# 3D Printed Soft Robotics

Prosthetic Hand

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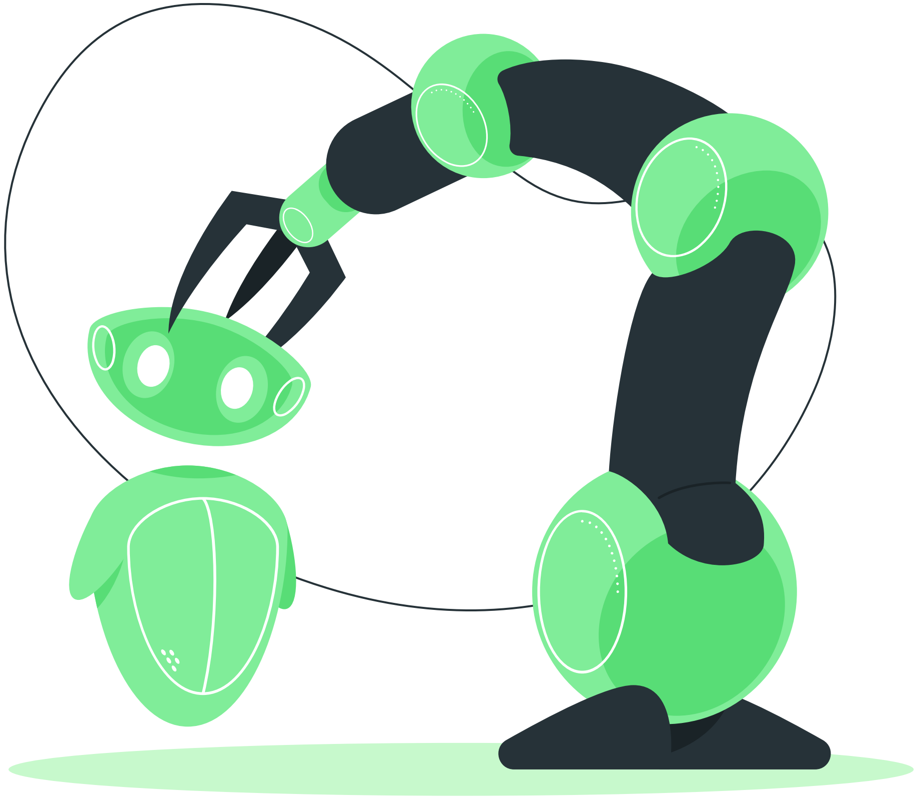
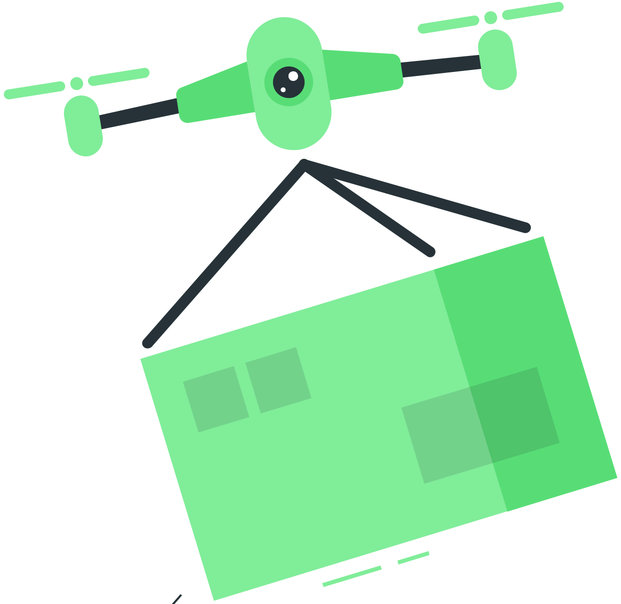


# Inspiration

Exploring the broader applications of 3D printing within the robotic prosthetics industry.



# Reasoning

1

## Speed

Rapid prototyping allows creators to design, manufacture, and test their custom palms and actuators at minimal cost in as little time as possible.

2

## Customization

Every use case is unique. Individuals can create custom solutions to suit their specific needs.

3

## Accessibility

Desktop 3D printers are becoming increasingly cost effective, allowing this technology to reach more people.

# Goals

1

### 3D Printed Actuators

Direct 3D Printing of personalized soft robotic fingers without the need for post-processing.

2

### 3D Printed Palm

Create a palm to house necessary components and act as an interface between fingers and the forearm.

3

### Integration of Valves

Unique to this project, the solenoid valves that operate the hand are stored inside the palm.

# The Solution

A fully 3D printed Soft Robotic Prosthetic Hand (Palm, Actuators, and Valves) utilizing pressured air.

