punyo

Version: 1.0

Soft Bubble Gripper

Build Instructions

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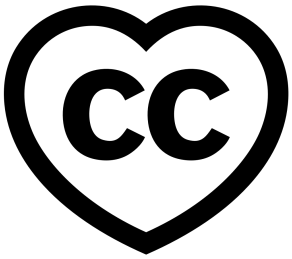

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PURPOSE

The following document provides instructions on how to build TRI's tactile sensing Soft-Bubble grippers, originally developed at Toyota Research Institute (TRI). After reading this document, users should understand the following:

- 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 gripper assembly
    - CAD and 3D printable file downloads
    - 3D printing your bubble gripper parts
    - Threaded insert installation
    - Internal depth camera installation
    - Bubble module installation
    - Pressure sensing electronics and installation
    - Final assembly
    - Pressure sensing electronics assembly
- Common mistakes

If you have any questions or comments, please email us!
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SAFETY

The Soft-Bubbles built for the purposes of this documentation were fabricated in a professional research and development lab environment. It is the user's (the individual building Soft-Bubbles) responsibility 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 manufacturer and your facility.
2. **Ensure proper ventilation,** as defined by your equipment and materials manufacturer, when performing the following tasks: laser cutting, 3D printing, installation of the heat-set inserts, soldering, and while generally printing 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. **Wear Personal Protective Equipment,** as defined and required by your manufacturers and facilities. (examples: respirator masks, eye protection, gloves)
5. **Supervise and monitor your automated work.**
6. **Have easy access to first-aid materials and be trained to utilize them.**
7. **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, 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.

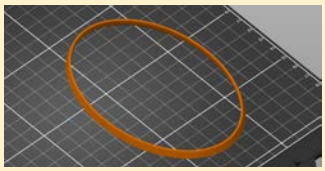
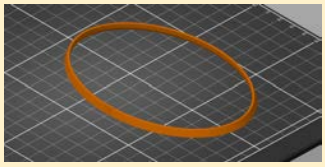
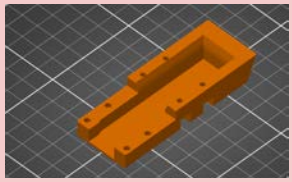
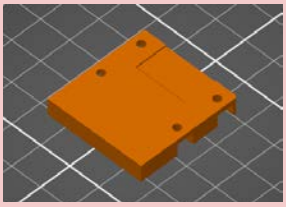
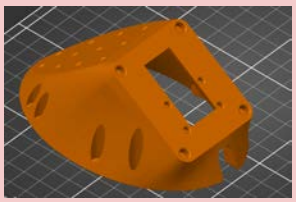
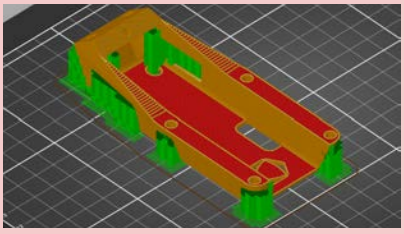
CAD, STL and Vector Files

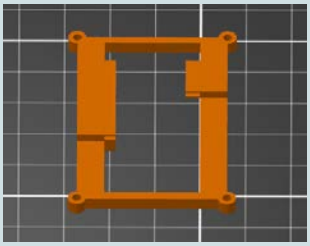
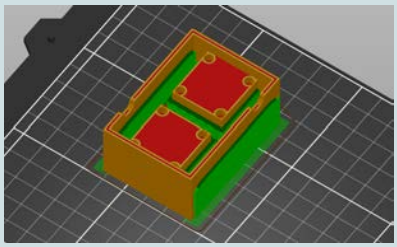
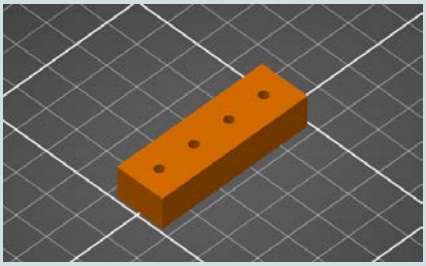
The downloaded build files will enable you to 3D print and laser cut all of the pieces you need for the complete Bubble Gripper assembly. STL files are 3D files used for 3D printing. Vector files are used for laser cutting. CAD files are source SOLIDWORKS files that can be used to modify components.

	3D Printing: STL	Laser Cutter: Vector
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	-
Dot Pattern Stencil	-	Low Density Dot Pattern.pdf
	-	Medium Density Dot Pattern.pdf
	-	High Density Dot Pattern.pdf
Gripper Assembly	Pico Case Back.stl	-
	Pico Case Front.stl	-
	Bubble Gripper Body.stl	-
	Gripper Finger Mount.stl	-
Pressure Sensor System	Microcontroller Fixture.stl	-
	Pressure Sensor System Mount.stl	-
	Tube Connector Fixture.stl	-

3D PRINTING PREPARATION

In preparation for the build, it is ideal to have the following parts 3D printed in advance. Section "3D Printed Sealing Band" specifies the sealing band 3D printing instructions and section "Bubble Gripper Assembly" specifies the gripper 3D printing instructions. Section "Pressure Sensor System" specifies 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	Pico Case Back.stl	
	Pico Case Front.STL	
	Bubble Gripper Body.stl	
	Gripper Finger Mount for WSG 032-068.STL, Gripper Finger Mount for WSG 050-110.STL	

Pressure Sensor System	Microcontroller Fixture.stl	
	Pressure Sensor System Mount.stl	
	Tube Connector Fixture.stl	

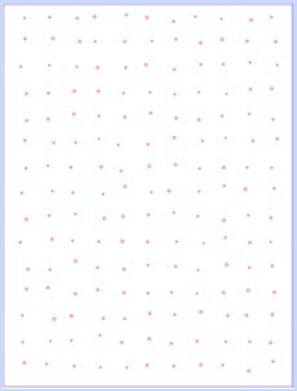
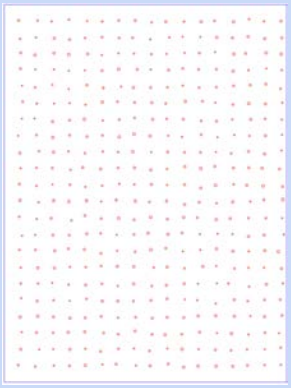
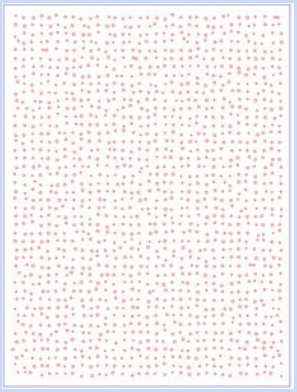
DOT PATTERN STENCIL

