ME23N - Soft Robotics for Humanity
Stanford University
Mechanical Engineering
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Lab 3: Pneumatic Artificial Muscles

(adapted from UC Santa Barbara course ME 125EH with the help of Prof. Elliot Hawkes)

I. Overview

In this lab we will investigate pneumatic artificial muscles, a class of actuator that uses air pressure to imitate the function of biological muscles. We will construct one type of pneumatic artificial muscle called a series pneumatic artificial muscle (sPAM for short) and then use the actuator to control a continuum robot arm.

Biologic muscle acts by contracting to produce force and movement. If the muscle is attached around a joint, this can cause the joint to rotate. Muscles also often work in pairs since each muscle can only cause force in the contraction direction. These pairs are called *antagonistic*, since they are arranged to “fight” each other. Pneumatic artificial muscles share these properties, acting in antagonistic contracting pairs or groups.

Continuum robots are a type of robot that have a flexible “backbone”. Continuum robots move by bending this backbone. Unlike traditional robot arms, which are very precise and repeatable but not robust to unknown environments, soft continuum robots are light and easily deformable, making them safe and adaptable.

II. Materials and Equipment

- Thin Plastic Tubing (1.5” and 2” wide when flat)
- Air Tube (¼”)
- Squeeze Valves
- Push-to-Connect Connectors and Adaptors
- Double-Sided Tape
- Zip Ties

