Independent Study Final Deliverable

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Introduction

This semester, I worked in the Morphable Biorobotics Lab at Boston University, working under Tommaso Ranzani and Pranav Sultania. My main responsibilities this semester consisted of connecting the SBAs (soft balloon actuators) to the robot body, creating a magnet tower casing, and developing new technology for magnetic valves to be used to actuate the SBAs.

Connecting the SBAs to the robot body

The first task this semester was to design and create a modular system to connect the SBAs to the main body of the jet propulsion robot. The design was created in Fusion 360, and based on the SBA and robot body dimensions. The CAD was then 3D printed and assembled. The design process included trial and error, and going back and fixing parts in the CAD when the assembly didn't fit properly or needed adjustments.


Figure 1

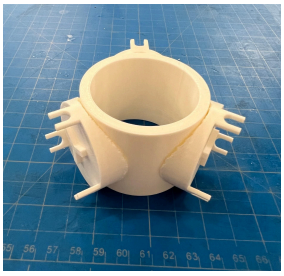
Figure 2

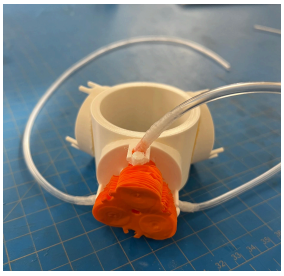
Figure 3

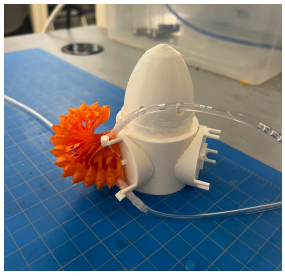
Figure 4

The final product's parts are shown in figure 1, including the ring to fit snugly on the jet body, three attachment pieces to fit around the ring and allow for the SBA to fit into, and knobs to secure each hose from the SBAs in place. Figure 2 shows the complete assembly of the parts designed. Figure 3 shows the fit of the SBA into the mechanism, and figure 4 shows the ring around the robot body, demonstrating the full configuration of the robot.

Magnet tower case

The main body of this robot has a magnet tower which is part of how the jet propulsion operates. This magnet tower consists of 3 magnets stacked, however their polarities are next to each other, meaning the magnets are constantly trying to repel each other. The glue holding them together does not hold these magnets well, popping apart easily.

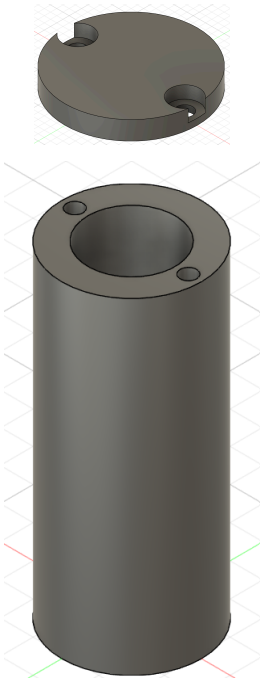

Figure 5

Figure 6

A solution to this problem is to create a casing to hold the magnets together. The design was created in Fusion 360 and is shown in figure 5, and the 3D print of this case is shown in Figure 6. The magnet tower fits snugly into the casing, and the top gets screwed together using non-magnetic screws and nuts.

Valve technology

To fluidically actuate the SBAs on the robot, there are tubes that go into each chamber. Each tube gets fluid through it through channels that are controlled by valves. These valves were designed and developed almost from scratch this semester. The purpose of these valves is to control multiple fluidic channels in the SBAs using a single pump source and be able to selectively open and close these channels.

Preliminary Iterations

The premise of this valve is to have a copper wire solenoid surrounding part of a magnet that is attached to a bistable beam. Under the magnet is a flexible channel and below the channel is a spring steel plate. When the bistable beam curves downward, the solenoid magnet is attracted to the spring steel plate, pinching and therefore closing the channel. An electric pulse can be sent through the solenoid, changing the direction of polarity in the solenoid magnet, forcing the bistable to bend upward. This causes a gap below the solenoid magnet, opening the channel and allowing a fluid to pass through.

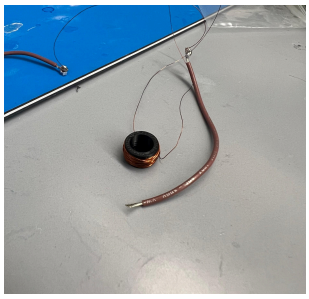

Figure 7

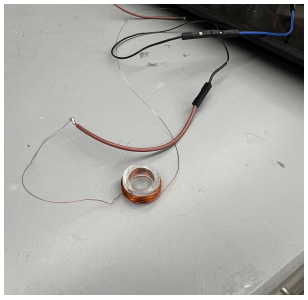

Figure 8

Figure 9

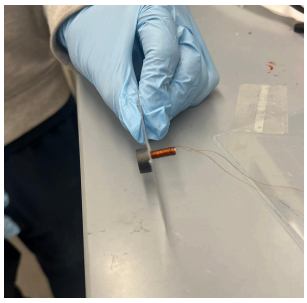

Figure 10

During the initial stages of development, many different magnets and solenoid configurations were tested. Figures 7-10 show some of the types tried and failed.