Tools

1. Laser Cutter

Materials

1. Adhesive Shipping labels, 8.5 x 11”

	Laser Cutter: Vector	Image
Dot Pattern Stencil	Low Density Dot Pattern.eps, Low Density Dot Pattern.pdf	
	Medium Density Dot Pattern.eps, Medium Density Dot Pattern.pdf	
	High Density Dot Pattern.eps, High Density Dot Pattern.pdf	

BILL OF MATERIALS

All required materials and tools necessary to build the Soft-Bubble Gripper are listed in the *Punyo Bubble Gripper BOM (.pdf)* 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.

See video: “Bubble inflation pump assembly”

Tools

1. Standard bike pump for schrader valves

Materials

1. Standard bike pump for schrader valves
2. Soft PVC Plastic Tubing (2 mm ID, 4 mm OD), 50 ft (5233K112)
3. Push-to-Connect Tube Fitting for Air, Straight Adapter (8 mm STEM OD, 4 mm Tube OD) (5225K183)
4. Compressed air duster

Assembly

1. Cut one meter of the PVC plastic tubing.

Figure 1: A meter of PVC plastic tubing

2. Turn the compressed air duster upside-down with the nozzle aimed away from you. Then, spray one end of the PVC plastic tubing generously until it frosts up and stiffens about 3 cm of tube.
    a. It is important that the plastic tubing is frosted stiff before inserting it into the fittings to avoid leakage when filling the bubbles. The stiffened tubing is easier to insert fully into the connector.

Figure 2: Compressed air duster is used to frost the tubing before connector insertion

3. Firmly press the frosted end of the plastic tubing into the push-to-connect end of the push-to-connect fitting until you feel a “click” (Figure 3).

Figure 3: Tubing inserted into the push-to-connect end of fitting.

4. Insert the cylindrical “stem” end of the fitting into the hole labeled “S” or “schrader valve” of the bike pump (Fig 4). Make sure the fitting is pressed deep inside the bike pump nozzle.

Figure 4: Connector-tubing assembly stuck into bike pump nozzle

5. Lift the lever up into the sealed position (Fig 5).

Figure 5: Connector-tubing assembly with sealed pump

BUBBLE MODULE FABRICATION

The bubble module of the 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 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 thickness, or swapping internal patterning based on the needs of the perception system.

Figure 6: Fully assembled, deflated bubble modules, underside and top views

LATEX PATTERN PRINTING

See video: “Latex membrane preparation and pattern printing”

Before You Start

- Read SDS for each latex paint 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. Painters tape
7. Isopropyl alcohol
8. Shop towels
9. Disposable nitrile gloves

Figure 7: Tools for latex printing

Materials

1. Latex sheet
2. Dot (or other) pattern stencils
3. Latex screen printing ink

Figure 8: 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 fingers), cut and paint two sheets of latex (minimum). It's never a bad idea to make extras.

Figure 9: 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 10).
    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 10: Latex sheet taped to cutting board

5. Use an isopropyl wipe to gently clean the upward facing matte surface of the latex.
6. Open and mix latex screen ink with a mixing stick or large popsicle stick.

Figure 11: Mixing latex paint

7. Prepare a timer for 1 minute and 30 seconds. Do not press “Start” yet.
    a. The timer is necessary to limit the time from application of the latex paint to the removal of the stencil from the latex. The stencil will be removed before the paint dries.
8. If you do not already have pattern stencils, you can laser cut your stencils out of adhesive-backed label paper.
9. Remove paper backing of the adhesive stencil and “dog ear” one corner towards the backing to make a tab for easier removal (Fig 12).

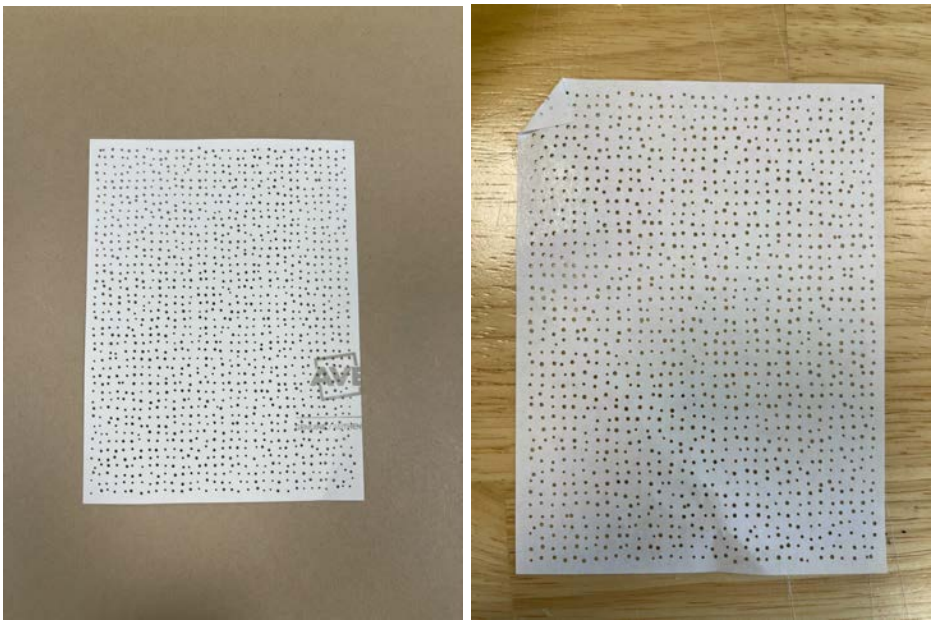


Figure 12: Dog eared stencil after backing is peeled off

10. Stick pattern stencil to latex blank.

Figure 13: Stencil applied to latex after adhesive backing removed.
Note dog ears in top right.