- Scissors
- Heat sealer
- Ruler

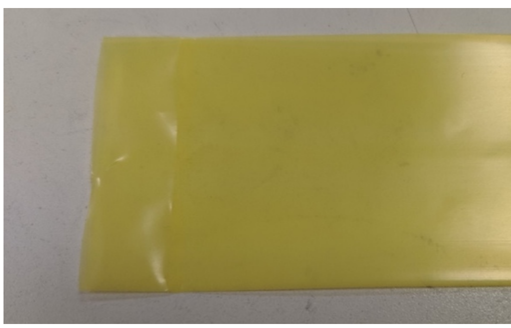
Thin Plastic Tube

Air Tube

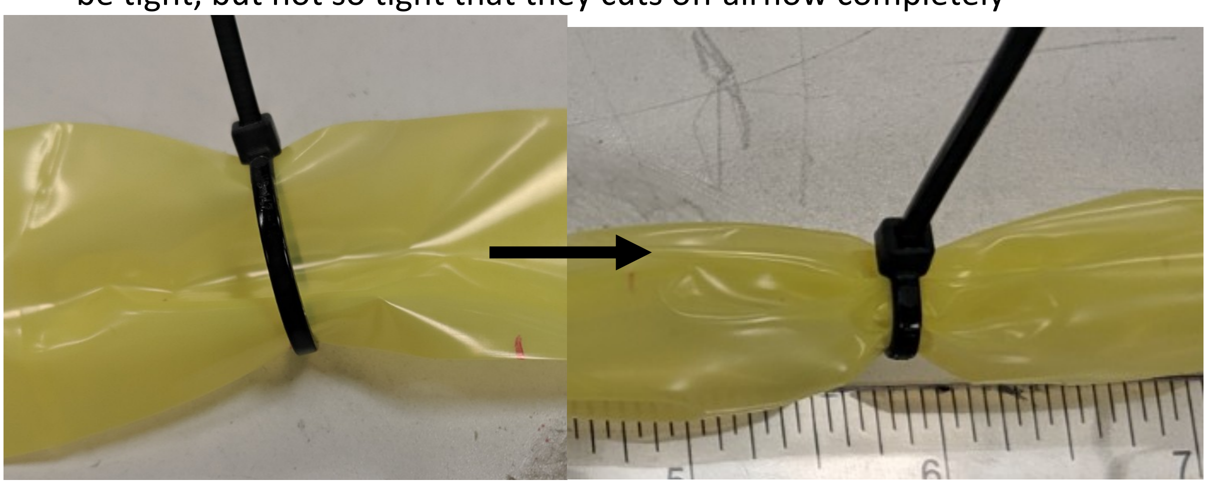
III. Steps

Part 1: Designing and Testing a Pneumatic Artificial Muscle

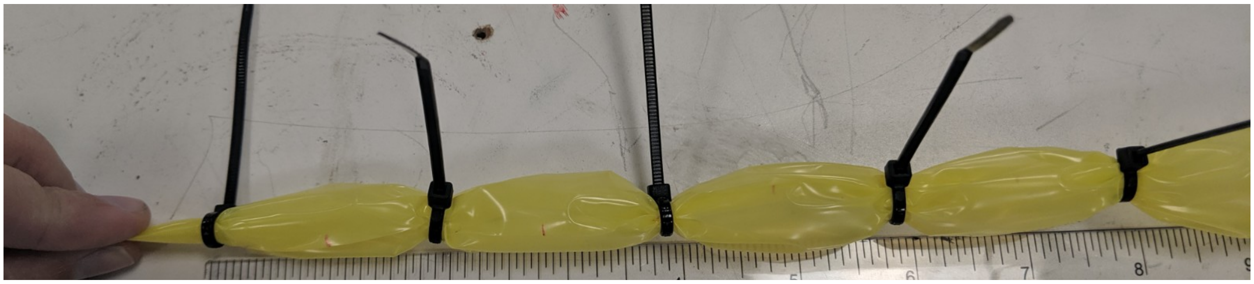
1. We will start by testing the pneumatic muscle (sPAM) by itself. Cut a 1 foot length of the 1.5” thin plastic tubing. Heat seal one end of the tubing. It should hold air (no leaks along the seal) when you inflate it.



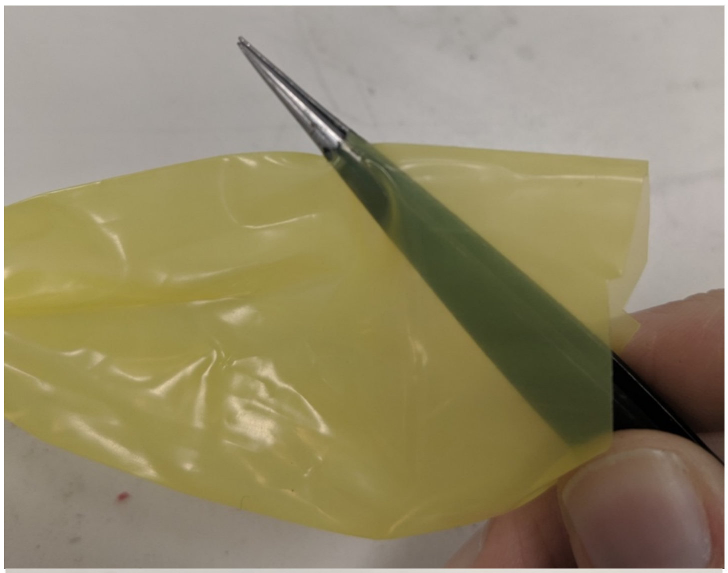
2. Attach zip ties around the tubing to create pinch points. The zip ties should be tight, but not so tight that they cuts off airflow completely



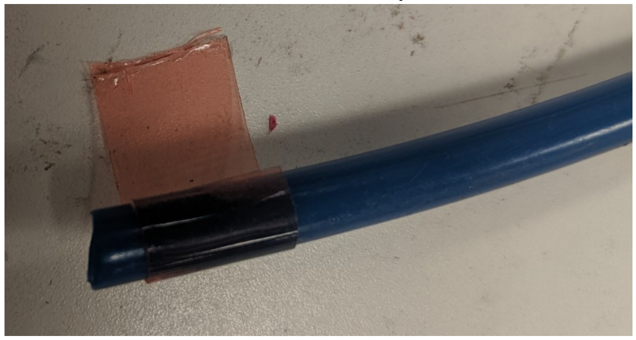
3. Add more zip ties, equally spaced out along the length of the tube. Try a spacing between ~0.5” and 2.5”. Try to make the make the spacings consistent.



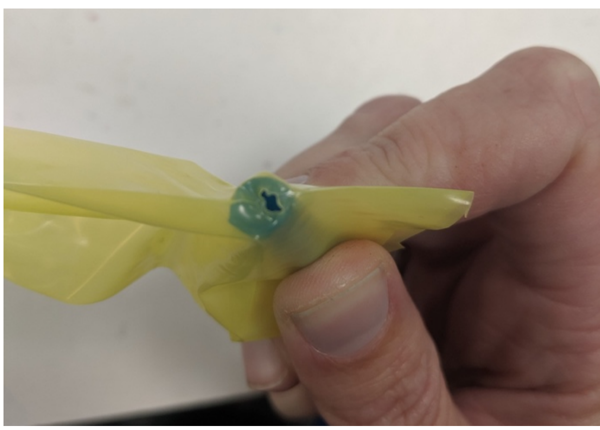
4. Add a tube for the air input. Start by poking a ***very small*** hole in the plastic on the opposite end of the 1.5” tube from the heat-sealed end.

