MARYLAND ROBOTICS CENTER
THE INSTITUTE FOR SYSTEMS RESEARCH

Collective Dynamics and Control Laboratory
UNIVERSITY OF MARYLAND

GRIPPING USING SOFT ACTUATORS WITH FEEDBACK CONTROL

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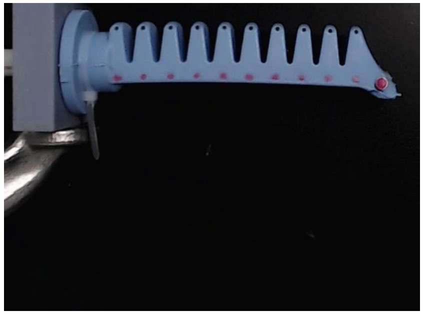
FEARLESS IDEAS

OVERVIEW OF SOFT ROBOTICS

- **Robotics made of elastic material**
  - Advantages: flexibility, compliance, safety
  - Disadvantages: rigid-body kinematics doesn't apply
- **Applications**
  - Artificial muscles, medical devices, wearable robotics
- **Bio-inspiration!**
  - Deformable organic material with sensory feedback to control actuation is readily found in nature
  - Example:



PROJECT MOTIVATION

- **Can soft actuators be used to grasp objects more effectively than traditional robotic grippers?**
- **Can sensors be attached to the soft actuators**
  - What modes of sensing are most important
  - What modes of sensing are most practical
- **Can those sensors be used for feedback control**

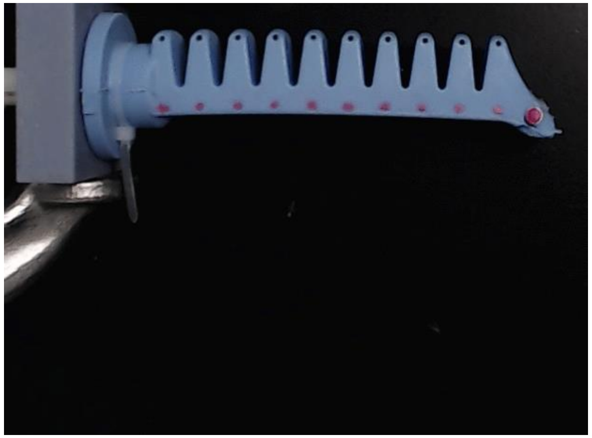
PROJECT OBJECTIVES

1. Design a gripper from soft actuators with on-board sensors
2. Implement feedback control using the sensors
3. Document advantages of traditional robotic grippers

SELECTED SOFT ACTUATOR

- **Soft Actuator: PneuNet (pneumatic network)**
  - Designed by Dr. Robert Wood's lab at Harvard
  - Made from casting silicone rubber in a 3D-printed mold
  - Pneumatically actuated: inflation of hollow channels creates motion

PneuNets wall thickness (softroboticstoolkit.com)



SELECTED SENSORS

- **Flex Senor: measures average curvature**
  - Curvature : $k = r^{-1}$

Spectra Signal Flex Sensor 2.2 in. (sparkfun.com)

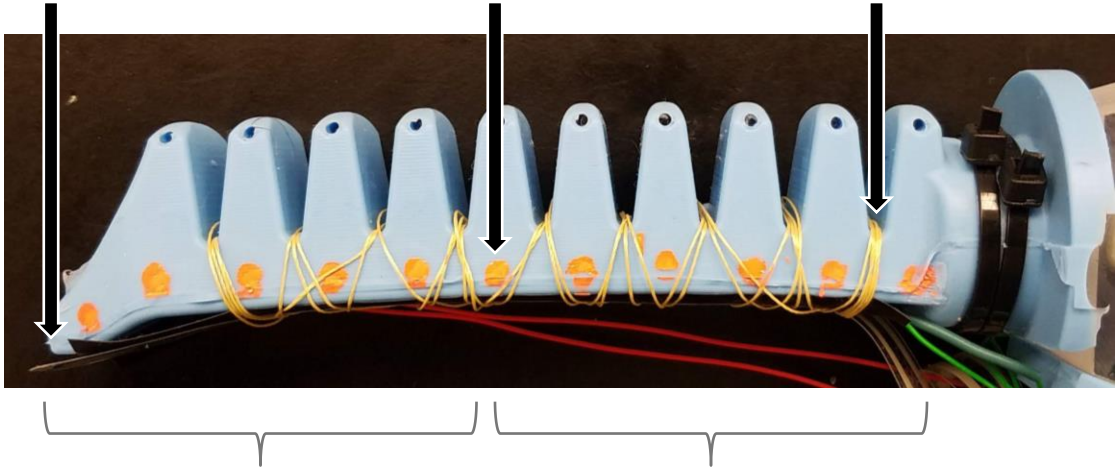
- **Force Sensor: measures normal force**
  - Normal force: force perpendicular to surface