# 3D Printing Technologies

## Fused Deposition Modeling (FDM)

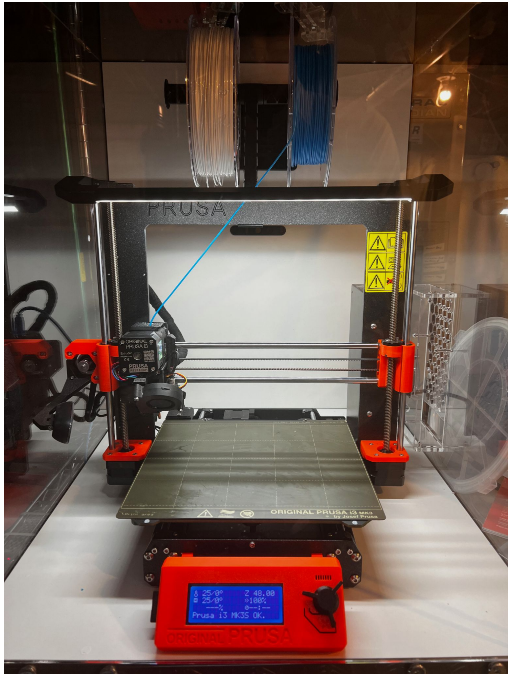
- FDM 3D printing works by extruding plastic filament through a heated nozzle and depositing layer after layer onto a heated print bed.

## Stereolithography (SLA)

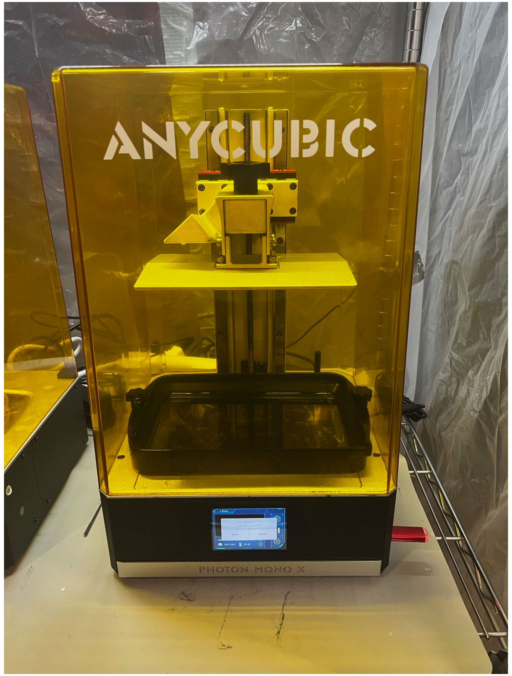
- SLA 3D printing uses UV lasers to systematically cure a polymer resin.

# 3D Printers

**Original Prusa i3 MK3S+**
**(FDM 3D Printer)**



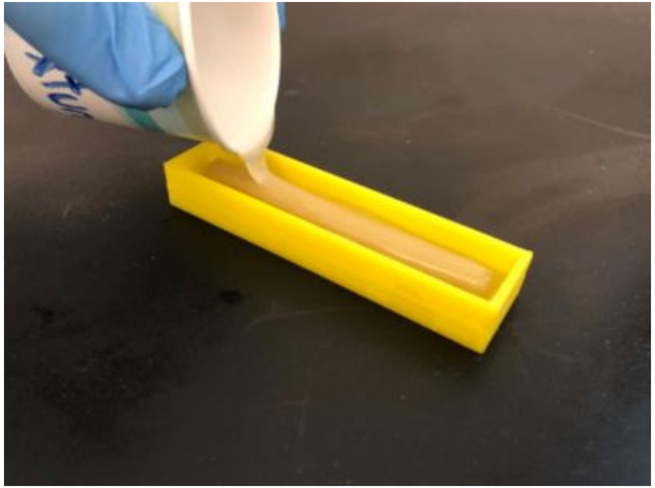
**Anycubic Photon Mono X**
**(SLA 3D Printer)**

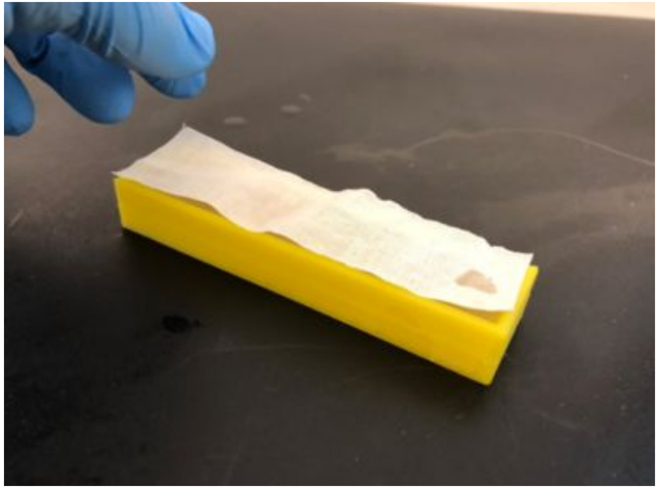


# How do Soft Robotics Work?

# Existing Soft Robotic Devices

- **Soft Robotics Toolkit**
    - Many actuator designs stemming from the Soft Robotics Toolkit involve a lengthy and technical fabrication process that involves:
        - 3D Printed Molds
        - Silicone
        - Fabrics





## 1

# Research Process

## Control Board

# Fluidic Control Board

## Soft Robotics Toolkit

- Tool used for prototyping and testing
- Allows for individual control of actuators
- PWM Control over Solenoid valves using Potentiometers
- Feedback from pressure sensors through serial monitor allow for verification and testing of vario levels of PSI.
- **Figure 1 –** Soft Robotic Toolkit Design
- **Figure 2 –** My own Fluidic Control Board