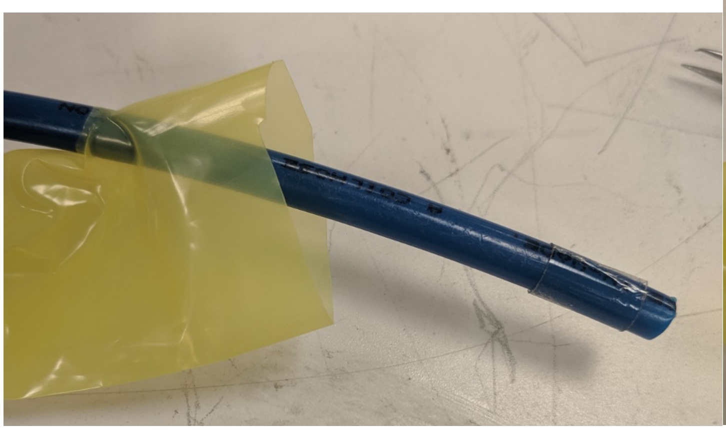


5. Take a piece of the ***squishy*** ¼” air tubing about 6” long (it should be clear, not blue like in the pictures) and put a piece of tape double sided tape around the end. Tape piece only needs to be ¼” to ½” wide. Don’t take off the backing until the end of the next step.

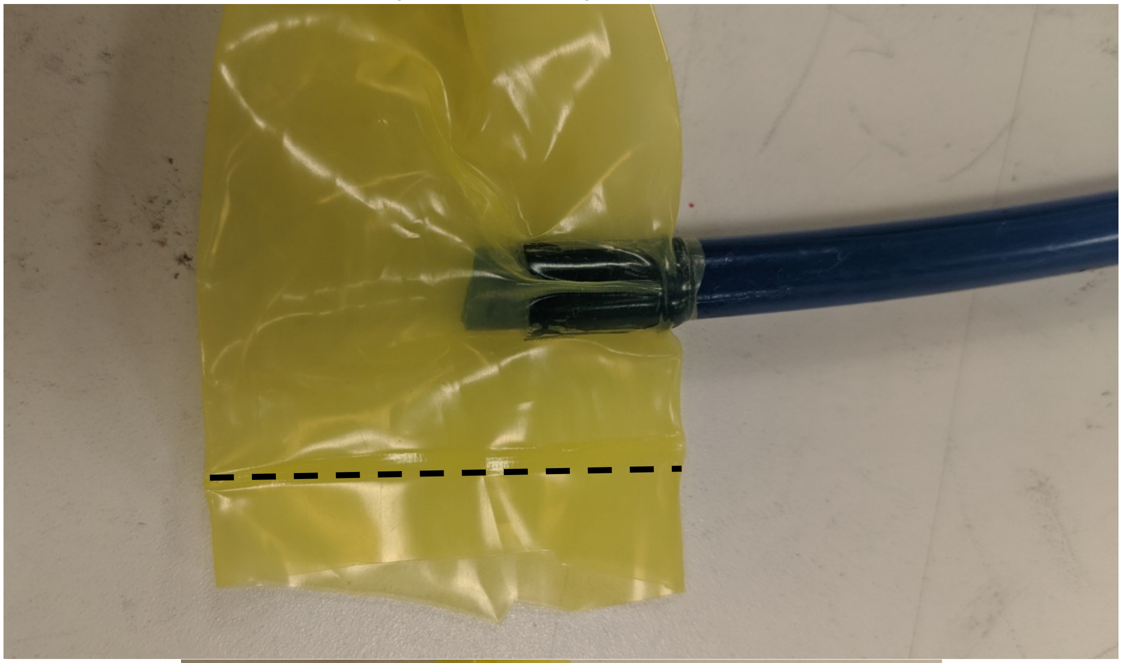


6. Push the un-taped end of the air tube through the hole you made **from the inside**. The air tube should be larger than the hole and you will stretch the plastic to get it through (Note this is difficult to do, try using tweezers if you are having trouble, or expanding the hold slightly). Pull until the tape is inside the 1.5” thin plastic tubing, remove the backing, and seal off the hole.