FlexiForce Pressure Sensor (sparkfun.com)

- **Vendor: SparkFun Electronics**

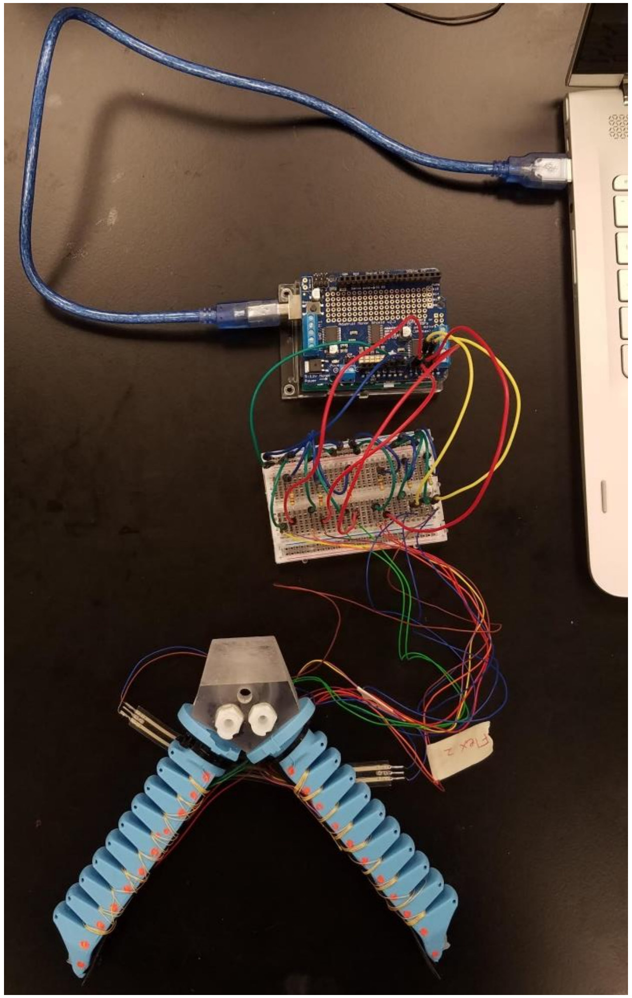
ATTACHING THE SENSORS

- **Sensor placement on each actuator**
  - Two flex sensors for more localized curvature readings
  - One force sensor at tip



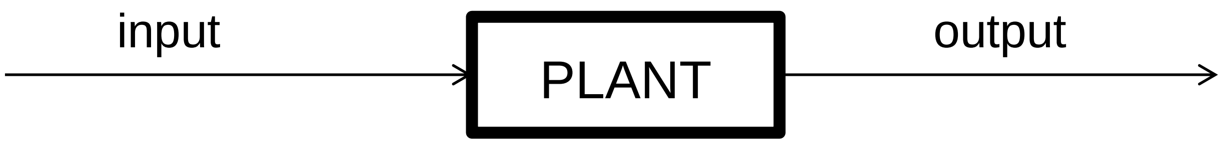
INTEGRATING THE SYSTEM

- **Arduino Uno**
  - Voltage divider circuit to Arduino for each sensor
  - Use analog pins on Arduino
- **Base Hub**
  - Fixes both arms at a 70 degree angle between each other
  - Actuates both arms from a single pressure input

