punyo

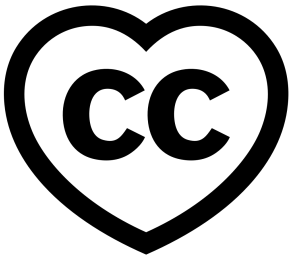
**Version:** 2.0

# Soft Bubble Gripper

## Build Instructions

SIHAH JOONHIGH, ALEX ALSPACH, RICHARD DENITTO, PHOEBE HORGAN, GORDON RICHARDSON, JAROD WILSON

TOYOTA RESEARCH INSTITUTE



TRI's Punyo project information is distributed using the
Creative Commons Attribution-NonCommercial 4.0 International license.

**Please view and acknowledge the license before continuing.**
https://creativecommons.org/licenses/by-nc/4.0/legalcode

# Punyo Soft-Bubble Gripper Build Instructions
# **Version 2.0**

If you have any questions or comments, please email us!
**punyo-info@tri.global**

# TABLE OF CONTENTS

# PURPOSE

The following document provides instructions on how to build Toyota Research Institute's (TRI) compliant, tactile sensing Punyo Soft-Bubble Gripper (https://arxiv.org/abs/2004.03691).

After reading this document, users should understand the following:

- Changes between Version 1.x to Version 2.0 of the hardware, process, and software
- Safety recommendations
- Bubble module fabrication
    - Tools, materials, supplies and fabrication files
    - Latex preparation and pattern printing process
    - Acrylic "window" laser cutting, etching and threaded insert installation
    - Production of 3D printed components
    - Assembly techniques
    - Inflation and deflation
    - Bubble storage
- Soft-Bubble finger assembly
    - CAD and 3D printable file downloads
    - 3D printing your Soft-Bubble Gripper parts
    - Threaded insert installation
    - Internal depth camera installation
    - Bubble module installation
    - Pressure sensing electronics assembly and installation
    - Final assembly
- Common mistakes

# CHANGE LOG

- The internal depth camera has been changed from a PMD Picoflexx to an Intel Realsense D405, which results in multiple hardware updates
- The pattern printed on the inside of the latex bubbles has been changed
- The process for printing the bubbles' internal pattern has been changed
- The electronics for pressure sensing have been updated
- The firmware for the pressure sensing electronics have been updated
- We now provide software in the form of a ROS package for reading depth, shear, and pressure
- The final assembly process and configuration of the completed bubble fingers to an electronic gripper have been updated to reflect hardware changes
- Minor process and documentation improvements

# SAFETY

The Punyo Soft-Bubbles built for the purposes of this documentation were fabricated in a professional research and development lab environment. It is the responsibility of the user (the individual building Soft-Bubbles) to understand and comply with the requirements set forth by the equipment and material manufacturers, and the safety policies of their manufacturing facilities.

## Safety Recommendations

*The following list provides general recommendations and is not intended to be all-encompassing. Please refer to your manufacturer and facility policies for specific guidance. If in doubt, ask!*

1. **Have adequate training and knowledge of your equipment and materials**, as defined by the manufacturers and your facility.
2. **Ensure proper ventilation,** as defined by your equipment and materials manufacturers, when performing the following tasks: laser cutting, 3D printing, installation of the heat-set inserts, soldering, and gluing.
3. **Proper storage of volatile materials.** The user should ensure that volatile materials (flammable materials, aerosol sprays, etc.) are stored properly in accordance with their facility's policies and local regulations.
4. **Proper disposal of materials**, as defined by your equipment and materials manufacturers.
5. **Wear Personal Protective Equipment,** as defined and required by manufacturers and your facilities. (Examples: respirator masks, eye protection, gloves.)
6. **Supervise and monitor your automated work.**
7. **Have easy access to first-aid materials and be trained to utilize them.**
8. **Have knowledge of your facility's emergency protocols and equipment.**

# FABRICATION FILES

## Bubble Module Tracking Spreadsheet

At TRI, we maintain an organized list of the bubble modules built, including the membrane material used, material thickness, pattern printed, and date assembled, among other notes and data. To track your own bubbles, use the *Bubble Module Tracking Spreadsheet (.xlsx)* downloaded with the build files.

## Mesh and Vector Files

The downloaded build files will enable you to 3D print and laser cut all of the pieces you need for the complete Soft-Bubble Gripper assembly. Mesh files are 3D files used for 3D printing (.stl). Vector (.eps, .pdf) and raster (.jpg) files are used for laser cutting/etching.

| | 3D Printing: Mesh | Laser Cutting: Vector and Raster |
|---|---|---|
| Acrylic Window | - | Acrylic Window Side 1.eps |
| | - | Acrylic Window Side 2.eps |
| Latex Cutting Template | Latex Cutting Template.stl | Latex Cutting Template.pdf |
| Sealing Band | 0.4mm Offset Sealing Band.stl | - |
| | 0.6mm Offset Sealing Band.stl | - |
| Internal Pattern Stamp | Internal Pattern Stamp Roller.stl | - |
| | | Intel Pattern.jpg |
| Gripper Assembly | Intel D405 Case.stl | - |
| | Soft-Bubble Gripper Body.stl | - |
| | Gripper Finger Mount for WSG 050-110.stl | - |
| | Heat Set Insert Stand | |
| Pressure Sensor System | Electronics Enclosure Top.stl | - |
| | Electronics Enclosure Bottom.stl | - |

## Firmware and Software Files

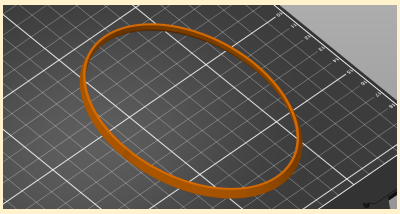
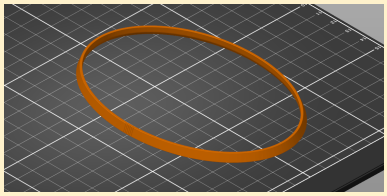
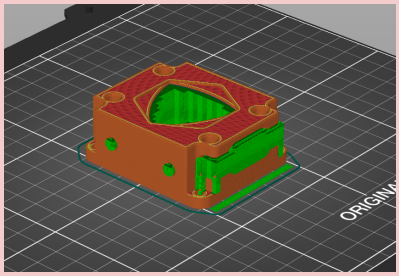
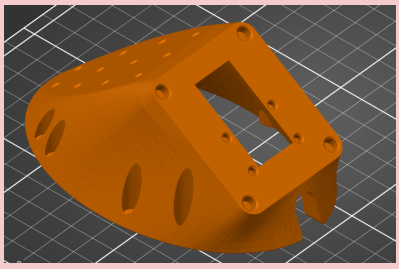
| | Arduino Script | Custom ROS Arduino Library |
|---|---|---|
| Pressure Sensor System | micro_ros_bubble.ino | micro_ros_arduino-2.0.5-custom.zip |

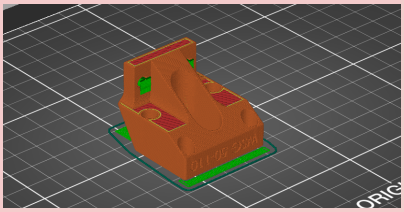
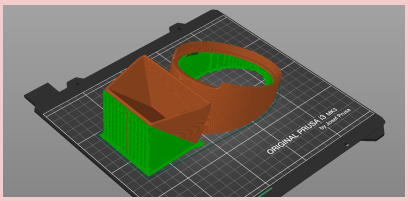
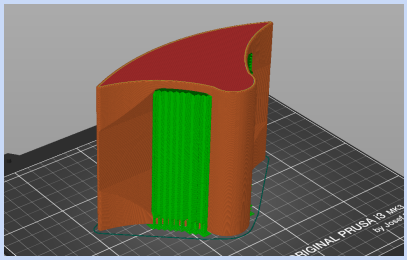
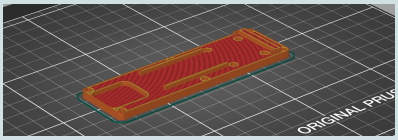
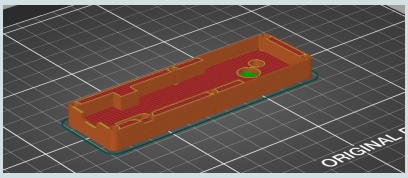

Contact us at punyo-info@tri.global

# 3D PRINTING PREPARATION

In preparation for the build, it is ideal to have the following parts 3D printed in advance. All of these files are included in the downloaded build files.

Section “Internal Pattern Stamp” provides the stamp roller 3D printing instructions.
Section “3D-Printed Sealing Band” provides the sealing band 3D printing instructions.
Section “Soft-Bubble Gripper Fab and Assembly” provides the gripper 3D printing instructions.
Section “Pressure Sensing System” provides the pressure sensor system 3D printing instructions.

| | STL File | Image |
|---|---|---|
| Sealing Band | 0.4mm Offset Sealing Band.stl |  |
| | 0.6mm Offset Sealing Band.stl |  |
| Gripper Assembly | Intel D405 Case.stl |  |
| | Bubble Gripper Body.stl |  |

| | | |
|---|---|---|
| | Gripper Finger Mount for WSG 050-110.stl |  |
| | Heat Set Insert Stand.stl |  |
| Internal Pattern Stamp Roller | Internal Pattern Stamp Roller.stl |  |
| Pressure Sensor System | Electronics Enclosure Bottom.stl |  |
| | Electronics Enclosure Top.stl |  |

# BILL OF MATERIALS

All required materials and tools necessary to build the Punyo Soft-Bubble Gripper are listed in the *Punyo Soft-Bubble Gripper BOM V2.0 (.pdf)* which is included with the file downloads. Please make sure you have everything on the list before getting started.

# BUBBLE INFLATION PUMP

The bubble inflation pump assembly combines a standard bike pump with the fitting and tube necessary to inflate bubble modules.

## Tools

1. Standard bike pump OR mini portable bike pump with output for schrader valves
2. PTFE Teflon tube cutter

## Materials

1. Firm Polyurethane Rubber Tubing (2.4 mm ID, 4 mm OD) (McMaster: 50315K68)
2. Push-to-Connect Tube Fitting for Air, Straight Adapter (8 mm STEM OD, 4 mm Tube OD) (McMaster: 5225K183)

## Assembly

1. Cut one meter of the PVC plastic tubing. This can be done using an x-acto knife or box cutter, however it is recommended to use the tube cutter for more consistent and higher quality cuts. ⚠️Make sure the tube is cut perpendicular to the length of the tube. An angled cut can be a hard-to-locate source of leaks later on. ⚠️
2. Firmly press the end of the plastic tubing into the push-to-connect end of the push-to-connect fitting until you feel a soft “click” (Fig. 1).

Figure 1: Tubing inserted into the push-to-connect end of fitting

3. Insert the cylindrical “stem” of the fitting into the hole labeled “S” or “schrader valve” of the bike pump (Fig. 2). Make sure the fitting is pressed deep inside the bike pump nozzle. You may want to use pliers to help jam this in. It’s best to have a dedicated pump so that this never needs to be removed.

Figure 2: Connector-tubing assembly stuck into bike pump nozzle

4. If necessary, lift the locking lever on the pump up into the sealed position (Fig. 3).

Figure 3: Connector-tubing assembly with sealed pump

# BUBBLE MODULE FABRICATION

The bubble module of the Punyo Soft-Bubble Gripper consists of a plain or patterned latex membrane, a clear acrylic backing plate, or “window”, a ring that mounts the membrane onto the acrylic, threaded inserts, and a fitting-tube assembly for inflation, deflation, and internal pressure sensing. The modular design allows for quick swapping of bubbles for various reasons including replacement of a damaged module, switching mechanical properties like membrane material or thickness, or swapping internal patterning based on the needs of the perception system.

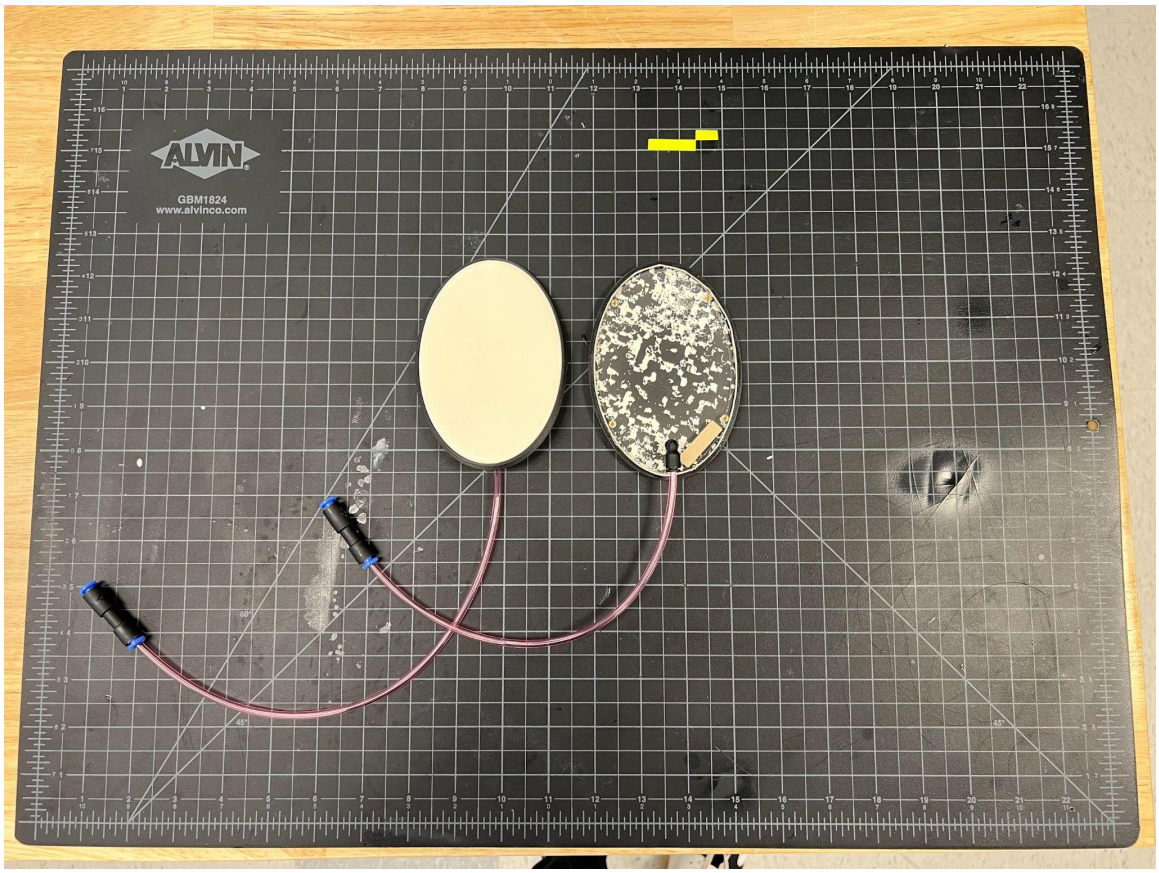



Figure 4: Fully assembled deflated bubble modules, top and underside views

# Internal Pattern Stamp

For the Soft-Bubble Gripper configuration documented in this guide, which utilizes the Intel Realsense D405 depth camera, it is recommended to use the pattern provided in the self calibration guide for the D405 (https://dev.intelrealsense.com/docs/self-calibration-for-depth-cameras). The Internal Pattern Stamp consists of a rubber sheet that has this pattern etched into its surface, and a 3D-printed roller. Use of the stamp allows for consistent and efficient pattern printing onto the latex used in the bubble module.

It is important to note that the randomized pattern provided by Intel is not required when using the D405 as the depth sensor for the Soft-Bubble Gripper. Any randomized pattern printed in black latex screen printing ink is sufficient, but you may find you have better results using the one provided by Intel.

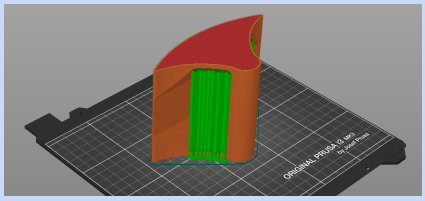
## Tools

1. Laser cutter
2. 3D printer
3. Ruler
4. Box cutter
5. Cutting board

## Materials

1. Rubber stamp sheet for laser engraving
2. VHB double-sided tape
3. 3D-printing plastic filament

## 3D Printing the Internal Pattern Stamp Roller

| | STL File | Image |
|---|---|---|
| Internal Pattern Stamp | Internal Pattern Stamp Roller.stl |  |

### Print Setup

1. Print the internal pattern stamp roller using the following settings:
    a. 15% infill
    b. Support everywhere above a 50 degree overhang

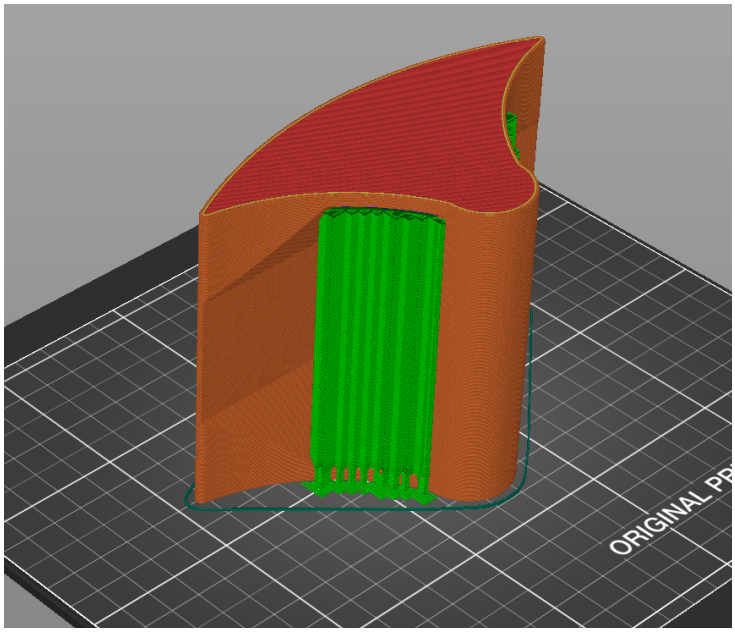
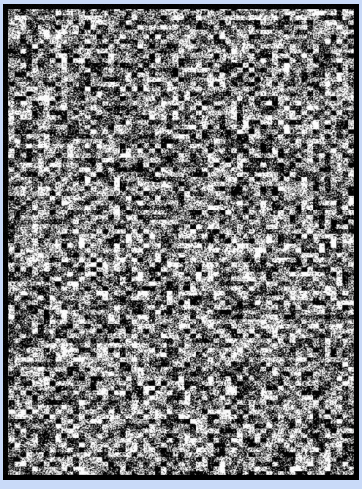


Figure 5: STL model of the Internal Pattern Stamp Roller with support material in slicer

## Etching Pattern onto Rubber Sheet

### Raster Files

| | Laser Cutter: Raster | Image |
|---|---|---|
| Internal Pattern Stamp | Intel Pattern.jpg |  |

1. Select the proper material settings for your respective laser cutter that will work with the 0.09” thick rubber sheet for laser etching.
    a. The random pattern consists of black and white areas only. As such, the rubber does not need to be etched using gradient settings or varying power level. Only a single material setting needs to be determined and assigned to properly etch the pattern.
    b. Complete test etches on a small patch to determine the settings for your respective laser cutter; aim for settings that produce an etch 1 mm deep over a 1 cm solid square.
    c. If using an unedited version of *Intel Pattern.jpg*, assign these laser parameters to the color black.

Figure 6: A 1 cm square with depth 1 mm etched into the rubber sheet

2. Load the raster file *Intel Pattern.jpg* onto your respective laser cutting program.
    a. Scale the image so that its final size measures 10 cm x 14 cm.
3. Load the rubber sheet into the top-left corner of your laser cutter.
4. Run the laser cutter to etch the pattern into the rubber sheet. Clean off any powder or residue created during the etching process.

Figure 7: The Intel random pattern etched into to the rubber sheet

## Stamp Assembly

1. Using a box cutter, trim the excess rubber from the 10 cm x 14 cm etched area. The etched border running around the outer edge of this area can be used as a guide.
2. Apply VHB double-sided tape to the back (untextured) side of the rubber.
3. Fix the textured rubber sheet to the curved surface of the Internal Pattern Stamp Roller.

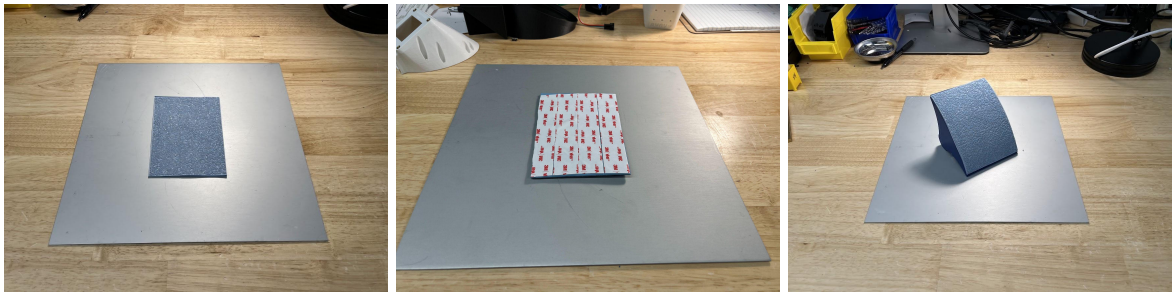


Figure 8: Assembly of the Internal Pattern Stamp

# Latex Pattern Printing


Figure 9: Tools for latex printing

## Before You Start

- Read SDS for each latex ink and glue.
- PPE: Safety glasses, nitrile gloves, lab coat.
- Turn on necessary ventilation.
- Gather all tools and materials below.