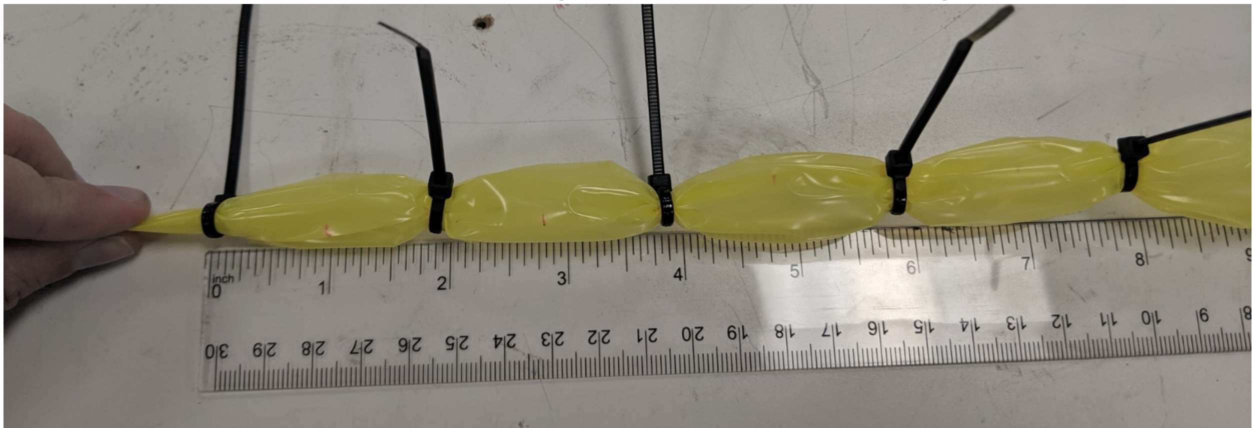


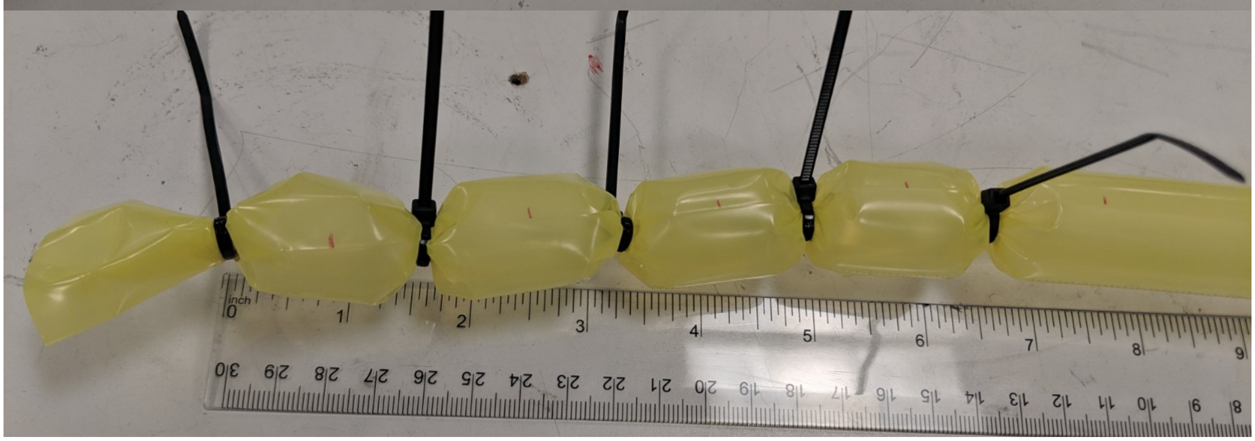



7. Heat seal the open end of the thin plastic tube. **Wrap some additional tape around the connection point to keep it sealed.**



8. Test out the actuation! Attach the ¼” air tube to the air line and open the squeeze valve to open the air flow. Measure the amount of contraction (the ratio between the inflated length and the stretched length).