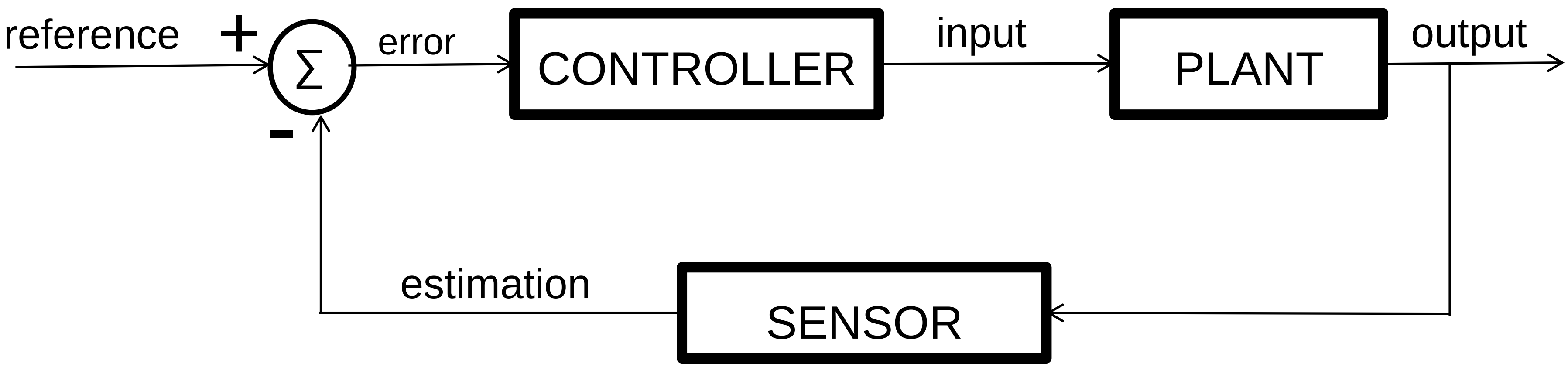


OPEN-LOOP VS. CLOSED-LOOP

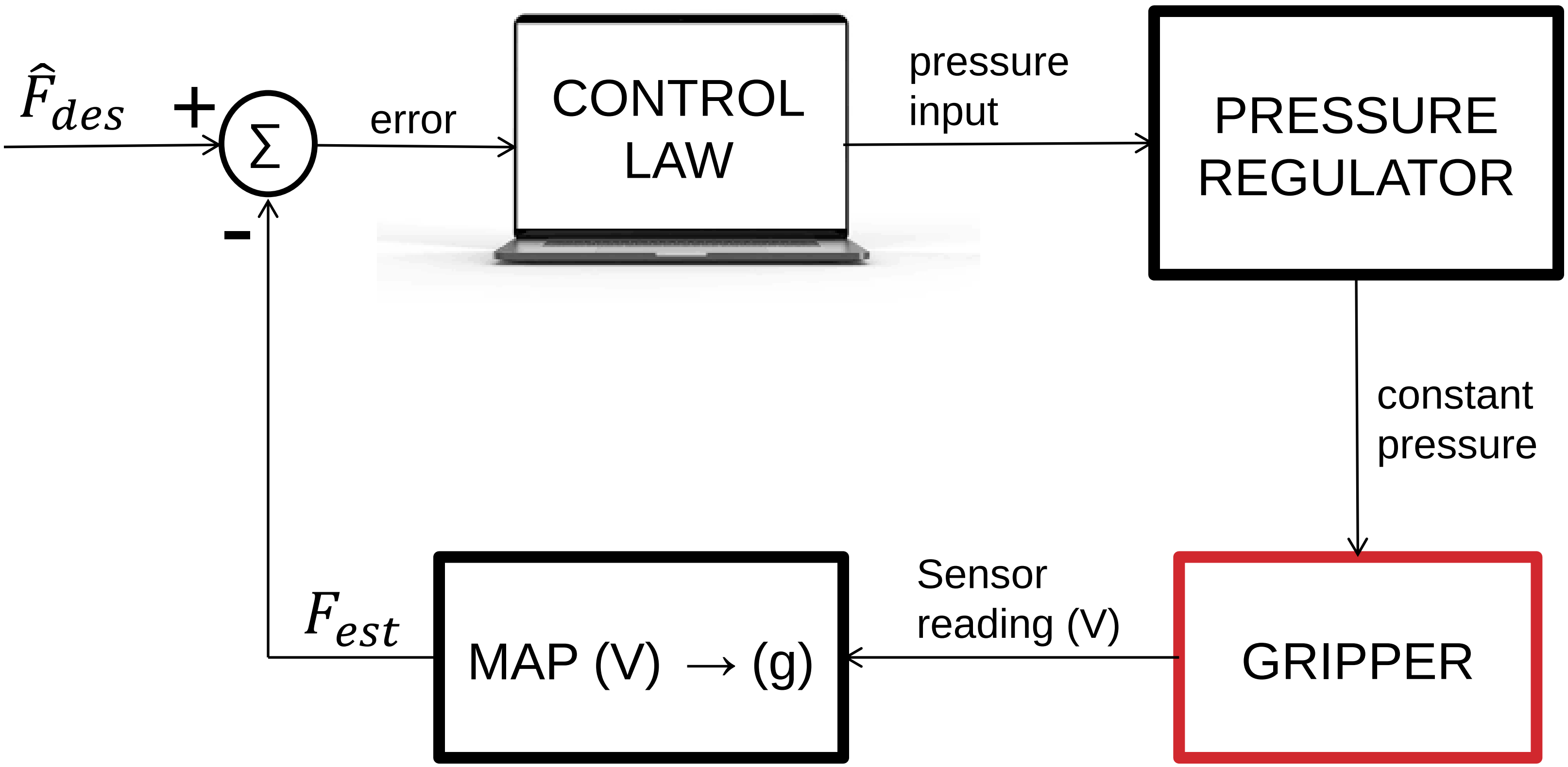
- **Open-loop diagram**



- **Closed-loop diagram**



MY SYSTEM DIAGRAM

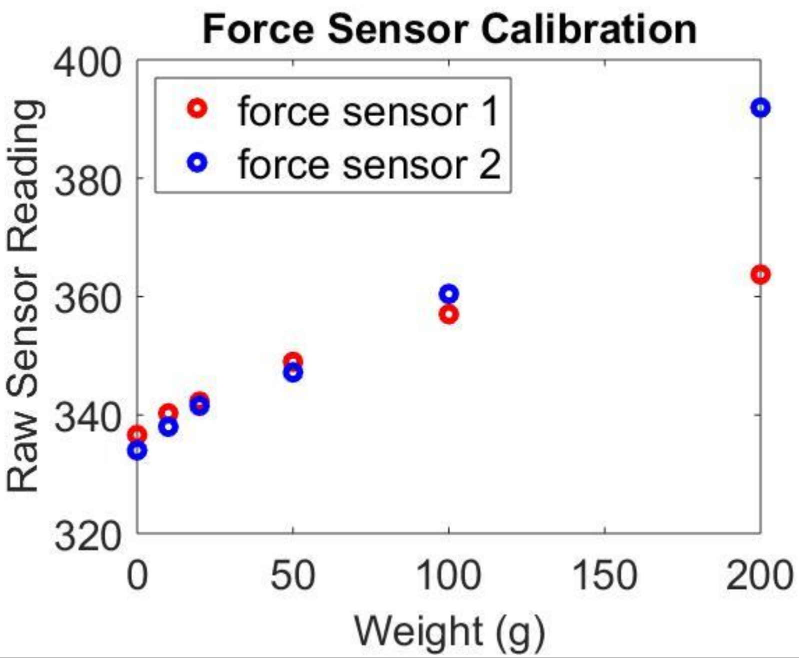


CONTROL SCHEME

- **Idea**
  - Input pressure is updated from the error of $\hat{F}_{des} - F_{est}$
  - Accomplished by a discrete time Proportional Derivative (PD) control law
- **PD control law**
