

PiQSaR

Pneumatic Bio-Inspired Quadrupedal Soft Actuator Robot

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PROBLEM STATEMENT

Traditional Rigid Robots

- Not suitable for lifting fragile or irregularly sized objects and can damage produce in agricultural use cases
- Can become dysfunctional under unexpected conditions/impacts, eg, subsea vehicle that imploded during exploration
- Fixed joints and hard parts limit flexibility and can harm humans, eg, damage tissues during medical procedures. (From *Advanced Materials*)

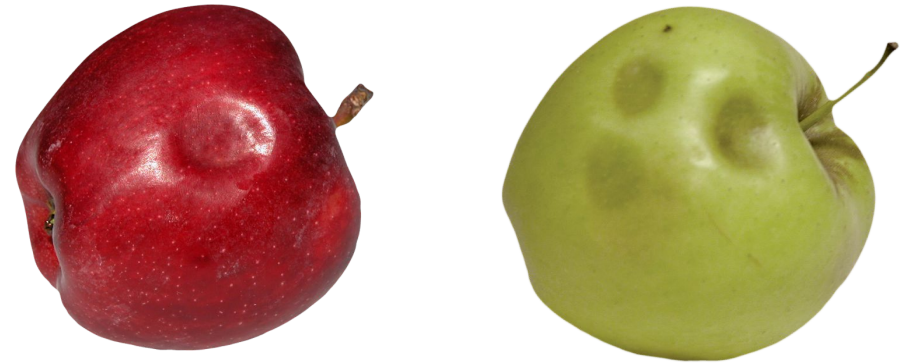


Image From: Washington State University

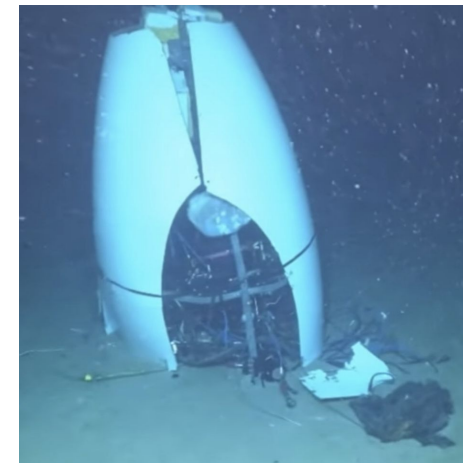


Image From: The Guardian

Investigate technologies like soft robotics and machine learning to solve problems with rigid robots.

BACKGROUND RESEARCH

Soft robotics: Bio-inspired, elastic & adaptable, can access hard-to-reach places & deal with delicate objects without causing damage.

Sensors & Machine Learning: Used for collecting data points through sensors and analysis using ML code resulting in powerful capabilities like object recognition, precise control and handling for robots.



Image from: WLRN

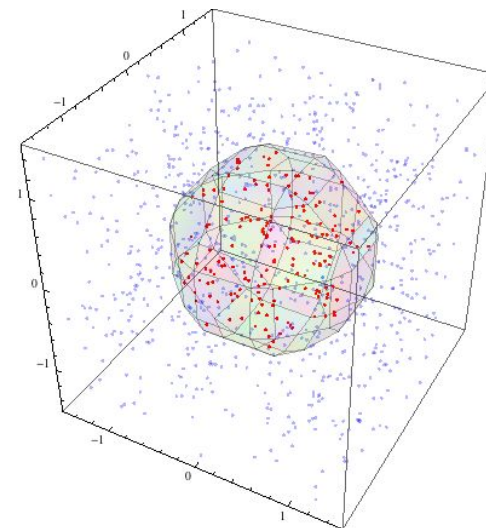


Image from: Mathematica Stack Exchange

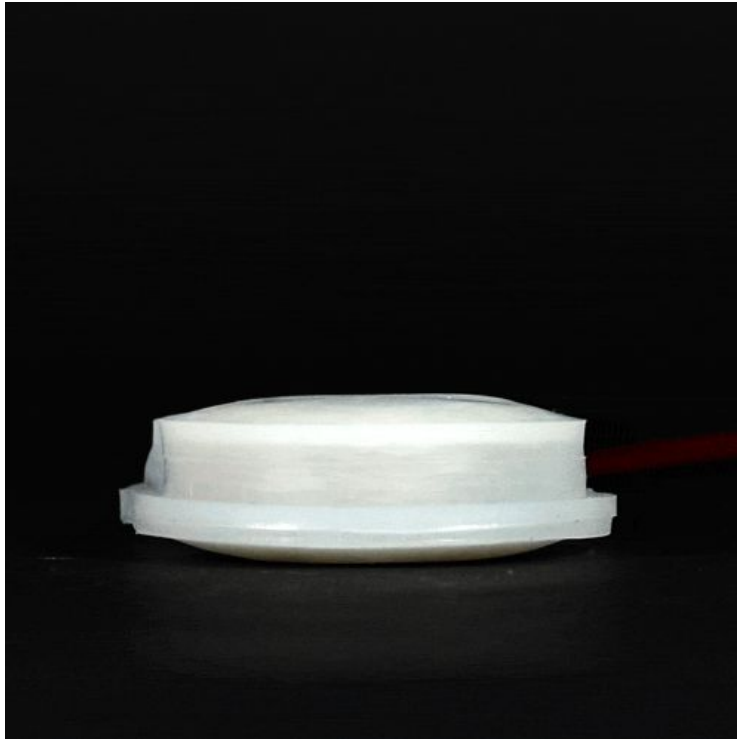
BACKGROUND RESEARCH

- According to a study by **Robotics Tomorrow**, soft robotic **exosuits** reduced injuries drastically;
 - Without exosuits: 1 in 7 full-time workers got injured
 - With exosuits: 1 in 47 full-time workers got injured
 - 6.7-fold improvement
 - 36% reduction in unsafe lifts for workers who wore the suit for five months or longer
 - Reduced hip injuries by 60-85%
- Impacts from soft robots have 40-50% less peak impact forces than rigid robots.

This study shows that soft robots can reduce injuries.

EXISTING SOLUTIONS

Artimus Robotics



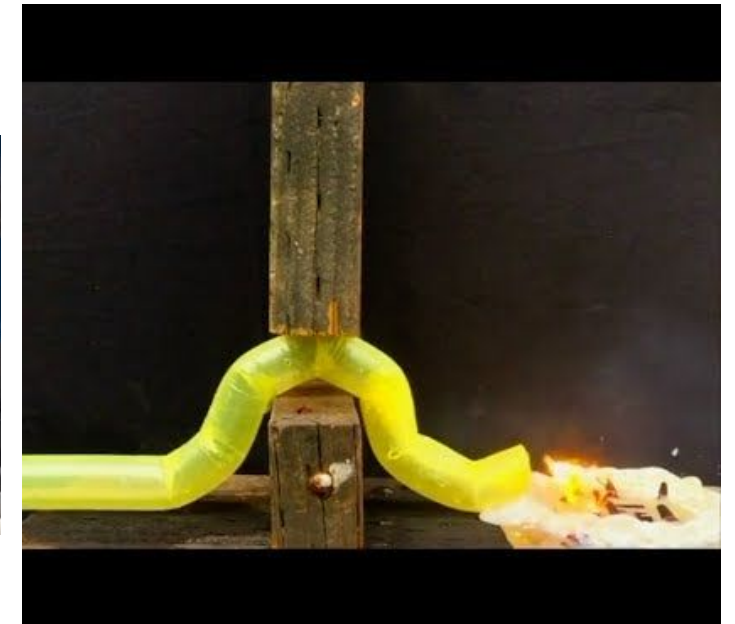
- Electrically controlled using electrostatic technologies
- Pass high voltage