## Tools

1. Large sponge paintbrush
2. Mixing (popsicle) sticks
3. Ruler
4. Scissors
5. Cutting board
6. Painter's tape
7. Isopropyl alcohol
8. Shop towels
9. Powder free nitrile gloves
10. Internal Pattern Stamp (Created in section "Internal Pattern Stamp")
11. Rubber brayer
12. Plastic ink tray

## Materials

1. Latex sheet
2. Latex screen printing ink


Figure 10: Materials for latex printing

## Printing

1. Put on powder-free nitrile gloves and a lab coat. Bring a trashcan nearby.
2. Using scissors, cut out a 14 cm x 18 cm rectangular blank from a roll of latex sheet.
3. If you plan on making one gripper (two bubbles), cut and paint two sheets of latex (minimum). It's never a bad idea to make extras.

Figure 11: Blank latex sheet, 14 cm x 18 cm

4. Tape down each latex blank onto a flat surface like a cutting board using painter's tape (Fig. 12).
    a. The tape should cover about 1 cm of the latex on each side.
    b. ⚠️ Make sure matte surface of the latex is face up. We will be printing on this surface ⚠️

Figure 12: Latex sheet taped to cutting board

5. Use a lightly dampened isopropyl wipe to gently clean the upward facing matte surface of the latex. If the latex gets too wet, it will warp and you will have to wait for it to dry.
6. Open and mix latex ink with a mixing stick or large popsicle stick.

Figure 13: Mixing latex ink

7. Pour the latex screen printing ink into the plastic ink tray.

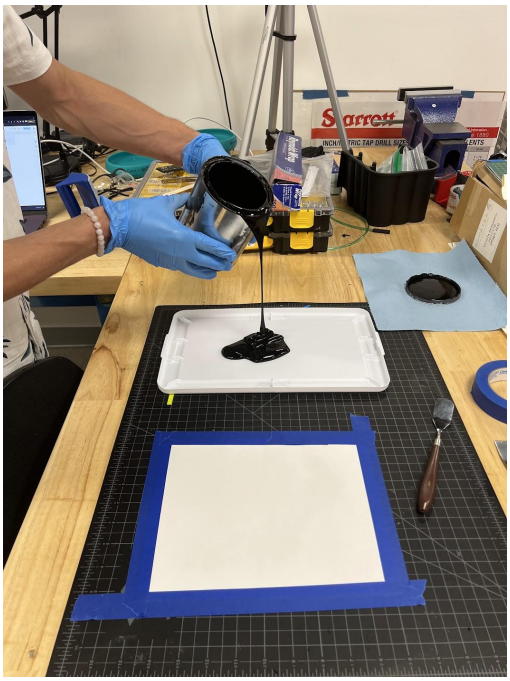


Figure 14: Pouring the ink into the ink tray

8. Roll the rubber brayer in the ink such that there is a consistent, even coating of ink across its entire surface.

Figure 15: Applying ink to the rubber brayer

9. Apply ink to the textured surface of the Internal Pattern Stamp. Make sure to coat the entire surface of the stamp in ink, taking care to not apply excessive amounts.

Figure 16: Using the brayer to apply ink to the Internal Pattern Stamp

10. Using the Internal Pattern Stamp, print the pattern onto your sheet of latex. Start by placing the bottom edge of the stamp at the bottom of the latex sheet. Slowly roll the stamp forward, applying even pressure, until the top edge of the stamp makes contact with the latex sheet. Gently pull the Internal Pattern Stamp away from the latex, taking care to not drip excess ink.

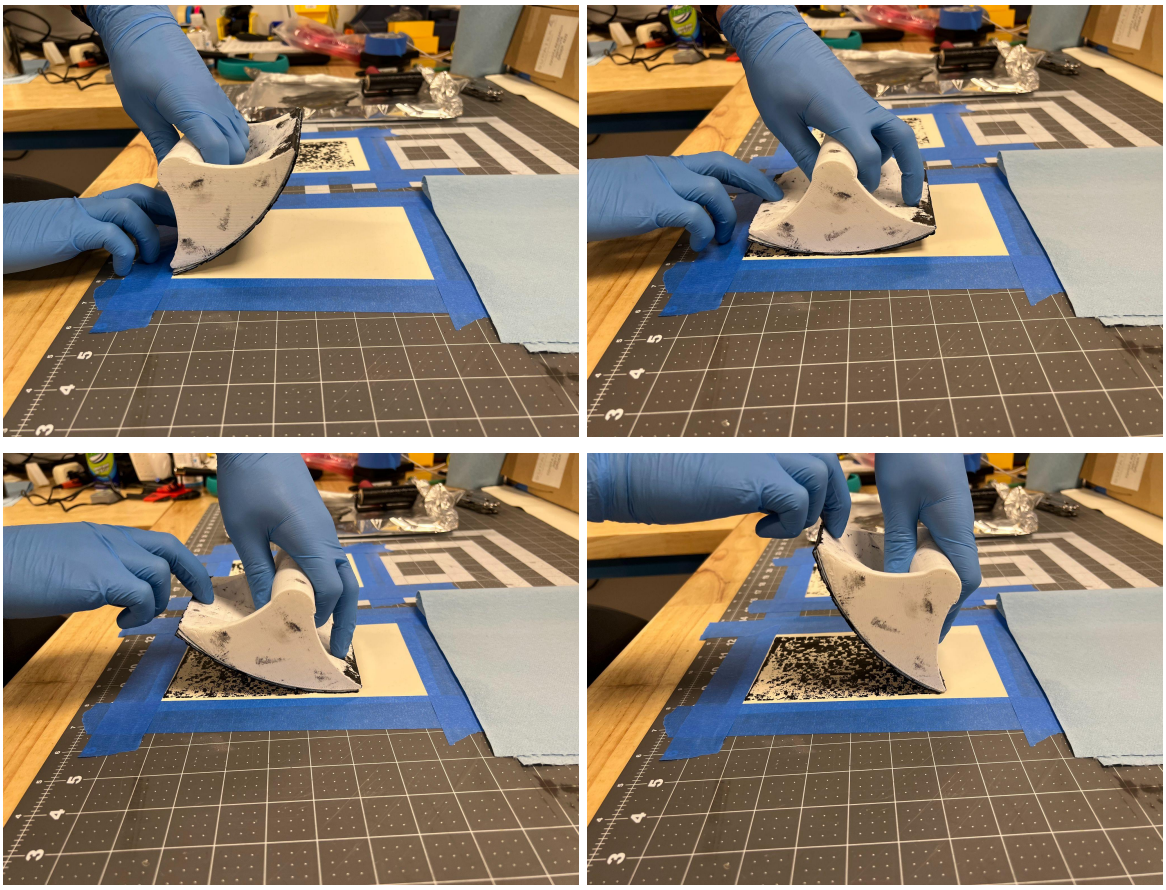


Figure 17: Using the Internal Pattern Stamp to apply ink to the latex sheet

11. Set printed latex aside to dry for one hour or more (we leave them overnight).
12. Remove tape once dry and store patterned latex in a cool, dry place.

# 3D-Printed Sealing Band

## STL Files

| | 3D Printing (STL) |
|---|---|
| Sealing Band | 0.4 mm Offset Sealing Band.stl |
| | 0.6 mm Offset Sealing Band.stl |

## Fabrication

1. Print two sealing bands for a pair of Soft-Bubble gripper fingers (one two-fingered gripper).
    - The 0.4 mm sealing band is used for latex with a thickness of 0.45 mm.
    - The 0.6 mm sealing band is used for latex with a thickness of 0.65 mm.
    - These parts should be printed with a 100% concentric line infill pattern, or alternatively as many concentric walls as is required to fill the part completely.
2. Debur any sharp 3D-printed defects with sandpaper or a deburring tool (especially on the interior of the band).

Figure 18: 3D-printed sealing band

# Acrylic Window Fabrication

The acrylic bubble backing plates are called “windows” because these plates provide a rigid, optically clear, airtight frame for the latex bubble modules to be built upon and the camera to see through.

**See video:** “Acrylic Window Fabrication"

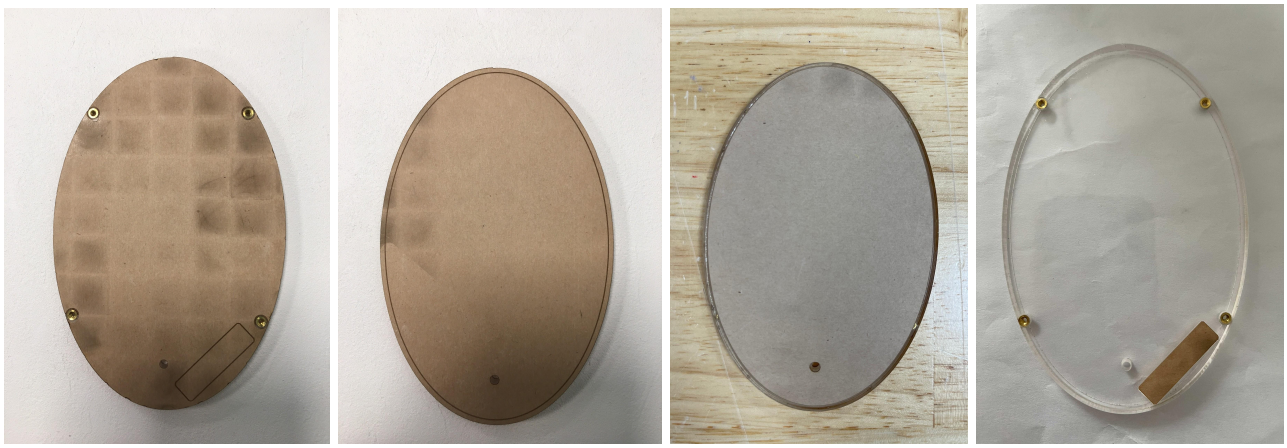


Figure 19: From left to right: Acrylic window Side 1, Side 2, outer paper ring removed, and protection paper removed

## Before You Start

- Make sure the laser cutter lenses are clean before and after any etching process.
- Clear the laser cutter bed of any dust or chips before and regularly throughout the build.
- Turn on necessary ventilation.
- Gather all tools and materials below.

## Tools

1. Laser cutter
2. Temperature controlled soldering iron (McMaster: 6997A23)
3. M3 thread tap (McMaster: 2703A71)
4. Tap wrench and aligner (McMaster: 2548A12)
5. Thermally insulated flat metal load
6. Canned air

## Materials

1. Acrylic 3/16” sheet (McMaster: 8560K215)
2. Gaff tape or similarly thick tape (McMaster: 7612A25)

## Fasteners

1. M2 heat-set inserts, 2.9 mm installed length, qty 4 (McMaster: 94180A307)

2. M2 x 5 mm socket head cap screw, qty 1 (91290A012)

## Vector Files

| | Laser Cutter (EPS/PDF) |
|---|---|
| Window | Acrylic Window Side 1.pdf |
| | Acrylic Window Side 2.pdf |
| Latex Cutting Template | Latex Cutting Template.pdf |

## Overview of Acrylic Window Laser Cut Process

A drawing of the acrylic window is shown below (Fig. 20), including the top and side views. Vector drawings (what is to be cut and etched) are shown below it for Side 1 (Fig. 21) and Side 2 (Fig. 22).

Before beginning the cutting process, it is necessary to understand the features being cut and etched for the acrylic windows. The acrylic windows receive four heat-set threaded inserts that are used to mount the bubble module to the Soft-Bubble Gripper body. The window also has a threaded hole used to secure an airtight fitting to inflate or deflate the bubble. It is dependent on the user to find the right settings on their laser to cut and etch the acrylic to the specs/depths shown in the drawing.

It is recommended to test on a small piece of acrylic to find the proper settings for the four etched heat-set pockets and various acrylic and paper-only cuts to follow.

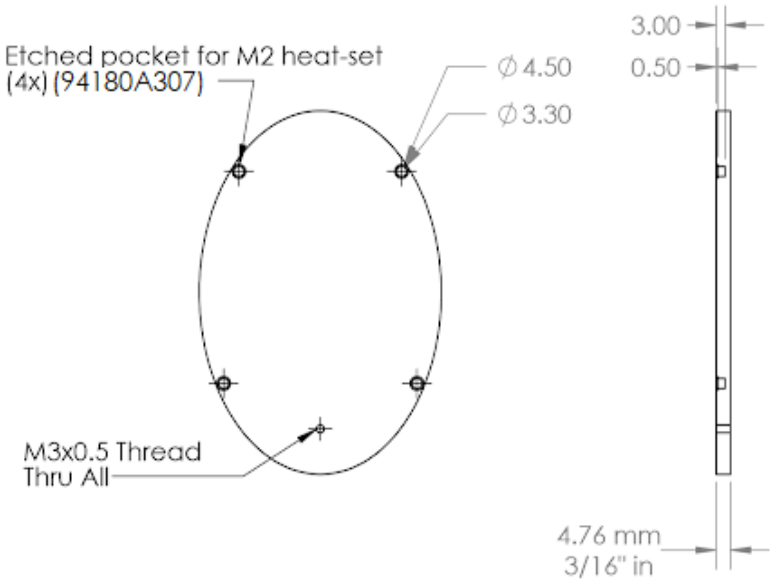



Figure 20: CAD drawing of acrylic window

The different colors of the lines found in the vector files for Sides 1 and 2 of the acrylic window (Fig. 21 and 22) represent a different laser cutting or etching process and are explained below:

- Blue area - Rastered pockets 3.0 mm deep
- Magenta area - Rastered pockets 0.5 mm deep
- Red lines - Cut through acrylic
- Cyan lines - Cut through protective paper only (a little overshoot is okay)
- Yellow line - Outline of rectangle shape for reference - neither cut nor etched

First, Side 1 gets etched and cut. On Side 1 (Fig. 21), we are etching pockets into the acrylic to a certain depth and diameter. These pockets will receive heat-set threaded inserts in a later step. It is important to etch only slightly deeper than the length of the heat-set insert (3.0 mm deep, magenta area) which is 2.85 mm long. It is also important to etch a second wider, shallow pocket (0.50 mm deep, blue area) that captures the melted acrylic overflow when heat-setting . These depth measurements should be used as targets when tuning the laser cutter settings before producing the acrylic windows. You must not etch so deep as to poke all the way through the acrylic at any point, as this will compromise the module's ability to hold air.

After the heat-set insert pockets are etched, a rectangle is cut (red lines) from the acrylic with alignment markings. These alignment markings are critical as we must carefully remove the workpiece after cutting Side 1, install the heat-set inserts, then flip and realign the workpiece for the Side 2 laser operations.

⚠️ To achieve the pocket depth required, you will need to adjust the settings of the laser cutter. Experiment on a sacrificial test piece until you achieve the desired laser power and speed settings. ⚠️

⚠️ Be very careful only to etch pockets about 3 mm deep. If you accidentally etch completely through the acrylic, the part must be discarded as this will compromise the module's ability to hold air. ⚠️

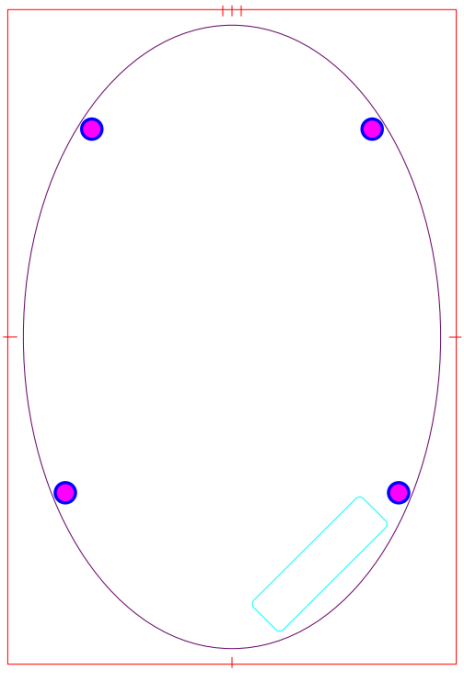


Figure 21: Image of vector file for cutting and etching the acrylic window, Side 1

On Side 2 (Fig. 22), the smaller ellipse (cyan line) is cut only through paper to create a mask for spraying adhesive onto the acrylic window's perimeter for an assembly step to follow. The perimeter ring of paper around the edge is removed to expose the surface that will be sprayed with adhesive.

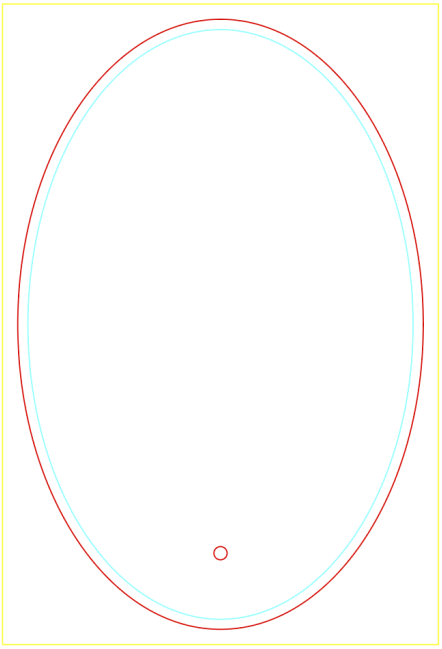


Figure 22: Image of vector file for cutting and etching the acrylic window, Side 2

## In-Depth Acrylic Window Laser Cut Process

1. Load laser cutter with 3/16 in thick acrylic and align to the top-left corner, leaving protective paper on both sides. Apply a bit of tape on the edges to keep from accidentally moving it.
    a. ⚠️ It is important to keep paper on while cutting to avoid clouding of the material. ⚠️
    b. ⚠️ Once loaded, do not move the acrylic sheet at any point in the process. ⚠️
    c. ⚠️ Be careful not to hit the laser head as you load and/or work. ⚠️

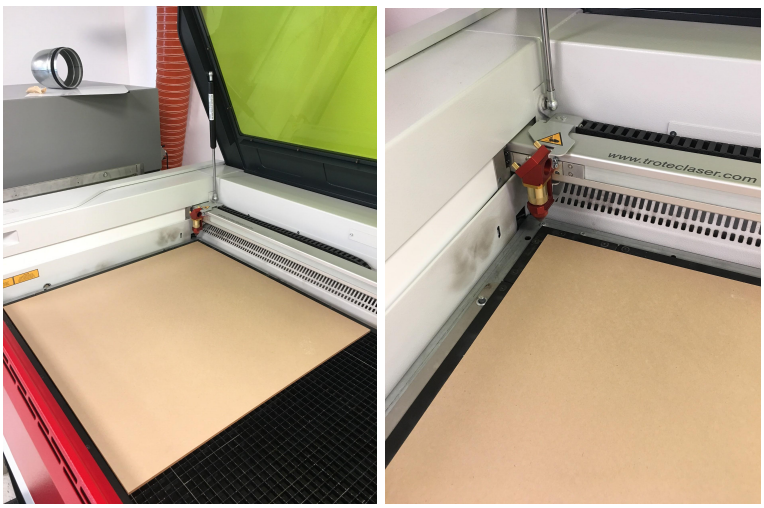



Figure 23: Alignment of acrylic into the laser cutter

### Etching Heat-Set Locations (Side 1)

1. Tune and select your laser parameters for cutting and etching the pockets as described above and save them with clear names and descriptions for continued use.
2. Tune and select your laser parameters for cutting 3/16 in Cast Acrylic material.
2. Load the vector file for Side 1 (ellipse_bubble_window_side1_new.ai) onto your respective laser cutting program.
    a. ⚠️ Side 1 is cut first so that heat-sets can be inserted before the ellipse is cut. ⚠️
3. Run the Side 1 etching job and cut the rectangle. If you plan on making one gripper (two fingers), laser cut two windows at a minimum.
    a. ⚠️ Our laser parameters were tuned to etch two 3mm deep pockets per horizontal row. We have found that if more than one window is placed next to one another (i.e. etching more than two pockets in a single pass) while etching, the pocket depth will be incorrect. Stick with etching the same number of pockets at any given time as you etched while tuning the etching parameters. ⚠️
    b. ⚠️ Record the X and Y coordinates of each window in your laser cutting layout software during Side 1. This is important for placing the files Side 2 in the same positions in the next steps. ⚠️

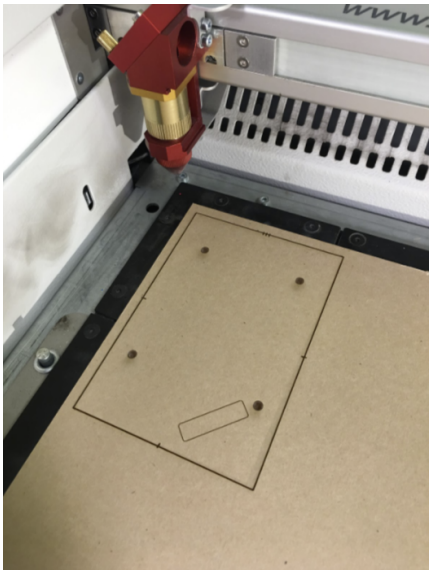


Figure 24: Side 1 cut of the acrylic window

4. ⚠️ Carefully use a spudger or thin tool to pop out rectangular acrylic workpieces. Make sure that the base acrylic doesn't move (you can apply downward pressure to acrylic stock while removing parts to keep it steady). ⚠️

## Install Heat-Sets


Figure 25: Tools and materials required to install heat-sets

1. Use canned air to blow any acrylic dust out of the etched pockets. You may also use an X-acto knife or box cutter to scrape slightly-fused dust from the pockets. Any extra material left in the pocket will melt and prevent proper heat-set insertion.
2. Heat up soldering iron with a flat tip (McMaster: 92160A123) for M2 heat-set inserts.
3. Leave the paper on the acrylic rectangle and place the acrylic on a flat surface, heat-set pockets side up.