**Figure 1**

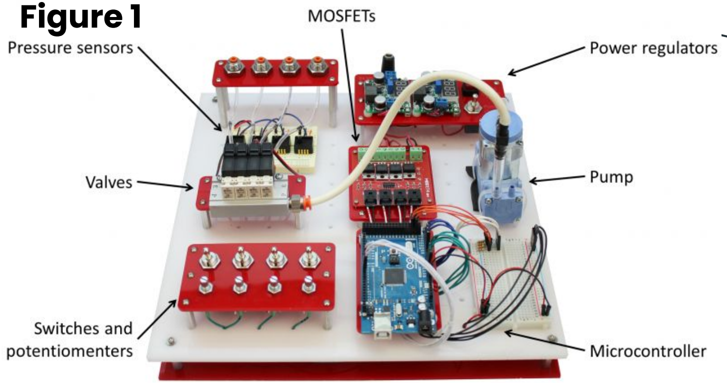
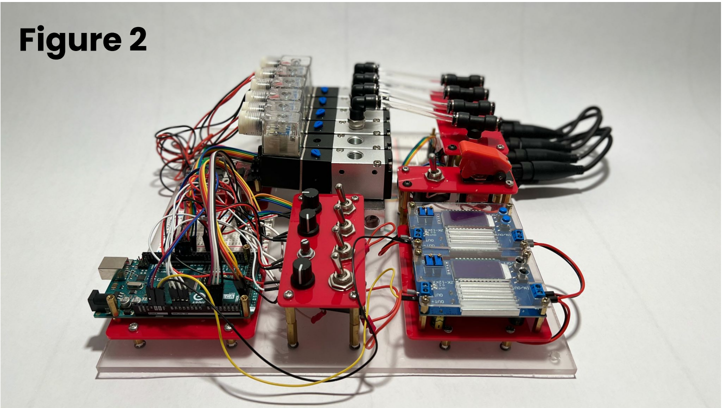
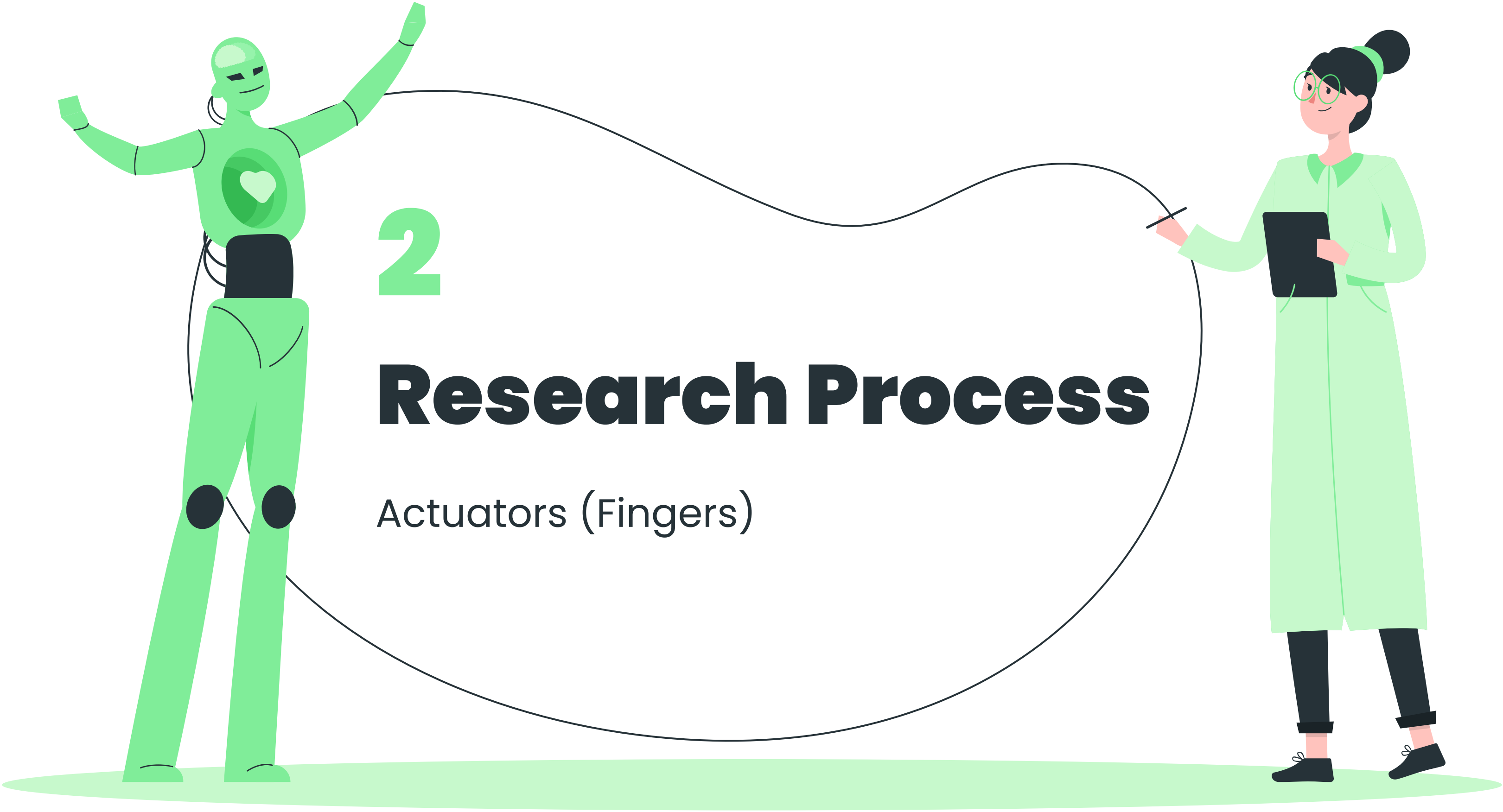