11. Get a generous amount of ink with the foam paint brush.
12. Start timer.
13. Immediately begin to brush over the stencil and latex and make sure all holes in the stencil are filled. Apply side to side from left to right, and then top to bottom (Fig 14).

Figure 14: Stencil painted over with latex paint

14. "Squeegee" excess paint to one side by pressing down hard and moving from left to right and then top to bottom. Painting and squeegeeing should be completed within about one minute.
    a. ⚠️ It is normal for the latex to bubble up a little. It regains its shape as it dries. ⚠️
15. When the timer is done, remove the stencil slowly, starting from the folded corner.
    a. The stencil will still be wet so avoid touching the printed pattern.
    b. If the stencil is left on longer than two minutes, it will leave behind adhesive when removed.

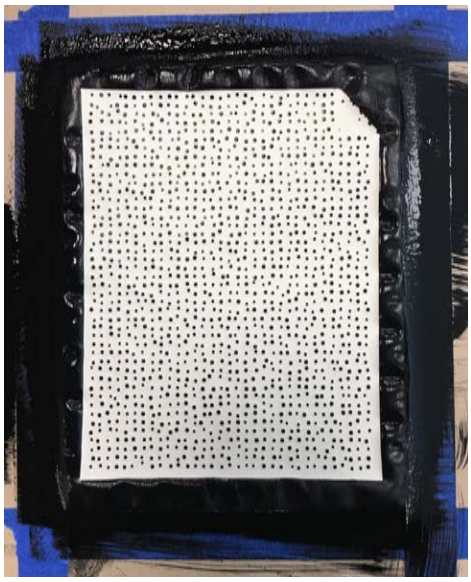


Figure 15: Stencil is removed leaving behind a printed pattern

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

3D PRINTED SEALING BAND

STL Files

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

Fabrication

1. Print two sealing bands for a pair of Soft-Bubble gripper fingers (one 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.
2. Debur any sharp 3D printed defects with sandpaper or a deburring tool (especially on the interior of the ring).

Figure 16: 3D printed 0.4 mm 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, including laser cutting, etching, threaded inserts and tapping”

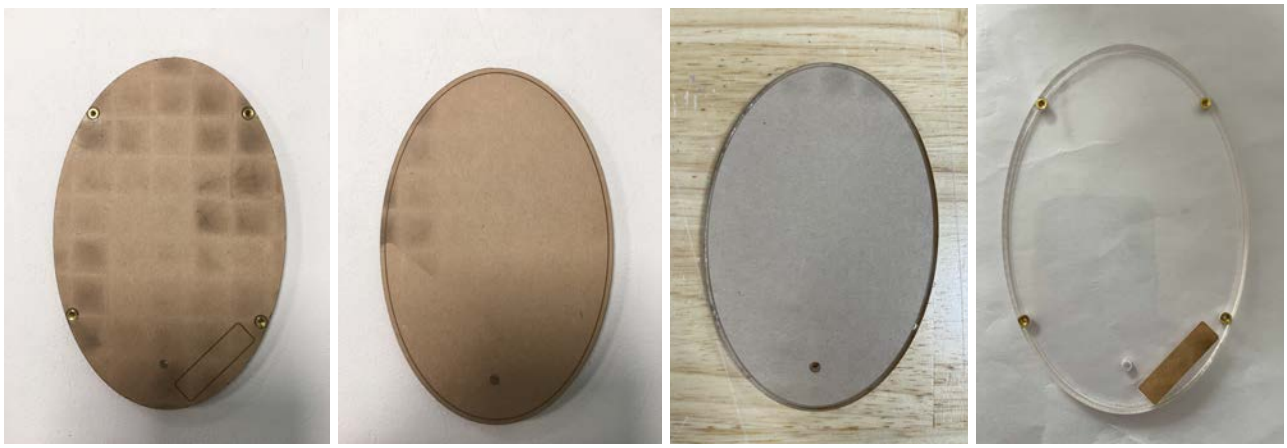


Figure 17: From left to right: Acrylic window Side 1, Side 2, outer ring removed, and protection paper removed

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
3. M3 thread tap
4. Thermally insulated flat metal load

Materials

1. Acrylic 3/16” sheet (8560K215)

Fasteners

1. M2 heat-set inserts, 2.9 mm installed length, qty 4 (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 CAD drawing of the acrylic window is shown below (Fig 18), including the top and side views. A vector drawing is shown below it for Side 1 (Fig 19) and Side 2 (Fig 20).

Before beginning the cutting process, it is necessary to understand what is being cut and etched for the acrylic windows. The acrylic windows have four heat-sets that are used to mount the bubble module to the bubble gripper body. The window also has a hole used to secure an airtight fitting-tubing assembly 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.

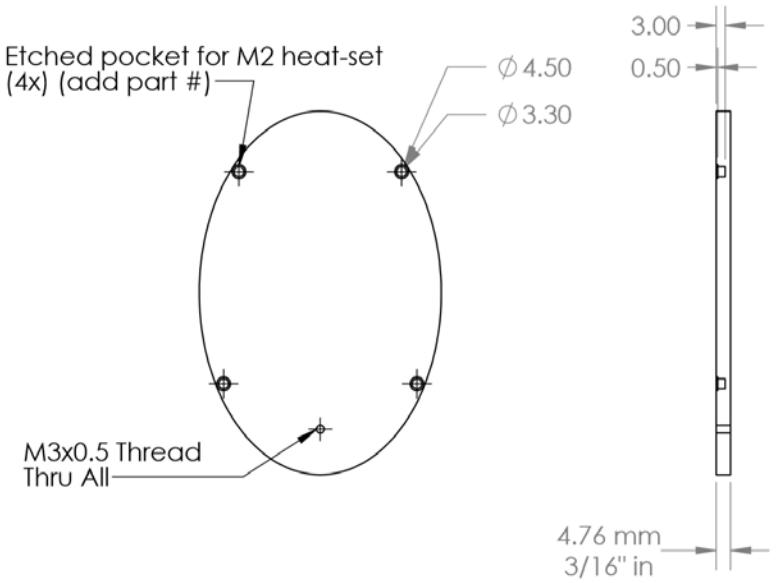


Figure 18: CAD drawing of ellipse acrylic window

The different colors of the lines found in the vector files for Sides 1 and 2 of the acrylic window (Fig 19 and 20) 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 19), we are etching pockets into the acrylic to a certain depth and diameter. These pockets will house 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 that captures the melted acrylic overflow when heat-setting (0.50 mm deep, blue area). These depth measurements should be used as targets for the person tuning the laser cutter settings before producing the acrylic windows. If you find the pockets you are producing are an appropriate depth (no through holes!) and allow the heat-sets to be installed securely and flush with the acrylic surface, you can stop tuning and move on! Lastly, a rectangle is cut (red lines) from the acrylic with alignment markings. These alignment markings are critical as we must remove the workpiece after cutting Side 1, install the heat-set inserts, then flip and realign the workpiece for the Side 2 laser operations.