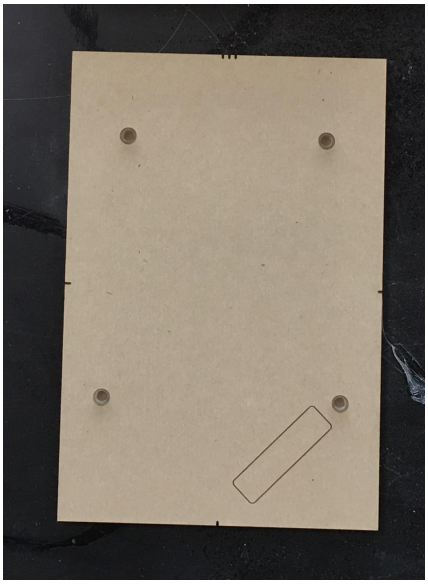


Figure 26: Acrylic window, heat-set pocket side up

2. Place heat-sets into the pockets with their smaller diameter side down (Fig. 27).

a. ⚠️ It's important to install the heat-sets before the final elliptical cut to achieve a true final elliptical window shape, including around the heat-set locations. ⚠️

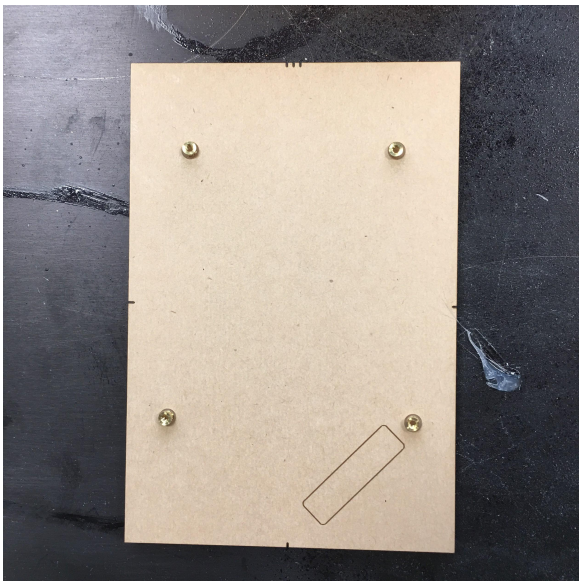


Figure 27: Heat-sets inserted into the pockets of the acrylic window

3. Place soldering iron perpendicular to the heat-set and allow the heat-set to slowly sink down as the acrylic softens. There should be no need to push, let gravity do the work.
    a. If the heat-set does not begin to sink under the weight of the soldering iron, allow the soldering iron to heat up for longer.

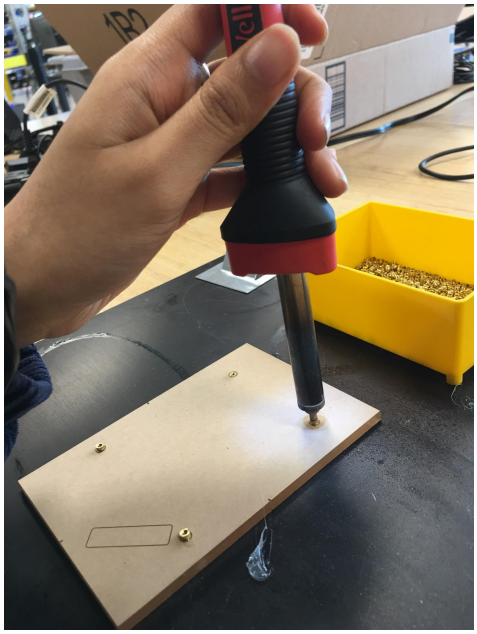


Figure 28: Sinking heat-sets into the acrylic window

4. Sink the insert until it is peeking up approximately half a millimeter then, leave the iron on the heat-set for 3-4 seconds more until the surrounding acrylic begins bubbling. Then use a flat, heavy tool to press the insert in the rest of the way. This causes the insert to set flush with the acrylic surface (Fig. 29). Complete this process one heat-set at a time.

a. If you apply too much heat, the acrylic surrounding the heat-set will melt and volcano out of the pocket, potentially covering the insert's threads (Fig. 29).

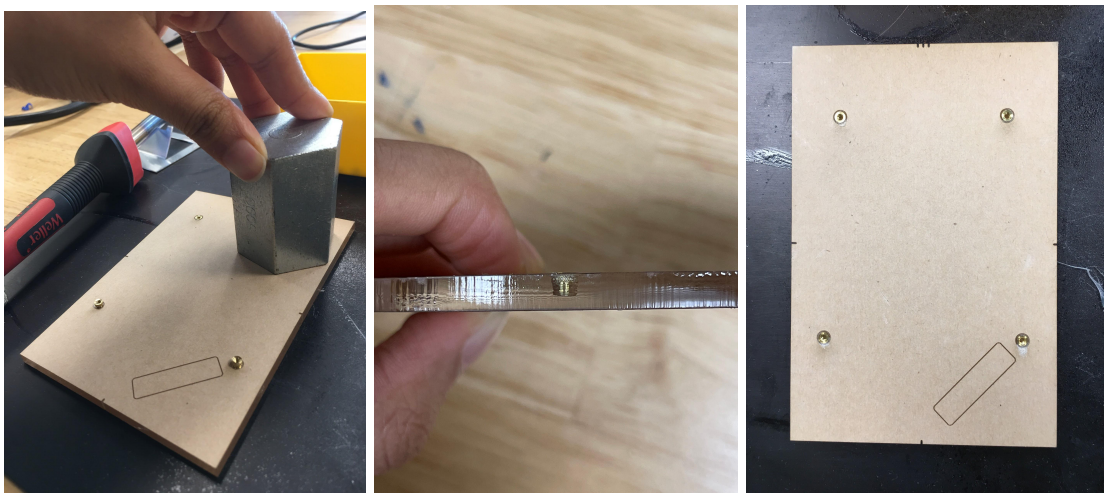


Figure 29: Insulated flat weight applied to the heat-set for flush insertion into pocket

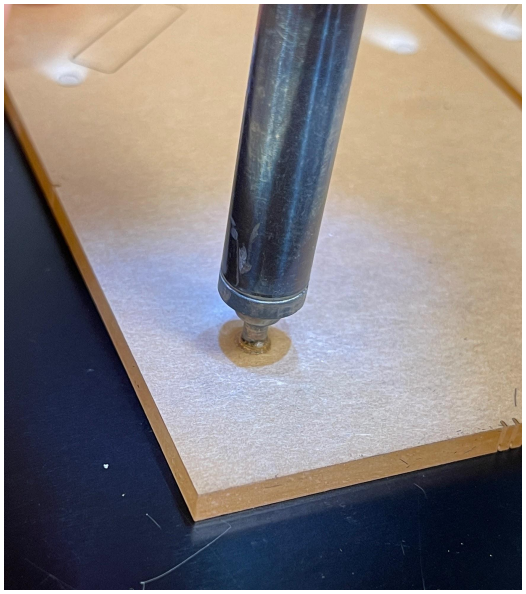


Figure 30: Bubbling reaction due to excessive amount of heat when sinking heat-set

5. Let cool.
6. Test with M2 x 5 mm socket head cap screw to make sure the threads inside of the heat-set are clean and free of excess plastic.

## Cutting Ellipse (Side 2)

1. Stick a small piece of gaff tape (or tape of a similar thickness) on each edge of the rectangle. This adds a slight thickness that helps realign it for laser cutting Side 2.
    a. ⚠️ If misaligned, it can result in an unusable bubble as a heat-set can be compromised. ⚠️

Figure 31: Alignment tape on the edge of the acrylic

2. Place the rectangle back into its previous location, this time with the heat-set inserts facing down.
    a. Use the dashes (three on the top side and one on each of the three other sides) to ensure that the rectangle is in the proper orientation (Fig. 33).

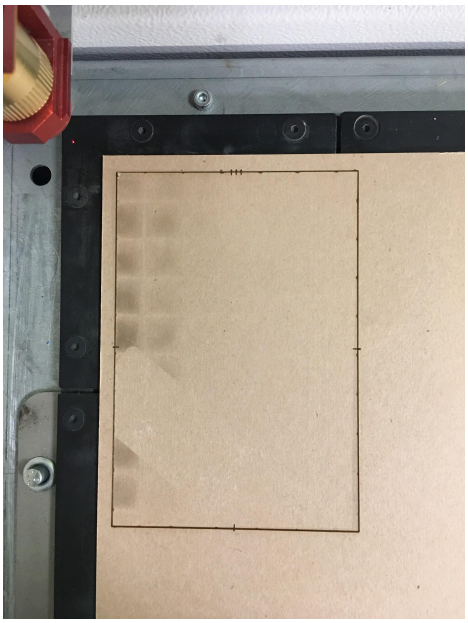


Figure 32: Preparation for Side 2 cut

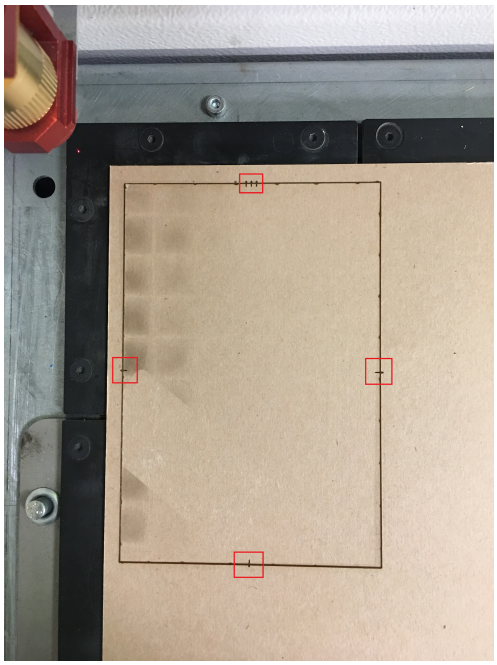


Figure 33: Alignment of the flipped window to the previous position for Side 2 cut

3. Load “ellipse_bubble_window_side2_new.ai” into your respective laser cutting program.
    a. ⚠️ Place the job for Side 2 at the same coordinates as the previous Side 1 job. ⚠️
    b. ⚠️ Set up the job to cut the inner line (cyan) through only the paper before you cut the outer line (magenta), otherwise the position of the ellipse may shift. ⚠️

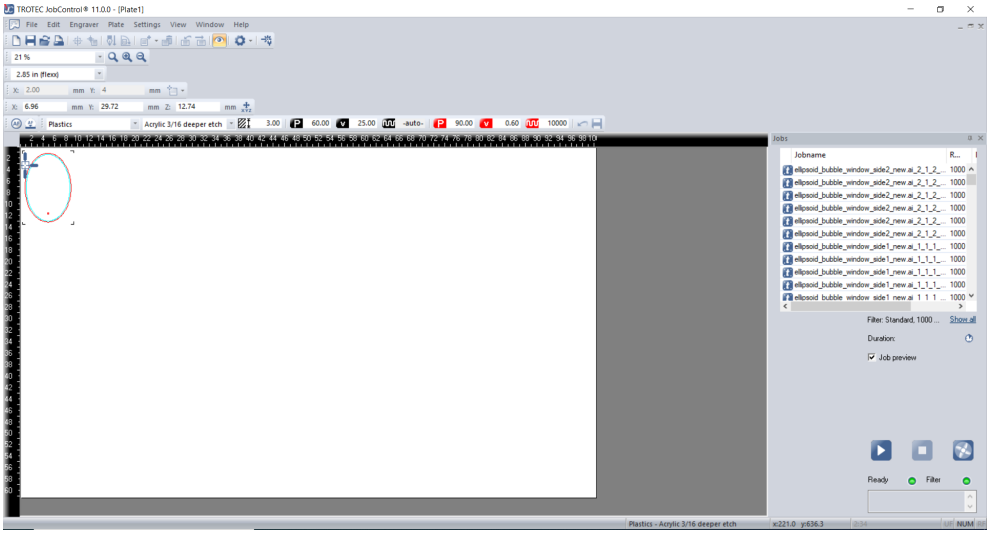


Figure 34: Side 2 is inserted into the program to laser cut

4. Verify the vector placement against workpiece alignment by going around the shape using the laser head control interface.
5. Run the laser cut.

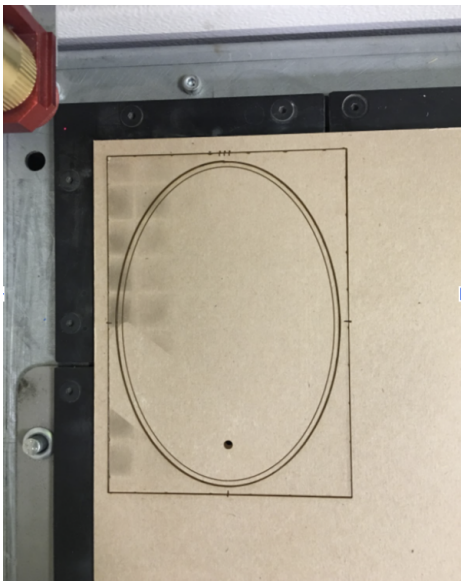


Figure 35: Laser cut results for Side 2

6. ⚠️ Carefully use a spudger to pop out rectangular acrylic workpiece. If more cuts are to be made, make sure that the base acrylic doesn't move (apply pressure to acrylic board before removing parts). ⚠️

### Thread Air Fitting Hole

1. Get M3 tap and tap wrench with aligner.
2. From the heat-set insert side, use the weight of the tap (don’t press down) and turn it clockwise to cut threads.

Figure 36: M3 tap is used to thread the air fitting hole

3. Tap through the entire depth of the hole.
4. Gently rotate counterclockwise to remove the tap.

5. Using the canned air, remove any acrylic shavings or dust from the tapped air fitting hole.
    a. ⚠️ If remnants of the acrylic are not properly removed from the hole, they can be blown into the inside of the bubble module when inflating it, potentially compromising the functionality of the depth sensor, pressure sensor, or integrity of the bubble. ⚠️
6. Label the acrylic window using the following format: YYMMDD_REV_LATEXTHICKNESS_UNIT#.

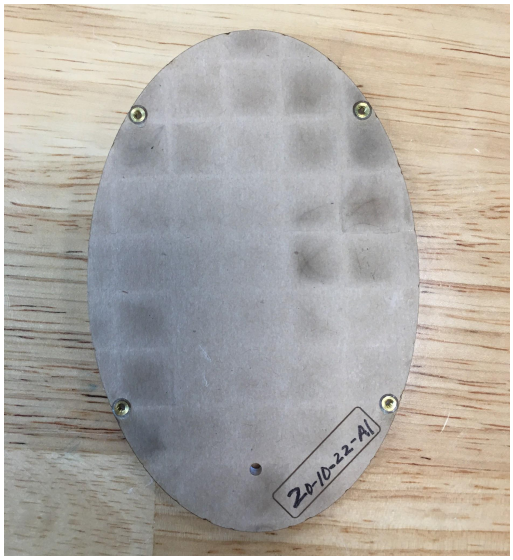



Figure 37: Labeled acrylic window

7. Draw a check mark on the paper to indicate that the hole has been tapped (Fig. 38).

Figure 38: Marked tapped hole on acrylic window

# Latex Cutting Template

The latex cutting template is used to trace/cut the elliptical shape of the latex (Figure 39). The latex ellipse is a few millimeters larger than the window so that the latex edges can be folded down around the window edges during the assembly and sealing process.

This template can be cut out of the same clear 3/16” material as the windows or nearly any other stock you may have. No special laser cutter settings are required beyond those appropriate for the material and thickness you choose to use.

## Materials

1. Acrylic 3/16” sheet (McMaster: 8560K215) - or any other stock of acrylic you may have.

Figure 39: Latex cutting template

| | 3D Printing (STL) | Laser Cutter (EPS/PDF) |
|---|---|---|
| Latex Cutting Template | Latex Cutting Template.stl | Latex Cutting Template.pdf |

# Bubble Fitting-Tubing Assembly

## Before You Start

- Wear Nitrile gloves.
- Work in a well-ventilated area.
- Gather all tools and materials below.

## Tools

1. PTFE Teflon tube cutter

## Materials

1. Push-to-Connect Tube Fitting with O-ring for Air (90 Degree Swivel Elbow, 4 mm Tube OD, M3 x 0.5 mm Pipe) ( McMaster: 5225K739)
2. Push-to-Connect Fitting with Shut-Off for Air, Straight Connector (For 4 mm Tube OD) (McMaster: 1201N56)
3. 8 cm piece of Firm Polyurethane Rubber Tubing (2.4 mm ID, 4 mm OD) (McMaster: 50315K68)

Figure 40: Materials for bubble fitting-tube assembly

## Common Errors and Considerations

1. Cut tubing perpendicular to the tube length. Angled cuts will likely leak. Do not use scissors; cuts can be done using an x-acto knife or box cutter, however it is recommended to use the tube cutter for more consistent and higher quality cuts.
2. Make sure that both ends of the tube are firmly inserted into the fitting, otherwise this location will likely leak.

a. When you pull on the tubing inserted into the connectors, it should not come out. Perform this simple pull test to see if you seated the tubing deep enough.

3. The bubble fitting-tubing assembly can be done in advance in large batches. Prepare and cut all materials before assembly.

## Assembly

Figure 41: Swivel elbow push-to-connect fitting and O-ring

1. Insert one end of the pvc tube into the swivel elbow push-to-connect fitting. Push the tube into the connectors until you feel it click. If you do not feel a click upon insertion, remove and try again.
    a. ⚠️ Make sure that the fitting has an O-ring on it! Some fall off. ⚠️
2. Insert the other end of the tubing into the push-to-connect fitting with shut-off for air.
    a. Fitting orientation matters! Check-valve ( ) location should be as shown below (circled in red, opposite the inserted tubing)

Figure 42: Completed bubble fitting-tubing assembly

# Bubble Module Assembly

**See video:** “Bubble Module Assembly”

**Note:** this video contains an outdated procedure which utilizes a can of compressed air to stiffen the polyurethane tubing. This is an outdated step and is no longer necessary to assemble the bubble module.

## Before You Start

- Work in a well ventilated area.
- Use a fume hood or paint booth for adhesive sprays.
- Wear PPE: safety glasses and powder free gloves (when working with adhesives).

## Tools

1. Suction cups
2. Scissors
3. Spudger
4. Bubble fitting-tubing assembly (created in section “Bubble Fitting-Tubing Assembly”)
5. Sandpaper
6. Felt marker
7. Nitrile gloves
8. M3 Threaded tap
9. 45 mm rotary cutter


Figure 43: Required tools

## Materials

1. High viscosity cyanoacrylate (CA) glue (McMaster: 74985A65)
2. Repositionable spray adhesive
3. Painter’s Tape
4. Parchment paper


Figure 44: Required materials

## Components

1. Acrylic Window (created in section "Acrylic Window Fabrication")
2. 3D Printed Sealing Band (created in section "3D Printed Sealing Band")
3. Patterned or blank latex rectangle (created in section "Latex Pattern Printing")
4. Bubble fitting-tubing assembly (created in section Bubble Fitting-Tube Assembly)
5. Latex cutting template (created in section "Latex Cutting Template")

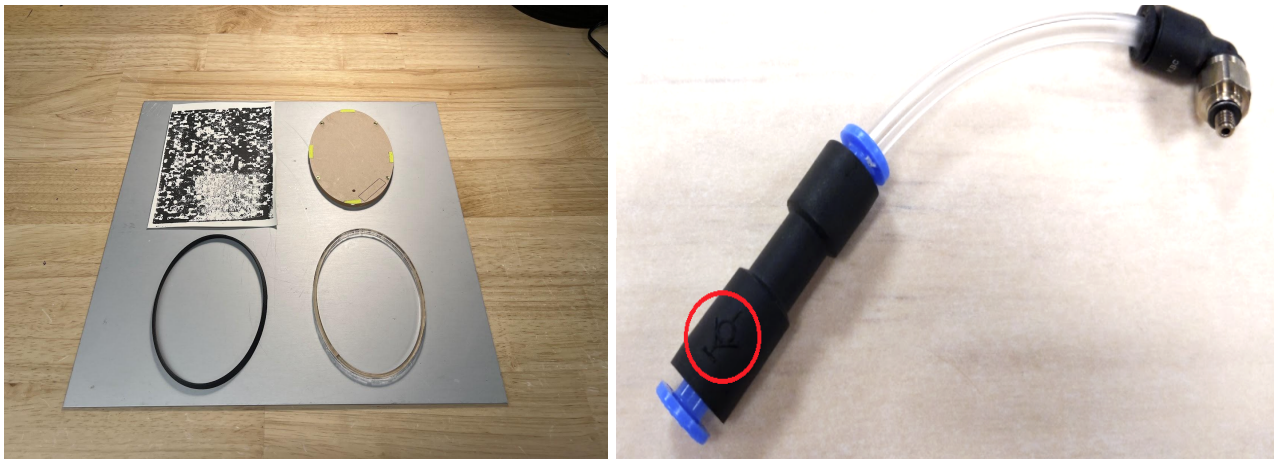


Figure 45: Components to make Bubble Module

## Assembly

Read this section is full before getting started, as there are some time sensitive steps you will want to be prepared for.