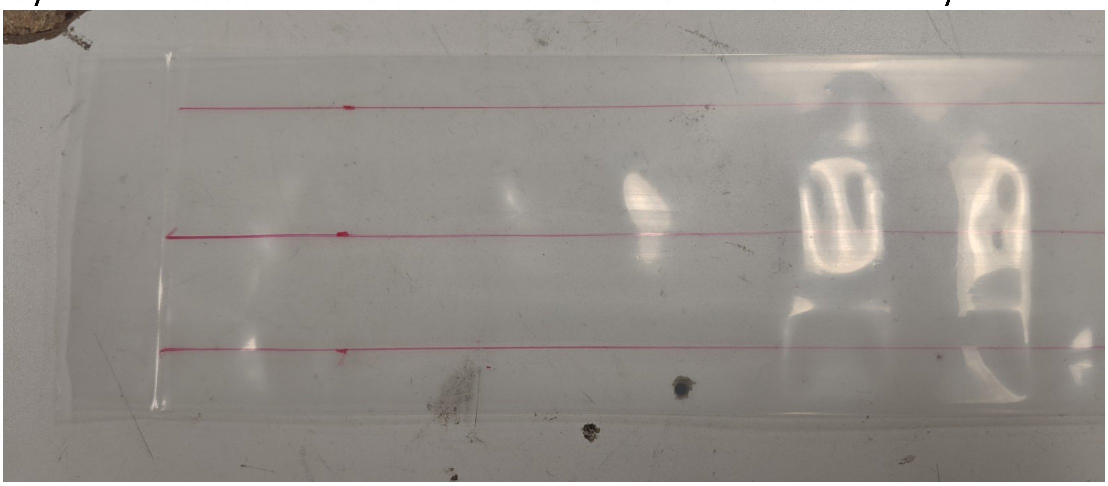
9. Move the zip ties around to see how spacing affects the contraction. Keep note of the spacings and contraction ratios. Try to find the best spacing to get the most contraction.

Part 2: Soft Continuum Arm

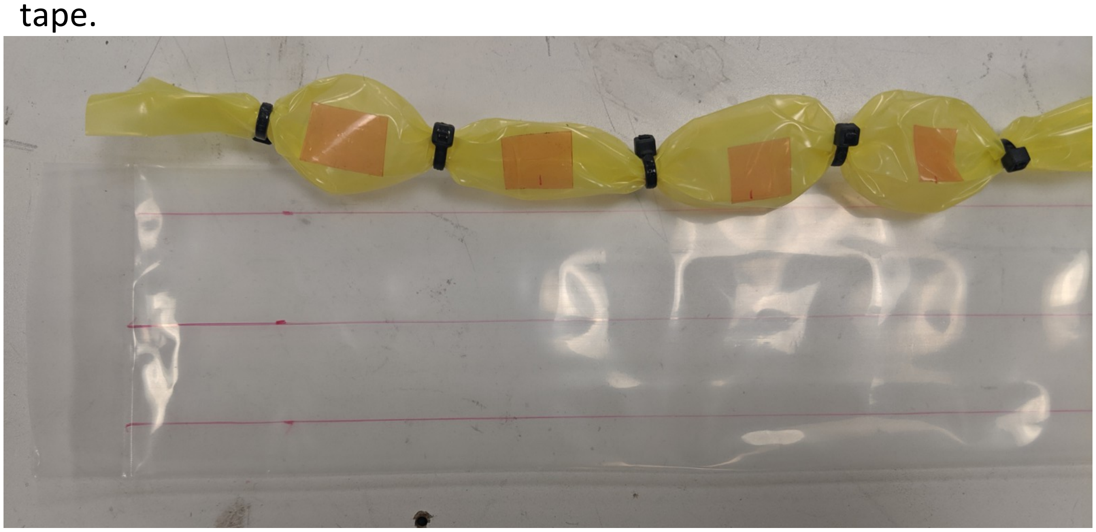
10. Cut about a 2-3 foot length of the 2" thin plastic tubing (use a longer length if you want a longer "arm"). Heat seal one end of the tubing and use Steps 4-7 above to attach an air tube to the other end and seal off the end.

11. Make **three** sPAM actuators. The actuators should be the same length as the piece of 2" thin plastic tubing you cut. Follow the directions in Part 1 but with a longer length, using the best zip tie spacing that you found. Trim the ends of the zip ties.