⚠️ 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 point will leak when assembled and pressurized. ⚠️

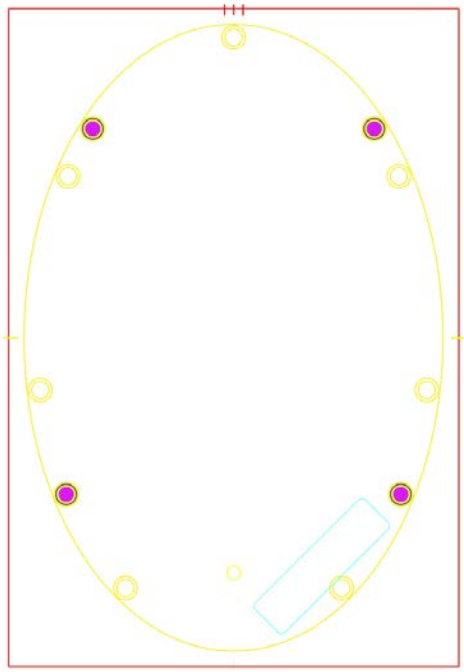


Figure 19: Side 1

On Side 2 (Fig 20), the smaller ellipse (cyan line) is cut only through paper to create a mask for spraying aerosol glue on the open acrylic surface. The perimeter ring of paper around the edge is removed to expose the surface that will be sprayed with adhesive glue.

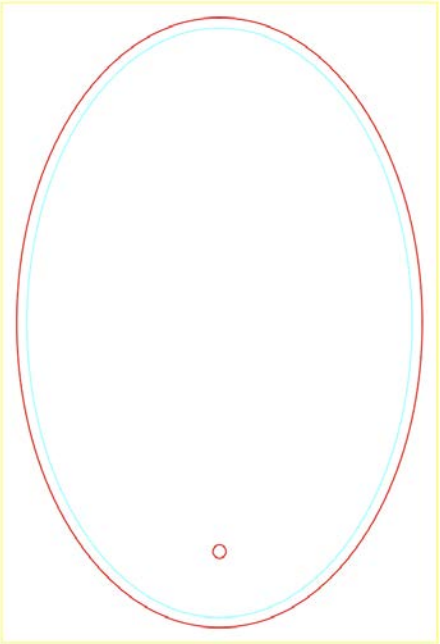


Figure 20: Side 2

In-Depth Acrylic Window Laser Cut Process

1. Load laser cutter with 3/16" acrylic and align to the top-left corner, leaving protective paper on both sides.
    a. ⚠️ It's important to keep paper on while cutting to avoid clouding up the material. ⚠️
    b. ⚠️ Once loaded, do not move the acrylic sheet at any point in the process. ⚠️
    c. ⚠️ Be careful and do not hit the laser head as you load and/or work. ⚠️

Figure 21: Alignment of acrylic into the laser cutter

Etching Heat-Set Locations (Side 1)

1. Select the proper material settings for your respective laser cutter that will work with 3/16” Cast Acrylic material.
2. The vector file for Side 1 (ellipse_bubble_window_side1_new.ai) should be loaded onto your respective laser cutting program.
    a. ⚠️ Side 1 should be laser cut first as the heat-set must be inserted before the final ellipse is cut. ⚠️
3. Our laser parameters were tuned to etch two 3mm deep pockets per horizontal row, and if more than one window is placed next to one another 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.
    a. ⚠️ Record the X and Y coordinates of each window during Side 1. This is important for the cutting of Side 2 as they need to be placed in the same positions. ⚠️
    b. If you plan on making one gripper (two fingers), laser cut two windows (minimum).
4. Run the Side 1 etching job and cut the rectangle.

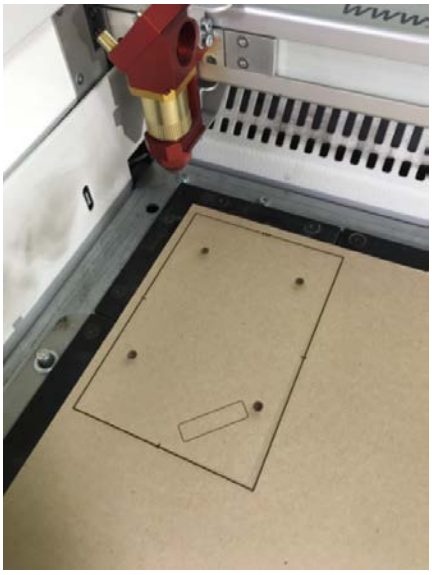


Figure 22: Side 1 cut of the acrylic window

5. ⚠️ Carefully use a spudger or thin tool to pop out rectangular acrylic workpiece. Make sure that the base acrylic doesn't move - apply pressure to acrylic stock while removing parts. ⚠️

Install Heat-Sets

Figure 23: Tools and materials required to install heat-sets

1. ⚠️ It's important to install the heat-sets before final elliptical cut to achieve a true final elliptical window shape, including around the heat-set locations. ⚠️
2. Heat up soldering iron with a flat tip (92160A123) for M2 heat inserts.
3. Leave the paper on the acrylic rectangle and place the acrylic on a flat surface, heat-set pockets side up.

