ME23N - Soft Robotics for Humanity
Stanford University
Mechanical Engineering
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# Lab 1: SMA Actuation and Origami Robots

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

## I. Overview

In this lab we will be making simple robots with fabric joints that can jump and crawl. These robots use a combination of Shape Memory Alloys and elastic bands to actuate. Here we'll investigate making simple flexure joints, different ways to use stored elastic energy, and the basics of using Shape Memory Alloys.

Shape Memory Alloy (SMA) is an alloy of Nickle and Titanium that exhibits a thermomechanical response. This means the alloy can be bent or twisted and then resume a "remembered" shape when heated. Some SMAs are formed into wires and can be programmed to *shrink* when heated, providing a large tension force relative to the weight of the wire. For soft robots, these SMAs can be used as actuators, acting like artificial muscles. SMAs can be heated in a variety of ways, but the most convenient method for robotics is to run an electrical current through the wire, causing it to heat up like the wire in a toaster (this is called Joule heating). Since we have to heat SMAs they are rather inefficient; most of the electrical energy goes into temperature change and only ~2% is converted to mechanical work (as a comparison, gas motors are ~50% efficient). As well, SMAs only actuate in one direction, so we need another energy source, like stretched elastic bands, to return the SMA to its starting state.

Origami robots, or laminated 2D structures, are multi-layer constructions with flexible and rigid layers. The natural compliance of the flexure materials allows it to act as a joint between the more rigid link materials. Origami robot construction is similar to traditional rigid robots but use flexure joints instead of pin joints.

## II. Materials and Equipment

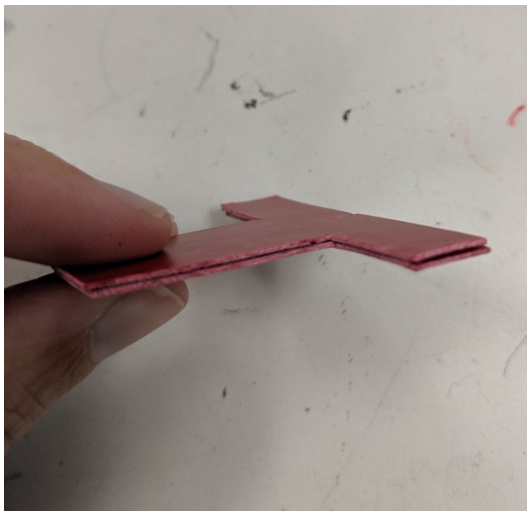
- Fiberglass sheet
- Fabric
- Rubber bands
- SMA wire (Muscle Wire, 375 um and 100 um, low temperature)
- Double sided tape
- Connector wire (Alligator clips) – x2
- Batteries (9v and AAx3)
- Aluminum foil

- Scissors
- Tweezers
- Wire clippers
- Sharpie
- Ruler

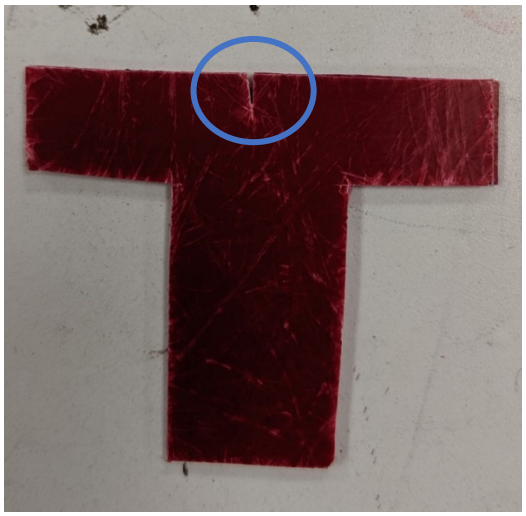
## III. Instructions

### Bistable Jumper

1. Cut all the template pieces for the fiberglass body of the bistable jumping robot (available at end of document)
2. Tape the T-shaped fiberglass layers together (you should have two layers per half of the robot).