Rochu



- Provides industrial soft robot solutions for automation and manufacturing
- Mechanically controlled

MIT and Stanford Labs



- Researching on medical applications of soft robots
- Vine-like soft robot can automatically grow

ENGINEERING GOAL

Develop PiQSaR

Pneumatic bio-Inspired Quadrupedal Soft actuator Robot

- Can mimic living species
- Can interact with fragile objects without causing any damage
- Has integrated sensing capabilities
- Can map the object shape/size in real-time
- Has integrated ML to detect objects based on values given by the flex sensors



Image From: Equal Experts

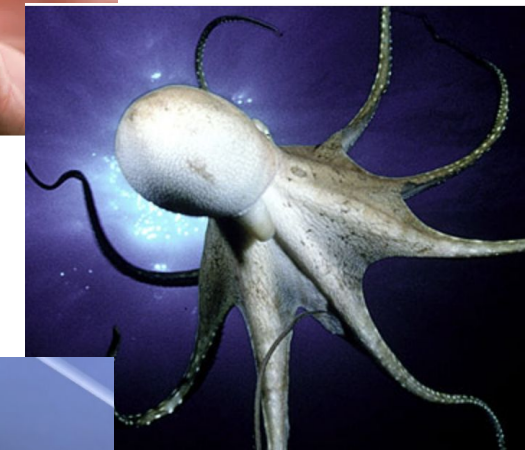


Image From: pbs.org



ENGINEERING GOAL

Why did we build PiQSaR?

- Interact with irregularly shaped objects better than rigid robots
- Interact with delicate objects
- Graph objects based on flex sensor values



Image from: Shutterstock

Who is it for?

- Farmers
 - Harvesting crops
- Marine Research Organizations
 - Visualize objects
 - Adaptable in unknown places
 - Handle fragile organisms