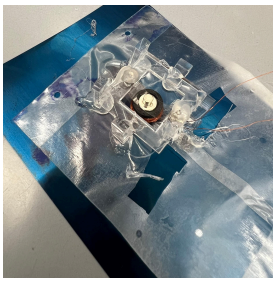

Figure 11

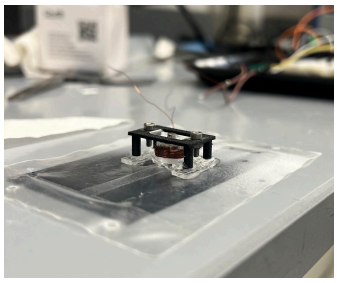

Figure 12

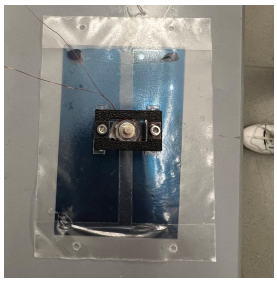

Figure 13

The initial assembly, shown in figure 11, consisted of the solenoid copper coil surrounding a cylindrical piece of acrylic. The beam holder was another piece of acrylic, and the entire assembly was attached by hot glue. Another iteration, shown in figure 12 and 13, consisted of less hot glue and a 3D printed beam stand. Both these iterations were successful in supplying an electrical pulse to push the magnets away from each other, bending the bistable beam to its other orientation, and opening the channel to allow fluid to travel through. The solenoids were also successful in performing the opposite occurrence, causing the magnet to snap the beam to its other position, attracting the magnets together and closing the channel, preventing a substantial amount of fluid to pass through.

Final technology

The final valve technology consists of many different components.

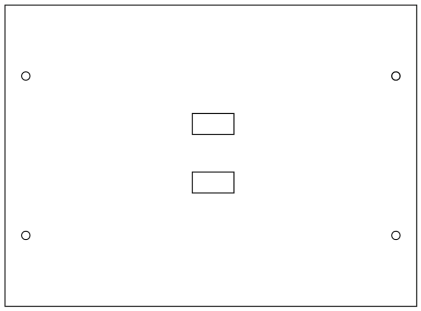

Figure 14

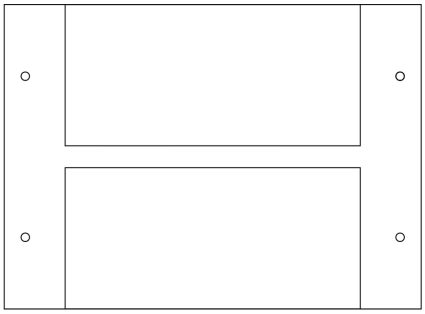

Figure 15

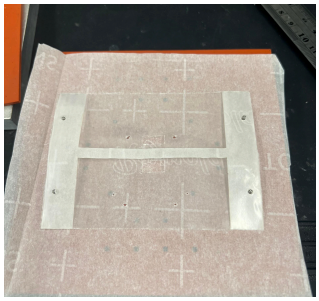

Figure 16

The channel consists of two TPU layers selectively heat pressed together with a thin open channel between the two connecting from one side to the other. This manufacturing process is as follows. Two pieces of TPU get laser cut as a pattern, shown in figure 14. One piece of parchment paper is cut out in the pattern shown in figure 15. One layer of TPU is placed down on the heat allowable plates, then the parchment paper cutout, then the second layer of TPU. This then gets heat pressed, as shown in figure 16. After the TPU is sticking to each other, the parchment paper can carefully be pulled out, making a channel in the TPU for a fluid to pass through.