**Figure 2**



# Pneumatic System

- **Pneumatic System**
  - Pneumatic air is used to precisely inflate the actuators (fingers) and bend them into desired positions.
  - Allows for ergonomic gripping of objects
- Initial work was done with a mini vacuum pump.
  - 40L/min
- Final testing used a pancake air compressor
  - 150 max PSI



## 2

# Research Process

Actuators (Fingers)

# Actuators - Final Design

**Important Elements:**

- Layer height - .2mm
- Infill - 100%
- Support under pneumatic extension
- Foot Wall thickness - .6mm
- Foot length - 4.2mm
- Initial air compartment size - 12.8mm
- Side wall thickness - 1mm
- Length of tubing interface - 13mm
- Thickness of tubing interface - 1mm

**Figure 1**

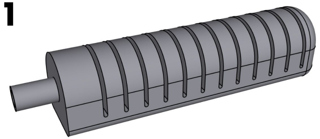
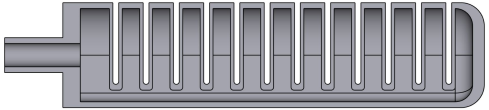


**Figure 2**



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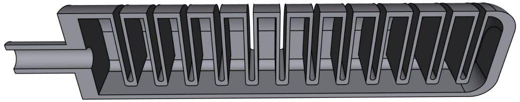
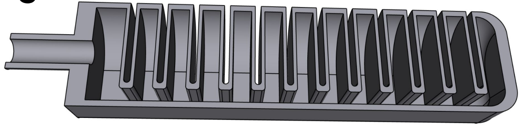


**Figure 4**



# Actuators - SLA Prototyping

- Printed using **Anycubic Photon Mono X**
- Materials
    - F69
        - Shore Hardness - 60-75A
        - Elongation at break - 255.1%
    - Flexible - X
        - Shore Hardness - 55A
        - Elongation at Break - 160%
- Post Processing
    - **Anycubic Wash & Cure Plus**
- 12+ Prototypes

# **Actuators** - FDM Prototyping

- Printed using **Original Prusa i3 MK3S+**
- Materials
    - Polymaker TPU
        - Shore Hardness - 95A
        - Elongation at Break - 331.1%
- 15+ Prototypes

# **Data** – Actuator Prototyping

| Version Number | Foot Wall Thickness (mm) | Distance Between Feet (mm) | Material | Result |
|---|---|---|---|---|
| MK-1 | 1 | 2 | Resione F69 | Structure Failure |
| MK-2 | .75 | 5 | Resione F69 | Structure Failure |
| MK-3 | .75 | 2 | Liqcreate Flexible-X | Structure Failure |
| MK-4 | .75 | 2 | Liqcreate Flexible-X | Structure Failure |
| MK-5 | .75 | 2 | Liqcreate Flexible-X | Structure Failure |
| MK-6 | 1 | 2 | Liqcreate Flexible-X | Structure Failure |
| MK-7 | 1 | 2 | Liqcreate Flexible-X | Structure Failure |
| MK-8 | 1.5 | 3 | Liqcreate Flexible-X | Structure Failure |
| MK-9 | 1.5 | 3 | Liqcreate Flexible-X | Structure Failure |
| MK-10 | 1 | 3 | Polymaker PolySmooth TPU95 | Low Flexibility |
| MK-11 | 1 | 2 | Polymaker PolySmooth TPU95 | Low Flexibility |
| MK-12 | .6 | 1 | Polymaker PolySmooth TPU95 | Success |

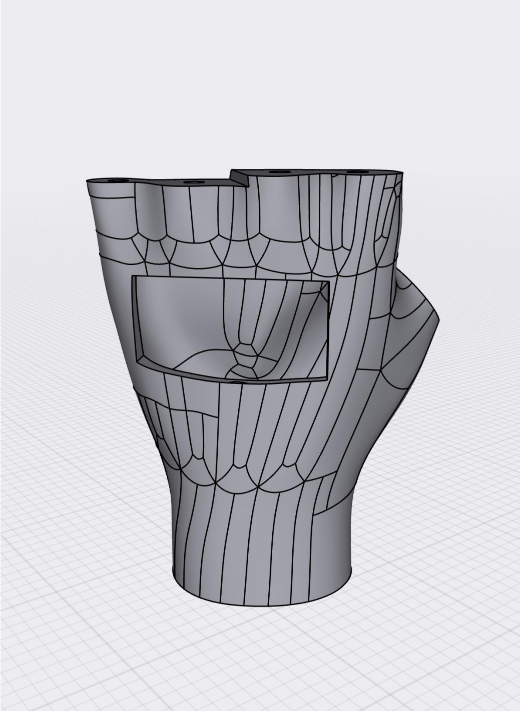
## 3

# Research Process

Main Body - Palm

# Palm - Design

- An existing 3D model of a Hand was used as a base for the design.
- Model was scaled and hollowed, followed by the creation of a cavity to house the components, and pathways were created for pneumatic tubing.
- The Fingers were removed systematically by using existing model lines and replaced with soft robotic actuators.



