Robotics Project Report – Soft-Robotic Fish

Submitted by:

2014-MC-01	**Usman Farooq Butt**
2014-MC-20	**Tajammal Nawaz**
2014-MC-24	**Taha Amjad**

Submitted to: Dr. Ali Raza

Course: Robotics (Lab)

Project Submission Date: 29th December, 2017

Report Submission Date: 5th January, 2018

Department of Mechatronics and Control Engineering

University of Engineering and Technology, Lahore

Abstract:

As our semester project, we had to develop a robot that would qualify for soft robotics category. Our group was assigned a 'soft robotic fish'. We reviewed the work already done about similar items. Initially a fluid control board was developed for control of the soft robot. Then we designed the 3D model of the fish. Plastic mold was then 3D printed using our design. RTV Silicon was used to make the robot. The soft robotic fish successfully mimicked the movement of a fish.

Intro to Soft Robotics:

Robots are machines designed to meet desired abilities of movement, perception and cognition. Soft robots do not have rigid links. Soft robots are motor-less and gear-less robots made from soft/flexible materials like elastomers, silicon, etc. To control soft robots, we use pneumatic or hydraulic pressure. Soft robots are specifically designed to meet the criteria like squeezing, stretching, climbing and morphing as these cannot be achieved using rigid links. These are also used for delicate tasks such as glass handling and in medical inspection.

Literature Review:

- Reference material for the development of control board was extracted from https://softroboticstoolkit.com/book/control-board.
- Introduction to the emerging field of soft robotics was studied from the paper '*Soft robotics: Technologies and systems pushing the boundaries of robot abilities'.*

We then reviewed four research papers to see how the fish like soft robots have been developed. The titles of papers are:

- '*A Bending Pneumatic Rubber Actuator Realizing Soft-bodied Manta Swimming Robot'*
- *'Autonomous Soft Robotic Fish Capable of Escape Maneuvers Using Fluidic Elastomer Actuators'*
- *'Hydraulic Autonomous Soft Robotic Fish for 3D Swimming'*
- *'The Design and Analysis of Pneumatic Rubber Actuator of Soft Robotic Fish'.*

We used the dimensions given in one of the papers in the manufacturing of our soft robot.

Working Principle of Fish:

The design mimics the rear portion of a fish, encompassing the posterior peduncle and the caudal fin. This tail can continuously bend along its vertical center constraint layer by fluidic actuation of two lateral cavity structures on each side. The inextensible and stiffer center constraint layer splits the tail evenly along a vertical plane. The rib structure allows for expansion or contraction of the thin exterior skin under positive or negative fluidic pressure, respectively. The sum of these expanding or contracting motions leads to bending of the inextensible center constraint layer.

3D Modeling:

Taking one of the reviewed models as our template, we designed the 3D model of the fish.

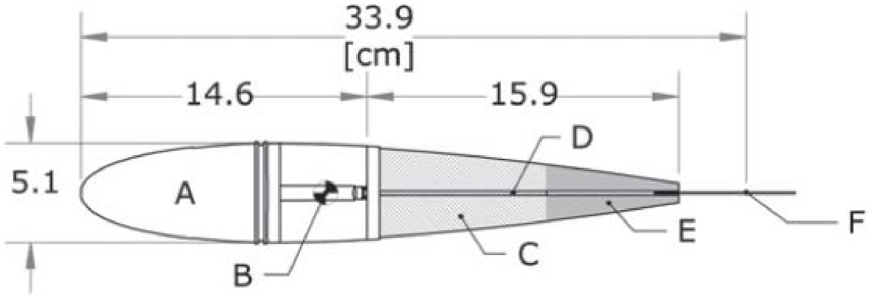


Figure 1: Dimensions of the fish

Designing the 3D model on Solidworks was a challenging task as there are no linear patterns in the fish. One half of the fish was first designed, and then the other half was extracted using mirror command as fish is symmetric from the middle. Then the mold was designed by using the model of fish. The summary of our 3D modeling is:

1. Two ends of the fish were sketched and then lofted.
2. Loft cut command was used for central pipe channel.
3. For pockets, individual planes were defined. The pockets were sketched on planes and then extrude cut was used.
4. Then this part was subtracted from a solid box using the cavity command to get the mold's male-part's model.
5. The mold was completed by attaching upper base to the resultant design of step 4.

The following figure shows what we set as our design target for fish:

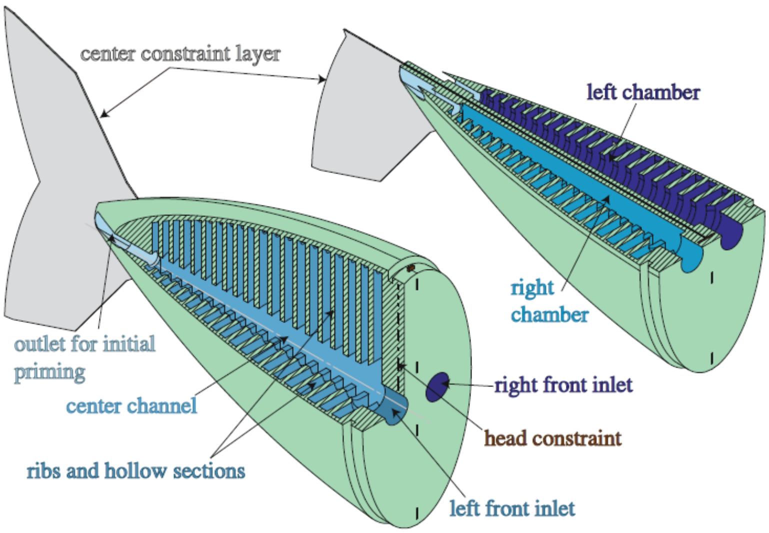


Figure 2: Expected 3D model of fish

Here are some snapshots from our 3D model:

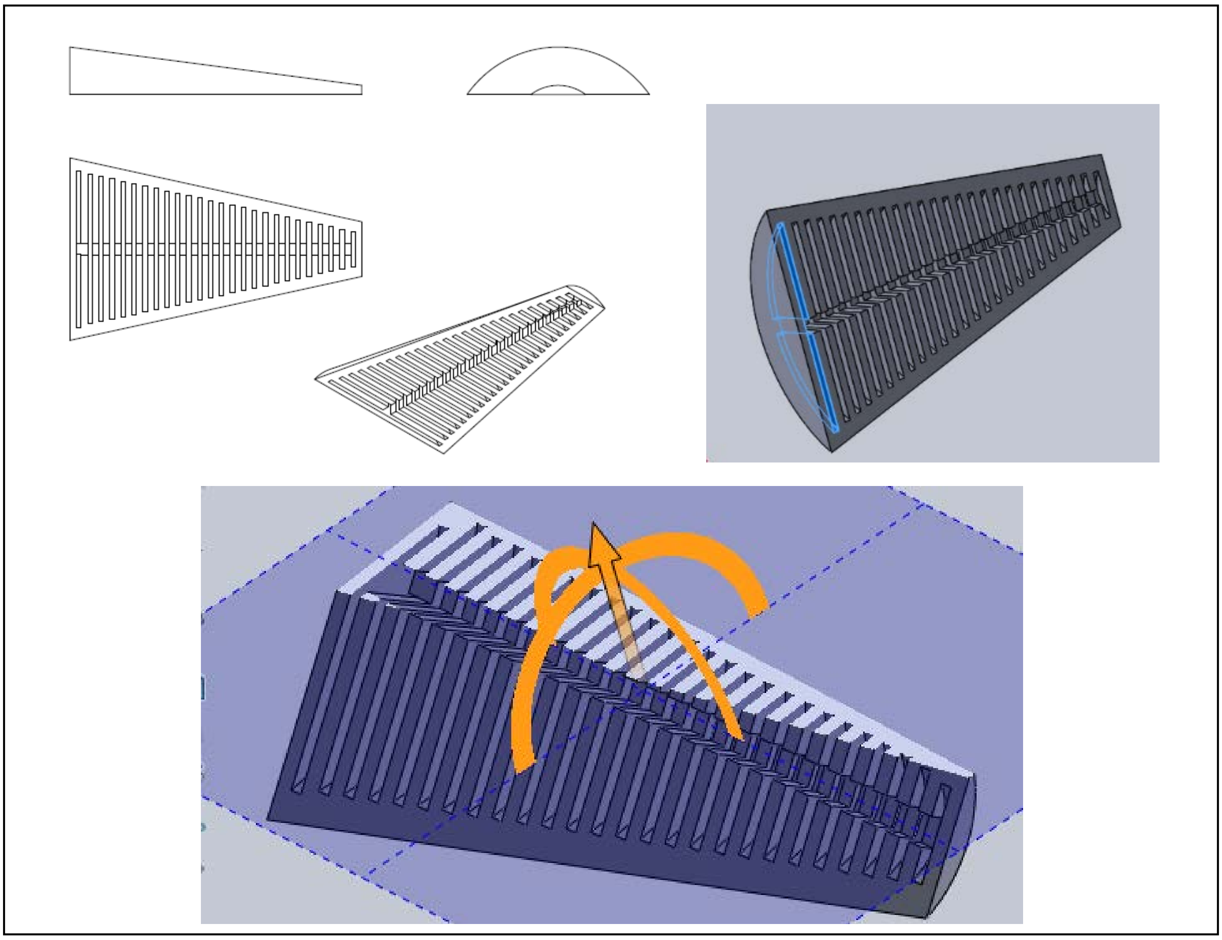


Figure 3: Various views of fish's 3D Model

Mold Making:

After completing the 3D model of fish, we used the cavity command in Solidworks to subtract that model from a box and get the mold. To complete the male mold, we attach a sheet to the part subtracted via cavity command. Here are snapshots of the 3D modeling of the mold:

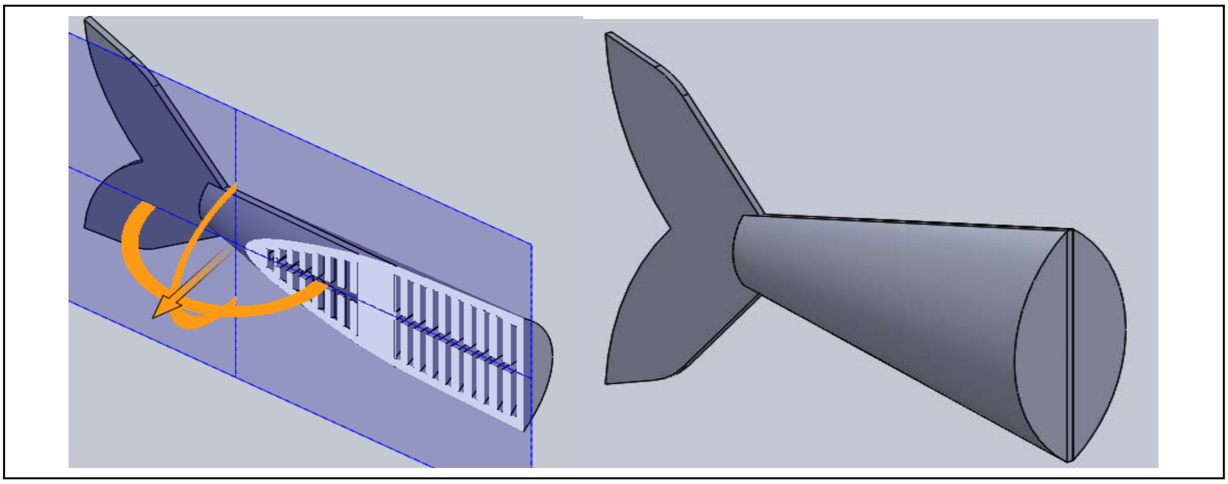


Figure 4: Views of the mold's target 3D model

The initial design of the mold turned out to be quite expensive in terms of 3D printing so we optimized our design to lower the printing costs. Here are the comparisons:

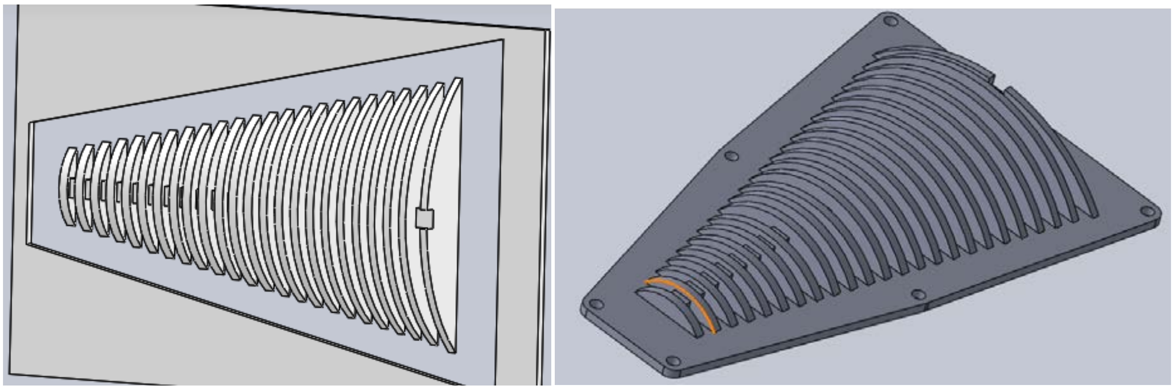


Figure 5: Male part of mold before and after cost effectiveness

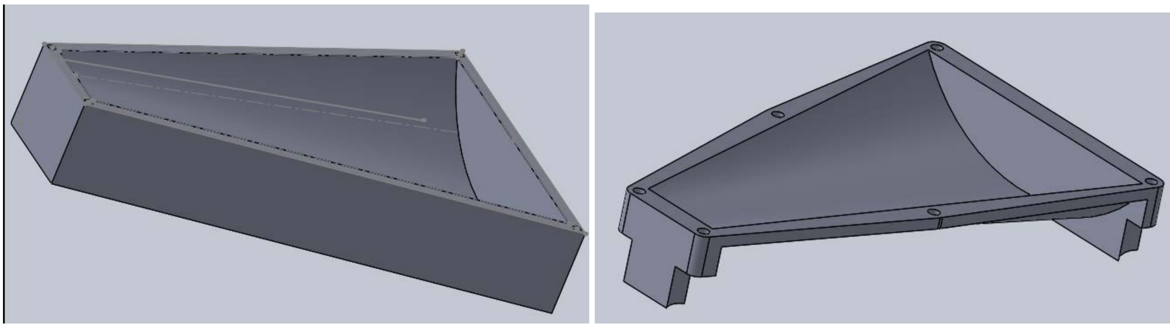


Figure 6: Female part of mold before and after cost effectiveness

3D Printing:

We studied about 3D printing and four main factors were involved in the 3D printing of a part.

1. Material: Various materials are used for 3D printing, depending on desired physical properties of the product e.g. PLA and ABS.
2. Infill %: Percentage of object's volume (inside) that is filled with material.
3. Layer Height: Thickness of each layer constituting the object.
4. Infill Shape: Depending on required rigidity, different infill shapes are used e.g. rectangular, triangular, wave and 3D honeycomb.