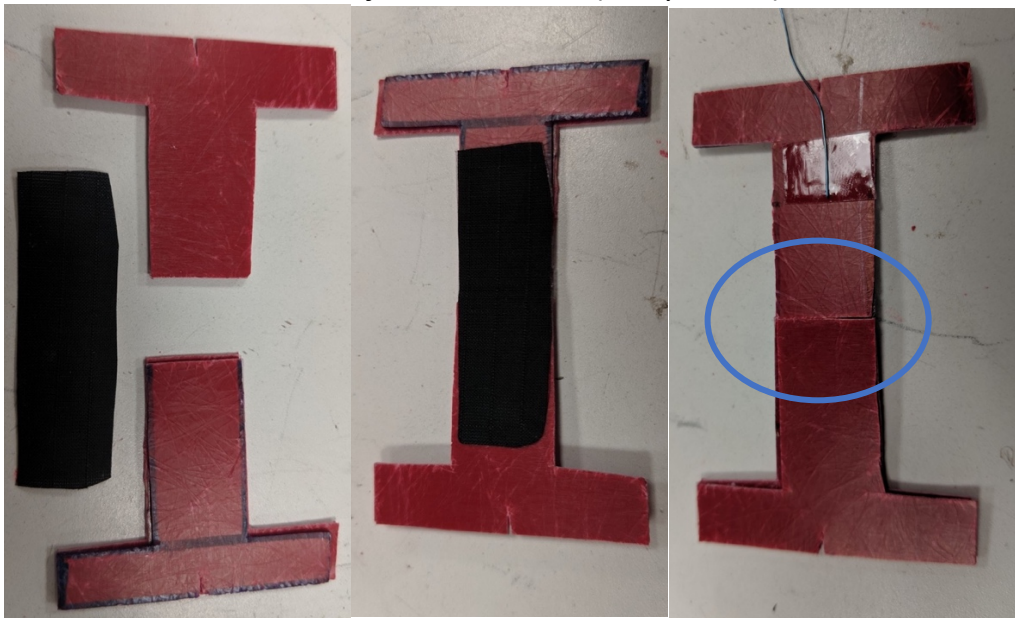


3. Cut a short slit at the end of the fiberglass pieces. This is where the SMA wire will be attached.

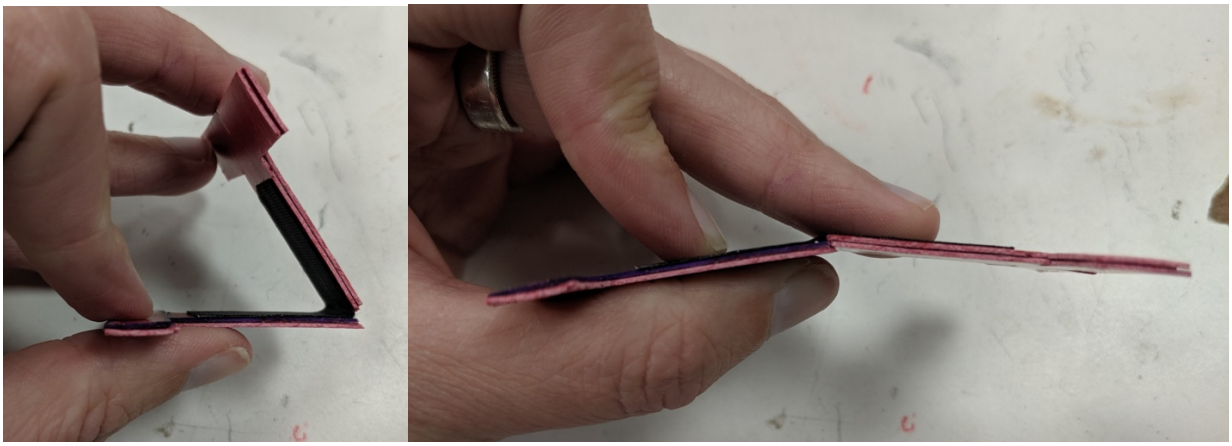


4. Cut the fabric for the joint from the template.

5. Create a joint by taping the fabric to the fiberglass body pieces using the double-sided tape. Note, try to keep the body pieces as close together as possible to limit how far the joint can bend (see picture).