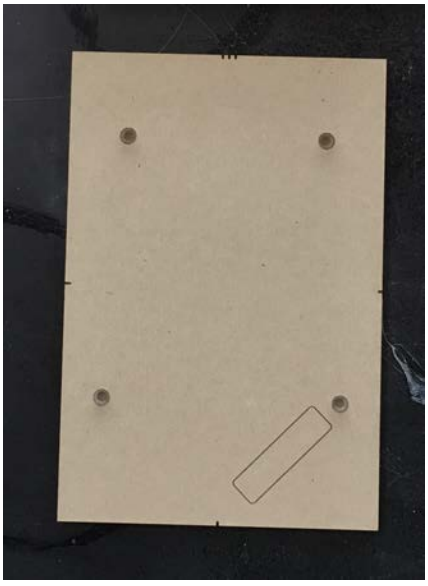


Figure 24: Acrylic window, heat-set pocket side up

4. Insert heat-set with smaller diameter side down, placed into the pocket (Fig 25).

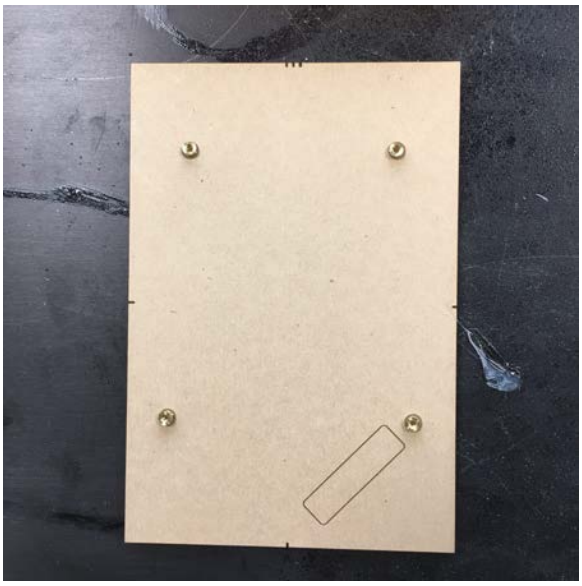


Figure 25: Heat-sets inserted into the pockets of the acrylic window

5. Place soldering iron perpendicular to the heat-set and allow the heat-set to slowly sink down as the acrylic softens.
    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.

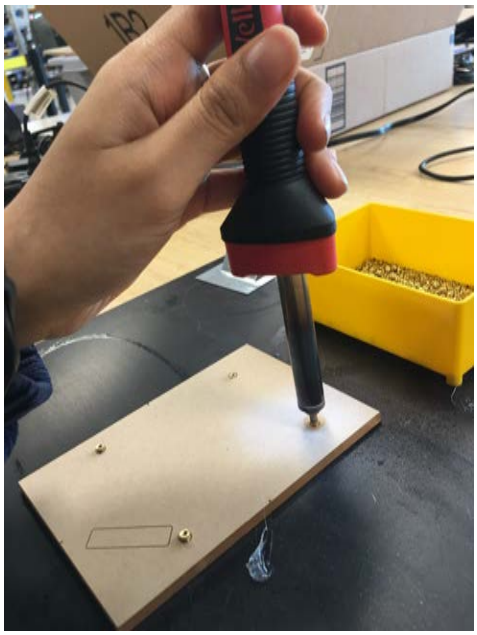


Figure 25: Sinking heat-sets into the acrylic window

6. Sink the insert until it is peeking up a half millimeter then leave the iron on the heat-set for 3-4 seconds more until the surrounding acrylic begins bubbling. Then use the flat, heavy tool to press the insert in the rest of the way so that it ends up flush with the acrylic (Fig 26). Complete this process for one heat-set at a time.
    a. If you apply too much heat, the acrylic surrounding the heat-set melts and volcanoes out of the pocket (Fig 27).

Figure 26: Insulated weight applied to the heat-set for flush insertion into pocket

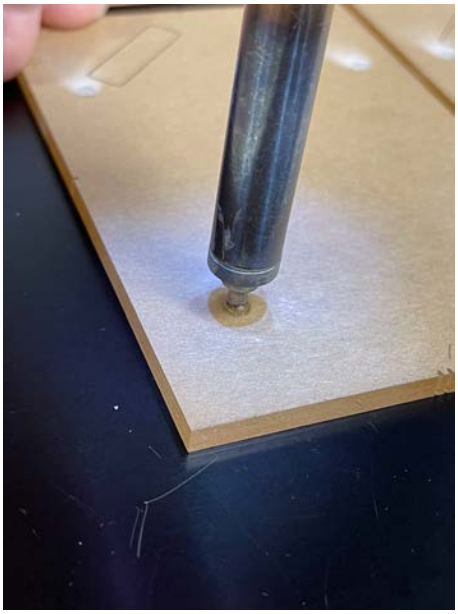


Figure 27: Bubbling reaction due to large amount of heat when sinking heat-set

7. Let cool.
8. Test with M2 x 0.4 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. Place the rectangle back into its previous location, this time with the heat-set inserts facing down.

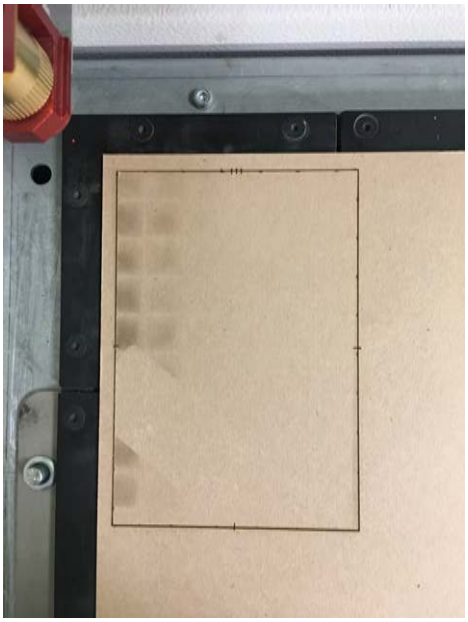


Figure 28: Preparation for Side 2 cut

2. Realign the now flipped rectangle to the board using the small, previously cut visual alignment features.
    a. The triple notches go at the top (Fig 29).
    b. ⚠️ If misaligned, it can result in a unusable bubble as a heat-set can be compromised. ⚠️