This table shows desired properties of the product against the factors of 3D printing:

Table 1: 3D printing factors

REQUIREMENTS				SETTINGS	
Strength	Quality	Low Cost	Speed	Infill %	Layer height
✖				100	0.25
	✖			10	0.1
		✖		10	0.1
			✖	10	0.3
✖	✖			90	0.15
✖		✖		70	0.2
✖			✖	90	0.3
	✖	✖		10	0.1
	✖		✖	10	0.15
		✖	✖	10	0.3
✖	✖	✖		80	0.15
✖	✖		✖	90	0.2
✖		✖	✖	70	0.3
	✖	✖	✖	10	0.15
✖	✖	✖	✖	70	0.2

We chose PLA as our printing material, 50% infill, 0.15mm layer height and honeycomb mesh design.

We contacted various 3D printing services in Lahore and got it printed from ‘3D Printing Arena’. Here is what our mold look like:

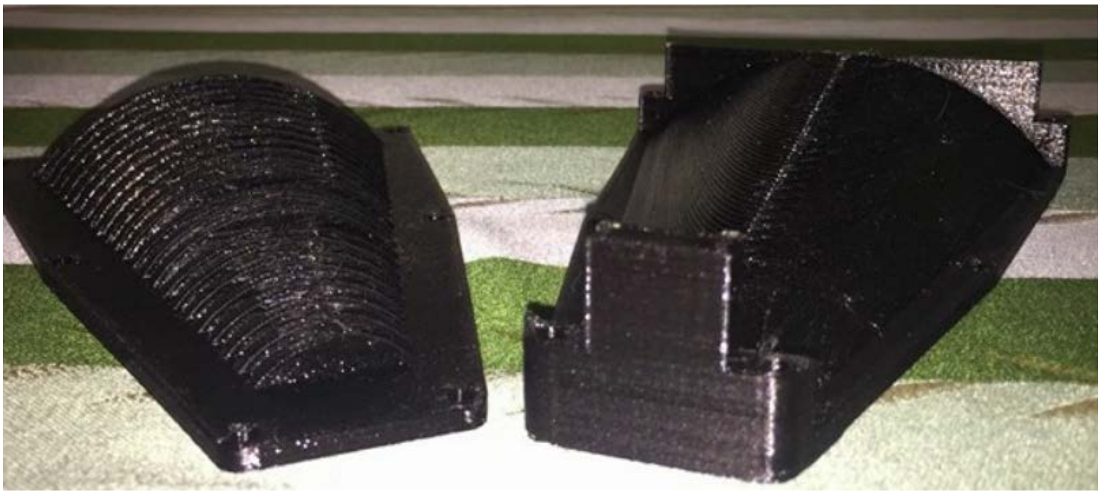


Figure 7: 3D printed mold

Soft Robot Making:

This was the most crucial and challenging stage of the project.

We started with the study of materials used for making soft robots. Materials included mold grade silicon, latex and elastomers (Ecoflex). The best choice was elastomers but these were not available in Pakistan, neither in the market nor via online services.

Latex was then used as the second option. Latex had low viscosity, high settling time and required air for cooling. Our mold was sealed hence we were not able to provide air contact to the latex hence this option failed to provide us the desired result.

As our next option, we decided to use 100% silicon. In market, HTV (High Temperature Vulcanization) and RTV (Room Temperature Vulcanization) samples were available. We proceeded with the RTV as it would have been harder to vulcanize than HTV.

The RTV Silicon had sticky nature so to avoid damage to our mold, we placed food wrap paper inside the mold and then poured silicon in it. Both the right and left parts of the fish were made this way. To provide rigidity, we placed cardboard paper in between the two parts. When we tested our robot, it failed to provide the desired movement, it expanded instead of making axial movement. Then we made a slot in 3mm acrylic sheet and poured silicon in it and used the dried silicon in between the two parts of the fish. The desired result was not achieved again. We concluded it was due to the food wrap used as it didn't allow the compartments to be made properly and as a result air didn't have much space to move through. Another reason was that the material did not exhibit the required adaptability features. Lastly, we needed a harder material to join the left and right parts of the fish.

We decided to move on with the same material with small alteration in its chemical properties to achieve the desired physical capabilities. For that purpose, we needed to react it with glycerin. So in a container of water and dish soap (which contains glycerin), we added silicon in it and it softened and the stickiness was reduced by a great factor. This also reduced the settling time of the silicon so we had to inject it into mold quickly after the reaction. We injected the softened silicon in our mold, and without food wrap paper this time so the channels can be made properly. After the silicon set, we achieved an excellent and fine design of the fish. The channels were properly made and so was the outer structure.