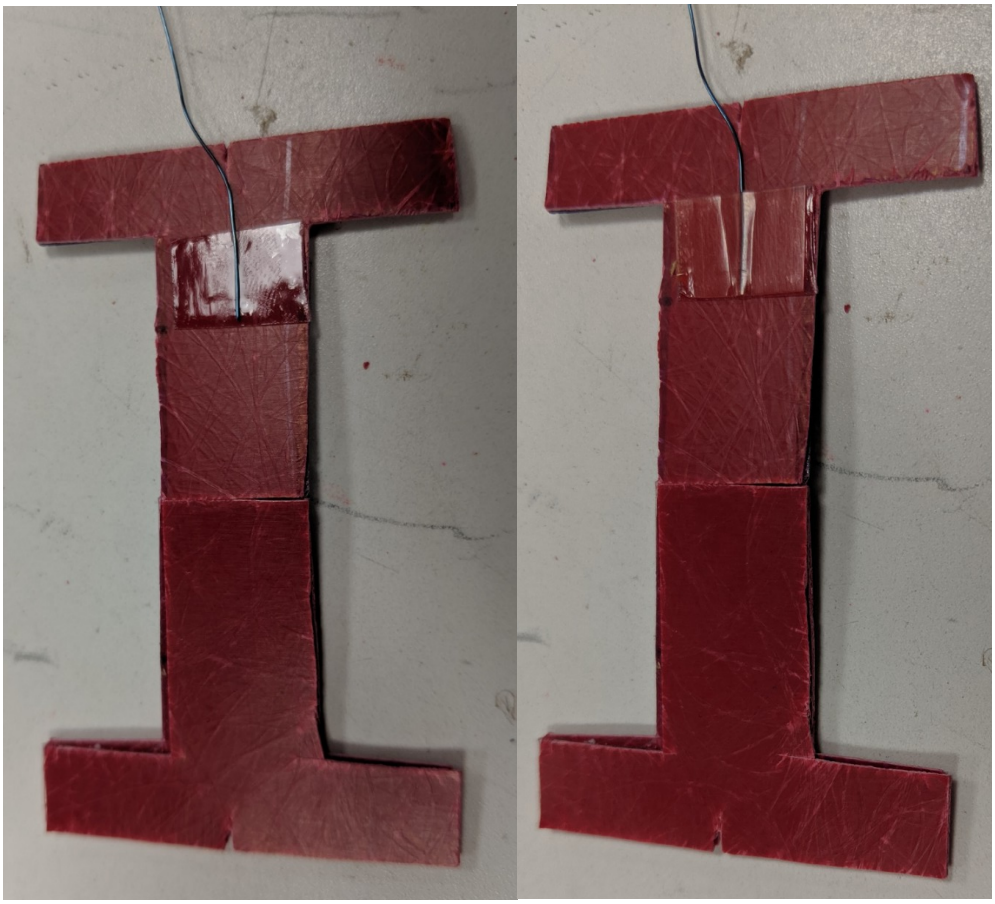


6. Check that the joint bends easily in one direction and only slightly in the other direction. Re-tape the joint if needed.