# Palm - Prototyping

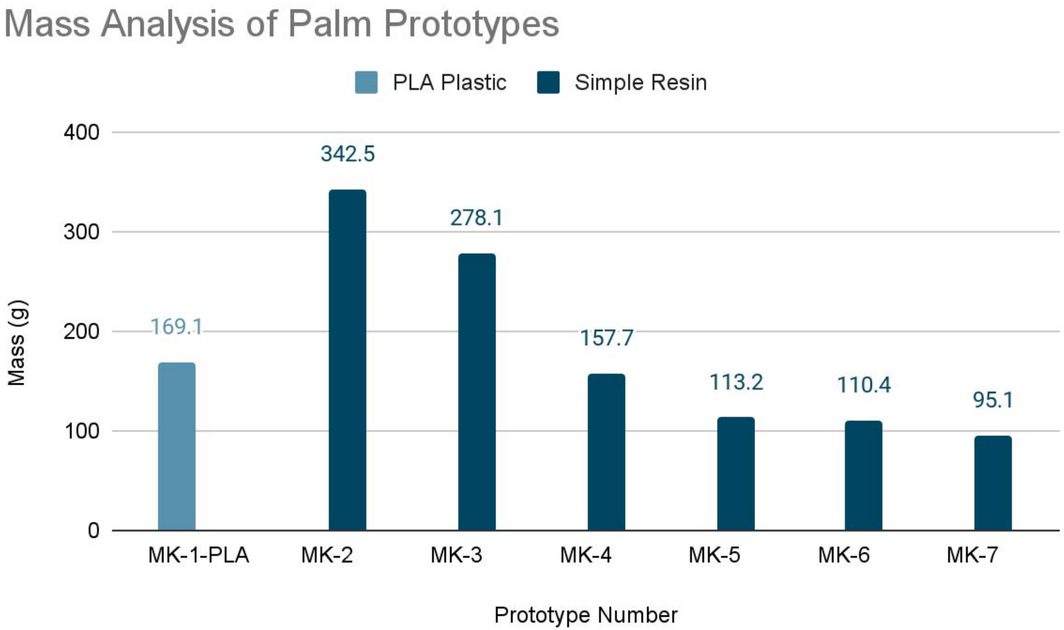
- Initial printing performed on FDM Printer
- Moved over to SLA for improved print quality and improvement of complex geometries on the interior.
- The translucent printing resin allows insight on the interior cavity.
- 7+ Prototypes

**Figure 1**

**Figure 2**

# Palm - Mass Reduction Analysis

- A Soft Robotic hand needs to be as lightweight as possible to ensure the comfort of the amputee and reduce fatigue.



# Palm - Components

- Five microvalves are utilized inside the palm
- Pneumatic Tubing is secured to the actuators using CA Glue and activator
- Figures 3-5 are ongoing research on embedding force sensors into the actuators.