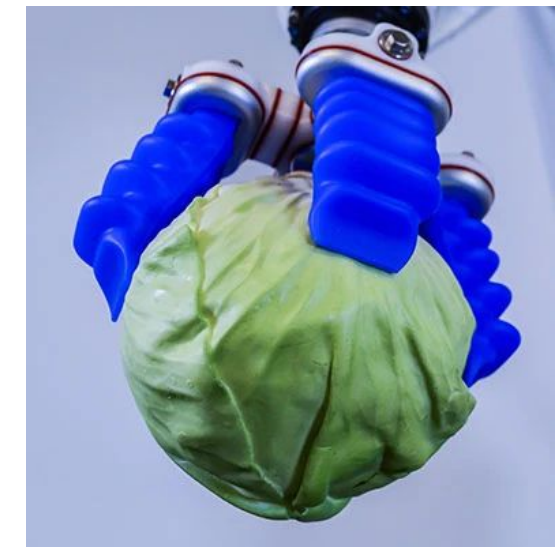


Image from: Croptracker

MATERIALS/RESOURCES



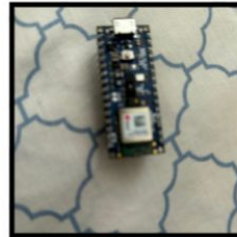
Picture from Amazon

**Silicone
Rubber
x2**

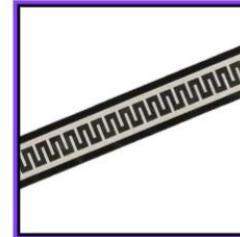


Picture from Amazon

**Syringe
Set x 2**



**Arduino
Nano 33 BLE
Sense x 1**

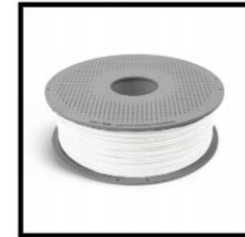


Picture from Amazon

**Flex
sensors
x 4**



**100KPa 370
Motor Mini Air
Pump x 1**



Picture from WOL 3D

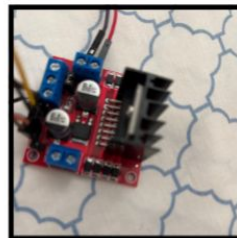
Filament



VS Code



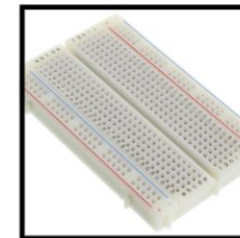
**Arduino
IDE**



**L289
Motor
Driver x 1**



**Bambu
3D
Printer**



**Bread
board x 1**



Picture from Amazon

**Jumper
Wires**

CRITERIA/CONSTRAINTS

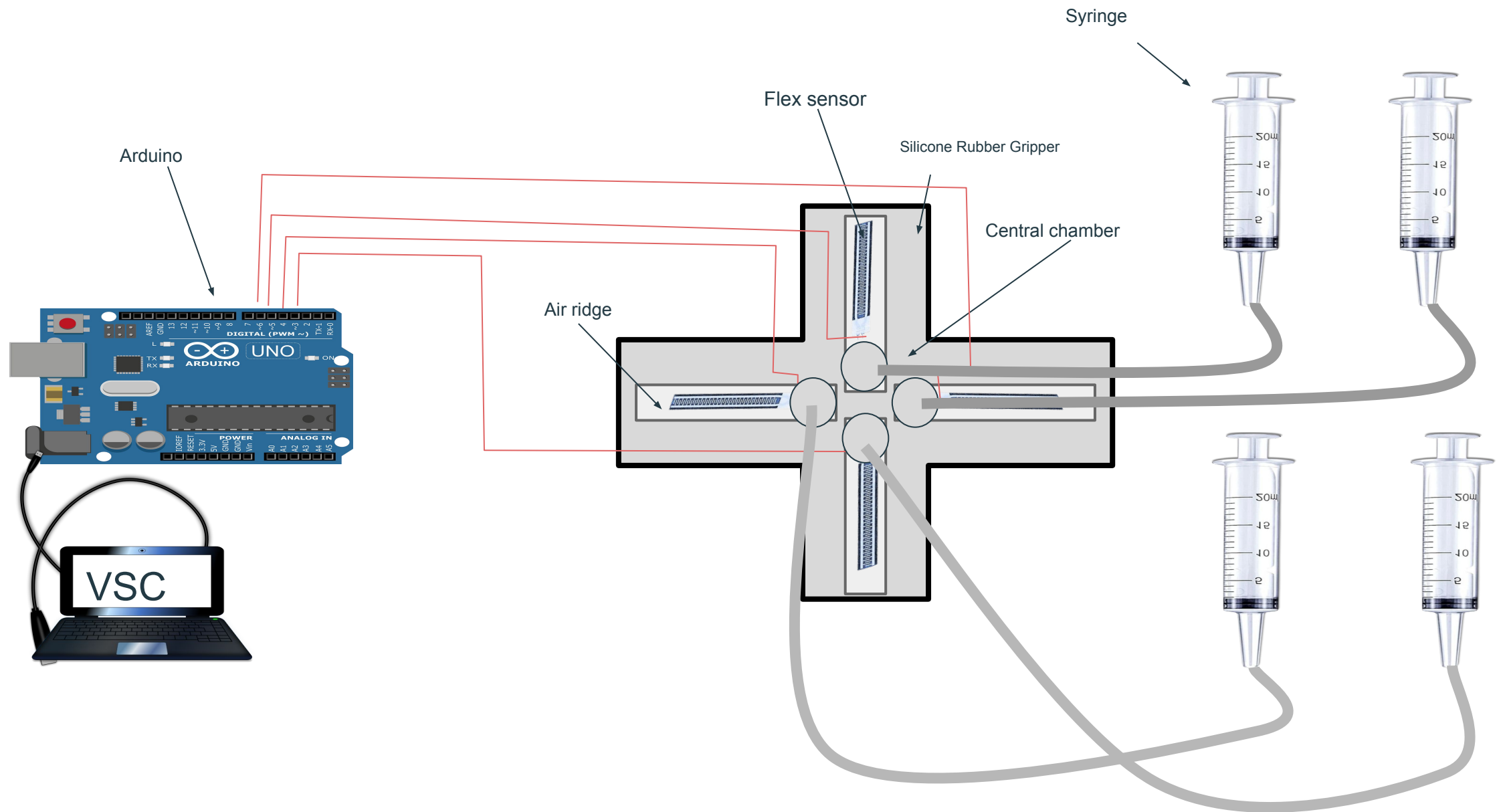
Criteria

- Soft robot should be able to bend and apply a secure grip upon applying pneumatic pressure
- Should be able to lift an object with over 75% accuracy
- Should be able to transmit flex sensor data to VSC in real time
- Software developed should be able to map a diagram of the object in real time

Constraints

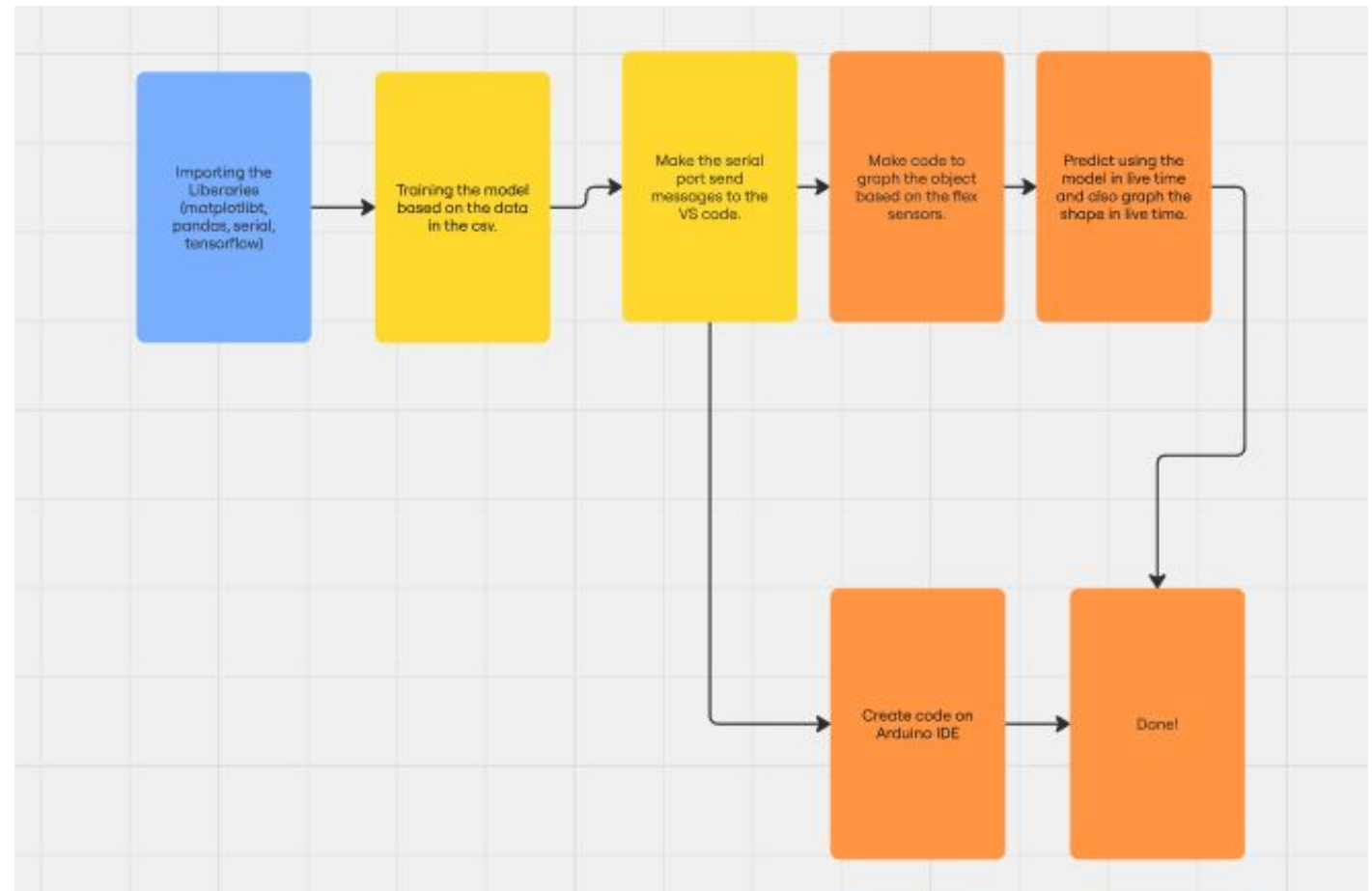
- Due to cost and accessibility constraints, we will use off-the-shelf silicone rubber; Ecoflex 00-30 instead of industrial strength rubber
- Limited air power - used syringes instead of air pump
- Should have a maximum size of 12.7 x 12.7 x 2.5 cm
- Arduino must be powered with a USB cable

DIAGRAM



CODE

- **Arduino & flex sensors**
 - Generates data points
 - Graphs the object shape using input data from flex sensors
- **Machine Learning**
 - Detects the object in real time given a trained data set.