1. Tape down parchment paper to protect your work surface and make parts easier to pick up (Fig. 46).

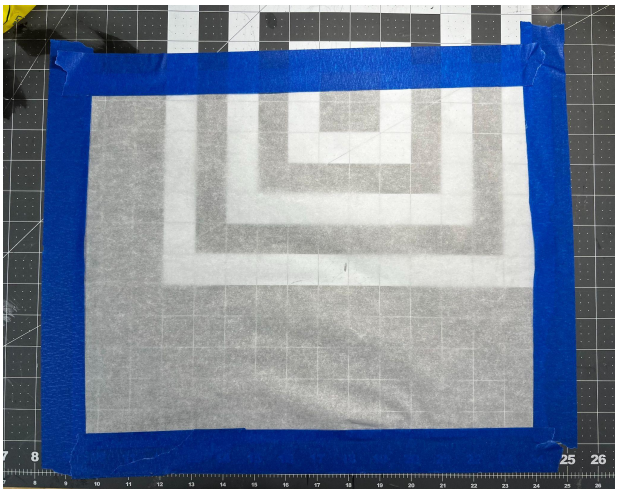


Figure 47: Parchment paper placed down and secured to the table

2. Wrap tape around the edge of the acrylic window to prevent adhesive from getting on the sides of the ellipse.
    a. Align the edge of the tape to the edge of the window to prevent adhesive buildup.

Figure 48: Tape wrapped around edge of acrylic window

3. Go to the fume hood with an acrylic window, repositionable adhesive spray, printed latex sheet, and a spudger.
4. Turn the fume hood on high.
5. Shake spray adhesive well (one minute).
6. Remove the thin outer paper ellipse on what will be the interior window surface of the bubble module (Fig. 49) to reveal an ellipse outline on the acrylic's border. This is the surface the repositionable spray adhesive will cover to stick onto the latex in a later step.

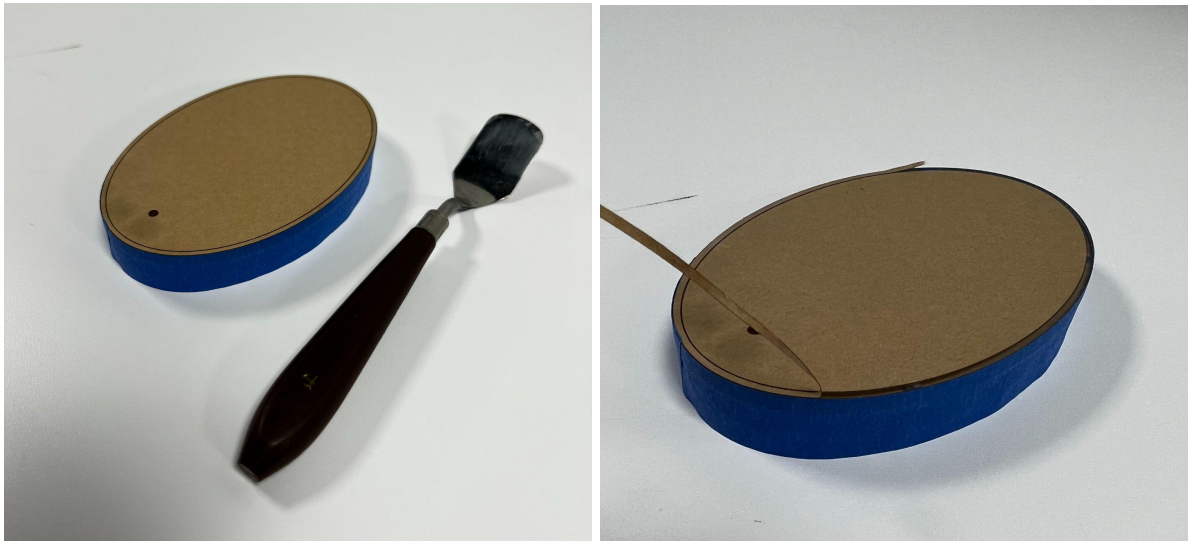


Figure 49: Removal of thin outer paper ellipse to reveal surface for adhesive spray

7. Prop the window up at an angle (Fig. 50)

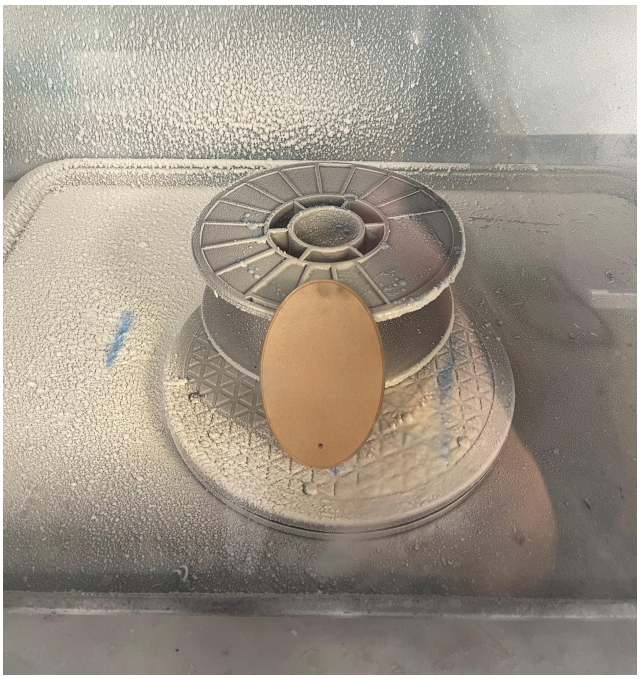


Figure 50: Acrylic window propped at an angle inside of a fume hood

The repositionable spray adhesive spray creates a seal that holds the latex in place during assembly and prevents cyanoacrylate (CA) glue from seeping in between the acrylic and latex.

8. Apply the adhesive spray:
    a. Spray the repositionable spray adhesive in the directions shown by the red arrows in Fig. 51, starting from the bottom of the line to the top of the line for each red arrow.
        i. Four sprays per line is the minimum.
    b. Rotate the acrylic part so that the blue arrows are facing upward and spray the repositionable spray adhesive in the directions of the blue arrow.

i. Four sprays per line is the minimum.

c. ⚠️ Spray enough adhesive so that the entire external ellipse is covered. ⚠️Fig. 52

i. After many applications of adhesive, it may be necessary to swap or clean the spray can nozzle. Replacement nozzles can be purchased in bulk.

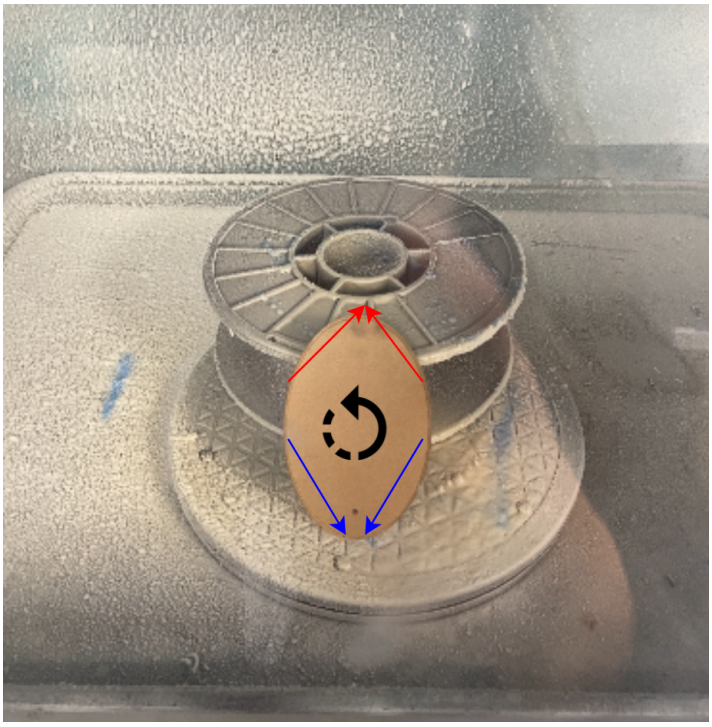


Figure 51: The adhesive is sprayed diagonally first in the red direction, then rotated as shown in black, and sprayed in the blue direction

Figure 52: The surface of the acrylic is shiny and tacky after the repositionable adhesive spray.

9. If there is any glue on your gloves, quickly change them. You'll want perfectly clean gloves for the next step.
10. Quickly remove the rest of the interior paper using a spudger to peel off the edge, then immediately place the glued surface face down on the matte/patterned side of the latex (Fig. 53).
    a. ⚠️ Do not touch the glue or exposed acrylic as your fingerprints will not be accessible after assembly. ⚠️

Figure 53: Removing interior paper and adhering to latex.

11. Apply pressure focused around the glued edges for about 30 seconds. A brayer roller can be used for this.
    a. It is recommended to apply a weight to the face down acrylic window for 10+ minutes. This will allow for the glued surface of the outer edge ring to form a better seal, and minimizes the chance of Cyanoacrylate (CA) glue applied later seeping between the acrylic and latex.
12. Place the 2.5 mm *Latex Cutting Template* around the window. Carefully use the rotary blade to trim the excess latex off of the sheet.
    a. Make smooth, long cuts, holding the rotary blade perpendicular to the cutting surface. Make cuts tangent to the curve of the *Latex Cutting Template*, going around its entire perimeter, until no excess latex can be seen beyond the outer edge of the *Latex Cutting Template*.
    b. ⚠️ Be very careful not to cut yourself with the rotary blade! It is very sharp ⚠️
    c. ⚠️ The blades dull quickly when cutting latex. If you notice your rotary blade not cutting the latex as well, swap the metal disc blade; dull blades are more dangerous to use! ⚠️

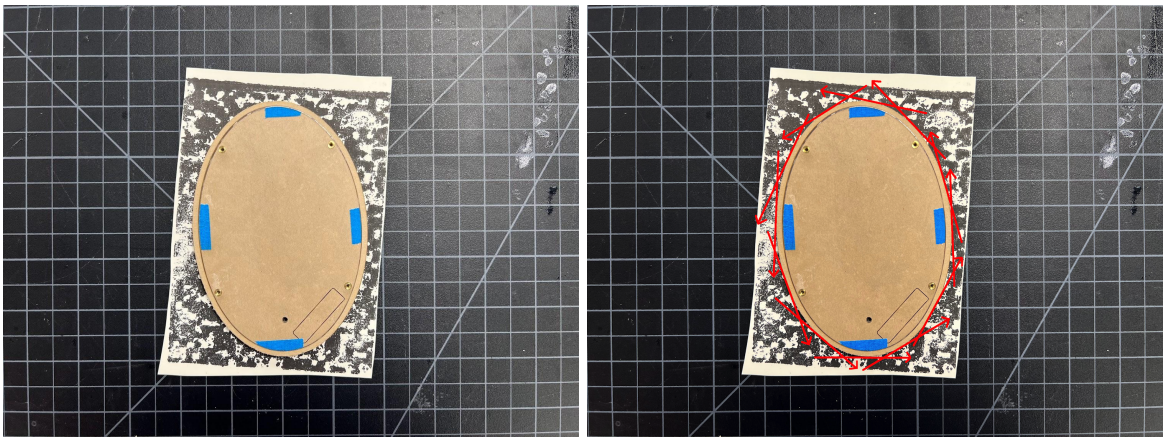


Figure 54: Acrylic window with the *Latex Cutting Template* placed around it, and general cutting pattern to trim excess latex


Figure 55: Using the rotary blade to trim the excess latex

Figure 56: Acrylic widow with excess latex trimmed away

13. Again, press down on the window around the adhesive sprayed edges to reseal any places that might have been released while handling and cutting.

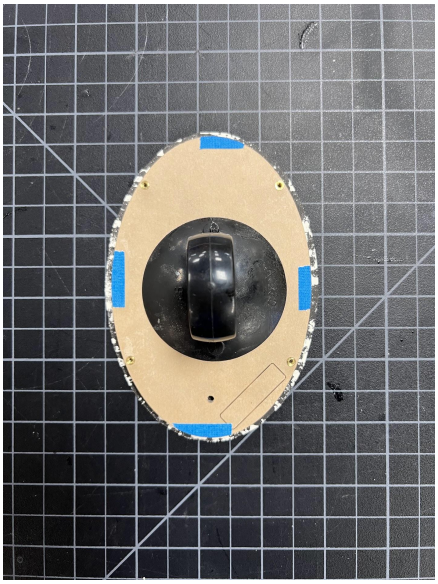


Figure 57: Apply suction cup to bubble module

14. Prepare the sealing band, glue, and prepared acrylic window together on the parchment paper.

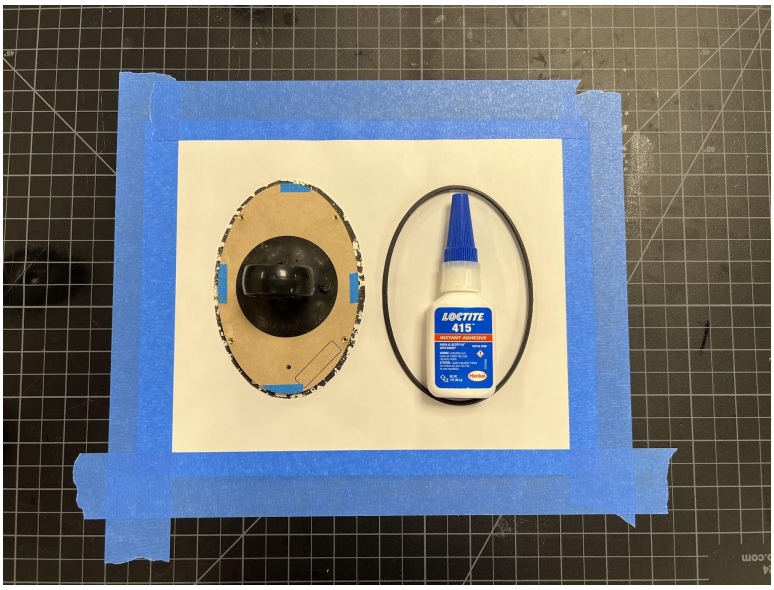



Figure 58: Sealing band and bubble module preparation.

⚠️ In the following steps, timing matters. Complete all steps within two minutes. ⚠️

15. Quickly and thoroughly apply high viscosity cyanoacrylate (CA) glue around the elliptical edge of the acrylic window. The goal is to apply glue all around the seam between the acrylic window edge and latex. (Fig. 59).
    a. Be generous and do not miss any spots. It can help to use a visual cue to remember where on the acrylic you started. Be extra careful not to get any glue inside the bubble.

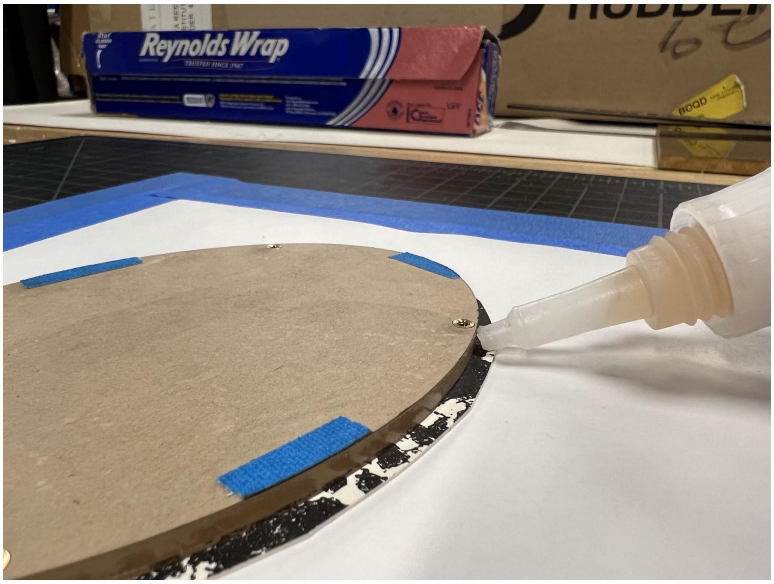



Figure 59: Glue is applied to the seam between the acrylic window edge and latex

16. On a perfectly clean surface (beware of stray glue), place your sealing band down on the table with the wider opening facing up. For latex a thickness of 0.45 mm, use a sealing band with the offset of 0.4 mm. If the thickness is 0.65 mm, use a sealing band with the offset of 0.6 mm.

17. Center the window over the sealing band and gently nudge the sealing band until well aligned. Push the latex and window assembly **straight down** into the sealing band using the suction cup (Fig. 60).
    a. If you find that the window did not get pushed in the acrylic all the way, manually press down on the surface of the window until it fits into the sealing band.

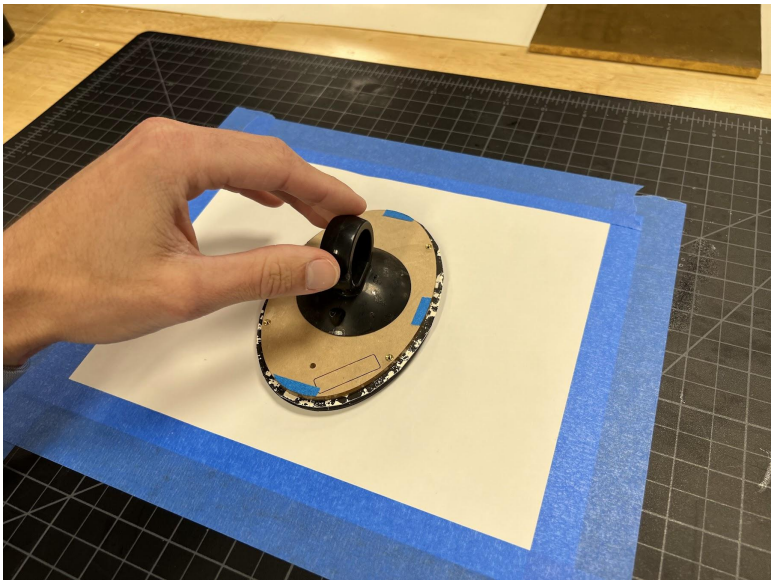


Figure 60: Alignment of bubble module over the sealing band

18. With the assembly on the table, apply strong downward pressure to hold the assembly together for at least five minutes until the glue cures. The goal is to have the acrylic seated all the way down into the sealing band evenly.
19. Use a shop towel to wipe away any excess glue that may have bubbled up.

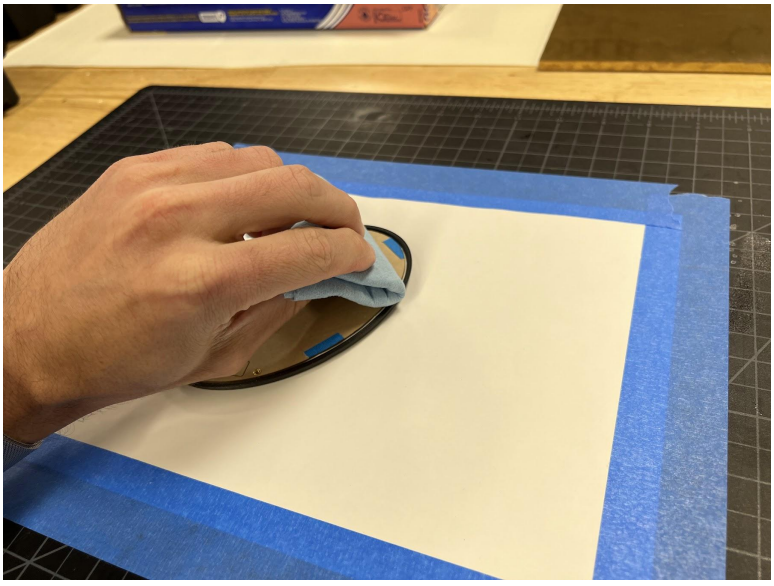


Figure 61: Wipe away excess glue.

20. After the glue has cured for five minutes, apply CA glue between the latex and the sealing band to hold the sealing band in place (Fig. 62). Carefully pull away the sealing band where it is loose and apply small amounts of cyanoacrylate (CA) glue, evenly spaced around the edge of the acrylic window. Reassemble the window and the sealing band and once again press firmly on a clean flat surface for alignment.

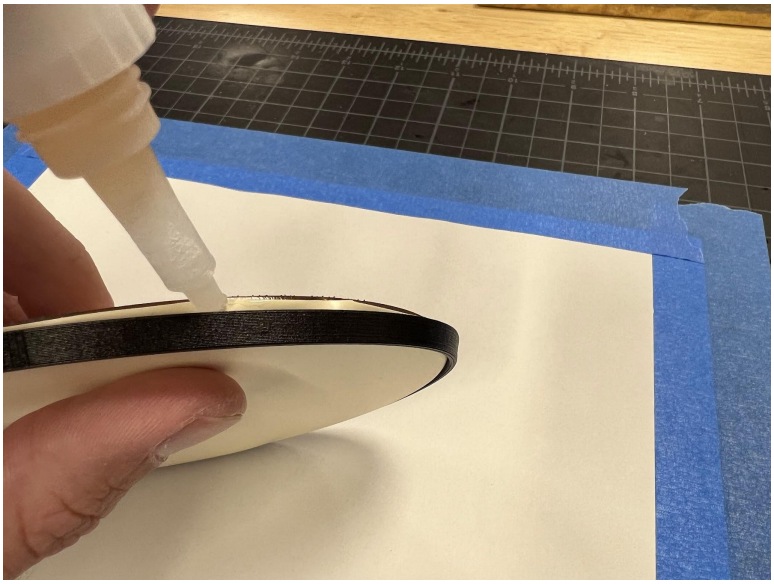


Figure 62: Extra CA glue applied to adhere the sealing band

21. Remove or replace gloves if there is glue on your fingers.
22. Use a spudger to lift a corner of the large remaining area of protective paper, leaving the small rectangular section reserved for the serial number.
    a. Avoid leaving fingerprints on the acrylic surface. You may choose to use a clean suction cup or other tool to hold down the bubble module while peeling away the protective paper.