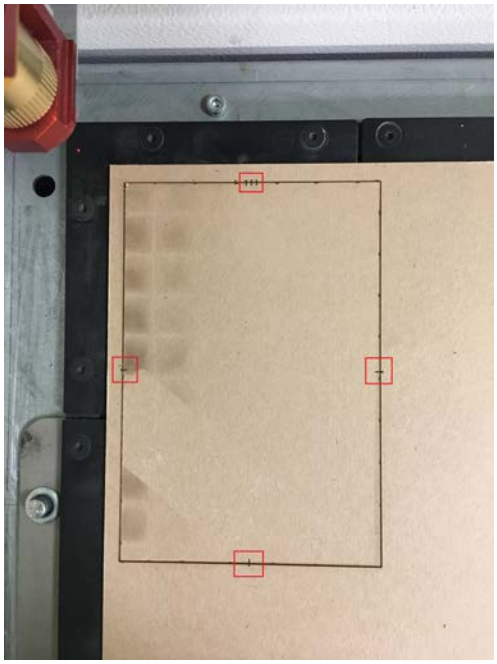


Figure 29: Alignment of the flipped window to the previous position for Side 2 cut

3. Side 2 is referred to as “ellipse_bubble_window_side2_new.ai” and should be loaded into your respective laser cutting program.
    a. ⚠️ Place the job for Side 2 at the same coordinates as the previous Side 1 job. ⚠️

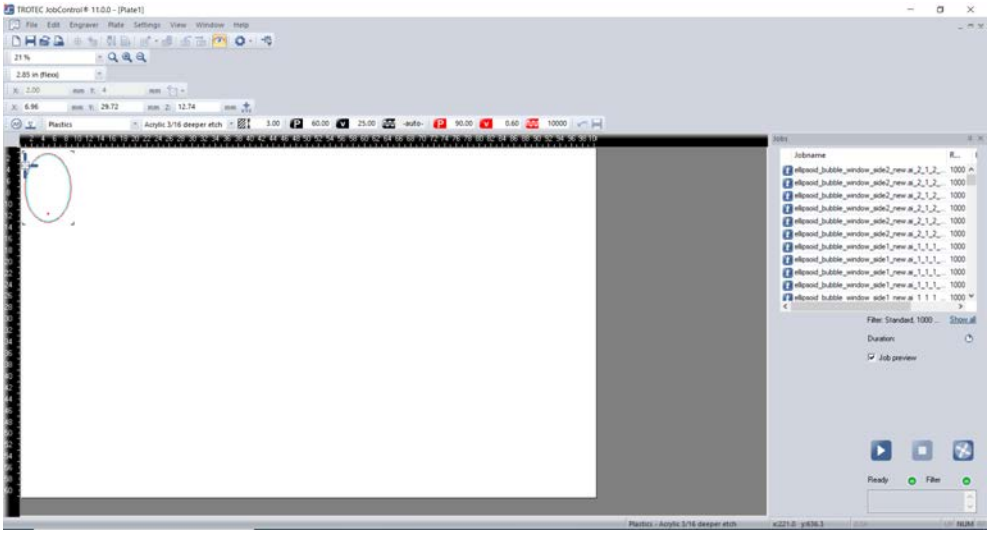


Figure 30: Side 2 is inserted into the program to laser cut

4. Verify the coordinates to make sure it is properly aligned by going around the shape using the laser head control interface.
5. Run the laser cut.

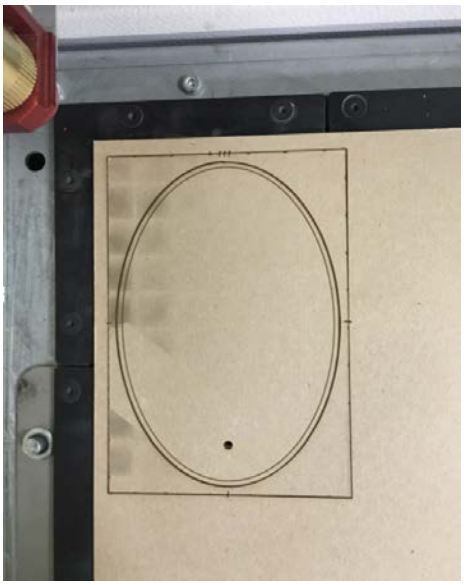


Figure 31: Laser cut results for Side 2

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 tap with M3 thread.
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 32: M3 thread is used to tap the air fitting hole

3. Tap through the entire length of hole.
4. Gently remove it back out by rotating counterclockwise.
5. Label the acrylic window using the following format: YYMMDD_REV_UNIT#.

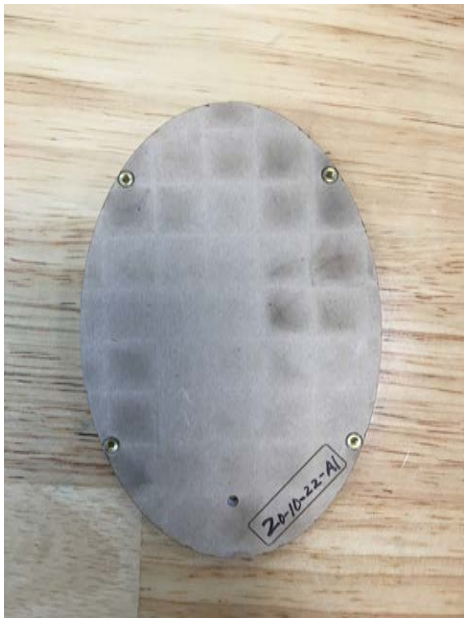


Figure 33: Labeled acrylic window

6. Draw a check mark on the paper to indicate that the hole has been tapped (Fig 34).

Figure 34: Marked tapped hole on acrylic window

LATEX CUTTING TEMPLATE

The latex cutting template is used to trace the elliptical shape of the latex. 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 sealing process.

Laser cut the latex cutting template following the laser cutting methods.

Materials

1. Acrylic 3/16” sheet

Figure 35: 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

See video: “Bubble module fitting-tubing assembly”

Before You Start

- Wear Nitrile gloves.
- Remain in a well ventilated area.
- Wear a mask that filters volatiles to avoid inhaling the compressed air duster.
- Gather all tools and materials below.

Tools

1. Compressed air duster

Materials

1. O-ring and Push-to-Connect Tube Fitting for Air (90 Degree Swivel Elbow, 4 mm Tube OD, M3 x 0.5 mm Pipe) (5225K739)
2. Push-to-Connect Fitting with Shut-Off for Air, Straight Connector (For 4 mm Tube OD) (1201N56)
3. 8 cm piece of Soft PVC Plastic Tubing (2 mm ID, 4 mm OD) (5233K112)

Figure 36: Materials for bubble fitting-tube assembly

Common Errors and Considerations

1. Make sure that both ends of the tube are frosted before you insert them into the connectors and properly seat the tubing in 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 test to see if you seated the tubing deep enough.