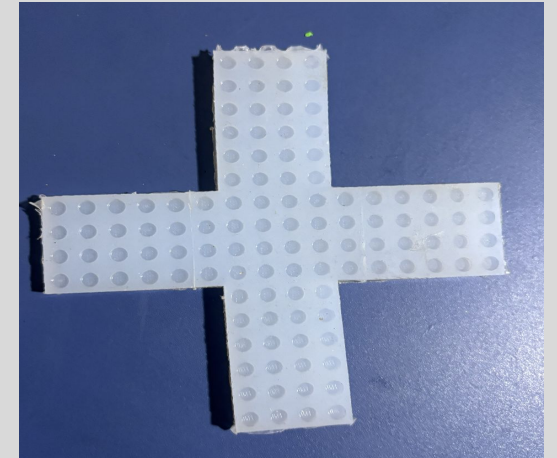
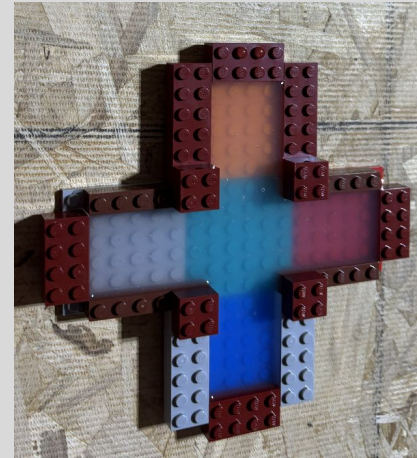


ITERATIONS

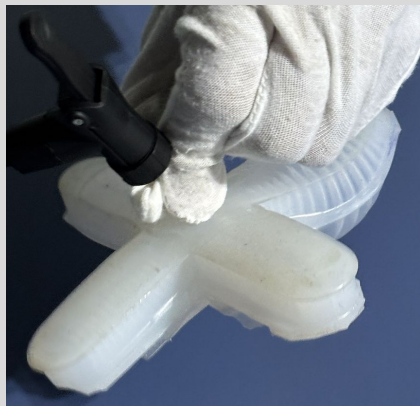
Soft tentacle using legos and ballpoint pen barrel



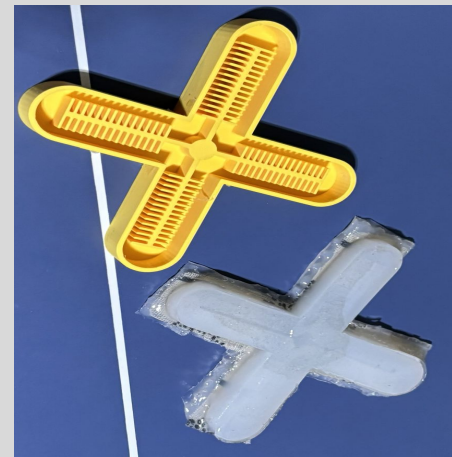
Soft gripper using lego



Quadrupedal Soft Gripper with central air chamber using 3D printed mold



3D printed soft gripper with cloth base

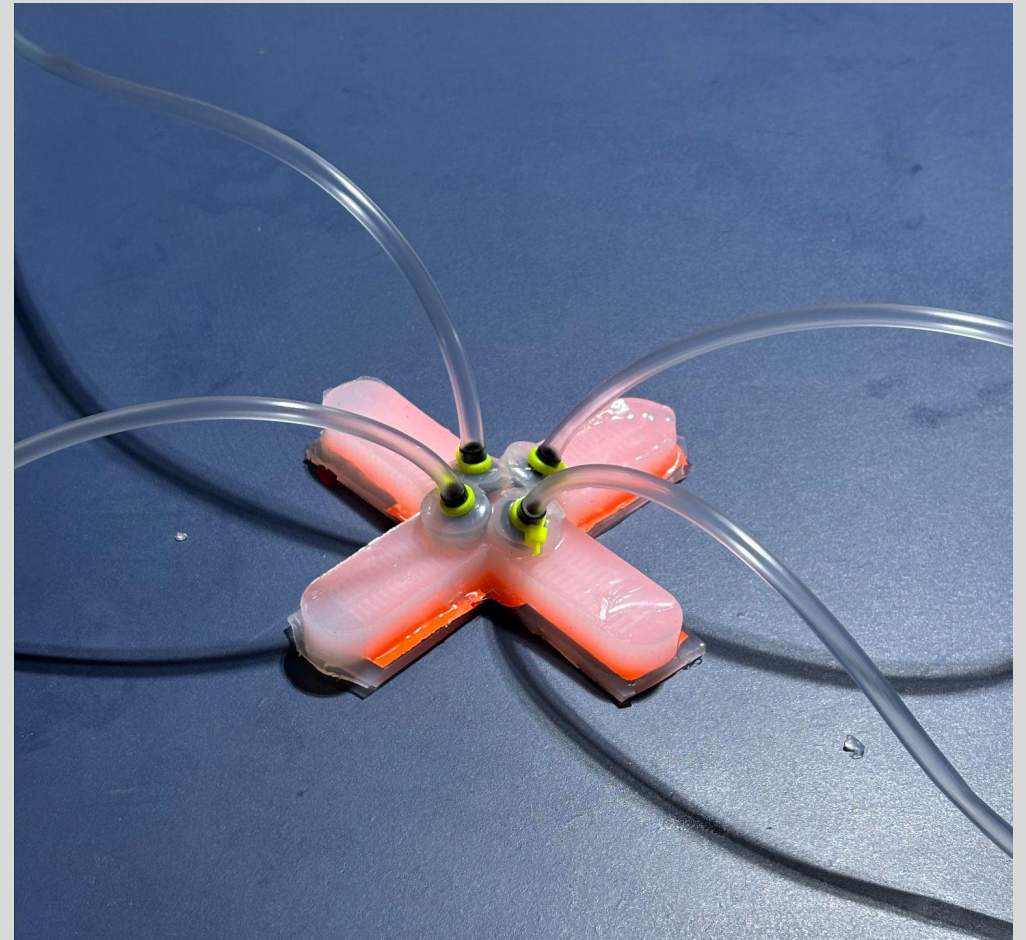


ITERATIONS

Soft gripper using 3D printed mold and a cloth base



Quadrupedal using 3D printed mold and a gorilla tape base



CODE

Gets value from Arduino Flex sensors

```
const int flexPin = A7;
const int flexPin1 = A6;
const int flexPin2 = A5;
const int flexPin3 = A4;

void setup() {
  Serial.begin(9600); // Start serial communication
}

void loop() {
  int value = analogRead(flexPin);
  int value1 = analogRead(flexPin1);
  int value2 = analogRead(flexPin2);
  int value3 = analogRead(flexPin3);

  // Map values from 0-1023 to 0-255
  value = map(value, 0, 1023, 0, 255);
  value1 = map(value1, 0, 1023, 0, 255);
  value2 = map(value2, 0, 1023, 0, 255);
  value3 = map(value3, 0, 1023, 0, 255);

  // Print sensor data as a CSV line
  Serial.print(value);
  Serial.print(" ");
  Serial.print(value1);
  Serial.print(" ");
  Serial.print(value2);
  Serial.print(" ");
  Serial.println(value3); // Newline to end the row

  delay(1000); // 1 second delay between readings
}
```