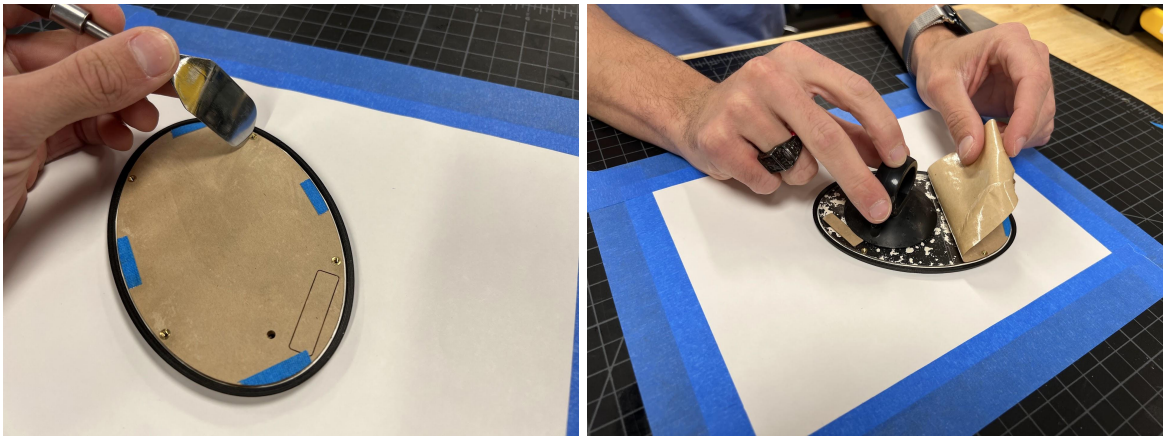


Figure 63: Removing the remaining paper and placing the suction cup.

⚠️ It's important to not scratch or get glue on the exposed acrylic surface as optical clarity is required. If glue does get on the surface, immediately remove with a cotton lens wipe. ⚠️

23. Place a small amount of high-viscosity cyanoacrylate (CA) glue onto the metal thread of the right-angle connector of Bubble Fitting-Tubing Assembly. Attach the Bubble Fitting-Tubing Assembly by hand-tightening the thread fully into the tapped hole at the bottom of the acrylic window. Once tightened, the fitting should be able to freely spin; adjust the direction of the tubing to its final position facing towards the closest edge of the eclipse (Figure 64).

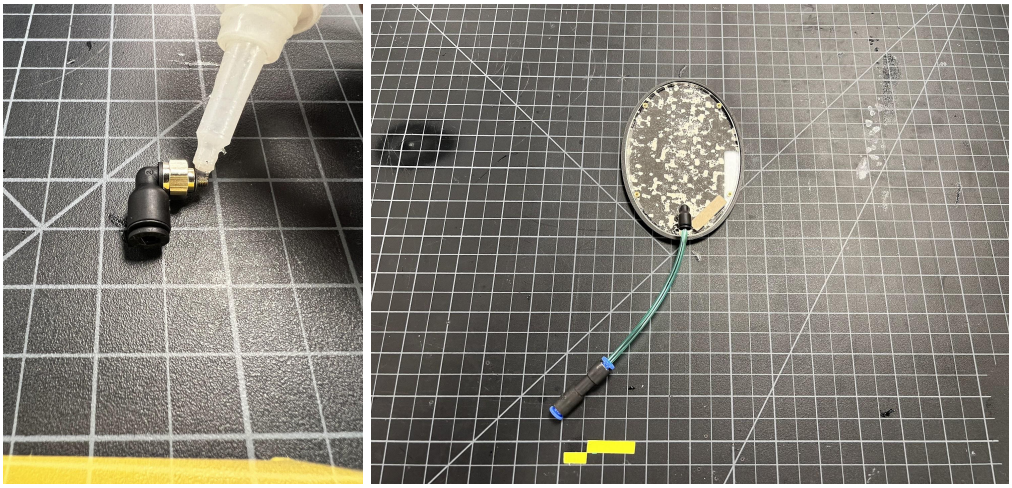


Figure 64: Application of CA glue to right-angle connector, and a completed assembly of a bubble module

24. Using the previously assembled Bubble Inflation Pump, insert the pump's open tubing end into the open end of the Bubble Fitting-Tubing Assembly.
25. Inflate the bubble up to 30 mm (Fig. 65) and quickly detach the pump's airline to seal the inflated bubble module.

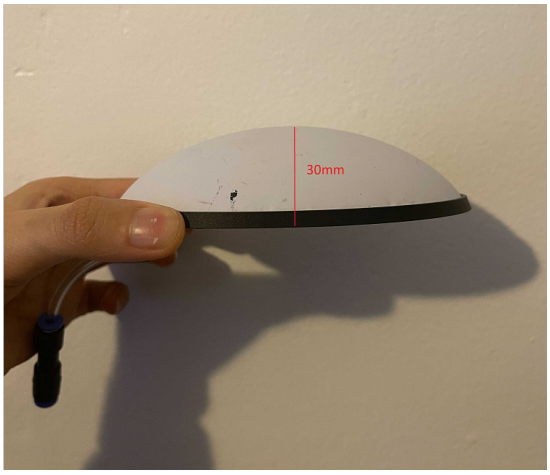



Figure 65: Inflated bubble module to a height of 30mm

26. Detach any edges still stuck to the repositionable adhesive spray by pinching the latex and pulling it upwards off of the acrylic plate to make sure it doesn't bond permanently.
    a. ⚠️ If the cyanoacrylate (CA) glue creeps under the acrylic and onto the latex, it is critical that the latex is detached before it fully dries. If a large area remains stuck, it will affect

the bubble's ability to comply and sense as intended. If only a small area remains stuck, the bubble is usable but aim to do a cleaner job next time. ⚠️

b. ⚠️ Do not pull too hard as you may accidentally detach the latex from the intentionally glued edges of the acrylic plate. ⚠️

Figure 66: Pulling off latex that is stuck to the acrylic

27. Evaluate the bubble using the following methods to see if it leaks.
    a. Squeeze it.
    b. Leave it on the table inflated for 24 hours and evaluate if it deflates.
    c. For hard-to-find leaks, inflate and squeeze under water and look for bubbles at the leak.
28. If you find a leak, deflate and dry the bubble then carefully apply CA glue into cracks between the latex and the acrylic at the leak site. You may wish to use a paintbrush so as to not apply too much glue.
29. Document the new bubble module in your tracker, including links to any photos.
30. Write the unique serial number generated by the tracker on the small reserved rectangle paper sticker left on the back of the bubble module acrylic.
31. Cover the exposed acrylic window with painter's tape to protect from dust and scratches.
32. **Congrats, you made a bubble!** After assuring the bubble is not leaking, keep the bubbles deflated and stored in a cool, dark area.

Figure 67: A variety of completed bubble modules

# SOFT-BUBBLE GRIPPER FAB AND ASSEMBLY

**Note:** These instructions document ONE Punyo Soft-Bubble Gripper Finger being assembled. The part quantities below are for TWO fingers. For a full gripper, construct two ‘fingers’ - this process is easier to complete in parallel.

## Before You Start

- Work in a well ventilated area.
- Gather all tools and materials below

## Tools

1. FDM 3D printer
2. 1.5 mm allen key (McMaster: 6958A21)
3. 2.5 mm allen key (McMaster: 6958A12)
4. Deburring tool (McMaster: 4289A71)
5. Phillips-head screwdriver

## Materials

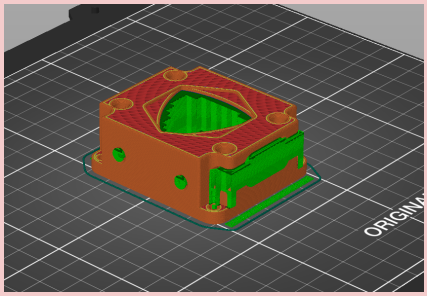
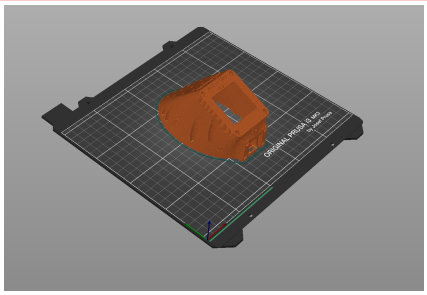
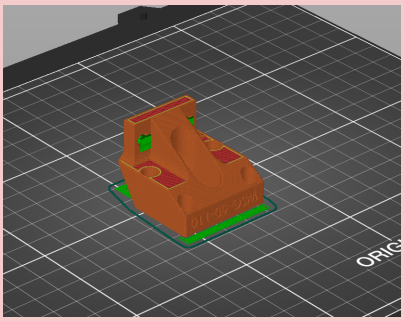
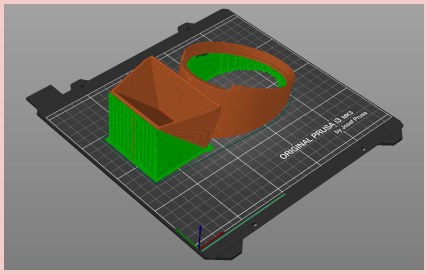
1. Plastic 3D printer filament
2. High viscosity cyanoacrylate (CA) glue (McMaster: 74985A65)

## Fasteners

1. M3 heat-set inserts, 3.8 mm installed length, qty 16 (McMaster: 94180A331)
2. M3 x 8 mm socket head cap screws, qty 16 (McMaster: 91290A113)
3. M3 washers, qty 8 (McMaster: 98269A420)
4. M2 washers, qty 8 (McMaster: 93475A195)
5. M2 x 5 mm socket head cap screws, qty 8 (McMaster: 91290A012)
6. Push-to-connect fitting clips (McMaster: 5779K433)

## Components

1. 3D printed parts
    a. *Intel D405 Case*, qty 2
    b. *Soft-Bubble Gripper Body*, qty 2
    c. *Gripper Finger-Mount WSG 050-110*, qty 2
    d. *Heat Set Insert Stand*, qty 1
2. Latex bubble modules (built in section “Bubble Module Assembly”), qty 2
3. NeoPixel LED, qty 2
4. Intel D405, qty 2
5. Female 3-pin connector, qty 2

| | 3D Printing (STL) | Image |
|---|---|---|
| Gripper Body Assembly | Intel D405 Case.stl |  |
| | Soft-Bubble Gripper Body.stl |  |
| | Gripper Finger Mount for WSG 050-110.stl |  |
| | Heat-set Insert Stand.stl |  |

## 3D Printing of Gripper Body Assembly

The components of the gripper body are entirely 3D-printed. It does not matter what type of printer you have (hobbyist or commercial). They have successfully been printed at TRI on a Markforged X7, Onyx, Taz 6 and Prusa i3 MK3.

### Print Setup

1. Print the *Gripper Finger Mount WSG 050-110* (Fig. 68) using the following settings:
    a. 100% infill
    b. Support everywhere above a 85 degree overhang
    c. ⚠️ If you are using a different gripper, this connecting part will have to be designed to fit your gripper's specific mounting pattern. When designing, consider the contact between the bubbles when the gripper is fully closed, and the distance between bubbles when the gripper is fully opened. ⚠️

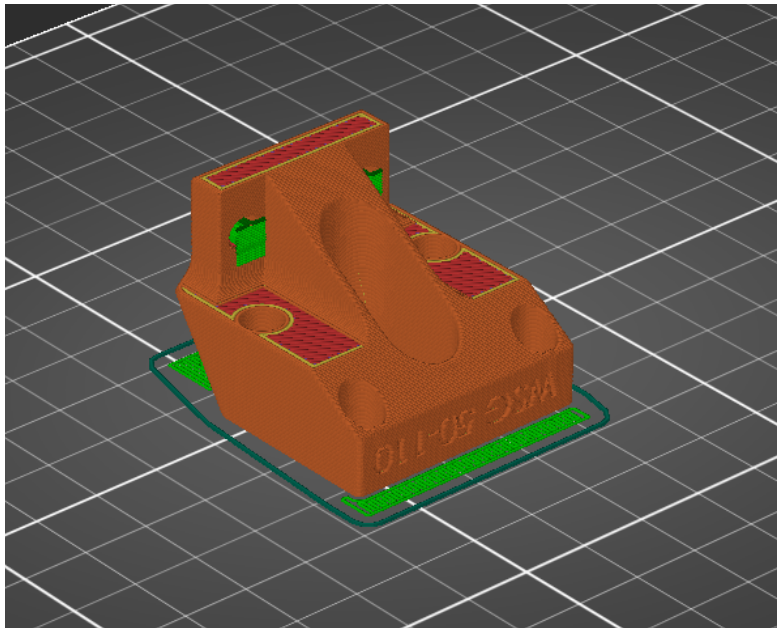


Figure 68: STL model of part *Gripper Finger Mount WSG 050-110* with support material in slicer

2. Print the *Bubble Gripper Body* (Fig. 69) using the following settings:
    a. 20% infill
    b. No support material

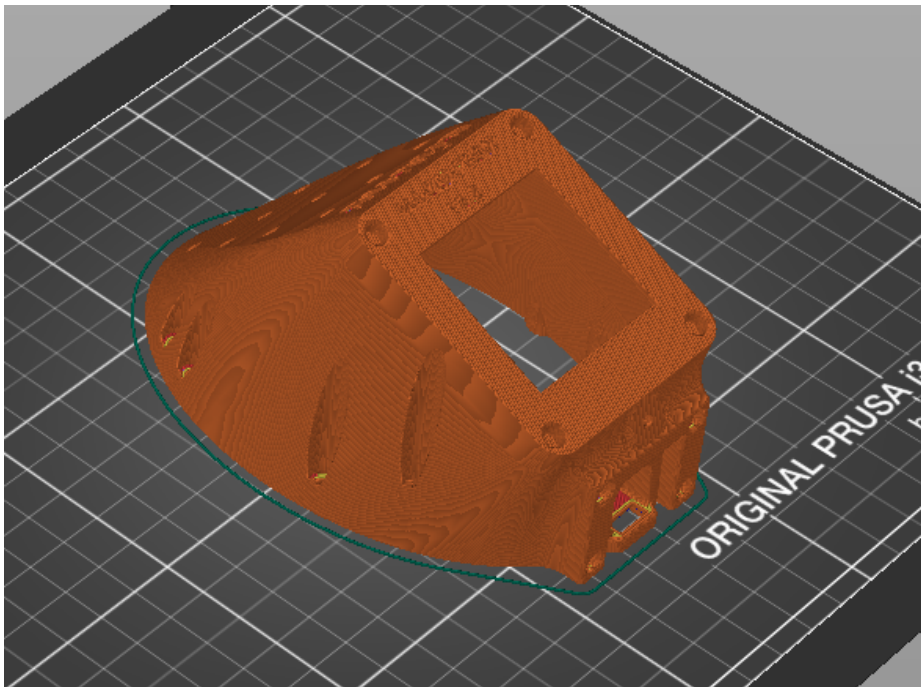



Figure 69: STL model of part *Bubble Gripper Body* in slicer

3. Print the *D405 Case* (Fig. 70) using the following settings:
    a. 20% infill
    b. Support everywhere above a 50 degree overhang

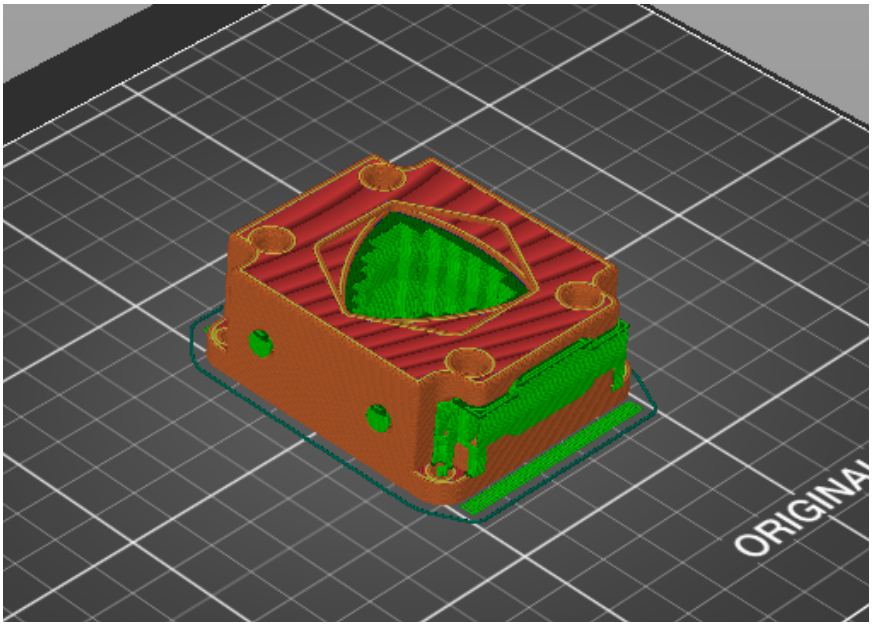


Figure 70: STL model of part *D405 Case* with support material in slicer

## 3D Printing of Heat-set Insert Stand

The *Heat-set Insert Stand* is not necessary for assembling the gripper body. We recommend its use to make the process of installing the threaded heat-set inserts both more efficient and more safe.

### Print Setup

1. Print the *Heat-set Insert Stand* (Fig. 71) using the following settings:
    a. 15% infill
    b. Support everywhere above a 50 degree overhang

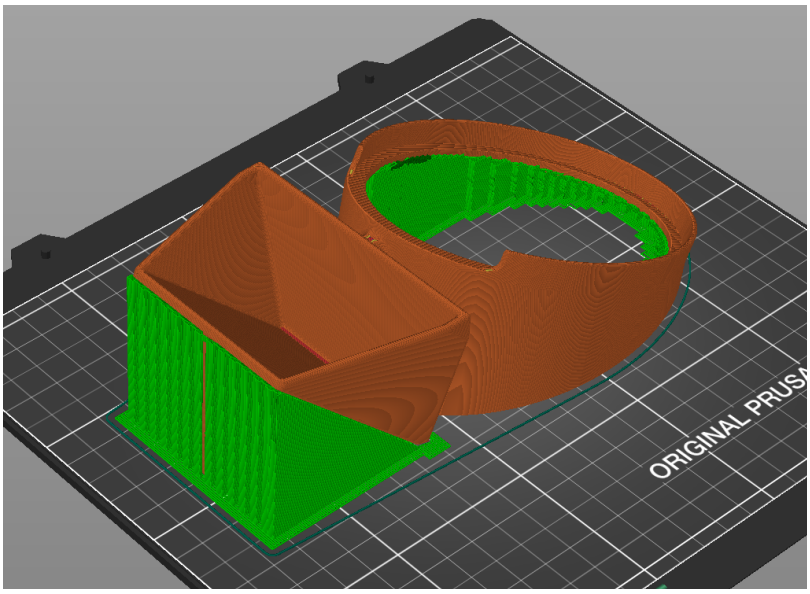



Figure 71: STL model of *Heat-set Insert Stand* with support material in slicer

## Assembly

1. Go to a ventilated area that is designated by your institution to be used for fumes.
2. Place the *Bubble Gripper Body* into the *Heat-set Insert Stand* resting on the slanted elliptical section.
3. Use a soldering iron with a heat-set insert tip to insert four M3 inserts 3.8 mm depth into the following positions on each *Bubble Gripper Body*. Leave the insert slightly proud of the surface and quickly move onto the next step.
4. Use a flat, heavy tool to press the insert in the rest of the way so that the insert is flush with the face of the *Bubble Gripper Body*.

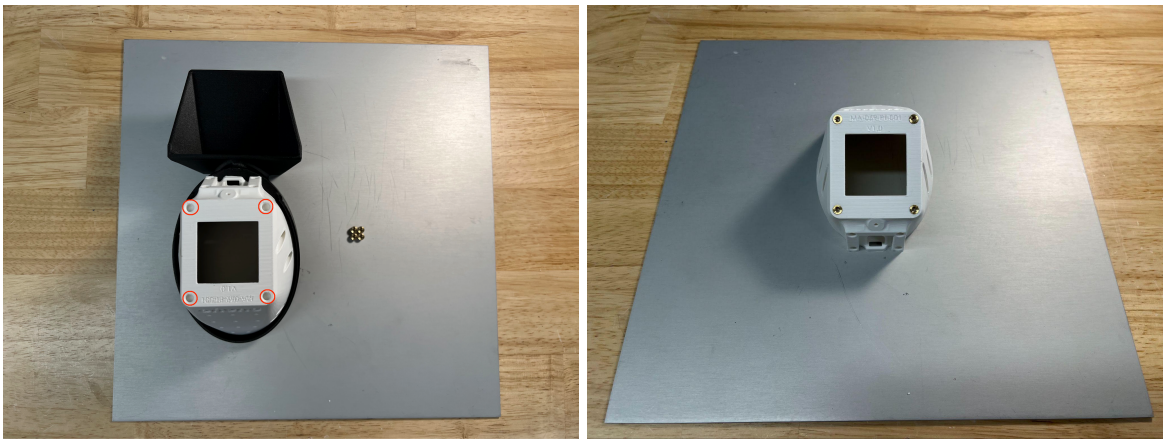


Figure 72: Left, the four locations for four M3 3.8 mm depth heat-set inserts are circled in red Right, the *Bubble Gripper Body* with the inserts installed.

5. Place the tip of the *Bubble Gripper Body* into the angled section of the *Heat-set Insert Stand*.
6. Use a soldering iron with a heat-set insert tip to insert four more M3 inserts 3.8 mm depth into the following positions on each *Bubble Gripper Body*. Leave the insert slightly proud of the surface and quickly move onto the next step.
7. Use a flat, heavy tool to press the insert in the rest of the way, so that the insert is flush with the face of the *Bubble Gripper Body*.