Assembly

1. The bubble fitting-tubing assembly can be done in advance in large batches. Prepare and cut all materials before assembly.
2. ⚠️ Make sure that the fitting has an O-ring on it! Some fall off. ⚠️

Figure 37: Swivel elbow push-to-connect fitting and O-ring

3. Get the compressed air duster and turn it upside down with the nozzle facing away from you. Spray at least 3 cm of ⚠️ both ⚠️ ends of the pvc tube until frosted and rigid.

Figure 38: Application of compressed air duster onto tubing

4. Insert one end of the pvc tube into the swivel elbow push-to-connect fitting and the other end into the push-to-connect fitting with shut-off for air.
    a. Push the tube into the connectors until you feel it click.

b. Fitting orientation matters! Check-valve ( ) location should be as shown below, where the tubing from the O-ring assembly is inserted into the end of the push-to-connect that is not marked.
c. If you do not feel a click upon insertion, remove, refreeze and try again.

Figure 39: Completed bubble fitting-tubing assembly

BUBBLE MODULE ASSEMBLY

See video: “Bubble module assembly and sealing”

Before You Start

- Work in a well ventilated area.
- Use a fume hood or paint booth for adhesive sprays.
- Wear PPE: safety glasses, 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. Small thin brushes
6. Sandpaper
7. Felt marker
8. Nitrile gloves
9. M3 Threaded tap

Figure 40: Required tools

Materials

1. Cyanoacrylate (CA) glue
2. Repositionable spray adhesive (7020) Spray
3. Compressed air duster
4. Painters Tape
5. Parchment paper

Figure 41: Required materials

Components

1. Acrylic Window (created in section "Acrylic Window Preparation")
2. 3D Printed Sealing Band (0.6 mm sealing band for 0.65 mm thick latex, 0.4 mm for 0.45 mm thick latex) (created in section "3D Printed Sealing Band")
3. Patterned or blank latex rectangle (created in section "Latex Printing")
4. Bubble fitting-tubing assembly (created in section Bubble Fitting-Tube Assembly)
5. Latex cutting template (created in section "Latex Cutting Template")

Figure 42: Components to make Bubble Module

Assembly

1. Sand down or deburr the 3D printed sealing band to eliminate rough edges, especially on the interior surfaces.
    a. To check for rough edges or bumps, run your finger on the interior of the sealing band.
2. Tape down parchment paper to protect your work surface and make parts easier to pick up. Tape a designated small square for glue to go as well (Fig 43).

Figure 43: Parchment paper placed down and secured to the table

3. Go to 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 44) to reveal an ellipse outline on the acrylic. This is the surface the repositionable spray adhesive will cover to stick onto the latex in a later step.

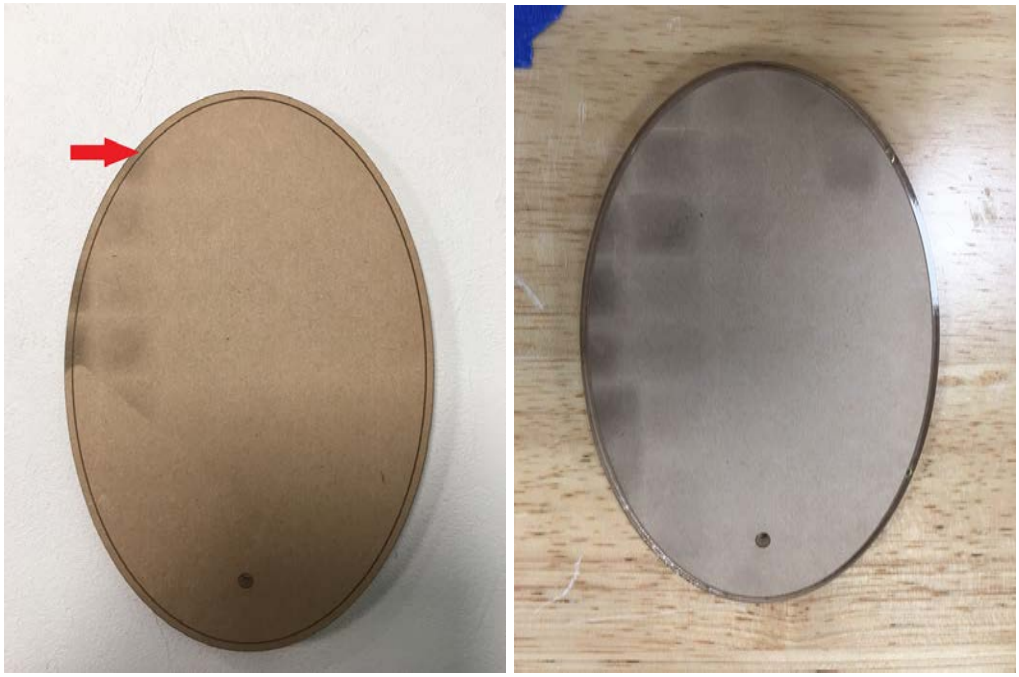


Figure 44: Removal of thin outer paper ellipse to reveal surface for adhesive spray

7. Prop the window up at an angle (Fig 45)

Figure 45: Acrylic window propped at an angle inside of a paint booth

8. To apply the adhesive spray:
    a. 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.
    b. Spray the repositionable spray adhesive in the directions shown by the red arrows in Fig 46, 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.
    c. 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.
    d. The goal is to get the exposed surface of the ellipse shiny and tacky as seen in Fig 47.
        i. ⚠️ Spray enough adhesive so that the entire external ellipse is sparkling. ⚠️
    e. After many applications of adhesive, it may be necessary to swap or clean the spray can nozzle. Replacement nozzles can be purchased in bulk.