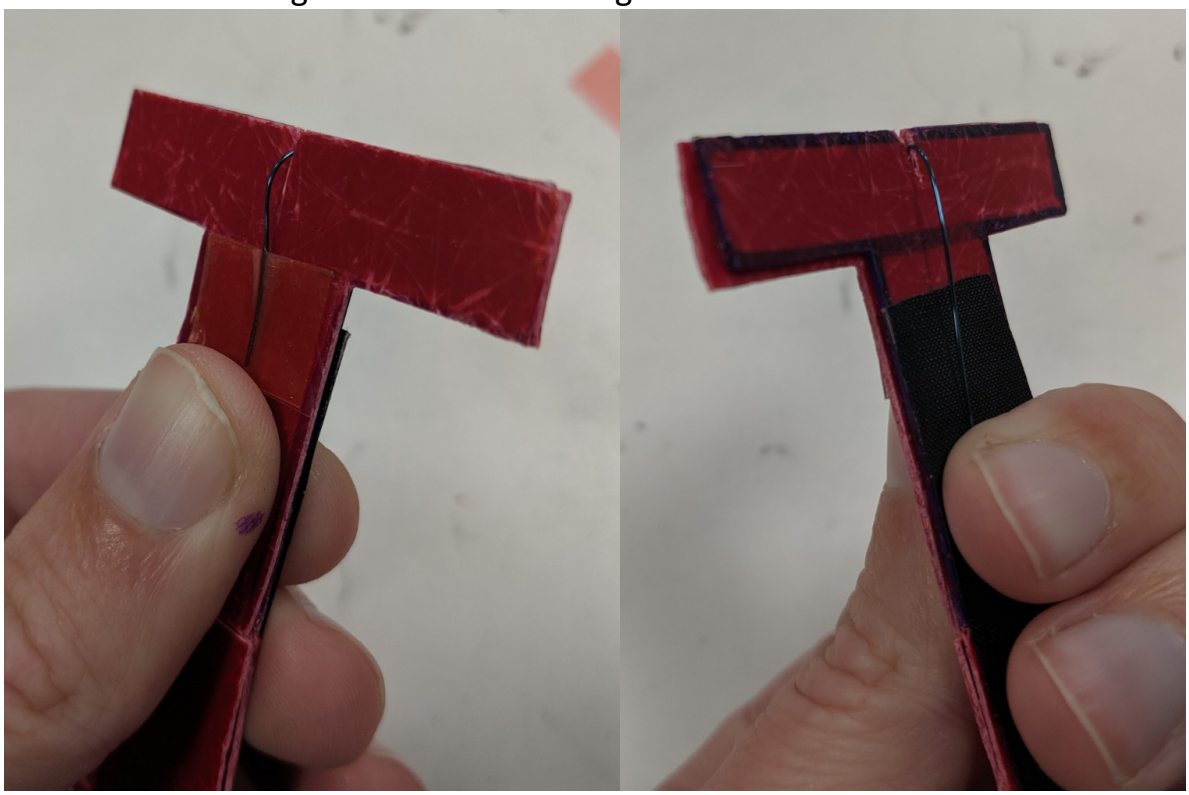


7. Cut a 12cm long piece of the thicker SMA wire (375 um)

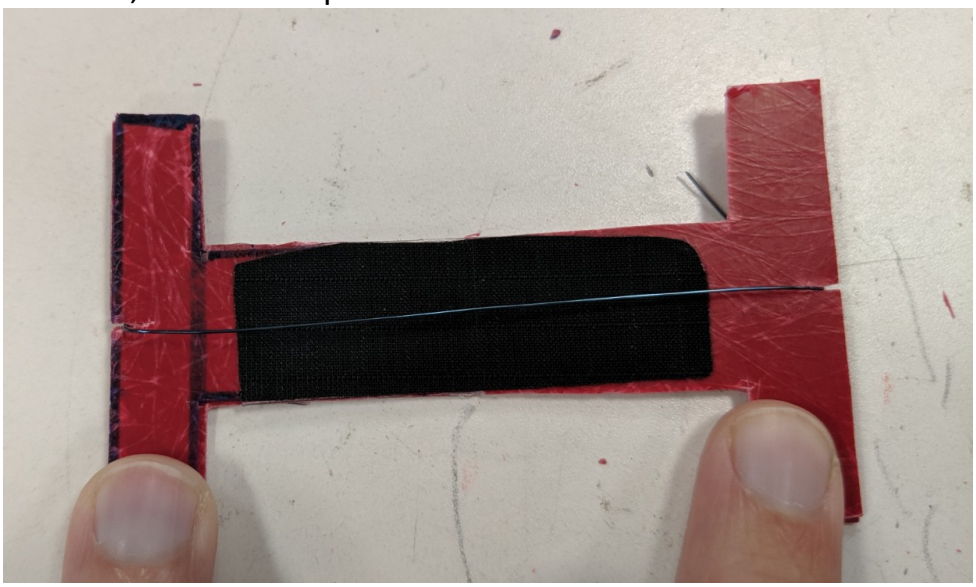
8. Attach the last ~1.5cm of the end of the SMA wire on the non-fabric side (put down a piece of double-sided tape, then sandwich the wire with another piece of double-sided tape, see pictures).



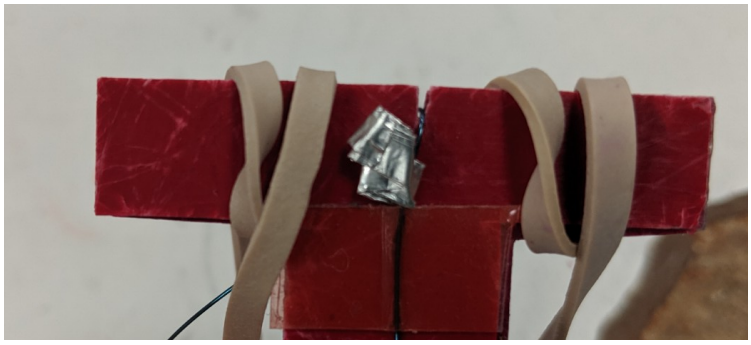
9. Pull the SMA through the slit in the fiberglass and around the fabric side.



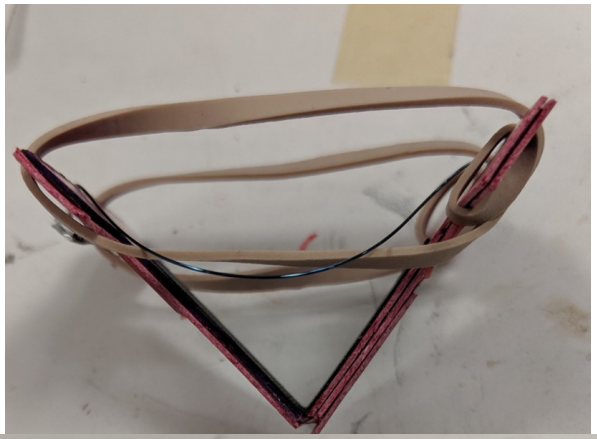
10. Pull the other end of the SMA wire through the second slit. The SMA should be on the same side as the fabric. Adjust the length so that the wire is taut when the joint is flat, and then tape down the end of the SMA wire.