Sensor
Pins

Flex
Sensors

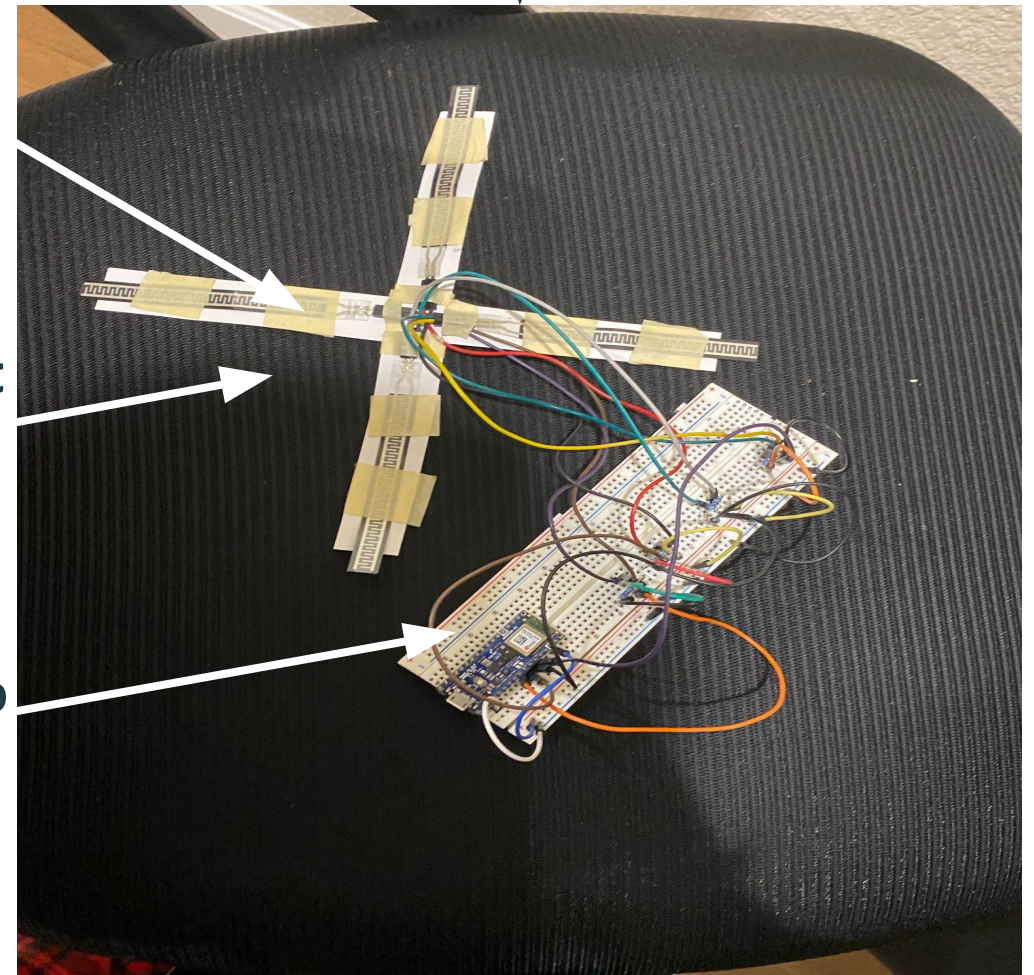
Robot
Arms

Reading
sensor

Arduino

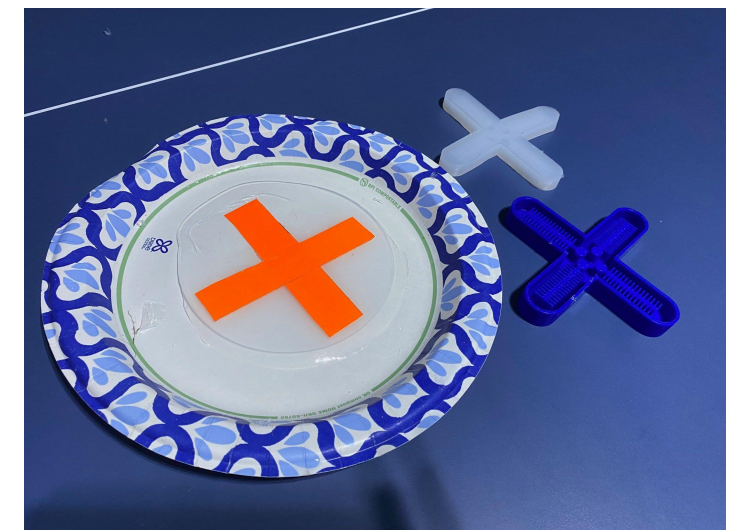
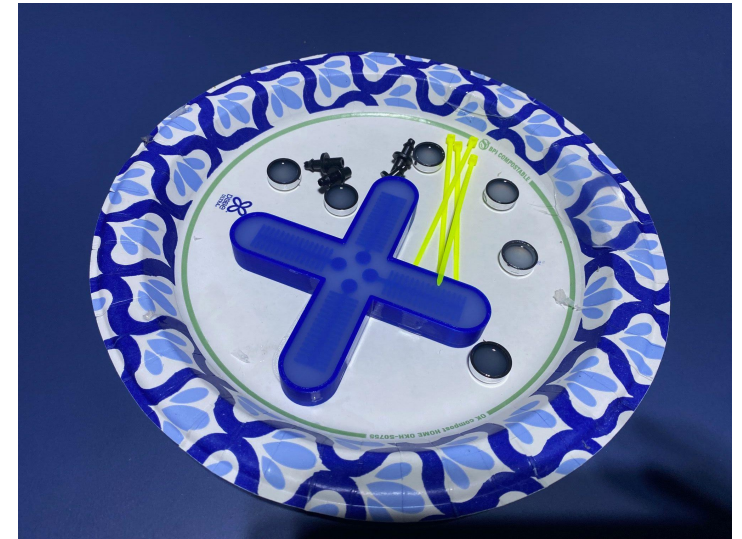
Changing
Value
Range

Image of flex sensors connected to arduino and
breadboard



PROCEDURE

1. 3D print a mold with four legs that each have a hole at the start of the legs. Add ridges that run through all the legs.
2. Mix the Ecoflex 00-30 1A & 1B with a 1:1 ratio to form the silicone rubber mixture.
3. Pour the mixture into the molds and let it dry for eight hours.
4. Remove the dried rubber silicone from the mold.
5. Attach a syringe to a barbed coupling to prevent air leaks.
6. Insert the syringe into the start of one of the legs. Secure it using zip ties.
7. Glue together the top and the base of the soft robot with a thin layer of silicone rubber.
8. Attach the Arduino flex sensors to the base of the soft robot and connect the Arduino to a computer to collect the data points.
9. Use our Python program to generate a 3D image of the object.



TEST PLAN - ROBOT

1. Place an object, such as a cup, on a surface.
2. Position the soft robot gripper on the top of the cup. Try to make it as centered as possible.
3. Inflate the soft robot using the syringe.
4. Once the soft robot has a secure grip on the cup, lift the cup into the air.
5. Hold it in the air for ten seconds.
6. Note if the cup is bent while it is in the air.
7. Put the cup back on your surface and deflate the robot.
8. Record if your robot was successful or not.
9. Repeat the process four more times.