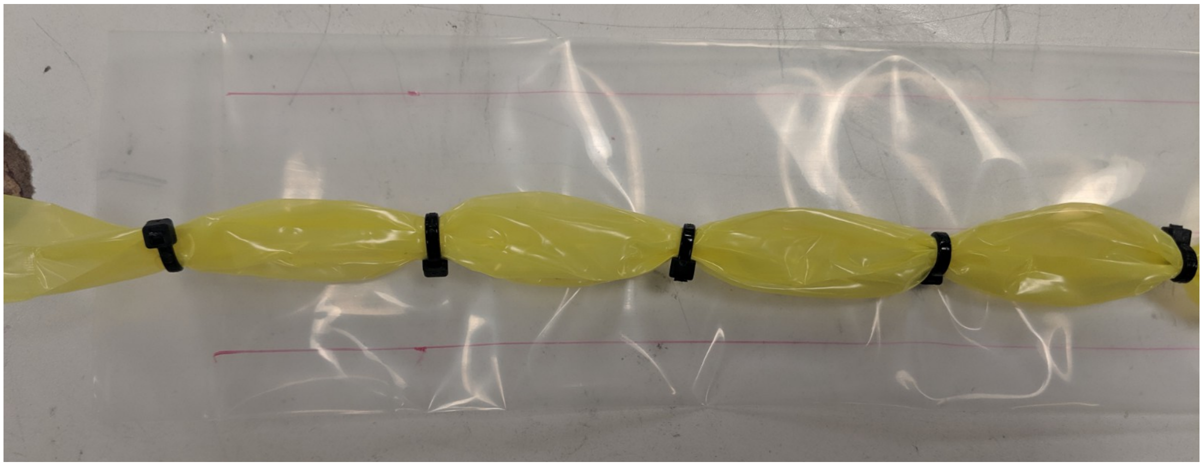
12. Draw three lines along the length of the 2" tubing, **evenly spaced around the circumference**. Note: in the picture below, one line is drawn on the top layer of the tube and the other two lines are on the bottom layer.



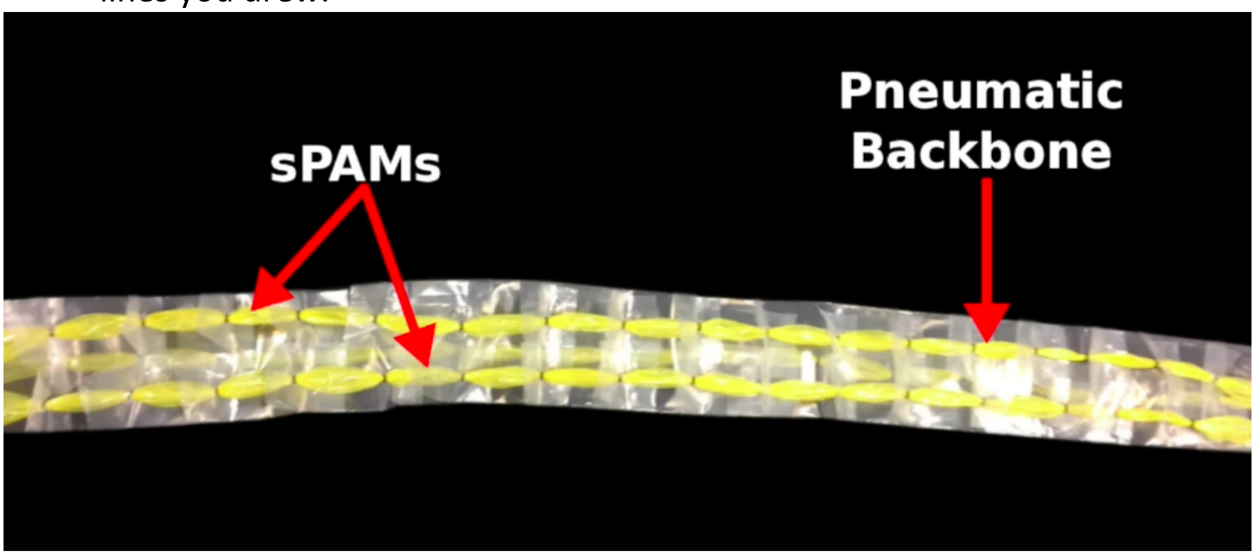
13. Take one actuator and place double sided tape on each section of the actuator. Try to smooth out the wrinkles where you place the square of tape.



14. Attach the actuator, placing the other side of the tape along the lines you drew on the 2” tubing. Make sure to keep the actuator stretched out as you attach it so that you’ll get the most contraction out of the actuator. The air tubes should all be on the same end.