11. Next, make the electrical attachments for the SMA wire. Use aluminum foil to wrap around the SMA and make a “foot” for each side of the wire. The aluminum foil should be on the non-fabric side and can stick out past the end of the robot.



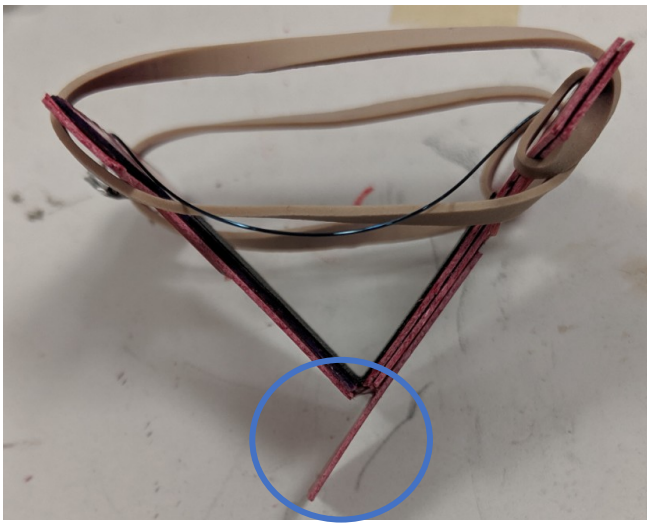
12. Place two more pieces of aluminum foil flat on the table and the length of the robot apart. These will be pads where we can place the robot and attach the battery leads.
13. Place the jumper robot on the pads and touch the 9V battery leads to pads for a **few seconds**. You should see the SMA wire move and shorten.
14. Attach rubber bands to crossbars to store energy for the jump. They should be tight enough to stretch when you put the jumper into the **pre-load state** (bottom picture). Try one wind (bottom pic) or two winds (top pic) of the rubber band.



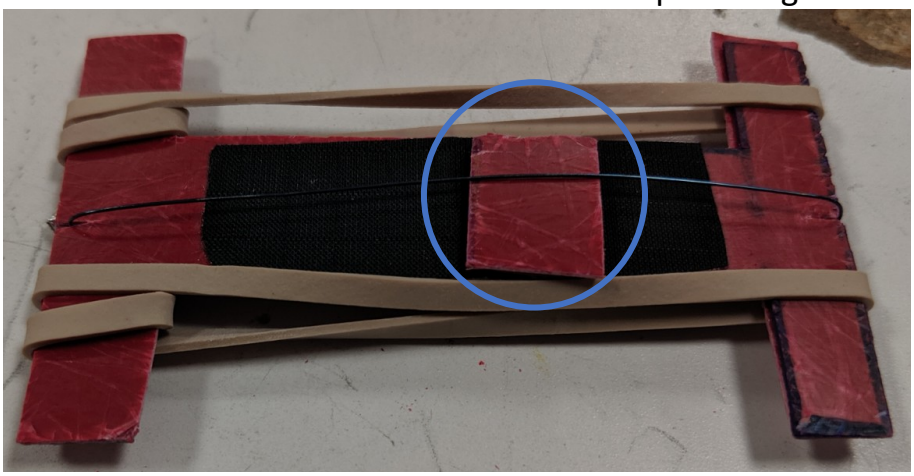
15. Set it up and TEST IT OUT!
    a. Preload the robot (the rubber bands should be stretched and the SMA should be taut like in the picture above)
    b. Place the aluminum feet on the aluminum pads
    c. Attach the battery leads to the aluminum foil pads

**16.Tips and tricks to solve common problems:**

d. Joint bending too far in the preload direction (i.e. the SMA is taut but doesn't contract enough to trigger a jump)→ Try adding a fiberglass hard stop, but make sure the robot will stay preloaded when waiting to jump



e. The SMA isn't taut; it moves but it doesn't trigger a jump → Add in shim of material under the wire to make the SMA path longer