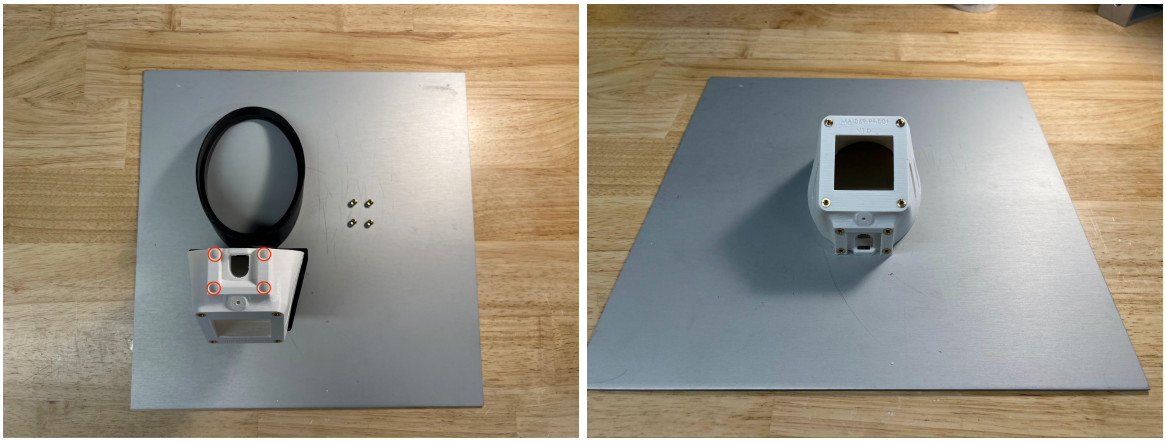


Figure 73: The four locations for four M3 3.8 mm depth

inserts circled in red, and *Bubble Gripper Body* with the inserts installed.

8. Solder the female 3-pin connector to the NeoPixel LED.
    a. The connector wires should be pre-tinned for soldering. If not, tin wires before soldering to the NeoPixel LED.
    b. Solder wires through the back of NeoPixel Board in this configuration: red to **+5V**, green to **GND**, and white to **In**.

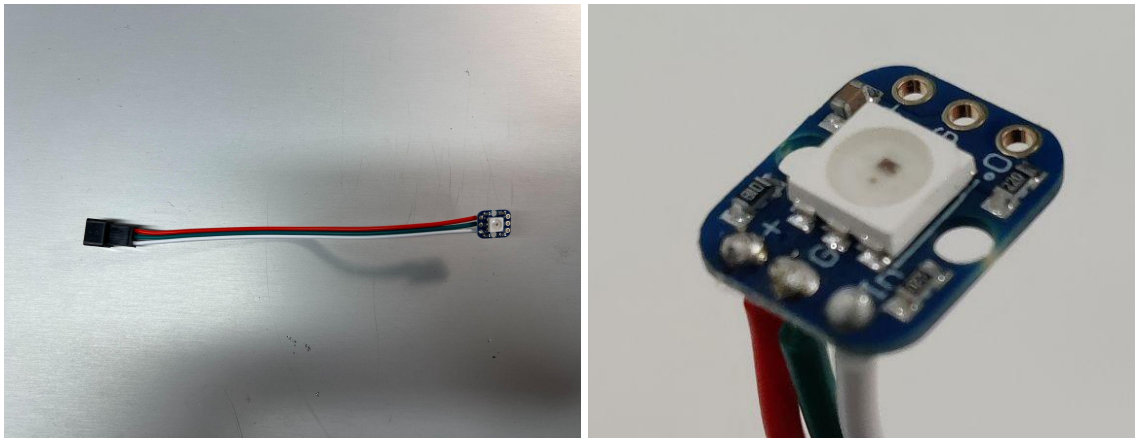


Figure 74: The female 3-pin connector soldered to the NeoPixel LED

9. Attach the NeoPixel LED to the *Bubble Gripper Body*.
    a. Place a small amount of high-viscosity cyanoacrylate (CA) glue onto the bridge across the rectangular cutout at the bottom of the gripper body, circled in red in Fig. 75.
    b. Route the connector through the *Bubble Gripper Body* wire/tubing port from the inside.
    c. Insert the NeoPixel LED into the rectangular cutout.
    d. Wait 5-10 minutes for the glue to dry. It may be helpful to use a small piece of tape to keep the NeoPixel LED Board in position while the glue dries.

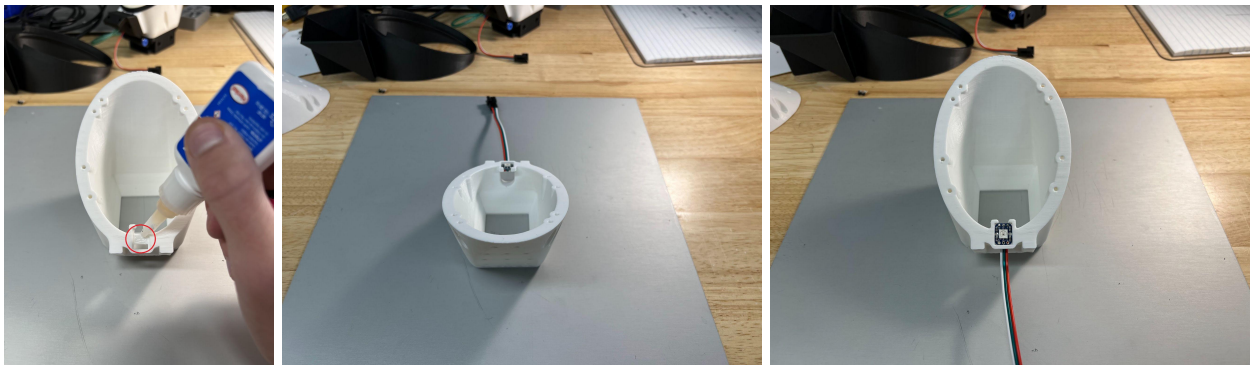


Figure75: Cyanoacrylate (CA) application to the *Bubble Gripper Body*,
and the *Bubble Gripper Body* with the NeoPixel Board inserted, front and rear view.

10. Attach the *Bubble Module* to the *Bubble Gripper Body*.
    a. Route the quick connect air tubing through the wire/tubing passthrough of the *Bubble Gripper Body* from the inside.

b. Carefully push the *Bubble Module* into position, with the latex facing away from the cavity of the *Bubble Gripper Body*. The four threaded heat-set inserts should align with the four positions circled in red in Fig. 76.
c. Insert four M2 washers and M2 x 5 mm socket head cap screws into these positions. Using a 1.5 mm allen key, and fasten the *Bubble Module* to the *Bubble Gripper Body*.

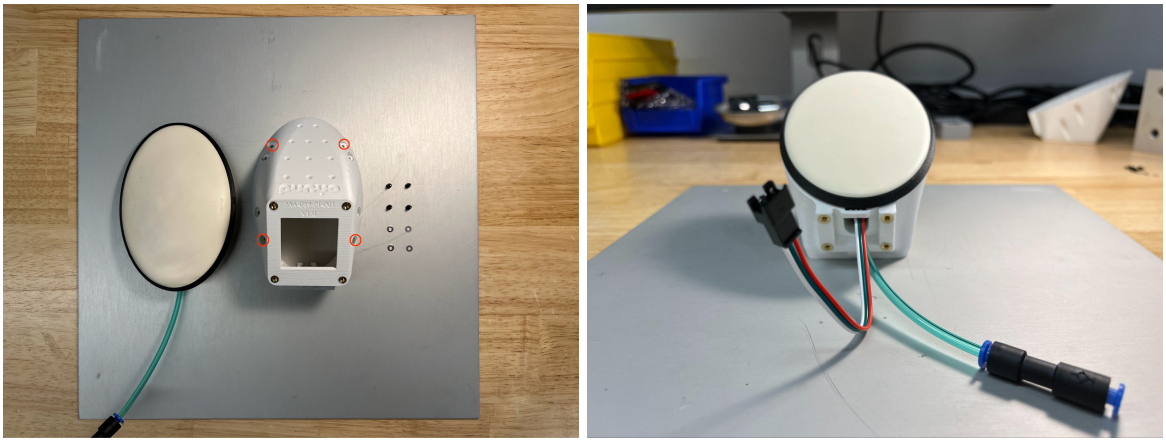


Figure 76: Locations and fasteners necessary to attach the *Bubble Module* to the *Bubble Gripper Body*

11. Insert the Intel D405 depth camera into the *Intel D405 Case*. Make sure that the USB port of the sensor is aligned with the bottom passthrough on the case.

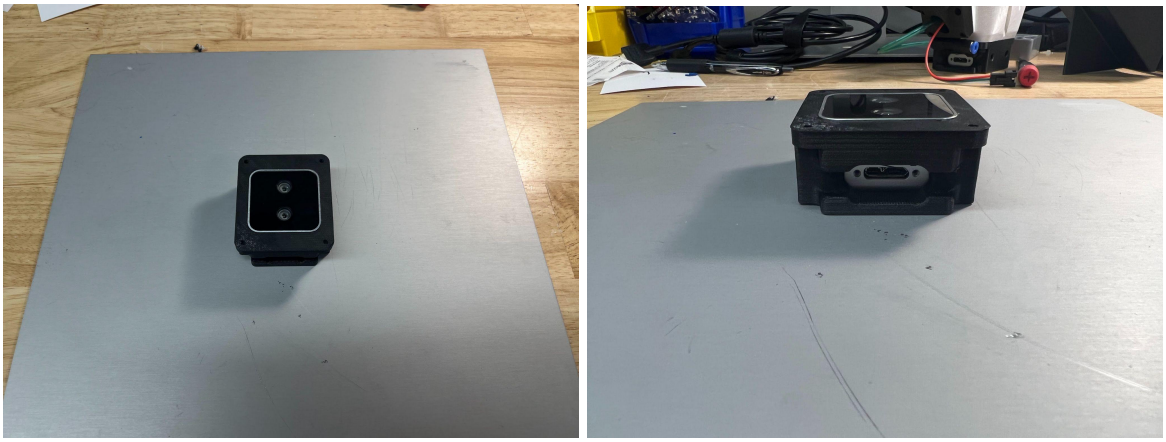


Figure 77: Intel D405 depth sensor inserted into its case

12. Insert four M3 washers and four M3 x 8 mm socket head cap screws through the holes circled in red on the *Intel D405 Case and* into the heat-set inserts in the *Bubble Gripper Body*, also circled in red. Using a 2.5 mm allen key, fasten the case to the gripper body.
    a. The D405 Case should be aligned so that the USB port faces the same direction as the tubing.

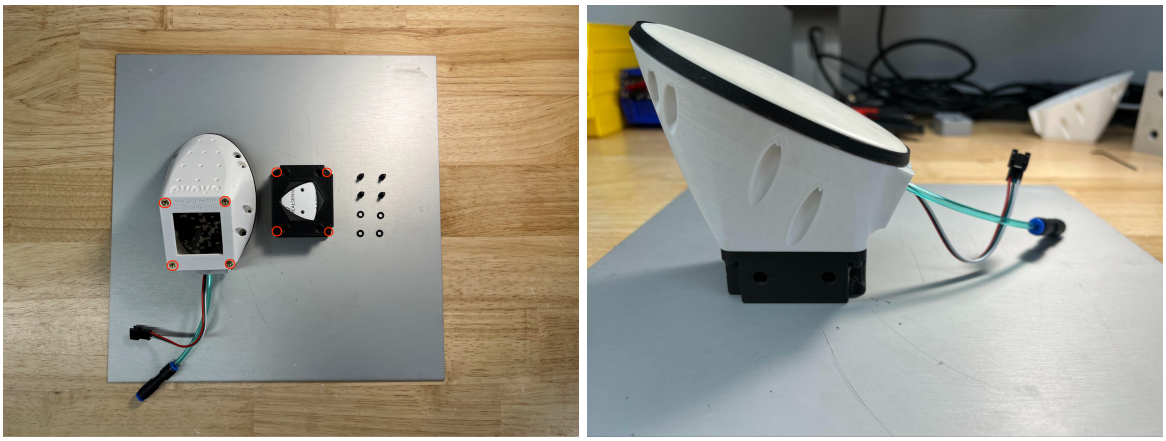


Figure 78: Locations and fasteners necessary to attach the *Intel D405 Case* to the *Bubble Gripper Body*

13. Attach the tube fitting clip with a thread forming screw to the hole circled in red using a phillips-head screwdriver (the screw is included with the fitting clip).
    a. The fitting clip is used to hold the push-to-connect connector of the fitting-tubing assembly. Align the clip so that its opening is parallel to the bottom edge of the *Bubble Gripper Body*.

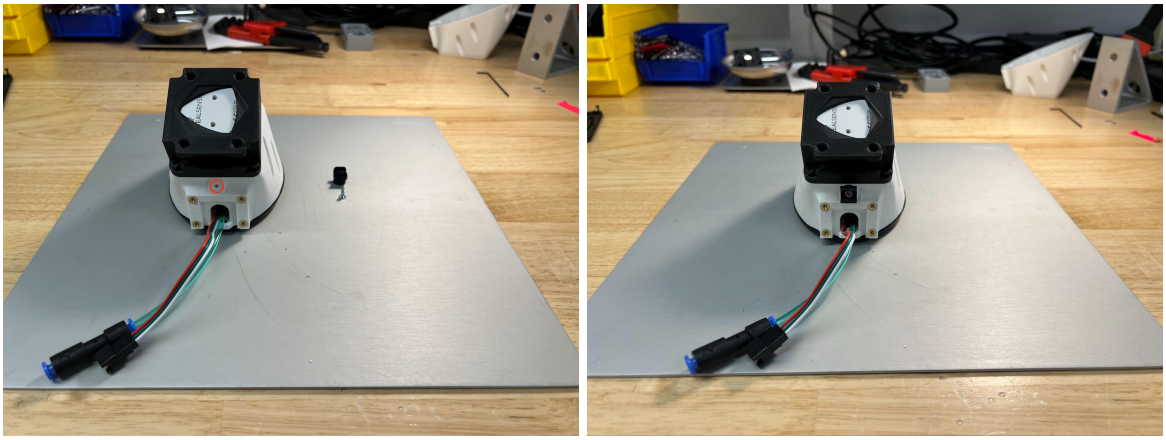


Figure 79: Location and fasteners necessary to attach the tube fitting clip to the *Bubble Gripper Body*

14. Insert four M3 washers and four M3 x 8mm socket head cap screws into the holes circled in red to attach the *Gripper Finger Mount for WSG 050-110* to the *Bubble Gripper Body* (Fig. 80).

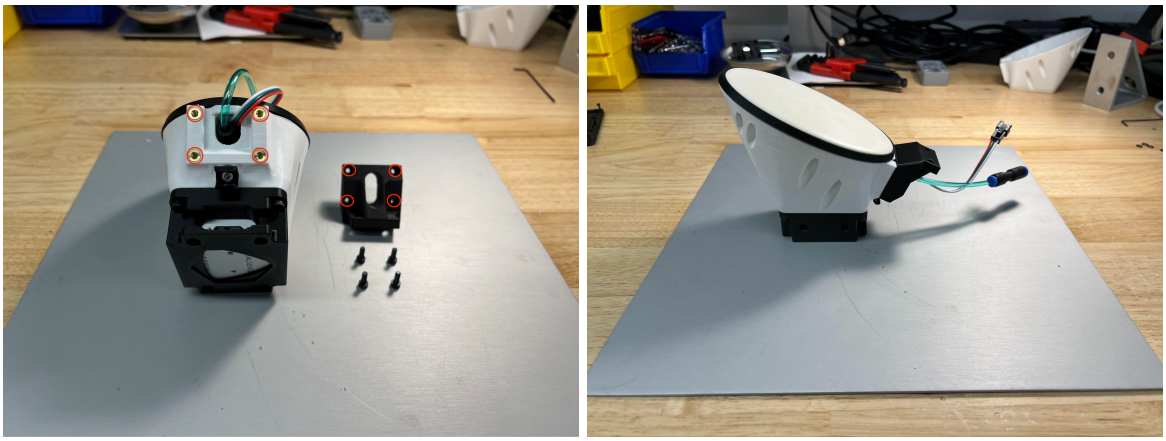


Figure 80: Locations and fasteners necessary to attach the *Gripper Finger-Mount WSG 050-110* to the *Bubble Gripper Body*

15. Click the push-to-connect fitting into the clip on the *Gripper Finger Mount* (Fig. 81).

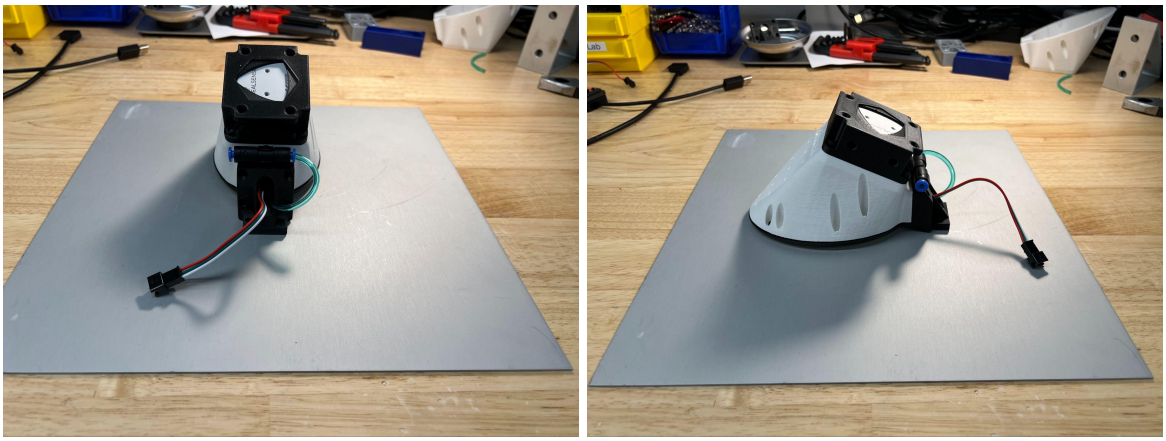


Figure 81: The push to connect fitting inserted into the tube fitting clip

16. If not already building your Bubble Gripper Fingers in parallel, repeat steps 2-11 to build your second finger.

Figure 82: Two completed Punyo Soft-Bubble Gripper Fingers!

# PRESSURE SENSING SYSTEM

The pressure sensing system consists of a microcontroller and a pressure sensor board that are connected to the Soft-Bubble Gripper Fingers; one complete pressure-sensing system per finger. The pressure readings can be observed while inflating the bubbles to a certain pressure, used to understand the state of a grasp or contact, used to detect leaks, etc. The microcontroller also delivers power to and controls the color of the Soft-Bubble Finger's NeoPixel LED. The compact, lightweight system can be mounted directly onto the robot's end-effector if desired.

**Note:** These instructions document ONE pressure sensing system being assembled. The part quantities below are for TWO pressure sensing assemblies. For a full gripper, construct two pressure sensing systems. This process is easier to complete in parallel.

**We recommend building a pressure sensing system for each Punyo Soft-Bubble sensor so that they may be used independently.** If you will use multiple Soft-Bubbles in a single system, e.g. a two-fingered gripper, you may choose to connect multiple pressure sensors to a single microcontroller with modified firmware.

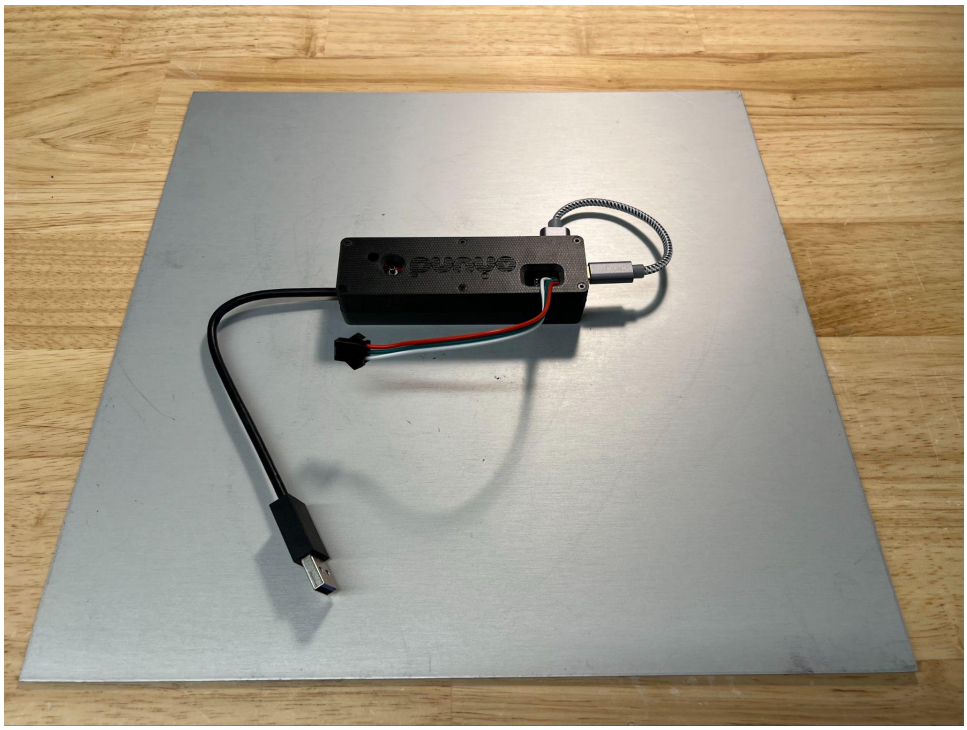



Figure 83: Pressure Sensing System connected to Anker USB hub.