The last stage was to join the left and right part with suitable hard material in between them so axial movement can be smooth. We tried card paper for the previous design. Now we tried by placing rigid links in the central part. In our final design, we used relatively rigid silicon mixture to join the two parts using silicon sealant. Here are some pictures of our soft-robotic fish:

Figure 8: Initial design of fish

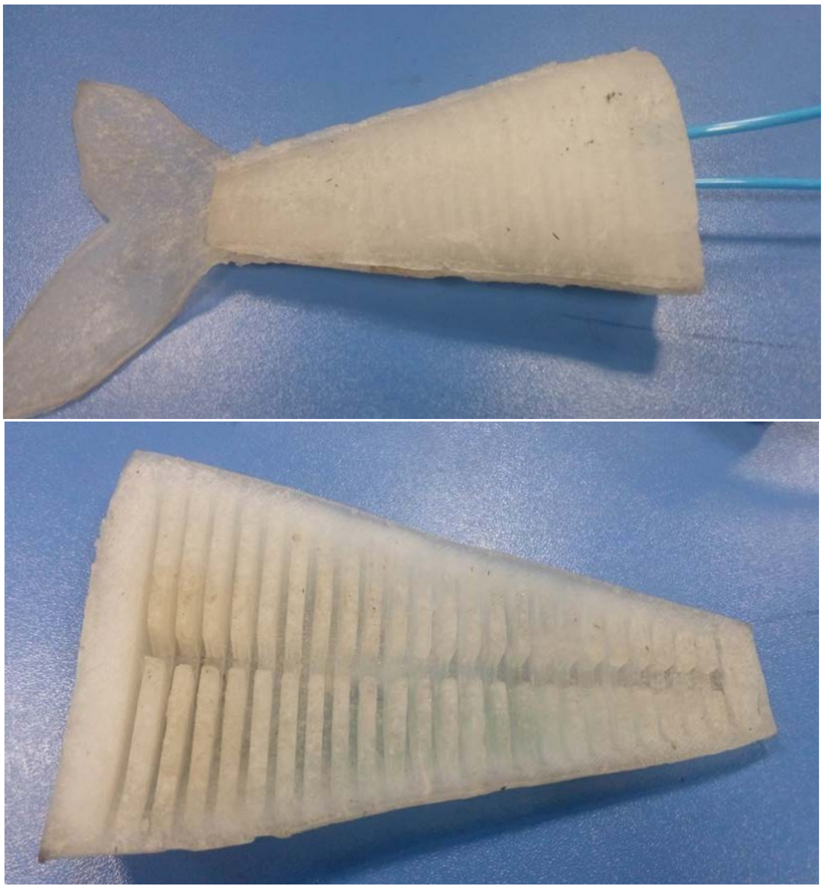


Figure 9: Final design of fish

Results and Discussion:

Our fish exhibited desired axial movement when pneumatic pressure was applied. The movement was slightly more in one direction as compared to the other. This was because both the left and right parts were made separately from silicon. The reaction with glycerin might not have been exactly same both times, thus the physical properties would have differed a bit.

Future Work:

We developed a tethered partial prototype. For future, a complete untethered prototype can be developed. This can be used for under water research purposes. These may include response of fish to emergency situations like being attacked by a bigger animal or being captured via a nest. The same rule can be applied to make various underwater research products.

Bill of Materials and Vendors:

Table 2: Cost of Project

ITEM	PRICE		Descrption	Vendor
3D Printed mold	Rs	5,800.00	PLA material 40rs per gram	3D printing arena
Arcyclic	Rs	160.00	center part mold 3mm 130rs per sqft	
Screws and nuts	Rs	60.00	closing mold	Rashid hardware
Silicon Caulk	Rs	840.00	Silicone Sealant 210 per bottle	Rashid hardware
Silicon Gun	Rs	220.00	Gun for smmoth extrusion of silicon sealant	Rashid hardware
Thinner	Rs	120.00	Walayiti Thinner (lower viscousity)	National Paint shop
Miscelanoues	Rs	100.00	Wood,Boxes,Elfy,dish soap,petrol,drill bits	Local

Acknowledgements:

We are thankful to Dr. Ali Raza for guiding us through the project, especially on the stages where we were struck. We also extend our gratitude to Dr. Farhan Saeed of Polymer Engineering Department for guiding us in the material selection process.

Introduction:

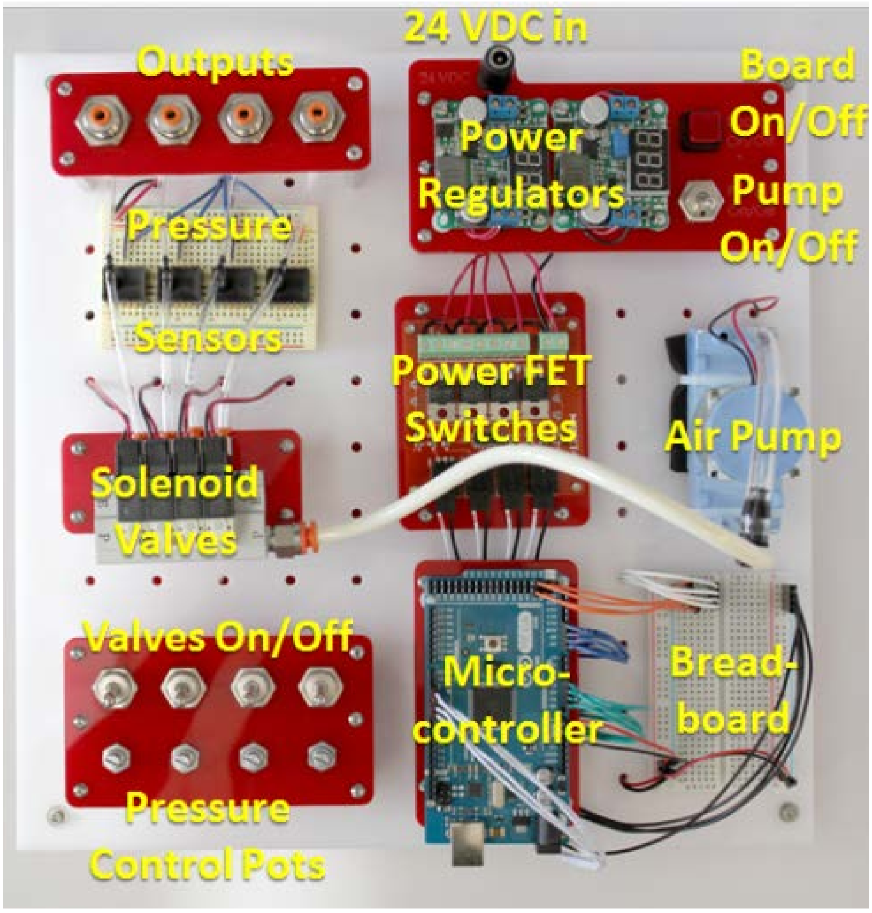
Fluidic Control Board was an integral part of our Robotics semester project. This control board is instituted to guide, regulate or control operation of the soft robot. It acts as a prototyping and testing tool, and provides us with a hands-on understanding of how to control fluid-operated soft robots. It also enables us to quickly test the behavior of pneumatic soft actuators.

Major Components:

Here is a list of major components that constitute the fluidic control board:

1. Solenoid Valve: To direct flow of fluid.
2. External Pump: To provide pressurized fluid.
3. Power Circuitry: Switches, IEC connectors, fuse and buck converter to ensure power supply to the board.
4. Microcontroller: To control/program the soft robot's movement via valves.
5. Manual Control Panel: To control the movement of robot manually for testing/prototyping.
6. Relay Module: For switching of solenoid valves.

Here is the design that we set as our target:



Components Required:

Here is a comprehensive list of the components used:

No.	ITEM
1	Arcyclic
2	Arcyclic
3	Screws and nuts
4	Sand papers
5	Wires
6	Extensions
7	Thimbels
8	Power Switch + Light
9	Banana Connectors
10	Buck Regulator
11	Relay Module
12	Rocker Switch
13	Fuse Holder
14	IEC Power Connector
15	terminal Blocks
16	Arduino Mega
17	Arduino Wires
18	Toggle Switches
19	POTs
20	Fuse
21	Panel Sockets
22	6m5 male connectors
23	6mm - 4mm convertors
24	6mm pipe
25	4mm pipe

Tools Required:

Here is a list of tools that were used while making the fluidic control board:

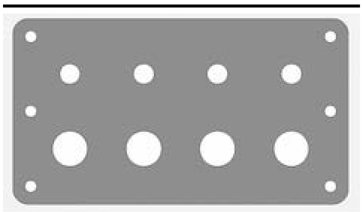
1. Drill machine and drill bits (4mm, 8mm, 14mm)
2. Jigsaw
3. Spanner set
4. Screw driver set
5. Soldering iron
6. Thimble plier
7. Sand paper

Design Methodology:

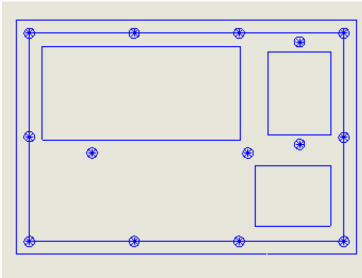
Design of Panel Layout:

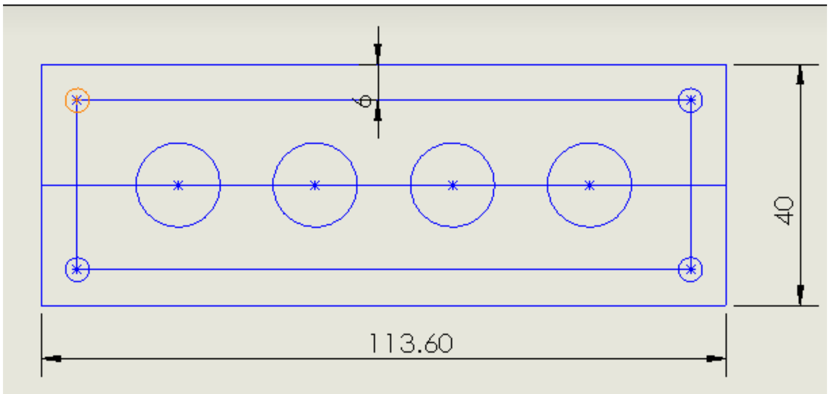
The 3D model of the panel was designed on Solidworks.