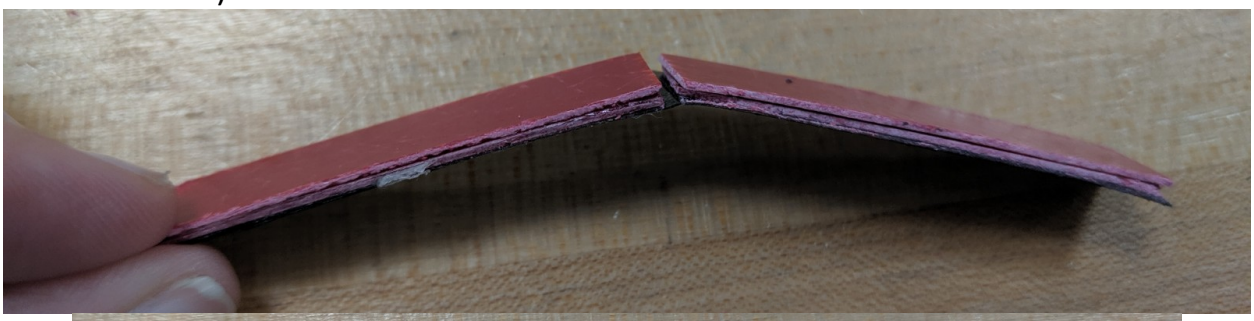


f. The robot is triggering but not jumping/not jumping high enough → Add rubber bands to create more stored energy or wrap rubber bands tighter to get a larger preload force

**Single Joint Crawler**

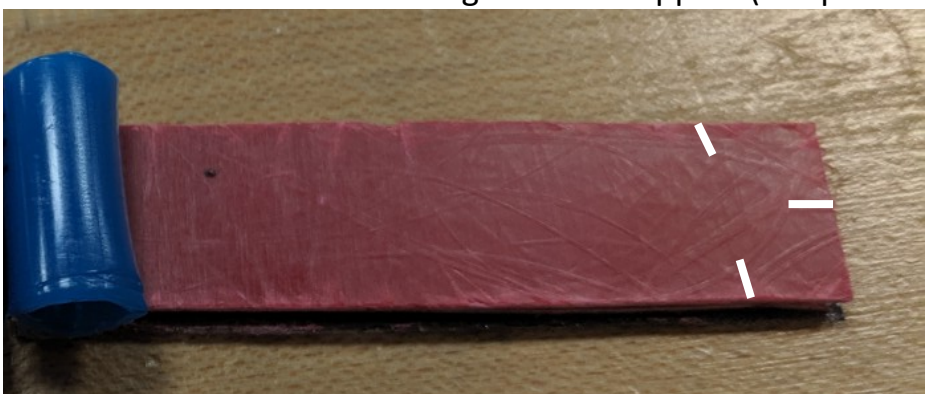
1. Cut all the fiberglass pieces (crawler body and feet) from the template below.
2. Tape together 2 layers of each body piece

3. Cut the fabric piece and attach it between the two halves of the crawler, forming a joint (note, the joint doesn't need to be as tight as the jumper, but try to keep the halves as close together as you can without restricting the movement).

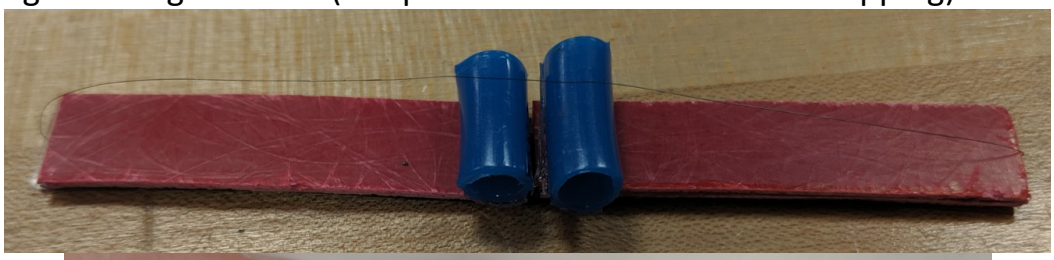


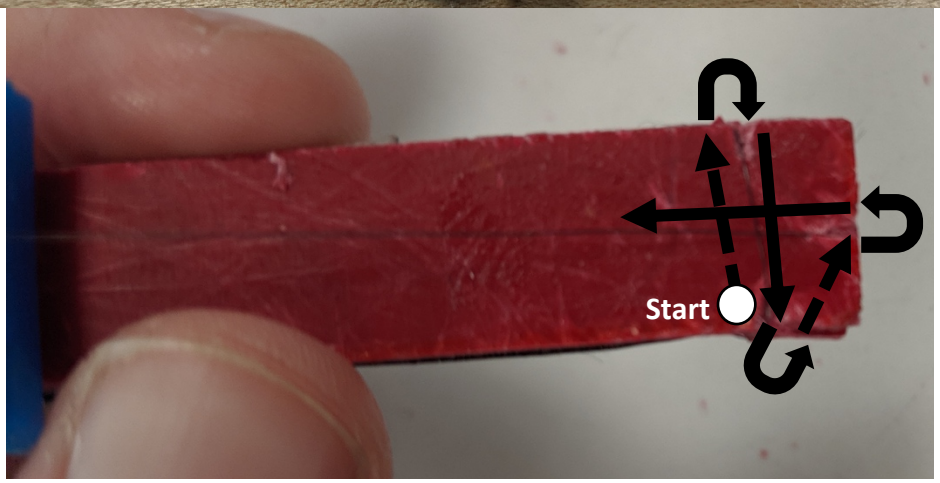
4. Tape the tube pieces on either side of the fabric joint. These serve to make the SMA wire path longer as the joint bends.