TEST RESULTS

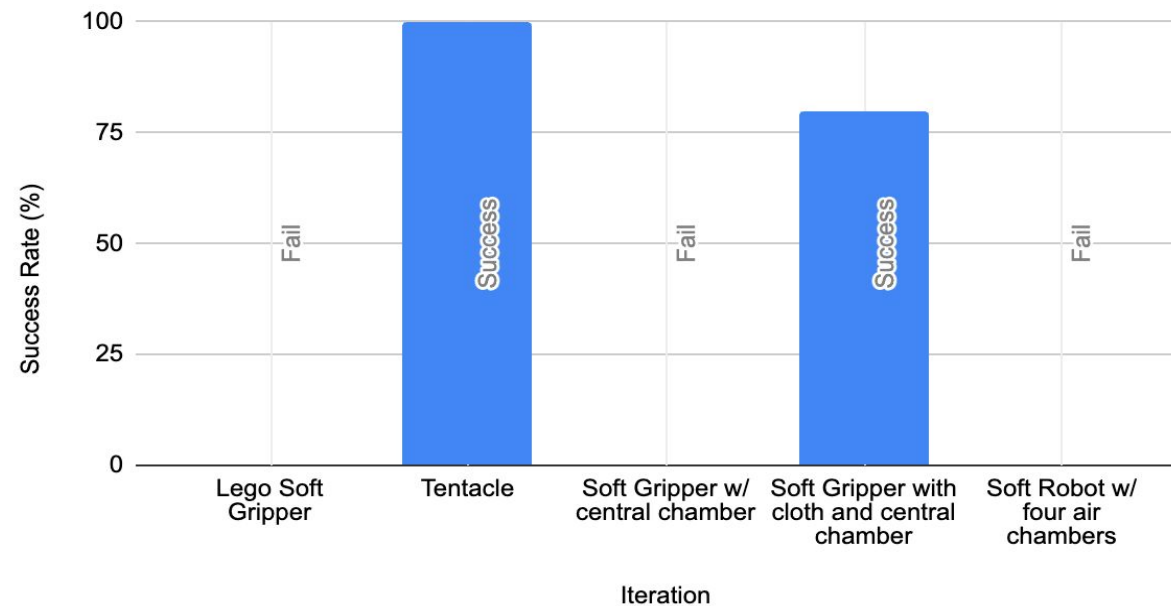
Soft Robots

- Made five iterations of PiQSaR
 - Lego based robot
 - Failed because the ridges inside the robot were too thick to be expanded by the syringe
 - Tentacle built using lego and a pen barrel
 - **Successfully** curled around the handle and lifted objects 5/5 times
 - 3D printed soft robot with central air chamber
 - Failed; the robot could not grip the object because the top and the base both expanded outwards
 - 3D printed soft robot with cloth base and central air chamber
 - **Successfully** gripped and lifted objects 5/5 times
 - 3D printed quadrupedal soft robot with air chambers for each leg; gorilla tape base
 - Failed due to the gorilla tape not sticking to the silicone rubber which created air leaks

TESTING - ROBOT

Iteration	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Success Rate (%)
<i>Lego Soft Gripper</i>	Fail	Fail	Fail	Fail	Fail	0
<i>Tentacle</i>	Success	Success	Success	Success	Success	100
<i>Soft Gripper w/ central chamber</i>	Fail	Fail	Fail	Fail	Fail	0
<i>Soft Gripper with cloth and central chamber</i>	Success	Success	Fail	Success	Success	80
<i>Soft Robot w/ four air chambers</i>	Fail	Fail	Fail	Fail	Fail	0

Iteration Success Rate

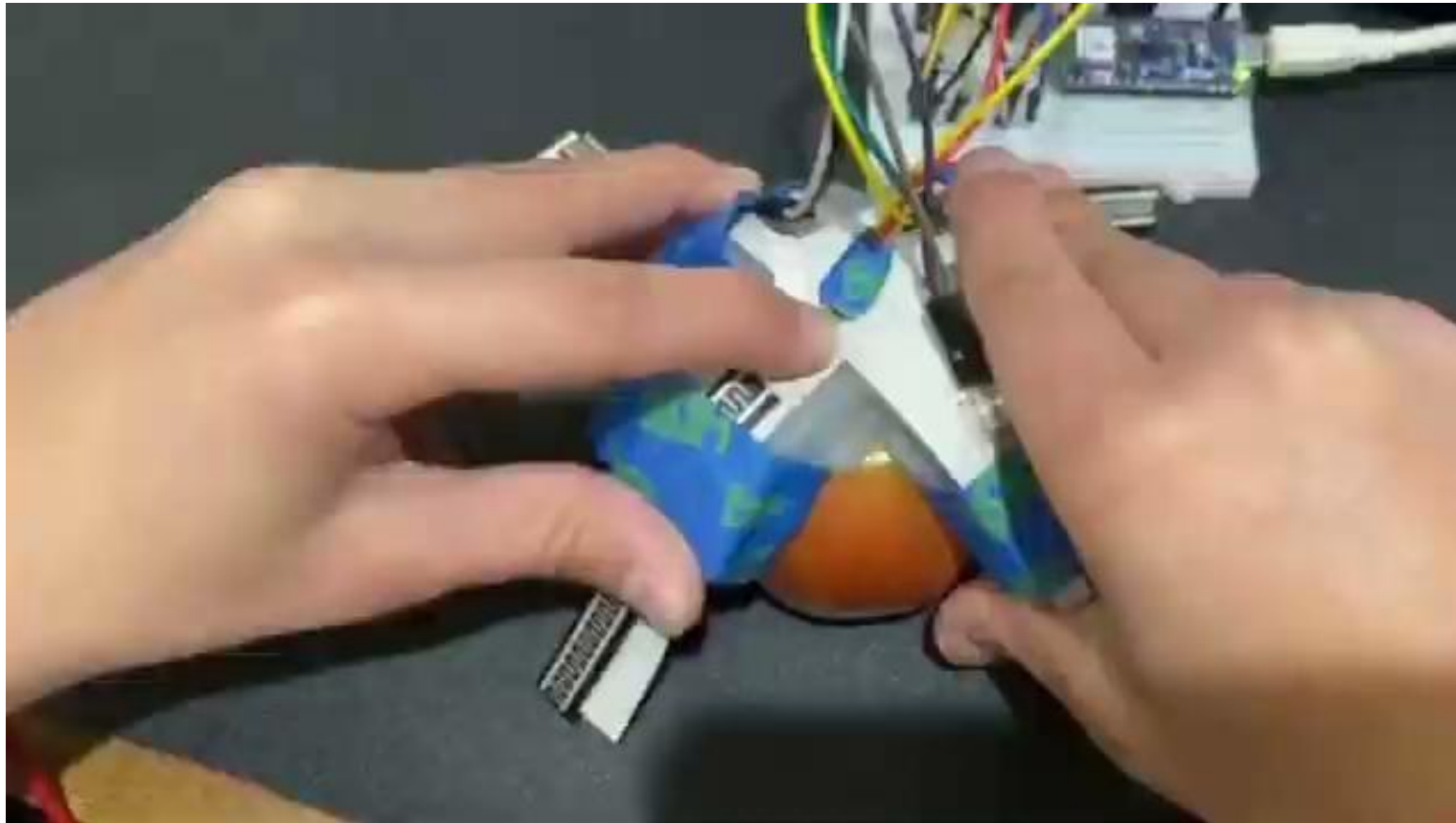


TEST PLAN - CODE

1. Put four flex sensors onto the robot, with each flex sensor going onto a separate leg.
2. Use syringes to inflate and deflate the robot.
3. Get real time data of the flex sensors and use it to predict the object with given data, and see if accurate.
4. Map the object and see if it is close to the right object.
5. Record your data and repeat the process four more times.