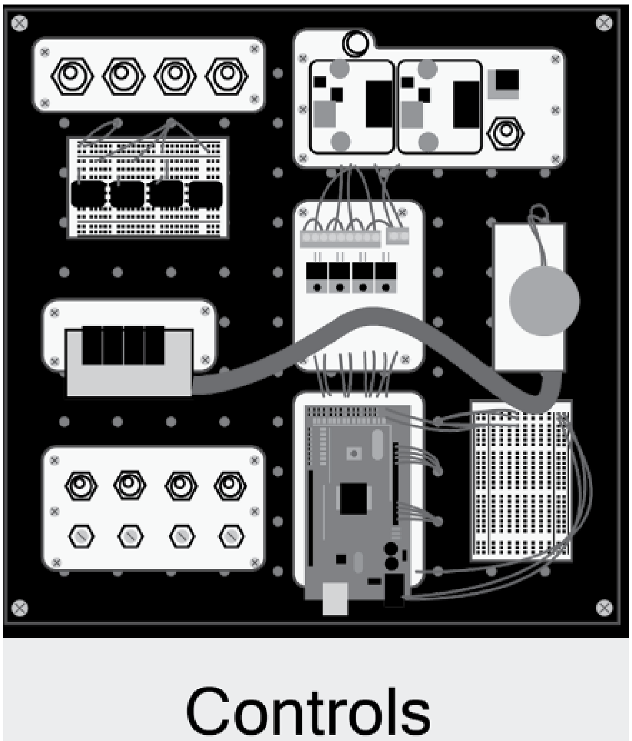
Output ports



Switches







Cutting of Panel:
The panel was cut as per the layout designed in previous step. Jigsaw was used to cut it and holes were drilled.

Manual Control Panel:
Switches, potentiometers and extensions were mounted on the panel in this step.

The Switches used are standard toggle switches. The potentiometers are 10K which were not used. Originally, they were present to vary switching frequency of each valve hence regulating its output pressure.

Power Distribution Board:
Electrical components like fuse and buck converter were mounted on the board and wired.

The Power distribution board was designed keeping in view the ratings of solenoids valves, as our valves were operated on 24Vdc, and each valve had a nominal current load of 10mA. The first connector from top right, is IEC connector for connecting 24V supply, The orange lit push button is Mode selector(manual/code),right next to it is buck regulator to step down 24Vdc to 5Vdc

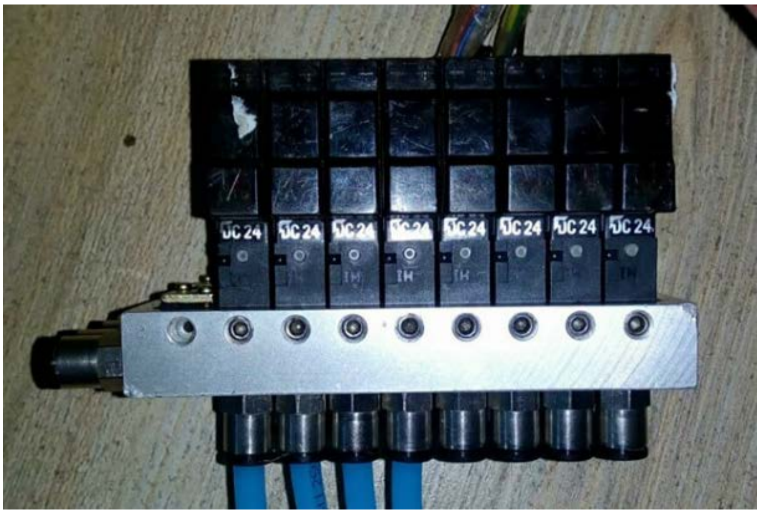
Relay Module:

Relay module was fixed on the panel and wired.

Relay Module used was active Low.

Valves:

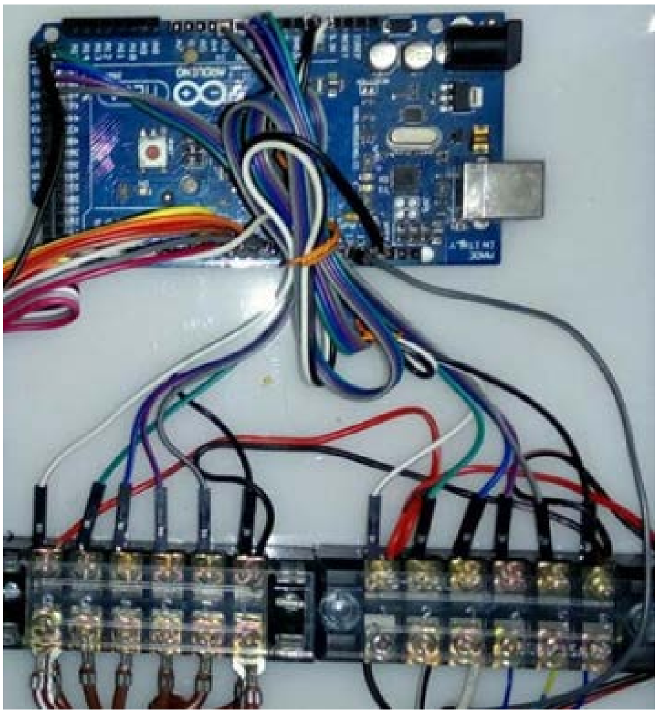
3x2 solenoid actuated valve was fixed on the panel. The valves had operating pressure range of 0-7 Bar.