  - $p_{k+1} = p_k + \Delta t(K_p e_k + K_d e'_k)$, where
    - $e_k = \hat{F}_{des} - F_{est,k}$
    - $e'_k = \dfrac{e_k - e_{k-1}}{\Delta t}$
    - $F_{est,k} = \dfrac{F_{1,k} + F_{2,k}}{2}$

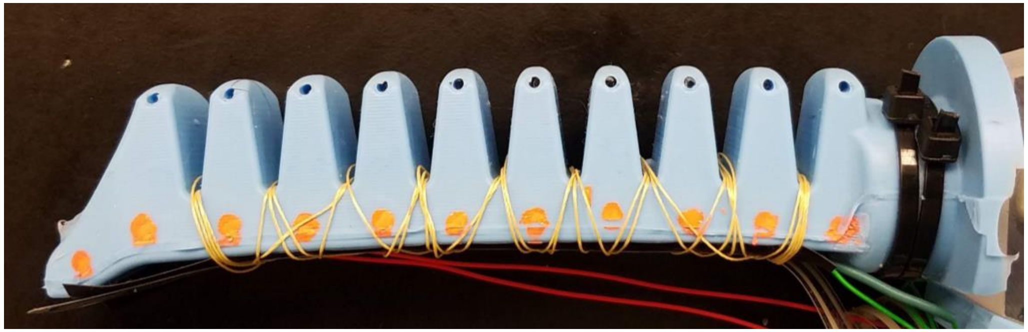
CALIBRATING FORCE SENSOR

- **Want to map raw force sensor readings to weight (g)**
- **Method**
  - put weights directly on sensor and record force sensor reading
- **Implementation**
  - Map using interpolation