5. Cut three short slots on each end using the wire clippers (see picture)



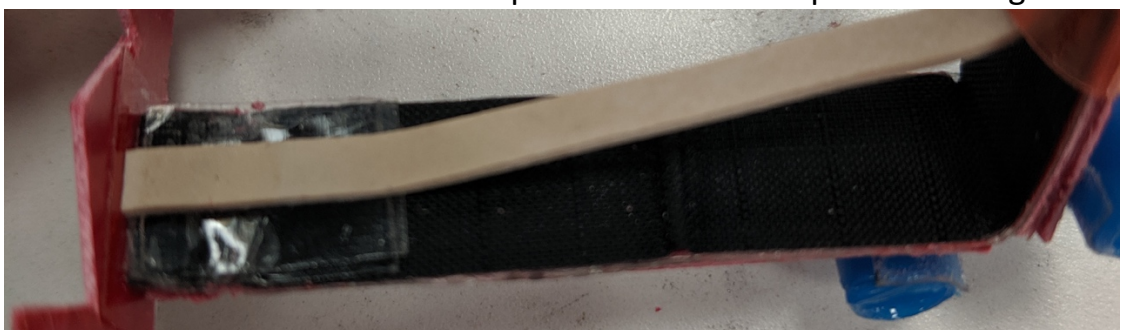
6. Cut a 25cm long piece of the thinner SMA wire (100 um)
7. Attach the SMA wire. The wire will run on the non-fabric side of the crawler. The wire is very thin, so it will tend to pull out of the tape. To keep it secured, tape the end of the wire on the fabric side and wrap it around the end of the fiberglass using the slots (see picture for recommended wrapping).



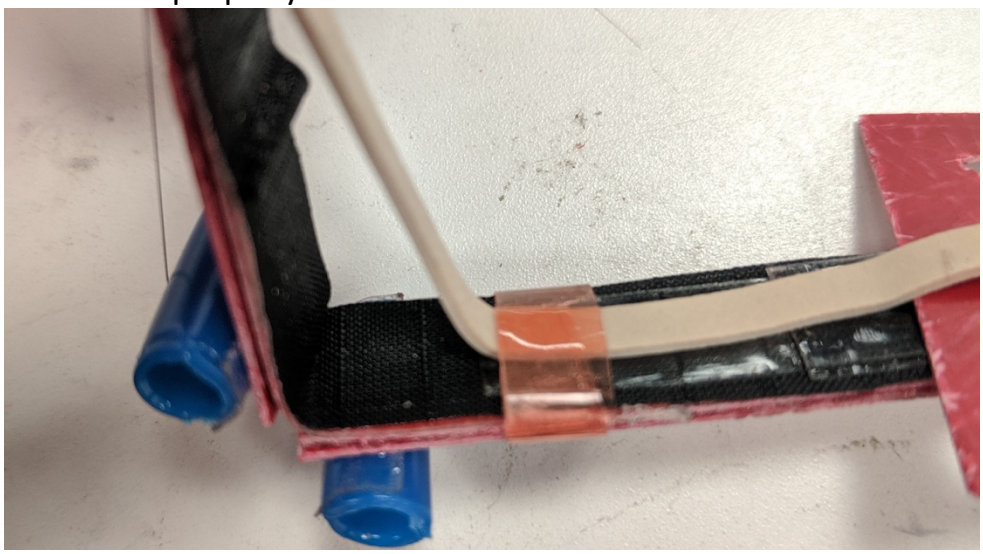



8. Pull the wire over top of the tubes and wrap the other half. The wire should be loose when the joint is flat and taut when the joint is at about 90 degrees. When you have the wire at a good length, tape the wire end down.