Live ML Object Detection & Graphing

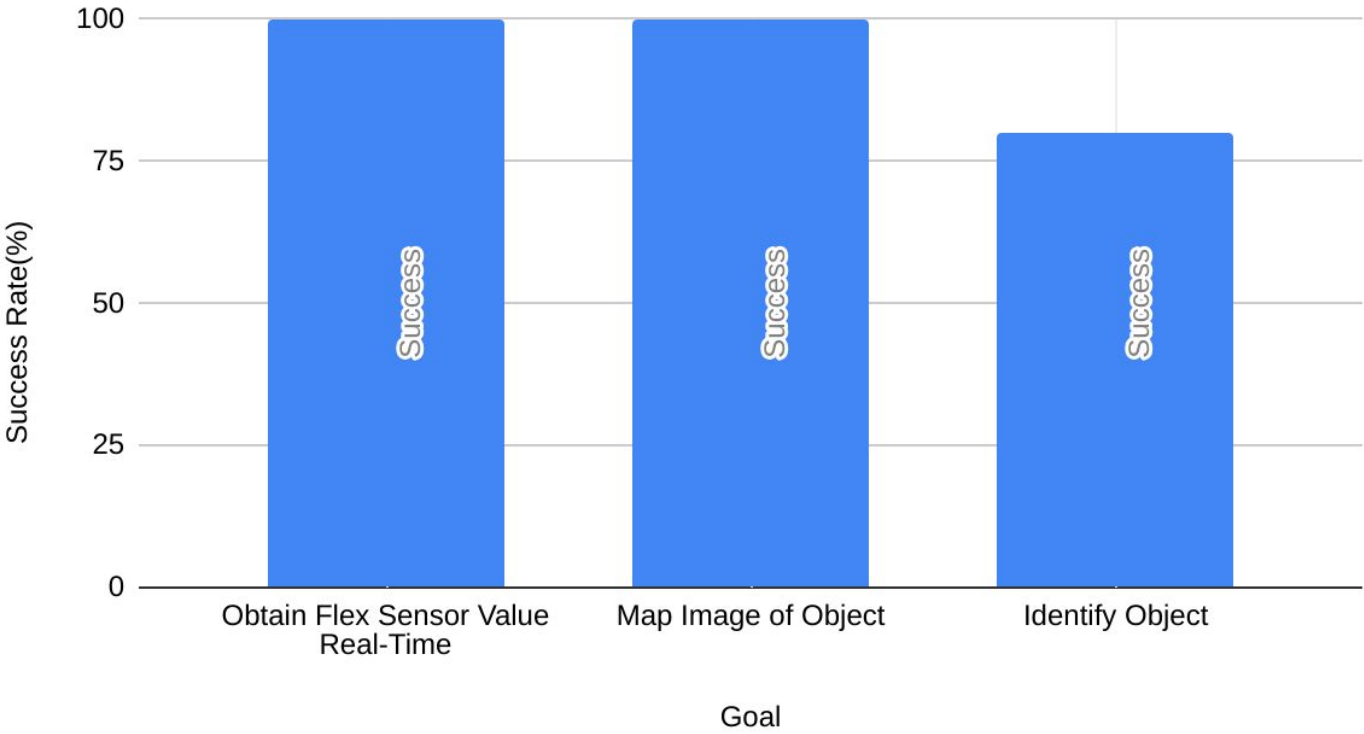
(Graphing is not fully refined)



TESTING - CODE

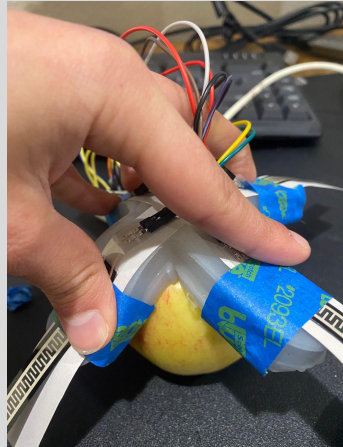
Goal	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Success Rate (%)
<i>Obtain Flex Sensor Value Real-Time</i>	Success	Success	Success	Success	Success	100
<i>Map Image of Object</i>	Fail	Success	Success	Success	Success	80
<i>Identify Object</i>	Success	Fail	Success	Success	Success	80