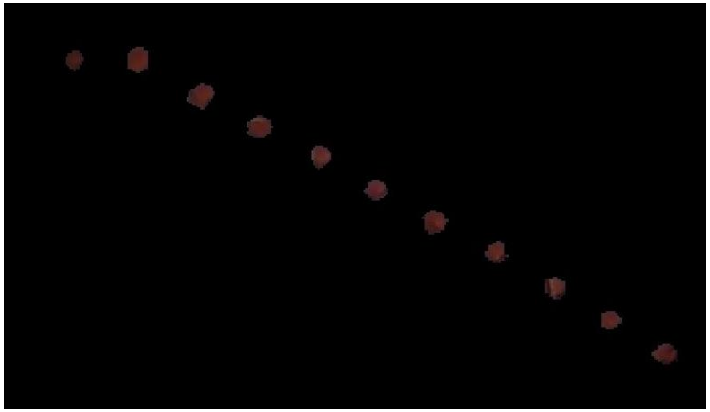
CALIBRATING FLEX SENSOR

- **Want to map raw flex sensor readings to curvature**
- **Method**
  - Use computer vision to track the position of each node (fluorescent dot)
  - Use a discrete elastic rod model to calculate the curvature at each node
  - Map each flex sensor to curvature of appropriate nodes

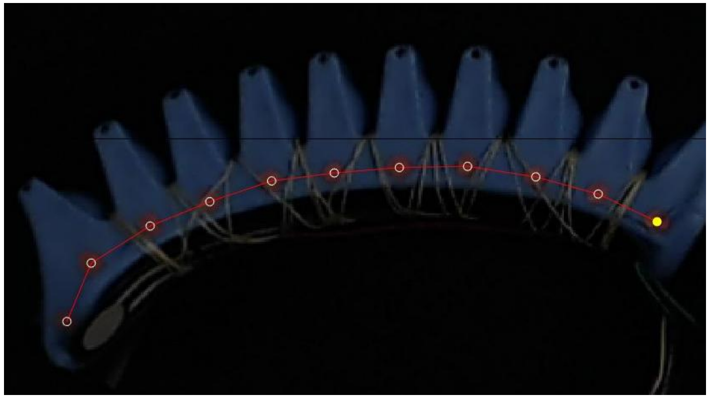


COMPUTER VISION TRACKING

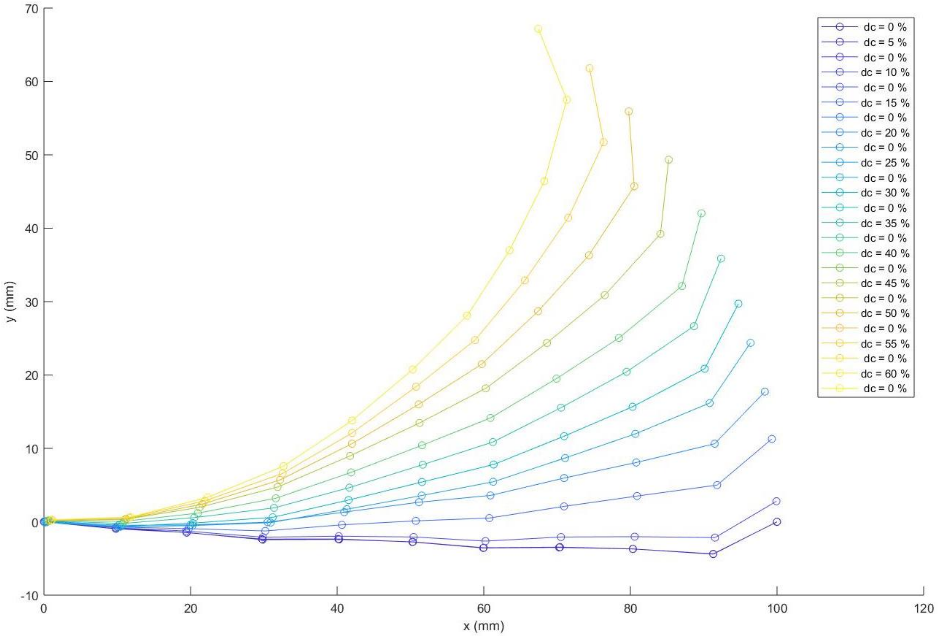
Step 1: Identification



Step 2: Tracking

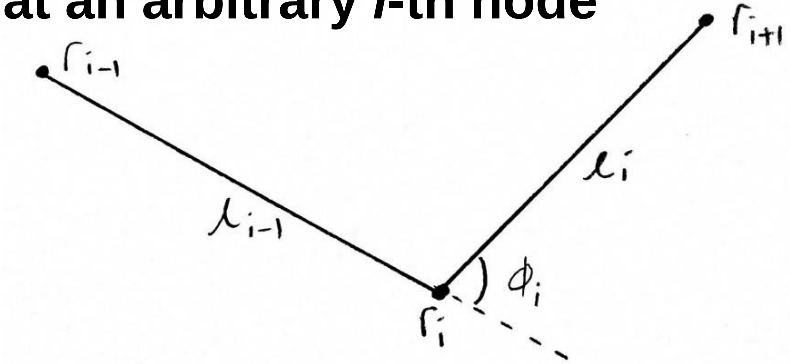