The valves were mounted on Aluminum base, 6m5 connectors were connected. The extremes ports on the base are pressure ports and the others two ports are exhaust. All the ports below base are individual outputs of each valve.

Microcontroller:

We used Arduino Mega 2560 to control the fluidic board.



Arduino Code:

Here is the code that we used to control our 'Soft-Robotic Fish'.

```
void setup() {
  pinMode(12,INPUT); // Mode Selector input toggle switches or code
  pinMode(0,OUTPUT);   pinMode(1,OUTPUT);   pinMode(2,OUTPUT);   pinMode(3,OUTPUT);
pinMode(4,OUTPUT);  pinMode(5,OUTPUT); // Relays (values) low activated
                                                        /*    2 == RED (1st)    ,  4
== Orange(2nd), 0 == yellow (3rd),
                                                              1  ==  magenda  (4th),
5 == Grey (5th) , */

  pinMode(46,INPUT);pinMode(48,INPUT);pinMode(50,INPUT);pinMode(52,INPUT);           //
Toggle Switches /* 46 == Grey (4th) , 48 == Magenda (3rd) , 50 == Blue (2nd) , 52 == Green
(1st) */
    /* switching off all the relayds initially*/
    digitalWrite(2,1);
    digitalWrite(4,1);
    digitalWrite(0,1);
    digitalWrite(1,1);
    digitalWrite(5,1);
    digitalWrite(3,1);
```

```
}
void loop()
{
  if (digitalRead(12)==LOW)
  {
     digitalWrite(2,digitalRead(52));
     digitalWrite(4,digitalRead(50));
     digitalWrite(0,digitalRead(48));
     digitalWrite(1,digitalRead(46));
  }
else if (digitalRead(12)==HIGH)
{
  // Write your Robot working code here
     digitalWrite(2,0);
     delay(1000);
     digitalWrite(2,1);
     delay(100);
     digitalWrite(4,0);
     delay(1000);
     digitalWrite(4,1);
}



}
```

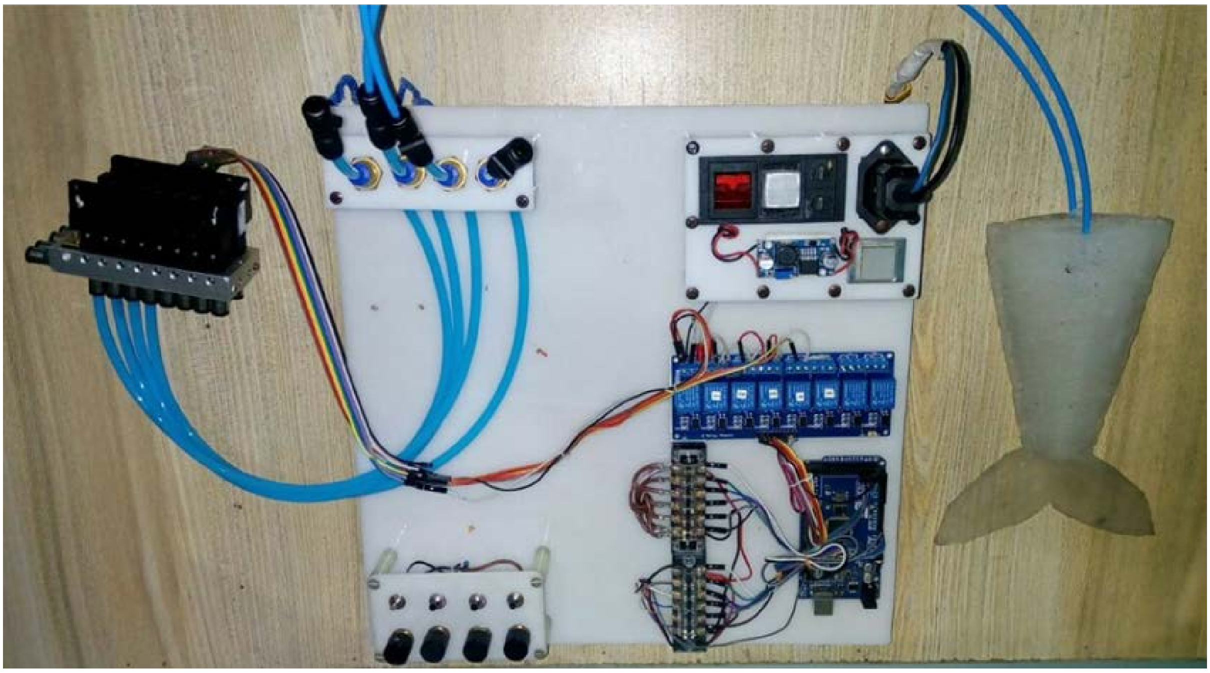
Cutting of Base:
5mm thick acrylic sheet was used as the base. It was cut into 1.5’ x 1.5’ dimensions.

Power Supply:

Power could be supplied to the control board using various sources, we used LiPo battery.

Final Product:

Here is what the fluidic control board looked like after successful completion:



.