iii. Cylinders of different sizes
  iv. Materials of different rigidity (PLA and soft clay)
- Try the LQR controller on hardware and compare the result to the simulation
- Quantify deformation induced on deformable material with LQR controller and compare to existing neural-network open-loop controller [1]

References

[1] R. Sukhnandan et al., LNCS, 2023