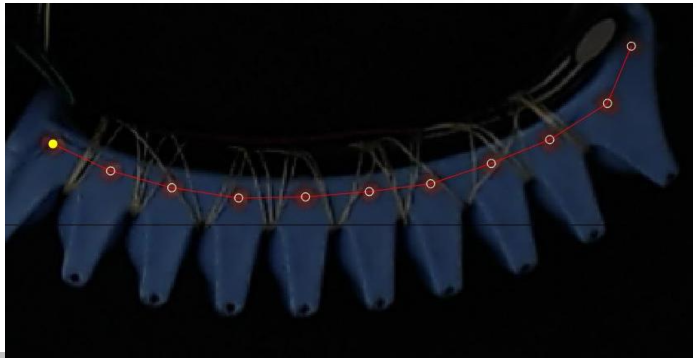
Step 3: Plot



CALCULATING CURVATURE

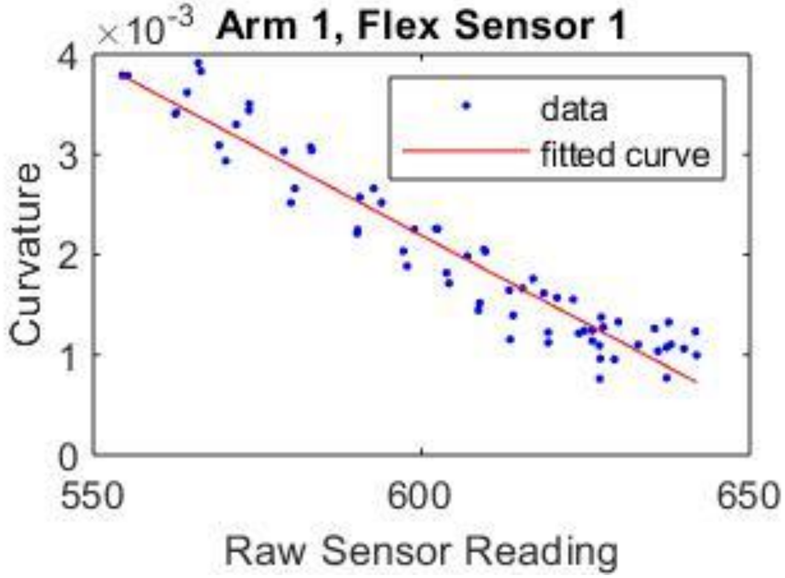
- **Consider a discrete elastic rod model of the actuator**
  - Nodes connected by edges
- **Equations for deriving curvature at an arbitrary *i*-th node**
  - Node Position: $r_i = \begin{pmatrix} x_i \\ y_i \end{pmatrix}$
  - Unit Tangent: $t_i = \frac{r_i - r_{i-1}}{l_i}$
  - Turning Angle: $\cos\phi = \langle t_{i-1}, t_i \rangle$
  - Curvature: $\mathrm{k_i} = \frac{4\tan\frac{\phi}{2}}{l_{i-1} + l_i}$