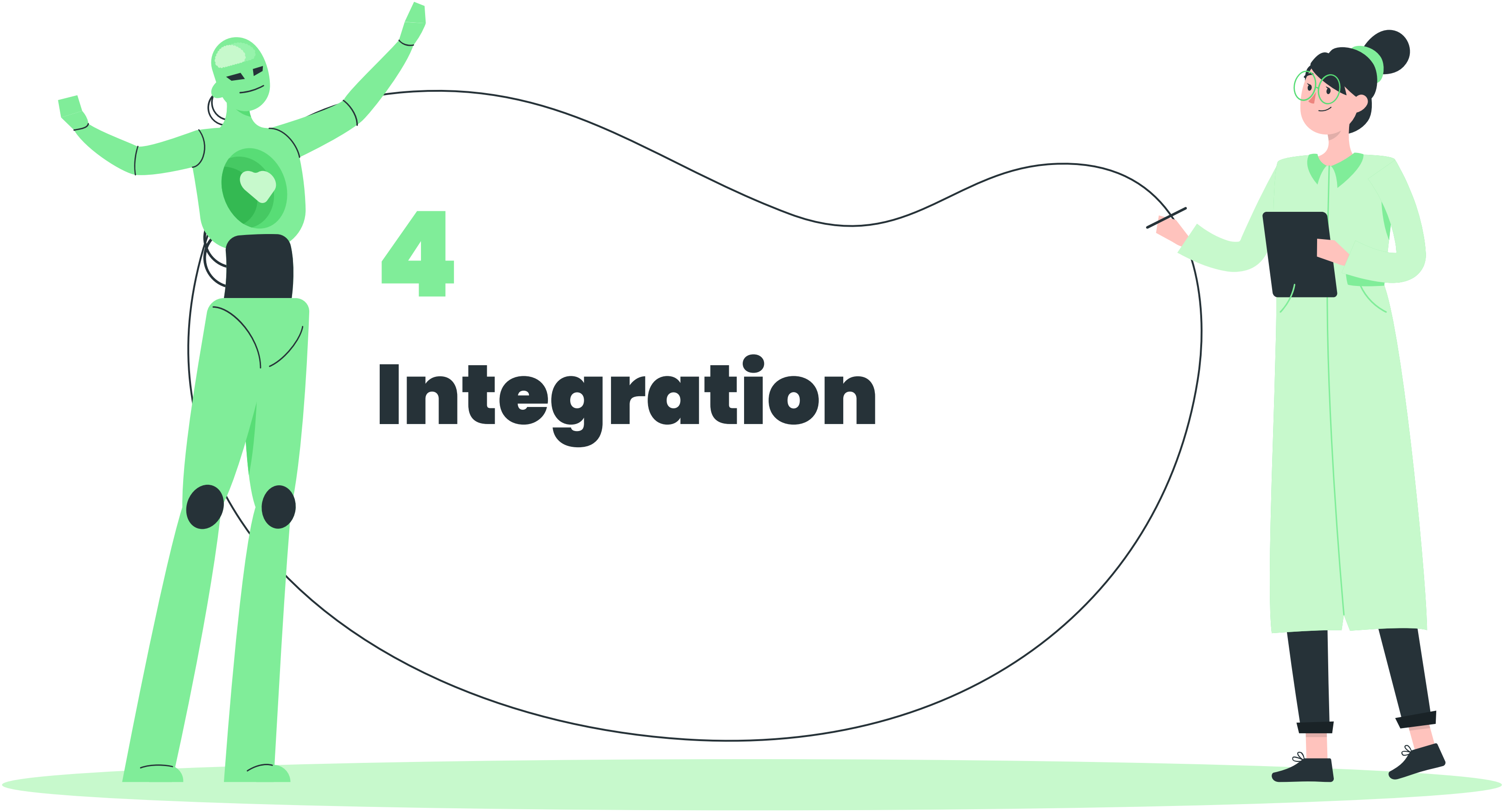
**Figure 1**

**Figure 2**

**Figure 3**

**Figure 4**

**Figure 5**



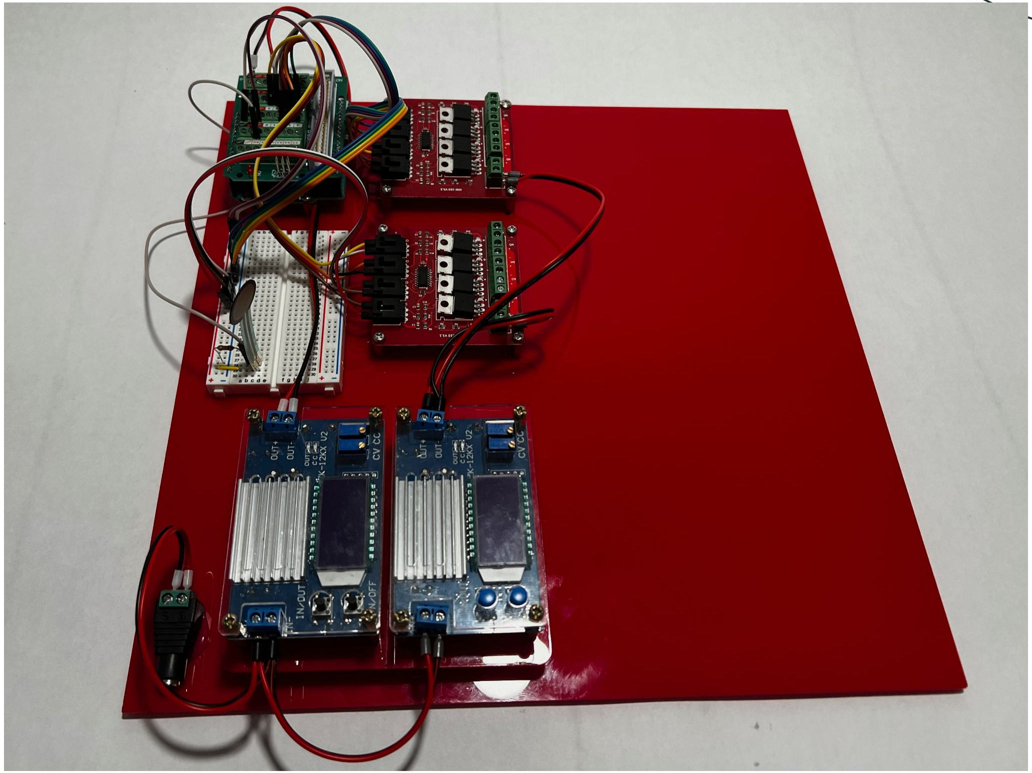
# 4

# Integration

# Custom Control Board

- Components
    - 2x Mosfet Switch Module
    - 1x Arduino Uno
    - 2x Voltage Regulator
    - 24V Power Supply

- Refined from Original Fluidic Control Board that included:
    - 1x Mosfet Switch Module
    - 1x Arduino Uno
    - 2x Voltage Regulator
    - 4x Manual Switches
    - 4x Potentiometers
    - 4x BP Pressure Sensors
    - 24V Power Supply