## Before You Start

1. Work in a well ventilated area
2. Gather all tools and materials below before getting started

## Tools

1. FDM 3D Printer
2. 1.5 mm Allen key
3. Temperature controlled soldering iron
4. Bench-top fume absorber
5. Solder scour pad with metal brass wire

## Materials

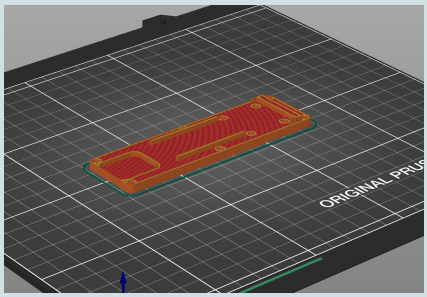
1. Plastic 3D printer filament
2. High viscosity cyanoacrylate (CA) glue (McMaster: 74985A65)

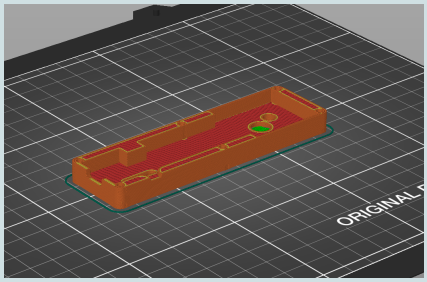
## Fasteners

1. M2 x 2.9 mm Heat-Set Inserts, qty 20 (McMaster: 94180A307)
2. M2 x 10 mm screws, qty 12 (McMaster: 91290A017)
3. M2 x 5 mm screws, qty 8 (McMaster: 91290A012)

## Components

1. 3D printed parts
    a. *Electronics Enclosure Bottom*, qty 2
    b. *Electronics Enclosure Top*, qty 2
2. USB Type A to Type C Braided Cable, qty 2
3. Male 3-pin connector, qty 2
4. Adafruit QT Py, qty 2
5. SparkFun Qwiic MicroPressure Sensor, qty 2 (SEN-16476)
6. 50 mm Qwiic Cable, qty 2 (PRT-14426)

| | .STL File | Image |
|---|---|---|
| Pressure Sensing System | Electronics Enclosure Bottom.stl |  |

| | | |
|---|---|---|
| | Electronics Enclosure Top.stl |  |

## Software

| | Arduino Script | Custom ROS Arduino Library |
|---|---|---|
| Pressure Sensor System | micro_ros_bubble.ino | micro_ros_arduino-2.0.5-custom.zip |

## 3D Printing of Pressure Sensing System Electronics Enclosure

The components of the pressure sensor system mounts are entirely 3D-printed. It does not matter what type of printer you have (hobbyist or commercial). They have successfully been printed at TRI on a Markforged X7, Onyx, Taz 6 and Prusa i3 MK3.

### Print Setup

1. Print the parts *Electronics Enclosure Top* and *Electronics Enclosure Bottom* (Fig. 84) using the following settings:
    a. 15% infill
    b. No support material.

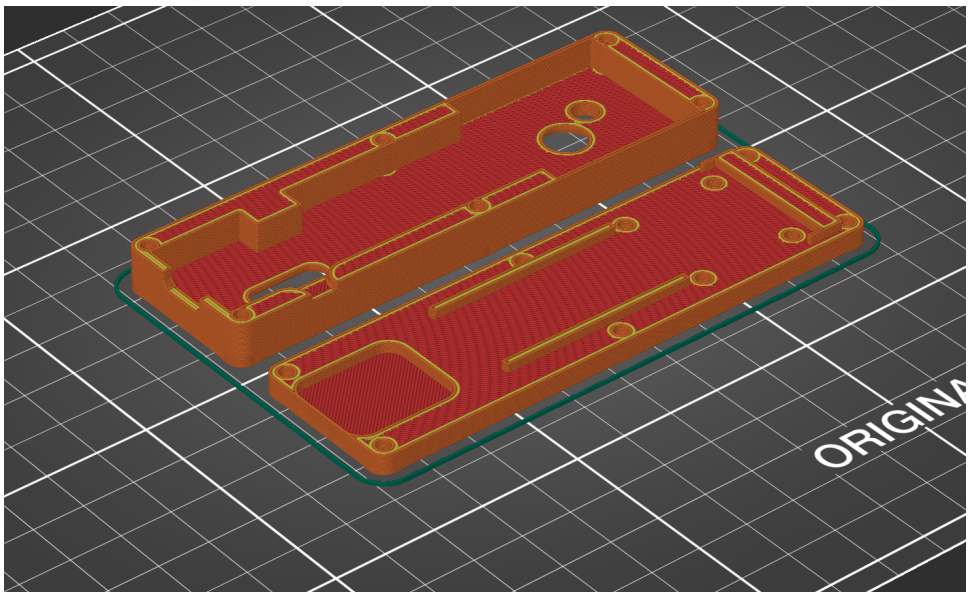


Figure 84: STL model of Electronics Enclosure *Top* and *Bottom* in slicer

## Assembly

1. Use a soldering iron with a heat-set insert tip to insert ten M2 inserts 3.9 mm depth into the positions circled in red on *Electronics Enclosure Bottom*.

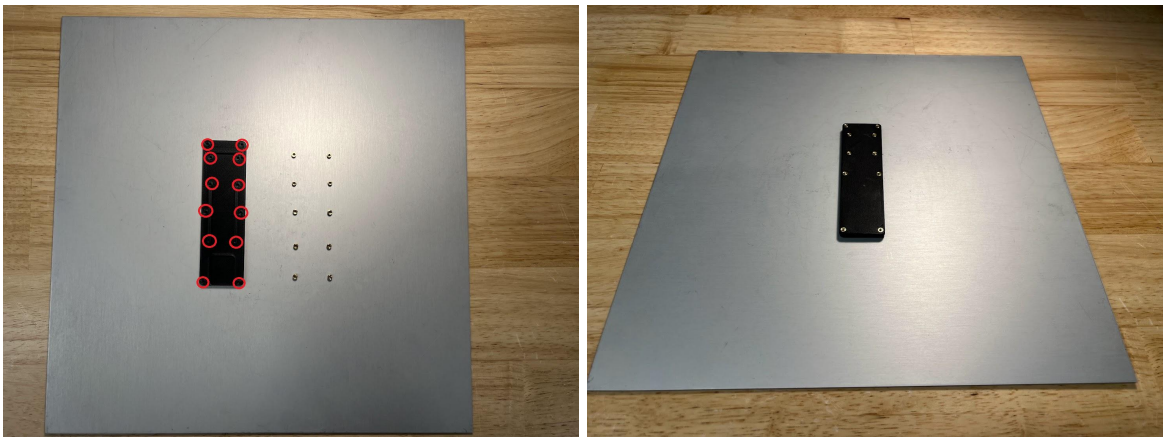


Figure 85: The locations for ten M2 2.9 mm depth inserts circled in red, and *Electronics Enclosure Bottom* with the inserts inserted

2. Insert the 50 mm Qwiic Cable into the Qwiic connect port on the Sparkfun Qwiic MicroPressure Sensor (Fig. 86).

Figure 86: Sparkfun Qwiic MicroPressure Sensor with 50 mm Qwiic cable inserted

3. Using a 1.5 mm allen key, insert four M2 x 5 mm socket head cap screws into the positions circled in red to attach the Sparkfun Qwiic MicroPressure Sensor to the *Pressure Sensor Board Bottom*.

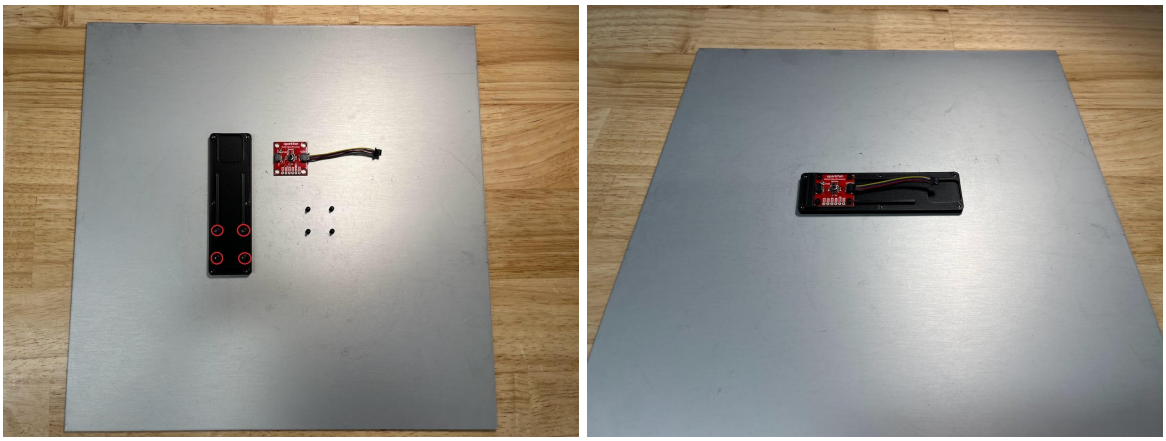


Figure 87: Locations and fasteners necessary to attach the pressure sensor board to *Electronics Enclosure Bottom*

4. Solder the Male 3-pin Connector to the QtPy board.
    a. The connector wires should be pre-tinned for soldering. If not, tin wires before soldering to QtPy.
    b. Solder wires to the front of the QtPy board in this configuration: red to **+5V**, green to **GND**, and white to **M0**.

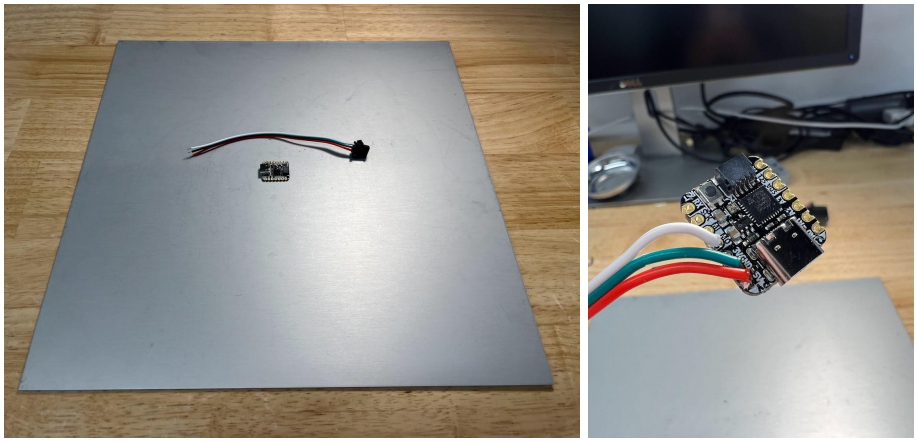


Figure 88: The male 3-pin connector soldered to the QtPy board

5. Install the QtPy board into the electronics enclosure:
    a. Insert the 50 mm Qwiic Connect Cable Harness into the Qwiic connect port on the QtPy.
    b. Note: although the firmware can be installed without this step, it *will not power the NeoPixel LED* without a pressure sensor connected.
    c. Insert the QtPy into the recess on the right hand side of the *Electronics Enclosure Bottom*. The board will be held in place by the *Electronics Enclosure Top*.
    d. Route the male connector through the rectangular cutout that is located on the right side of the *Electronics Enclosure Top* from the inside. Snap the top of the housing onto the bottom, making sure that the USB-C port on the QtPy board is properly seated, and the 50 mm Qwiic Connect Cable Harness is between the two raised bars found on the inside of the *Electronics Enclosure Bottom.*

e. Using a 1.5 mm allen key, insert six M2 x 10 mm socket head cap screws into the positions circled in red and fasten.

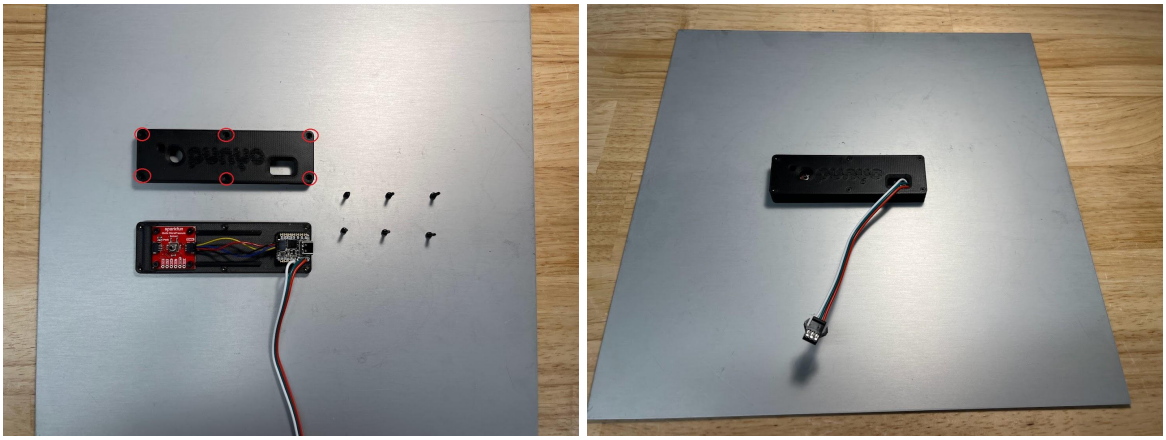


Figure 89: Locations and fasteners necessary to assemble the electronics enclosure

## Software Installation

1. Downloads for Arduino IDE for Windows, Mac, and Linux can be found at https://www.arduino.cc/en/software. Follow instructions to install Arduino IDE on your computer.

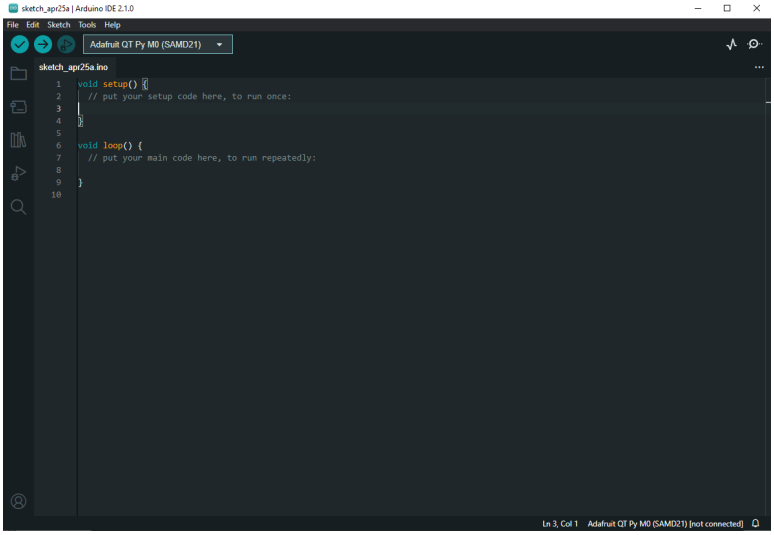



Figure 90: Arduino IDE

2. Open the Arduino script *micro_ros_bubble.ino* in the Arduino IDE.
3. Install four required libraries.
    a. Three of the four libraries can be installed via Arduino IDE's built-in library manager. Access the library manager via the stacked book icon on the left of the window (circled in red).

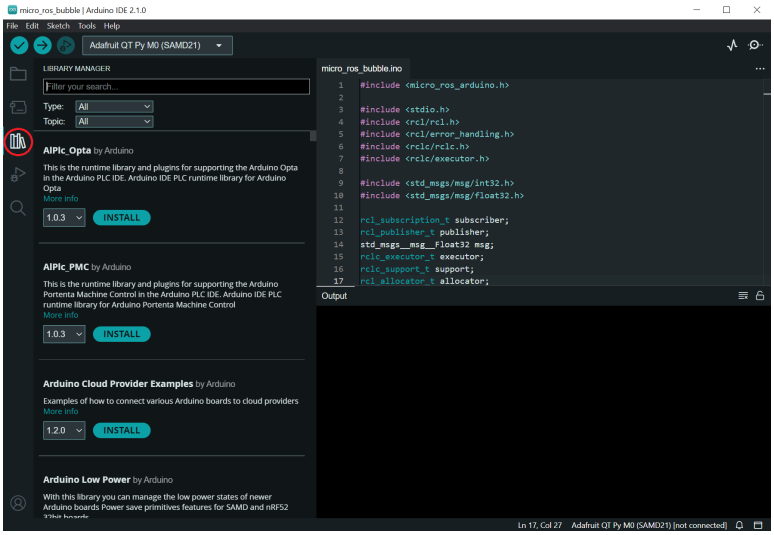



Figure 91: The libraries manager tab circled in red

    i. Using the textbox, find and install:
        1. "Adafruit MPRLS Library"
        2. "Adafruit Neopixel"
        3. "ArduinoUniqueID"

b. The fourth is a custom library. The .ZIP file to install it is included in the downloaded fabrication files for the pressure sensing system.
    i. In Arduino IDE, navigate the **Sketch** tab to **Include Library** > **Add .ZIP Library…**
    ii. Select *micro_ros_arduino-2.0.5-custom.zip* to install the library.

4. Install the QtPy board to your Arduino IDE.
    a. Navigate in the **File** dropdown to **Preferences**. In the **Preferences** window, enter this URL into the ‘Additional boards manager URLs:’ textbox at the bottom: https://adafruit.github.io/arduino-board-index/package_adafruit_index.json

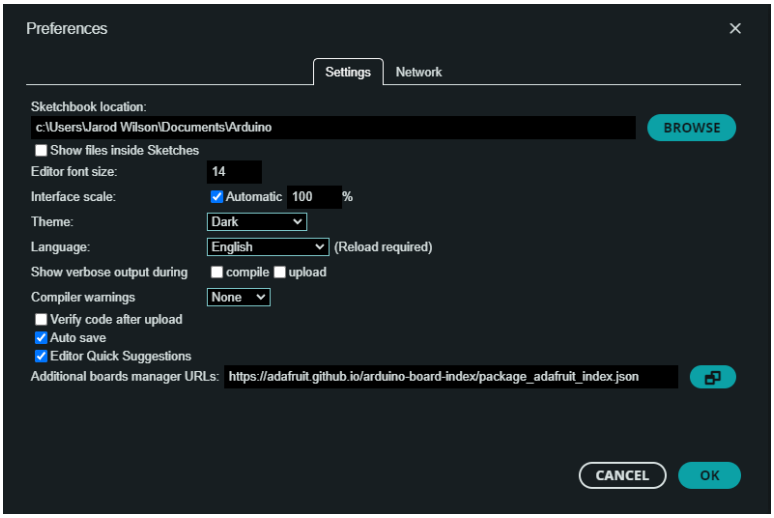



Figure 92: The preferences window of Arduino IDE

b. Access the boards manager via the board icon on the left of the window (circled in red).
    i. Install the Adafruit SAMD Boards package.

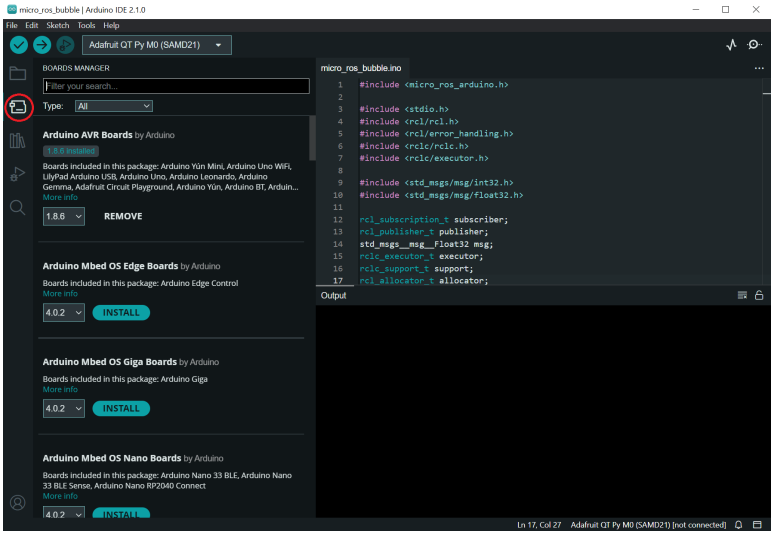



Figure 93: The boards manager tab circled in red

5. Select the COM port for the pressure sensing system.
    a. Navigate the **Tools** tab to **Port**.

b. Connect the USB-C to USB-A wire to the QtPy and your computer respectively. The COM port of the QtPy will become available to select in the dropdown that appears when hovering your cursor over **Port**.

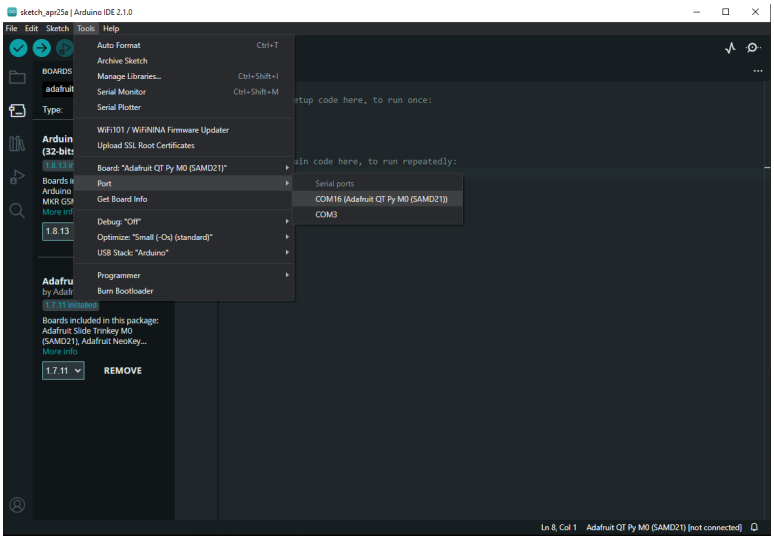



Figure 94: Selecting the QtPy COM port via the tools tab

6. Select the QtPy board by navigating the **Tools** tab to **Board** > **Adafruit SAMD Boards** > **Adafruit QT Py M0 (SAMD 21)**.