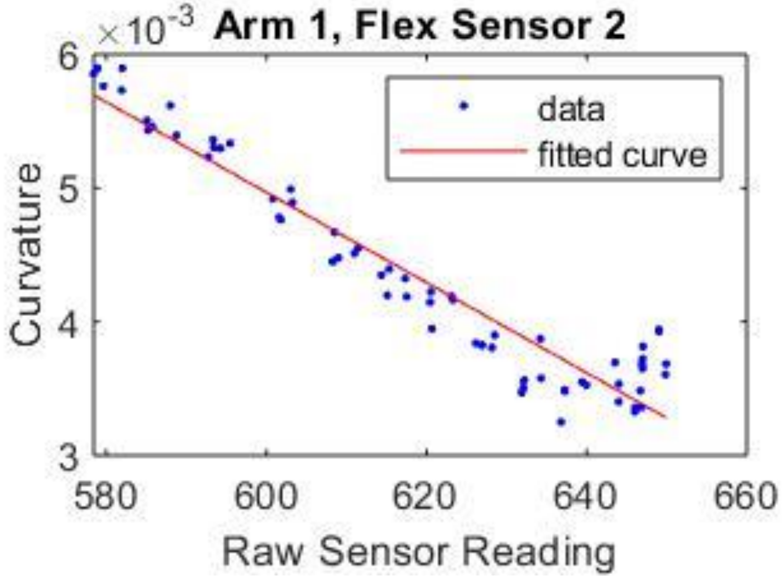




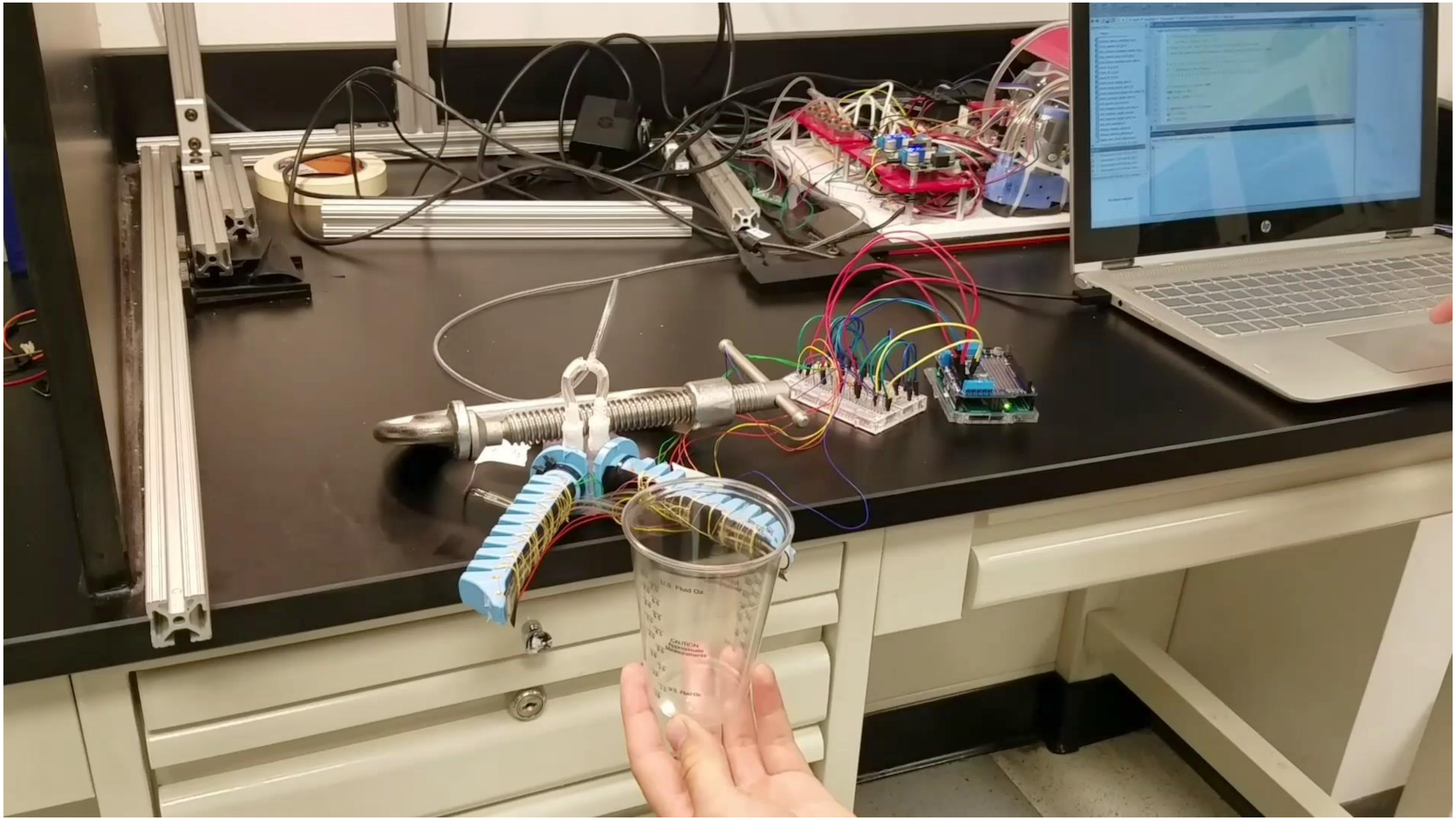
CALIBRATION IMPLEMENTATION

- Map first flex sensor to the average curvature of first 5 nodes
- Map second flex sensor to the average curvature of last 5 nodes
- After multiple trials, use linear regression to compute mapping



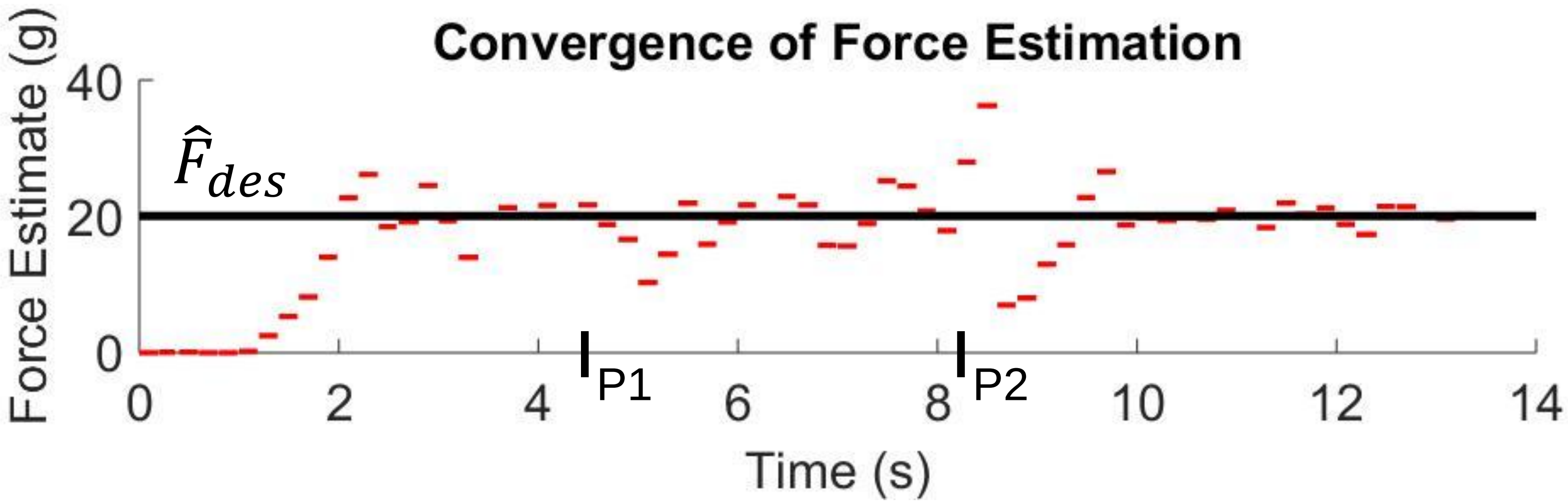


FINAL PRODUCT!



CLOSED-LOOP ADAPTABILITY

- 1st perturbation: moving cup up (P1)
- 2nd perturbation: moving cup back down (P2)



NEARLY FINISHED RESEARCH

- **Using flex sensor data to estimate the position of each node**
- **Idea:**
  - Map flex sensor readings to curvature at corresponding nodes
  - Use equations from the discrete elastic rod model to determine the turning angle at each node
  - Use turning angle and edge length to determine the position of the next node
- **Application:**
  - Distance between the last two node positions is an estimate of the width of the object being grasped

CURRENT TECHNICAL CHALLENGES

- **There is a force reading from only one location**
  - Gripping would be much more effective if there were multiple points of contact
- **With current sensors, there is no way of sensing the weight of an object**
  - Sensing the weight of the object is key to creating a more autonomous gripper
- **Smooth force sensor means there is less friction for gripping**

FUTURE RESEARCH

- **Have more force sensors along the actuator to allow for more points of contact**
- **Increase autonomy by sensing weight**
  - Shear force sensor?
  - Joint at base that detects a moment?
- **Investigate integrating the flex sensors in different ways**

ACKNOWLEDGEMENTS

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  - Dr. Paley
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