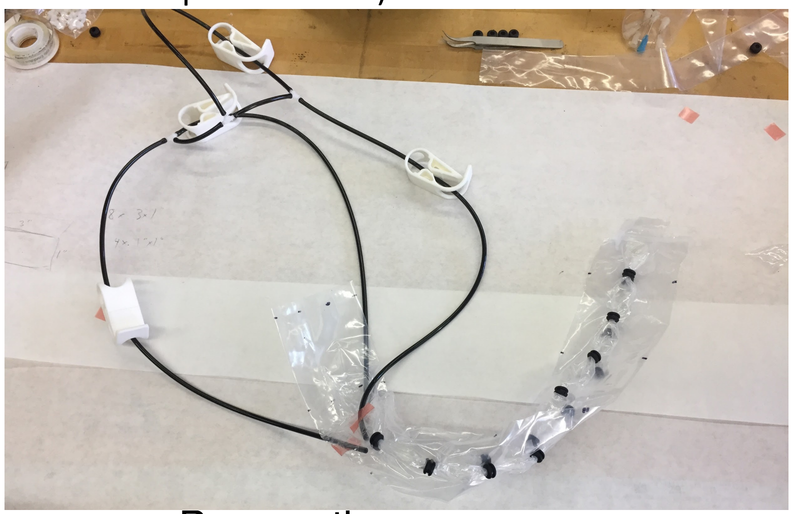


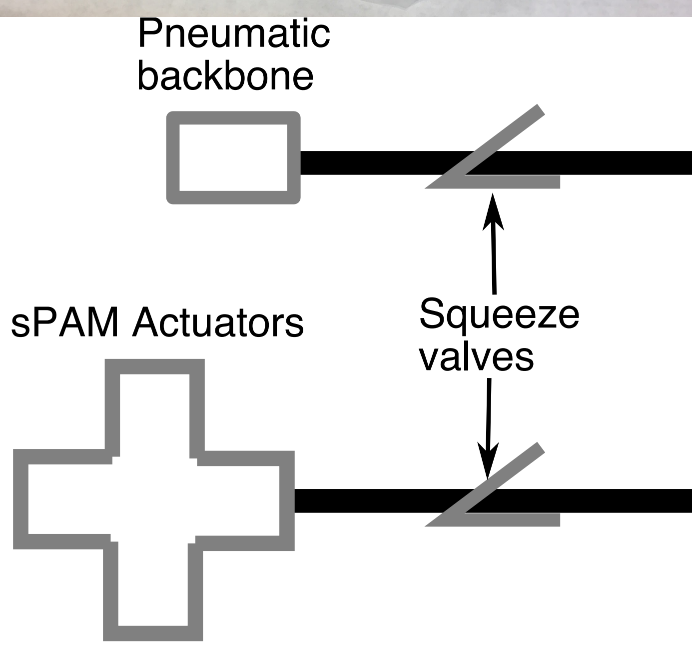
15. Repeat Steps 13 and 14 to attach the other two actuators along the other lines you drew.



16. Poke a ***very small*** hole in the non-tube end of each actuator and the pneumatic backbone to make sure they don’t explode when hooked to pressure.

17. Put squeeze valves on all of the tubes coming out of your soft arm and close them. Connect the actuator air tubes to the actuator air supply, and the pneumatic backbone tube to the other air supply. (Below picture may not exactly reflect the set-up of air supplies you have, look at the schematic for more accurate representation)





18. Open the squeeze valve for the pneumatic backbone tube supply to inflate the arm. Then open and close the actuator squeeze valves one or two at a time to move the arm.

IV. Questions

1. Describe how the sPAM actuator works.
   a) How does the actuator shorten as you pressurize it? What is the function of the zip ties?

   b) If you pull on the actuator, how does it respond in position and force (and how does change with the pressure you use)?

   c) Would the actuator work better/worse/the same if the tube was elastic instead of inextensible?

2. For Part 1, you tested different spacings of the zip ties. Measure and record the spacing, the starting length, and the actuated length. Calculate the contraction ratio (actuated length divided by starting length). What spacing gives the best contraction ratio (most contraction)? Why do you think this is the best spacing (or alternatively, why are other spacings worse)?

3. What happens when you actuate an sPAM attached to the pneumatic backbone? What about when you change the pressure, or when you actuate two sPAMs?

4. What could you use the soft continuum arm for? What else could you use the sPAM actuators for?

5. Any other thoughts?