Success Rate of Code



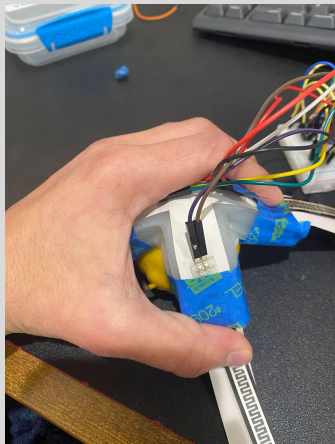
CODE TESTING IMAGES

Apple

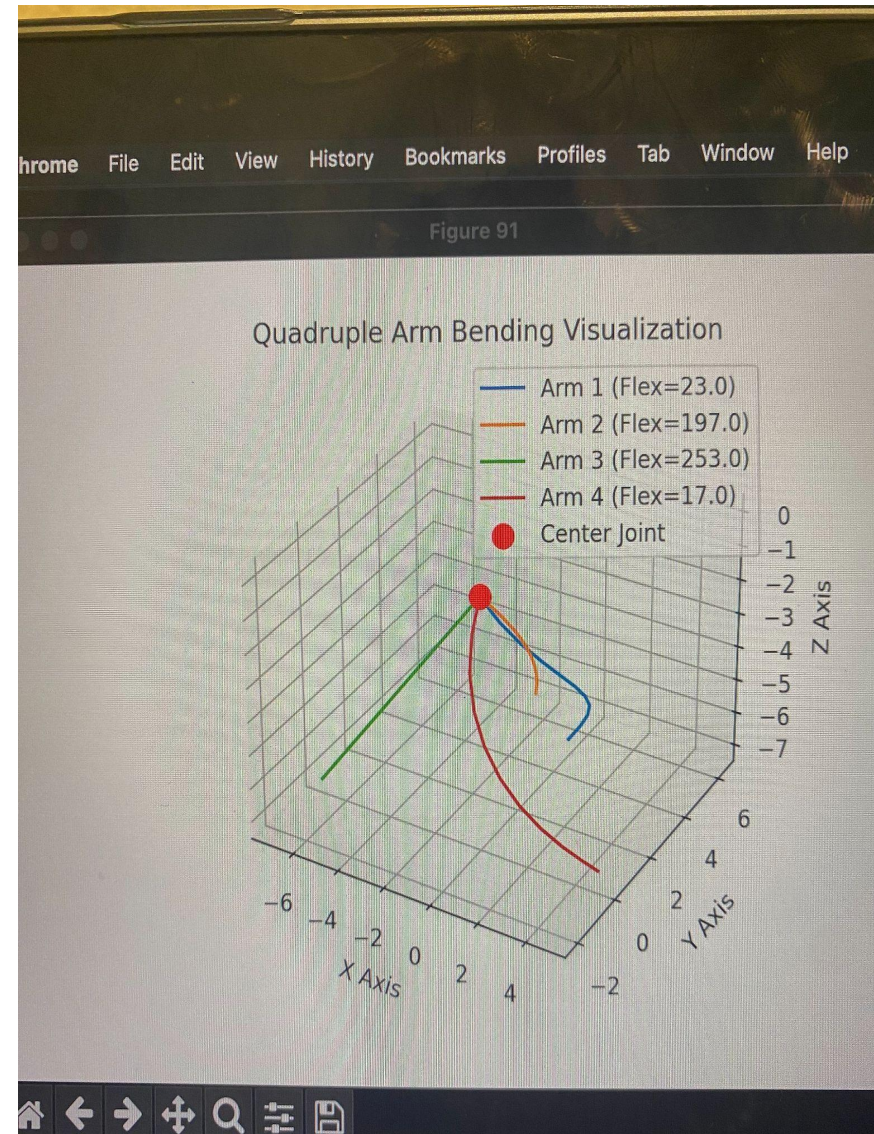


```
1/1 _____ 0s 10ms/step
1/1 _____ 0s 10ms/step
Predicted Object: apple, Flex Values: [2
1/1 _____ 0s 9ms/step
1/1 _____ 0s 9ms/step
Predicted Object: apple, Flex Values: [2
1/1 _____ 0s 9ms/step
1/1 _____ 0s 9ms/step
Predicted Object: apple, Flex Values: [25
1/1 _____ 0s 10ms/step
1/1 _____ 0s 9ms/step
Predicted Object: apple, Flex Values: [25
1/1 _____ 0s 9ms/step
1/1 _____ 0s 9ms/step
Predicted Object: apple, Flex Values: [25
1/1 _____ 0s 9ms/step
1/1 _____ 0s 10ms/step
Predicted Object: apple, Flex Values: [253
[]
```

Lemon



```
CONSOLE  TERMINAL
TERMINAL
1/1 _____ 0s 8ms/step
1/1 _____ 0s 9ms/step
Predicted Object: lemon, Flex Values: [24.0, 30.
[2.84591335 2.77199352 2.87055329 2.993753 ]
1/1 _____ 0s 9ms/step
1/1 _____ 0s 9ms/step
Predicted Object: lemon, Flex Values: [22.0, 183
[2.87055329 0.88703793 2.85823332 2.993753 ]
1/1 _____ 0s 9ms/step
1/1 _____ 0s 8ms/step
Predicted Object: lemon, Flex Values: [25.0, 219
[2.83359337 0.44351896 2.84591335 2.993753 ]
1/1 _____ 0s 9ms/step
1/1 _____ 0s 9ms/step
Predicted Object: apple, Flex Values: [20.0, 0.0
```



RESULTS / CONCLUSION

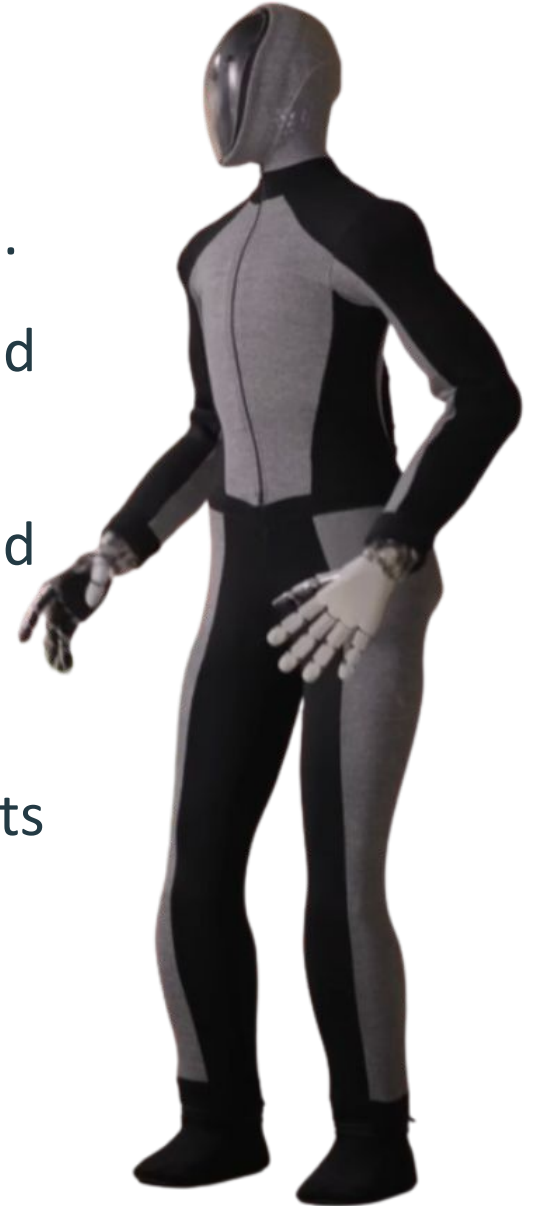
PiQSaR

- Developed a prototype of a bio-inspired flexible quadrupedal soft robot that can be controlled pneumatically and can lift objects consistently
- Flex sensors attached to the soft robot generates the shape of object and also detects the object using Machine Learning
- Can obtain flex data and map objects 100% of the time
- No damage was caused to any object the soft robot gripper picked up



FURTHER RESEARCH

- We also plan to have a PCB, which is the same circuit that we have but it will be smaller, allowing it to be more transportable.
- Order smaller flex sensors so that it can fit on the soft robot and be able to measure with full accuracy.
- Future experiments: mimic more human/bio body parts to build a soft robot that behaves, performs and reacts to all events/activities like living species
- Have more air power and have larger, more powerful soft robots built with industrial silicone rubber



CHALLENGES

- Soft robot gripper
 - Was expanding outwards instead of bending
 - Used cloth and gorilla tape on the base
 - Syringe was not staying glued to the robot, and there were some air leaks
 - Attached the syringe to a barbed coupling and then glued it with silicone rubber onto the robot
 - Used zip ties to secure the syringe onto the robot
- Code
 - Could not update map in real time
 - Transferred data which was meant to be received by Arduino to VSC
 - Used a serial port extension of Python
- Hardware
 - The Flex sensors were bigger than originally planned and didn't fit on the robot
 - Put Paper around to make a "+" shape which would fit the flex sensors.



Team Collaboration

- Advantages as working as a team
 - We were able to communicate very well
 - Common platform
- Vihaan N
 - Made the soft robots
- Devansh C
 - Helped Code
 - Made design of mold in TinkerCAD
- Vihaan P
 - Made Arduino circuit and code
- As a team
 - Worked on presentation
 - Were able to complete more slides at once
 - Helped and critiqued each other throughout the project



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