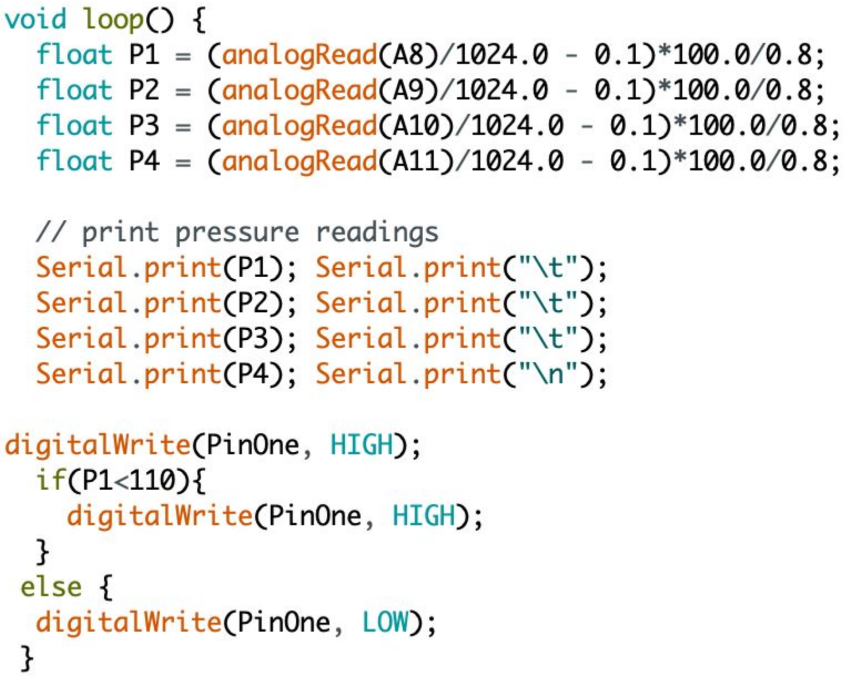


# Cost Summary

| | |
|---|---|
| Fittings | 52.95 |
| Valves (5x) | 658.58 |
| Mosfet Switch Module (2x) | 46.60 |
| Arduino Uno | 22.77 |
| Breakout Module | 20.99 |
| Voltage Regulator (2x) | 33.78 |
| 24V Power Supply | 20.99 |
| Total | $856.66 |

# Programming (Sample)

## Portion of BP Code

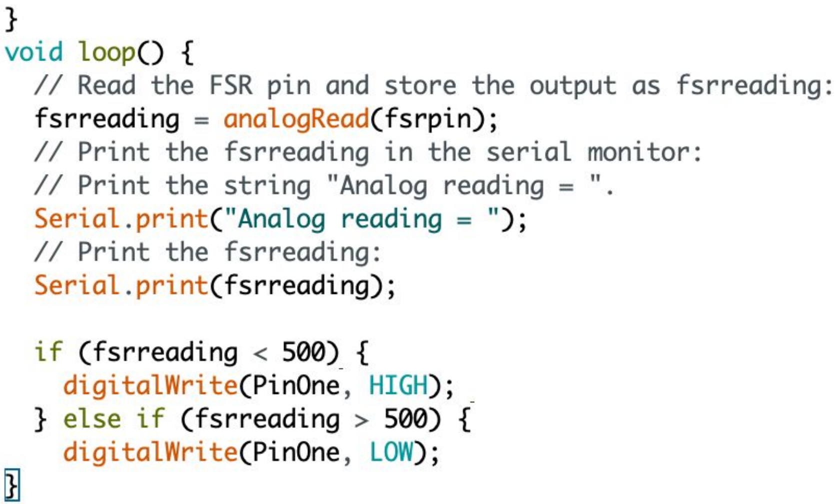


```
}
void loop() {
  float P1 = (analogRead(A8)/1024.0 - 0.1)*100.0/0.8;
  float P2 = (analogRead(A9)/1024.0 - 0.1)*100.0/0.8;
  float P3 = (analogRead(A10)/1024.0 - 0.1)*100.0/0.8;
  float P4 = (analogRead(A11)/1024.0 - 0.1)*100.0/0.8;

  // print pressure readings
  Serial.print(P1); Serial.print("\t");
  Serial.print(P2); Serial.print("\t");
  Serial.print(P3); Serial.print("\t");
  Serial.print(P4); Serial.print("\n");

digitalWrite(PinOne, HIGH);
  if(P1<110){
    digitalWrite(PinOne, HIGH);
  }
 else {
  digitalWrite(PinOne, LOW);
 }
```

## Portion of FSR Code



```
}
void loop() {
  // Read the FSR pin and store the output as fsrreading:
  fsrreading = analogRead(fsrpin);
  // Print the fsrreading in the serial monitor:
  // Print the string "Analog reading = ".
  Serial.print("Analog reading = ");
  // Print the fsrreading:
  Serial.print(fsrreading);

  if (fsrreading < 500) {
    digitalWrite(PinOne, HIGH);
  } else if (fsrreading > 500) {
    digitalWrite(PinOne, LOW);
}
```