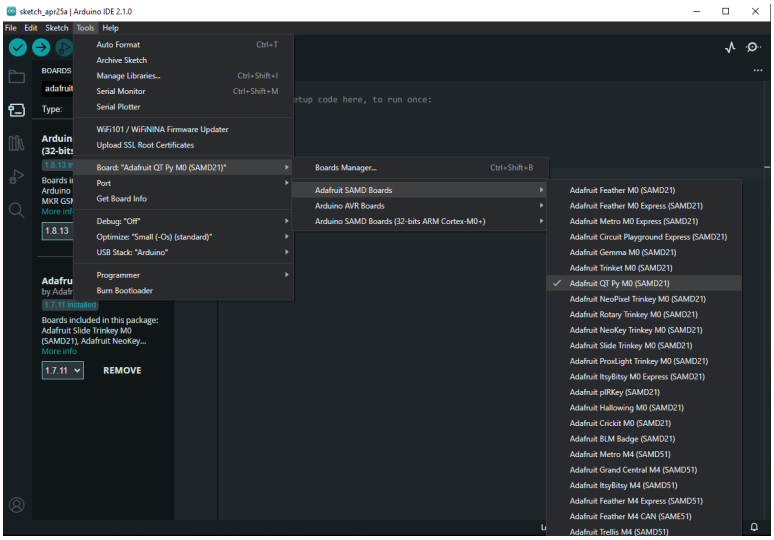



Figure 95: Selecting the QtPy board as the board via the tools tab

7. Install the software on the QtPy by selecting the ‘Upload’ button (icon with an arrow pointing right) located at the top left corner of the IDE window, circled in red.

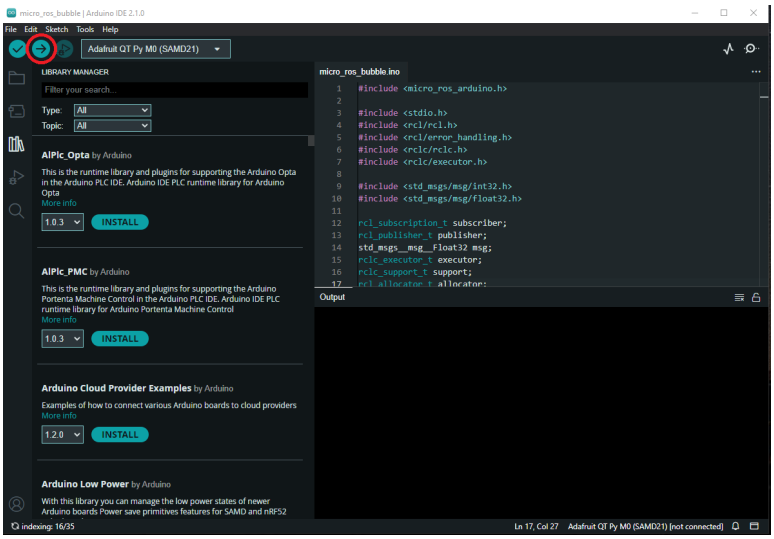



Figure 96: The upload button circled in red; this installs the software on the QPy

a. If successful, the LED on the Qt Py should turn blue after power-cycling the board. If a NeoPixel LED is plugged in before power-cycling, it will illuminate white.

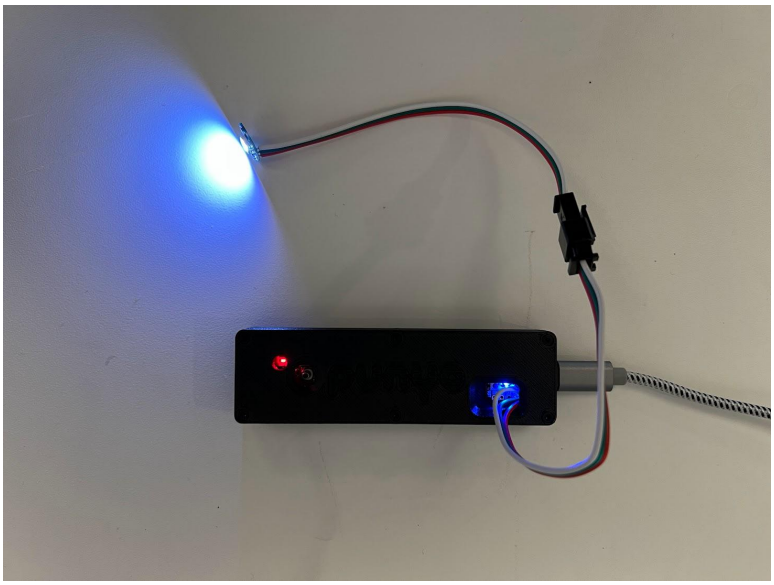


Figure 97: The pressure sensing system when
powered on after being power cycled with a successful software installation

8. Repeat the flashing process for the second pressure sensing system as well.

# FINAL ASSEMBLY TO GRIPPER

**Note:** This section details attaching the pressure sensing system units and grippers to a Schunk WSG-050-110-B. If another gripper/configuration is selected for use with the Punyo Soft-Bubble Gripper, another mount may be necessary and will not be supported by TRI.

Additionally, the configuration documented here couples two full Punyo Soft-Bubble Grippers and two full pressure sensing system units to a single gripper, ONE pressure unit to ONE Soft-Bubble Gripper. It is not required to use the grippers in this configuration; the Soft-Bubble Grippers and pressure sensing system units can be separated and used individually. It is also possible to use a single microcontroller to drive two pressure sensing boards. TRI does not currently support the latter.

## Tools

1. M3 allen key (McMaster: 7289A14)
2. Scissors

## Materials

1. VHB double-sided tape
2. 15 cm of firm Polyurethane Rubber Tubing (2.4 mm ID, 4 mm OD) (McMaster: 50315K68)

## Fasteners

1. M4 x 14 mm socket head cap screws, qty 4 (McMaster: 91290A150)

## Components

1. *Bubble Gripper Finger, qty 2*
2. USB 3.0 Type A to Micro B right angle cable, qty 2
3. USB 3.0 Type A to Type C cable, qty 2
4. Anker slim USB hub, qty 2
5. Schunk WSG 050-110 or other gripper

## Assembly

1. Using a M3 allen key, attach the *Bubble Gripper Fingers* to the Schunk WSG 050-110 by inserting the M4 x 14 mm socket head cap screws into the holes circled in red and fastening.

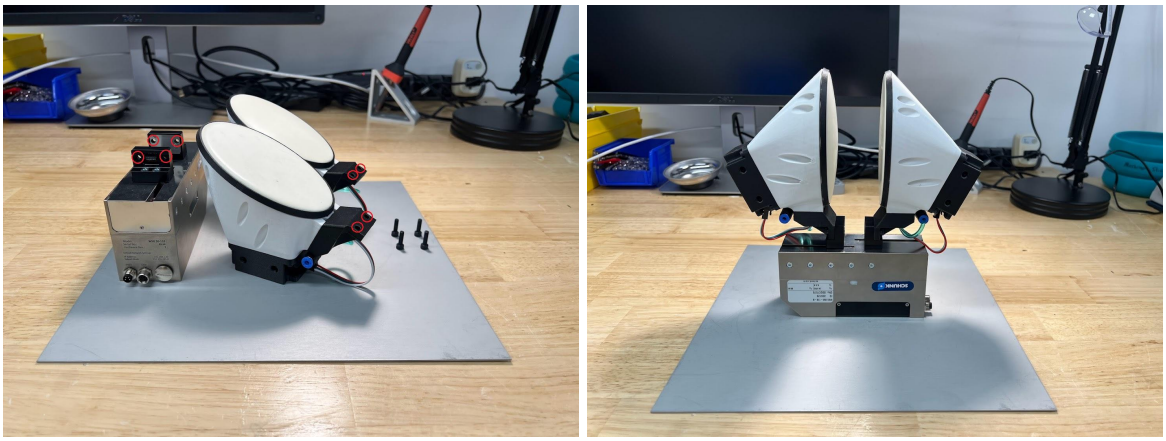


Figure 98: The locations and fasteners to attach the *Bubble Gripper Fingers* to the Schunk WSG 050-110

2. Using high-viscosity cyanoacrylate (CA) glue, affix the *Pressure Sensing System* to the Anker slim USB hub:
    a. Orient the USB hub such that the USB cable is on its left side, with the side the Anker label is on face-down.
    b. Apply glue to the top face.
    c. Orient the *Pressure Sensing System* such that its ‘Punyo’ inscription is legible; the cable on the right side with the pressure sensor board visible.
    d. Press the USB hub and pressure sensing system together, and let the glue dry for 10 minutes. It may be useful to secure the components with gaff tape while the glue dries.
    e. Note: It is not necessary to glue the components together; they can be affixed together with the adhesive of your choice (VHB tape, velcro, etc.)

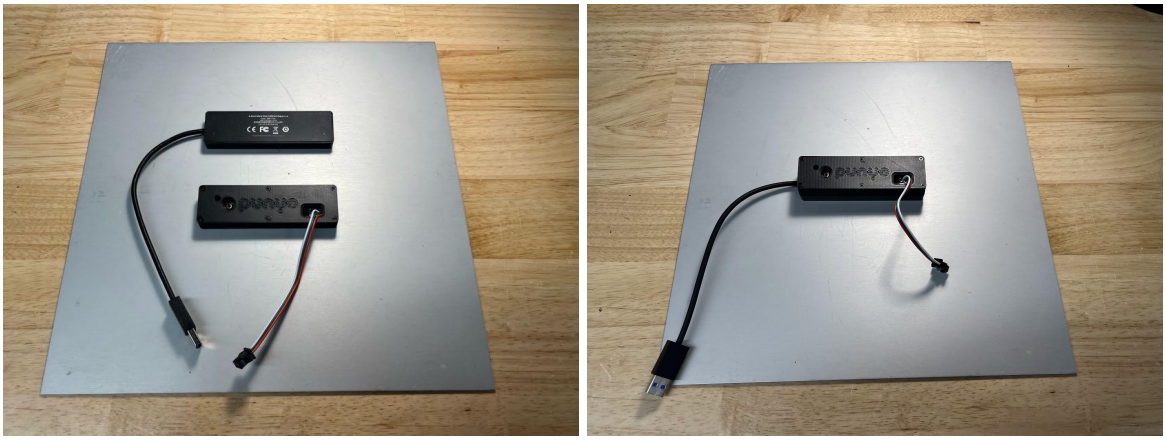


Figure 99: Orientation of the *Pressure Sensing System* and Anker USB hub before gluing together, and the combined unit

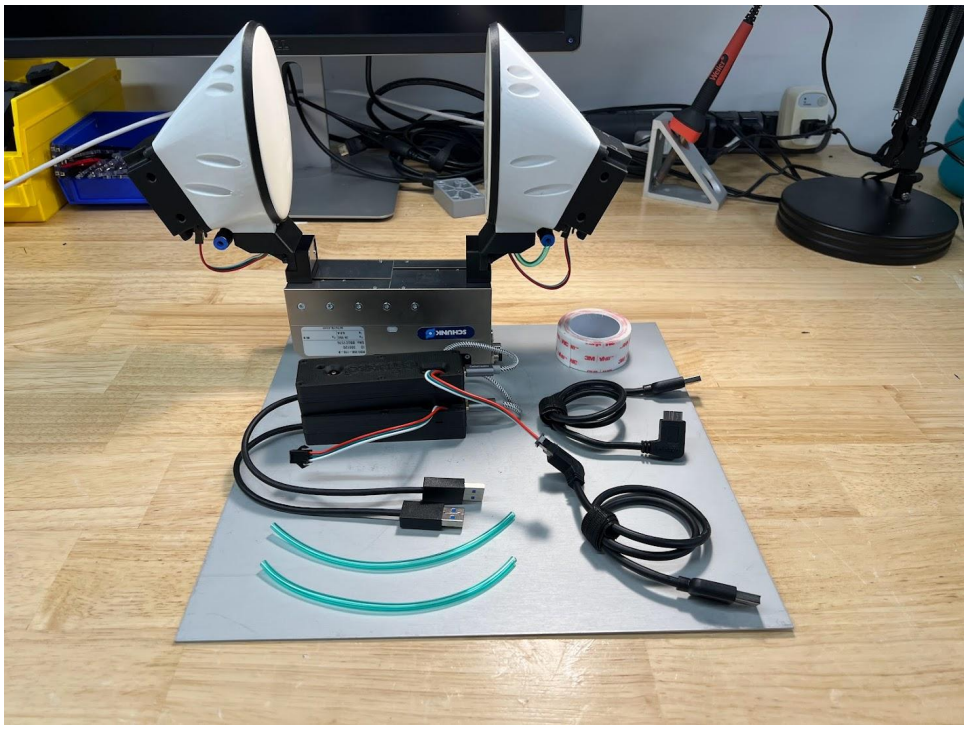


Figure 100: Components necessary to assemble
the the *Bubble Gripper Fingers* and Schunk gripper

3. Attach the *Pressure Sensing System* and USB hub unit to the gripper.
    a. Cut two strips of VHB double-sided tape to a length of 10 cm, and place them onto the USB hubs (on the face with the Anker logo).
    b. Attach the *Pressure Sensing System* and USB hub units to the WSG-050-110, one on either side, with the strips of VHB tape. Orient the units such that they are mirrored when viewing the gripper from the top (Fig. 101).

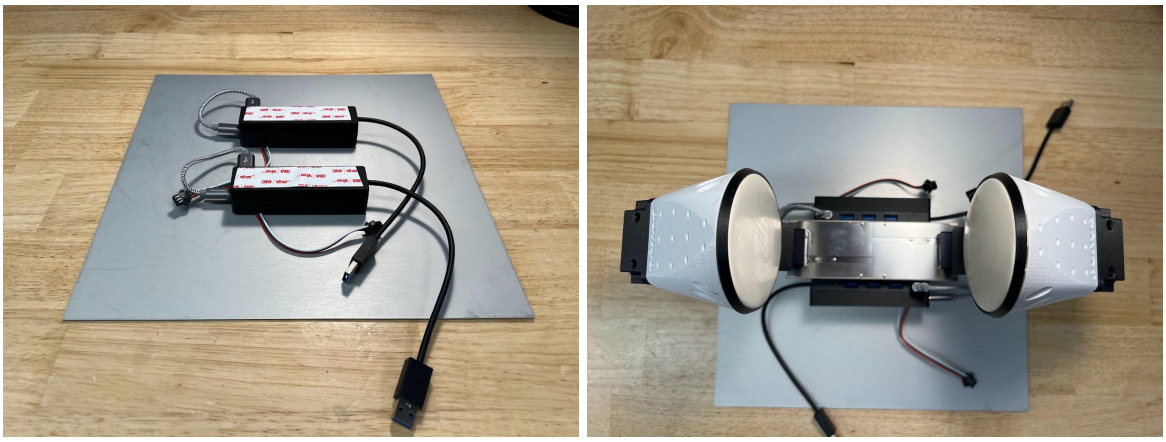


Figure 101: Attaching the *Pressure Sensing System* and USB hub Units to
the Schunk WSG-050-110 using VHB double-sided tape

4. Connect all of the cables and air tubing. Make sure that one pressure sensing system and USB hub unit connects to only one of the *Bubble Gripper Fingers*.The connections include:

a. The USB type A to USB type B micro cable from the Anker slim USB hub to the Intel D405
b. The USB type A to USB type C cable from the Anker slim USB hub to the QtPy board
c. 15 cm of firm polyurethane rubber tubing from the cylindrical metal port at the center of the pressure board to the push-to-connect fitting on the *Bubble Gripper Finger*.
d. The 3-pin cable male and female connectors from the QtPy board to the NeoPixel LED on the *Bubble Gripper Finger*.

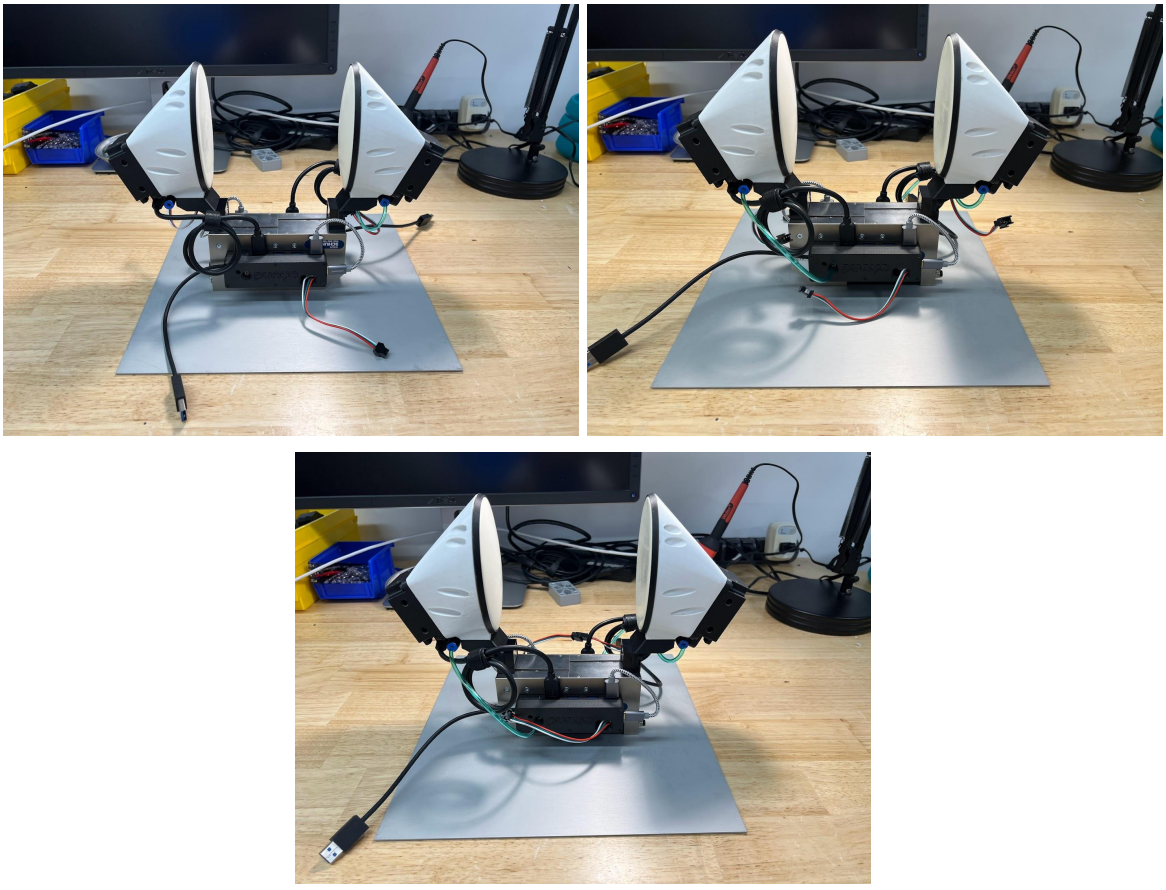


Figure 102: Connecting the cables and air tubing
from the *Pressure Sensing System* to the *Bubble Gripper Fingers*

5. Check that the connections do not inhibit the gripper from actuating across the full travel distance of the WSG 050-110.

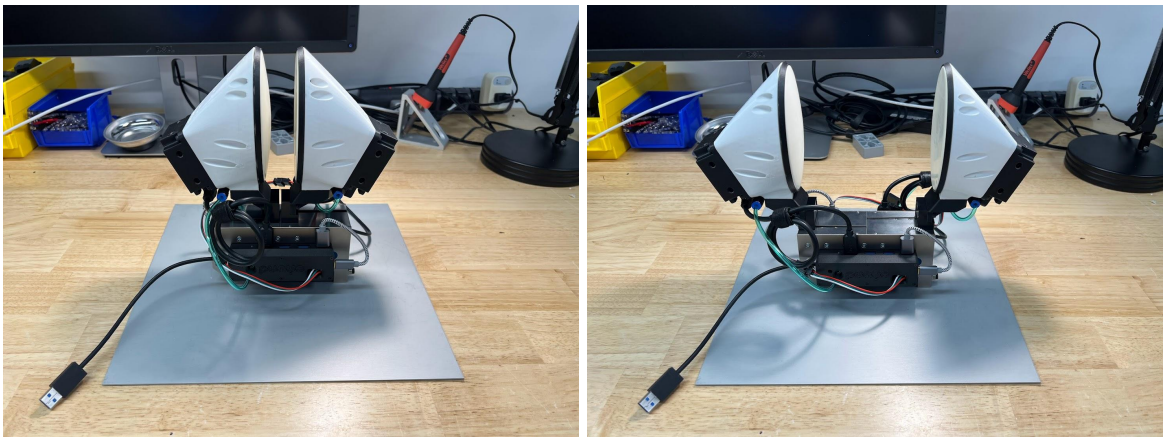


Figure 103: Checking the travel distance of the Punyo Soft-Bubble Grippers

# DATA ACQUISITION ROS2 PACKAGE

A ROS2 package for Soft-Bubble data acquisition can be found here:
https://github.com/TRI-DNA/punyo-bubble-kit

This package will give you access to the following data streams:

- Bubble module internal air pressure
- Raw camera images
- Bubble depth image
- Shear estimation

# Congratulations, you have successfully built a Punyo Soft-Bubble Gripper



Contact us at punyo-info@tri.global