9. Cut the rubber band so it is flat. Tape one end to the tip of the fiberglass.

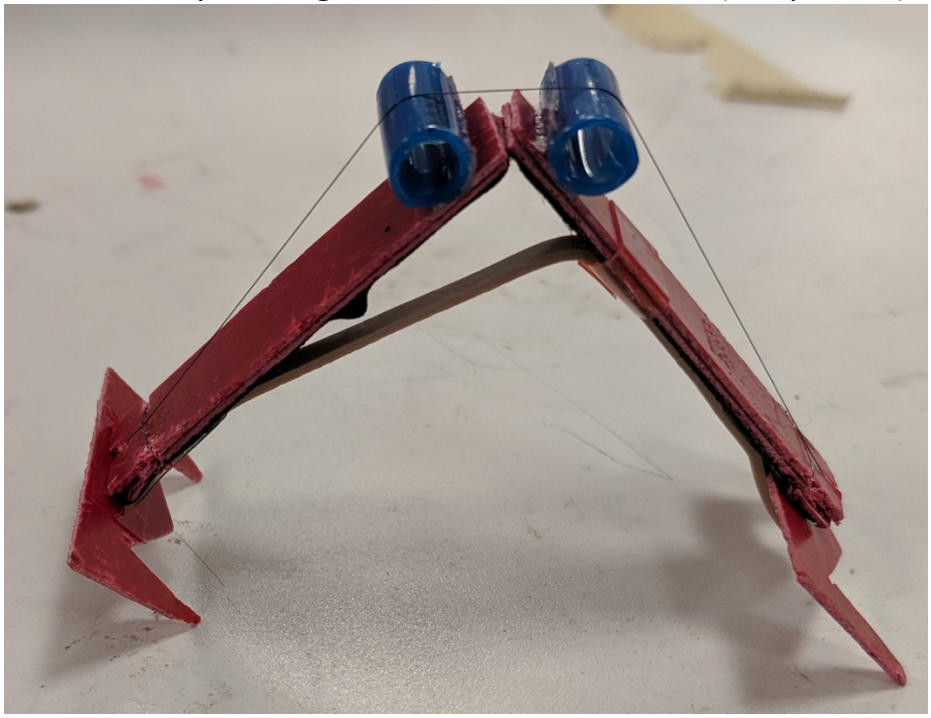


10. Attach the other end of the rubber band. To get proper tension on the rubber band, pull the SMA wire off to the side and then flex the joint slightly past the angle where the SMA is tight. Tape the rubber band about 1/3 of the way down the other half (you can wrap tape around to keep the rubber band attached). Then stretch the rubber band to bring the SMA back on the center of the robot. Note, you may need to adjust the rubber band tension to get the crawler to move properly.



11. Check the actuation. Use the 3 AA batteries and attach the alligator clips to each lead and to either end of the SMA as close to the end as possible. **Quickly turn the battery pack on and off (if you leave it on too long the wire will smoke).** The joint should flex as the wire shortens, stretch the rubber band, and then relax and return to the starting state. Adjust the rubber band tension as necessary.

12. Tape the feet so they are angled in the same direction (see picture).



13. Repeatedly turn the battery pack on and off quickly to cause the robot to crawl (leaving the power on too long will cause the SMA wire to smoke). Try placing the crawler on different materials to see how is moves.

## IV. Questions
**(Answer in your lab notebook)**

1. Describe/speculate on how the SMA jumper works. What does the SMA do, what do the rubber bands do? If you had to make any adjustments, how much did those adjustments improve the performance and why did they help?

2. How high could you get the jumper to jump? What do you think would improve the jumping: more stored energy in the rubber band, faster actuation of the SMA, etc.?

3. What else could you use SMA actuation like seen in the jumping robot for? What are the downsides of using actuation like this?

4. Describe/speculate on how the SMA crawler works. What does the SMA do, what do the rubber bands do? If you had to make any adjustments, how much did those adjustments improve the performance and why did they help?

5. What is the function of the feet on the crawler? How well do they work on different materials?

6. What else could you use SMA actuation like seen in the crawling robot for? What are the downsides of using actuation like this?

7. The jumper and crawler use all the same components but in different ways. Contrast the function of the SMA and rubber band in each robot.

8. What are the implications of SMA actuation? What are the possible benefits to society that could be achieved using SMAs? What are the downsides of SMAs, ethical or environmental?

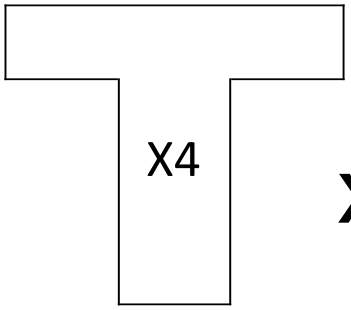
9. Any other thoughts?

## V. Part Templates

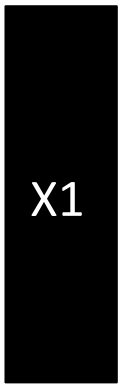
-Fiberglass

-Fabric

Jumper




x4




x1

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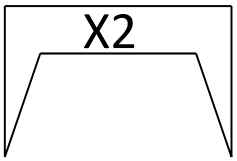
Crawler

x4




x2

Feet

Body

x1