# Final Design - Palm and Actuator

Assembled Mass - 310g

**Back**

**Front**

## 5

# Demonstrations

# Independent Movement


Figure 1


Figure 2


Figure 3


Figure 4

# Tennis Ball

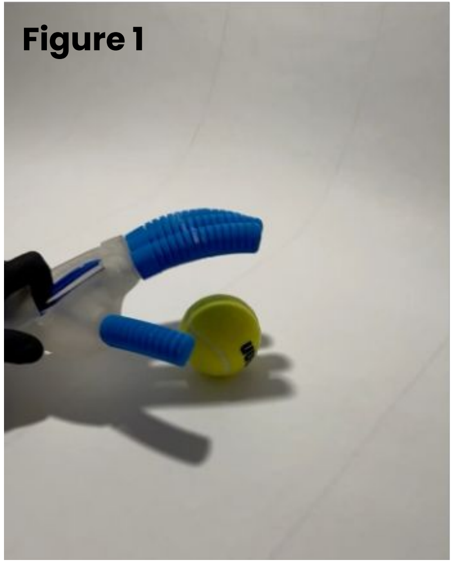


Figure 1


Figure 2

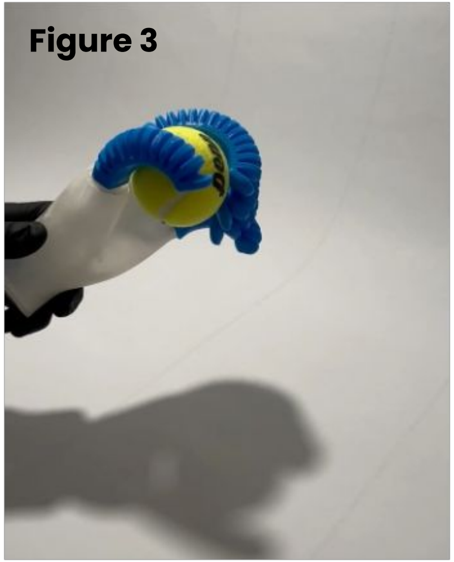


Figure 3

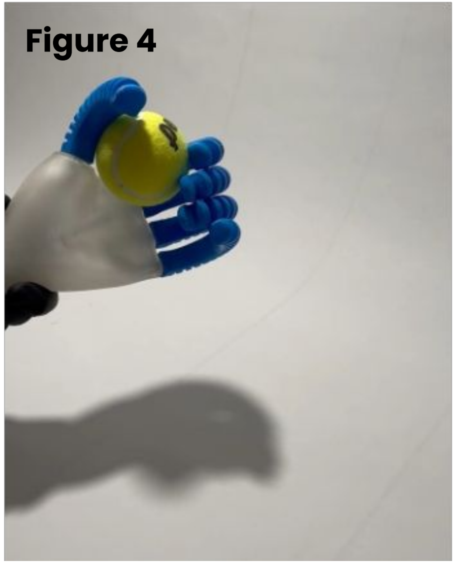


Figure 4

# Egg


Figure 1


Figure 2


Figure 3


Figure 4

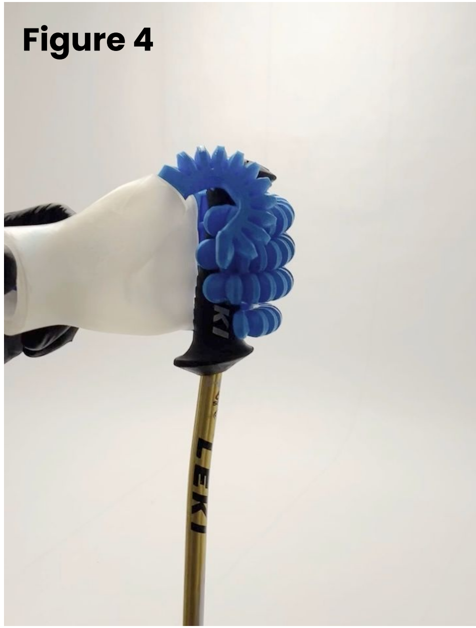
# Ski Pole

Figure 1

Figure 2

Figure 3

Figure 4



# Individual Finger Movement


Figure 1


Figure 2


Figure 3


Figure 4


Figure 5

# Future Research

1

### Soft Robotic Hand

Phase 1 of the project was the research presented here.

2

### Forearm Control System

Phase 2 of this project aims to create a control system that is small enough to fit in a forearm sized extrusion. This will be based of the custom control board presented earlier.

3

### Myoelectric Control

Phase 3 of the project aims to control the hand using electric signals generated by the subjects existing muscles. These will interact with Pressure sensors embedded in each actuator.

# Acknowledgements

- Harvard Soft Robotics Toolkit
- The Episcopal Academy
- The Clare Foundation

# Work Cited

- Soft Robotic Toolkit
  https://softroboticstoolkit.com
- Human Hand 3D Model
  https://grabcad.com/library/human-hand-1
- Presentation Template
  https://slidesgo.com/theme/robotic-workshop
- Existing Skiing Prosthetic
  https://www.trsprosthetics.com/product/snow-skiing-downhill-racer-ski-td/
- 3D Printing
  https://www.makerbot.com/stories/engineering/advantages-of-3d-printing/