Figure 17

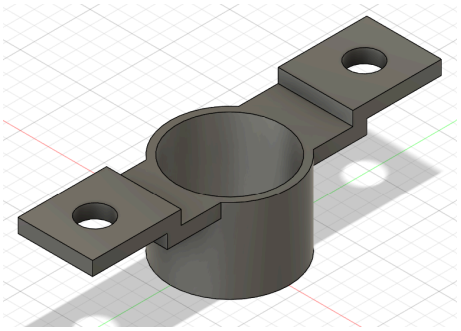

Figure 18

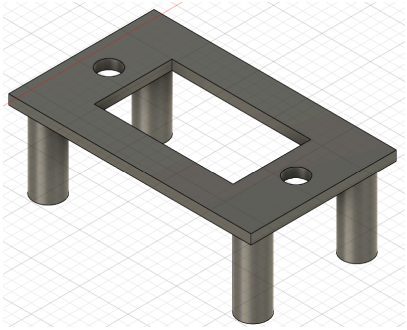

Figure 19

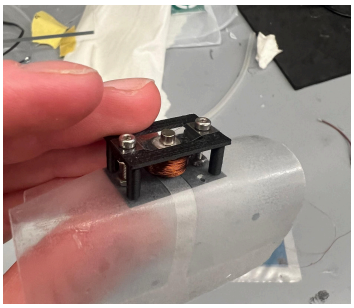

Figure 20

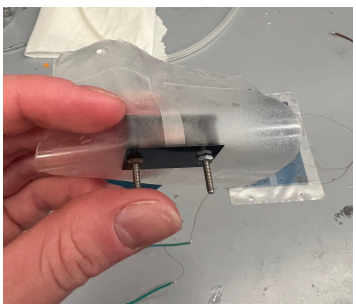

Figure 21

The assembly for a single valve is as follows. A steel piece is cut out, its pattern shown in figure 17. The channel, as described above, is placed on top of this steel plate with the holes aligned. A solenoid attachment piece is 3D printed, shown in figure 18, where the copper wire is wrapped around the cylindrical part. A beam holder is also 3D printed, shown in figure 19. The solenoid attachment and the beam holder fit together so the holes line up. The beam holder is then placed on top of the channel and steel plate, with all the holes aligned. On top of the beam holder is the bistable beam, with the holes aligned. All 5 components are attached by two long screws and nuts. The final assembly for a single valve is shown in figures 20 and 21. The ends of the copper wires are soldered to connection wires, which get connected to a circuit, arduino, and computer to generate the electric pulse that attracts and repels the magnets, closing and opening the channel. A small 2mmx2mm cylindrical neodymium magnet sits at the top of the beam, and on the other side of the beam is another larger 6mmx6mm neodymium magnet, both attracted to each other. Neodymium was chosen because of its strong magnetic fields (leading to high electromagnetic forces), high coercivity and durability. The larger neodymium magnet that is attracted to the steel plate is 6mm in diameter, larger than the 5mm channel to make sure the channel is completely closed every time. This technology performs very well and at low power, opening and closing the channel by requiring only around 100-200 mJ of switching energy. Current operational range is between 12-15V and operating at 0.1-1A. It only requires a 5-7 ms pulse to switch states and close/ open the channel.

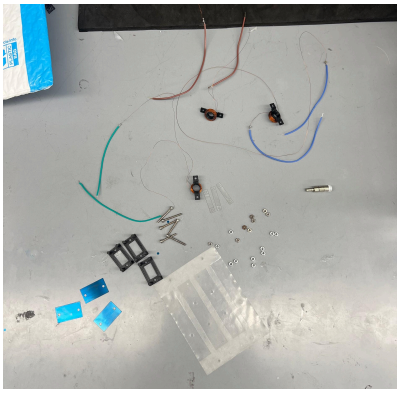

Figure 22

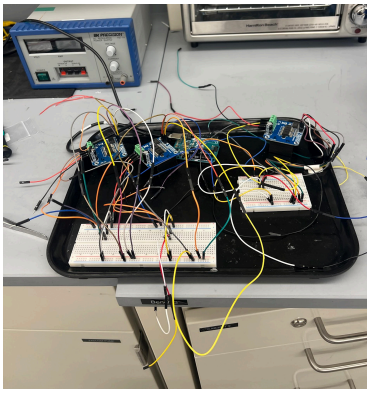

Figure 23

Because this technology works so well, the next step was to have 3 valves working simultaneously. Because there are 3 channels in each SBA, they each need 3 valves. The materials are the same as those used for the single valve technology, and is shown in figure 22. The circuit to provide the electrical pulses is shown in figure 23.

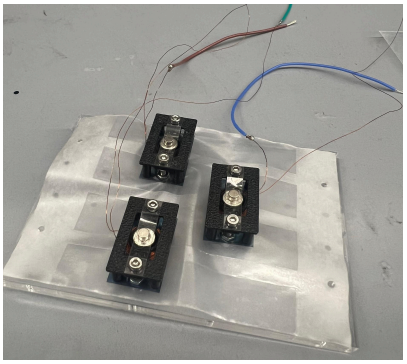

Figure 24

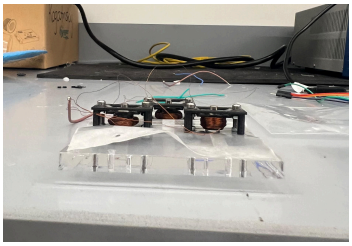

Figure 25

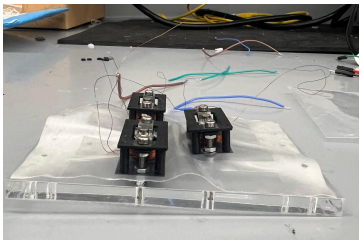

Figure 26

The final 3 valve assembly is shown in figures 24-26. They sit on top of an acrylic sheet with the long screws secured in, to help separate the 3 valves from becoming attracted to each other.

Future Work

The main next task to be done with this set of 3 valves is to connect them to the circuit, test if they work, and test their pressure allowances, such as how much pressure will the valve prevent from moving through the channel when closed. These valves can also be connected to SBAs and tested with them, as well as automating them so that they can be used properly for walking and grasping motions.