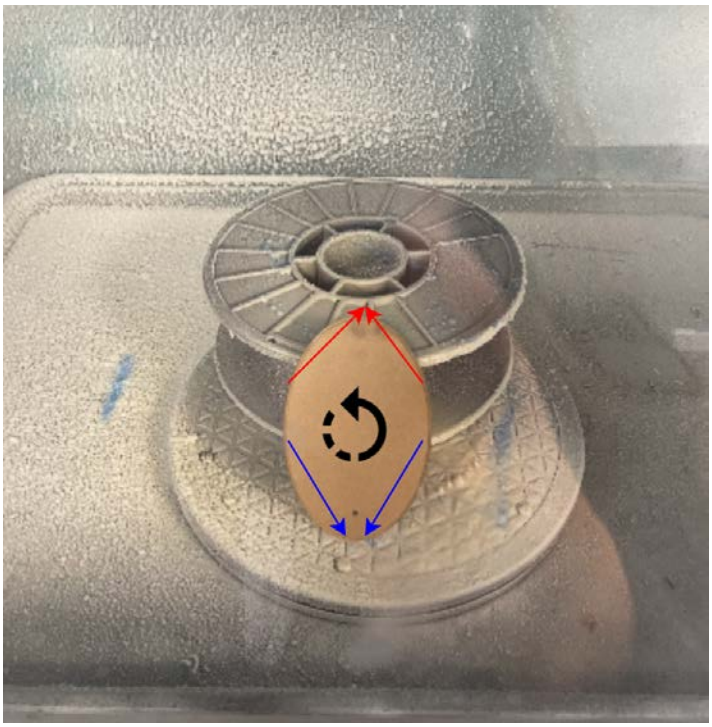


Figure 46: The adhesive is sprayed diagonally first in the red direction, then rotated as shown in black, and sprayed in the blue direction

Figure 47: The surface of the acrylic is shiny and tacky after the repositionable adhesive spray.

9. 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 48).

a. ⚠️ Do not touch the glue or exposed acrylic as your fingerprints will not be accessible after assembly. ⚠️

Figure 48: Adhering of the acrylic window to the latex after removing the interior paper

10. Apply pressure focused around the glued edges for about 30 seconds. A brayer roller can be used for this.
11. Place the 2.5 mm latex cutting template around the window (Fig 49).

Figure 49: The latex cutting template placed around the adhered window

12. Use a felt marker to trace around the outside edge of the latex cutting template (Fig 50).

Figure 50: The latex cutting template is traced

13. Remove the cutting template.
14. Using a pair of scissors, carefully cut out the marker traced ellipse from the latex.
    a. ⚠️ Cut just inside of your traced line. ⚠️

Figure 51: Traced figure that is cut out of the latex

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

16. Remove the remaining paper of the acrylic window and place a suction cup onto it in the center of the window. Try to avoid leaving fingerprints on the acrylic. Do not remove the rectangular section for the bubble module serial number.

Figure 52: Apply suction cup to bubble module

Figure 53: Final bubble module before sealing band application

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

17. Squeeze out an amount of Cyanoacrylate (CA) glue about the size of a dime onto the parchment paper section (Fig 54).

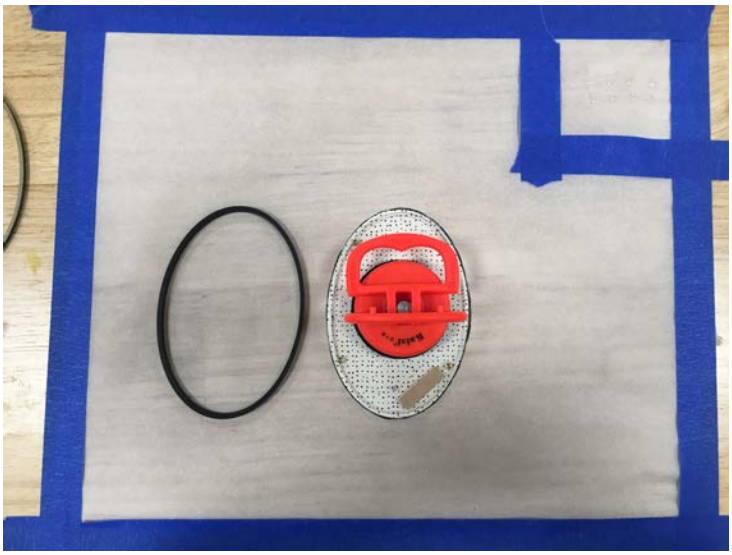


Figure 54: Sealing band and bubble module preparation

18. Using a disposable paintbrush, quickly and thoroughly paint around the elliptical edge of the acrylic window - the goal is to cover about half the height of the window from where the latex meets the acrylic to the middle of the edge of the window (Fig 55).
    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 let any glue get in between the latex and acrylic.

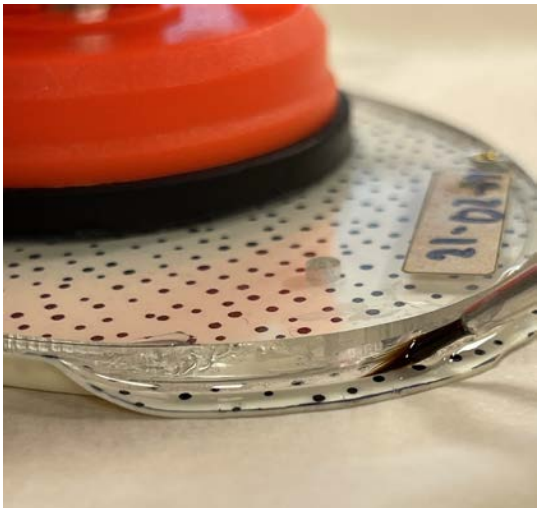


Figure 55: Glue is applied to the bottom half of the acrylic window edge starting from the base where the latex meets the acrylic

19. 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.
20. Center the window over the sealing band and gently nudge the sealing band until the well aligned. Push the latex and window assembly **straight down** into the sealing band using the suction cup (Fig 56).
    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 56: Alignment of bubble module over the sealing band

21. With the assembly on still 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.
22. After these five minutes, attach the bubble connector-tubing assembly and hand tighten the fitting. Its final position should have the tubing pointing down towards the closest edge of the ellipse (Figure 57).

Figure 57: Completed assembly of bubble module

23. Use compressed air duster chilling procedure to spray the tubing of the bubble inflation pump and insert it into the fitting-tubing assembly.
24. Inflate the bubble up to 30 mm (Fig 58) and remove the pump air line.

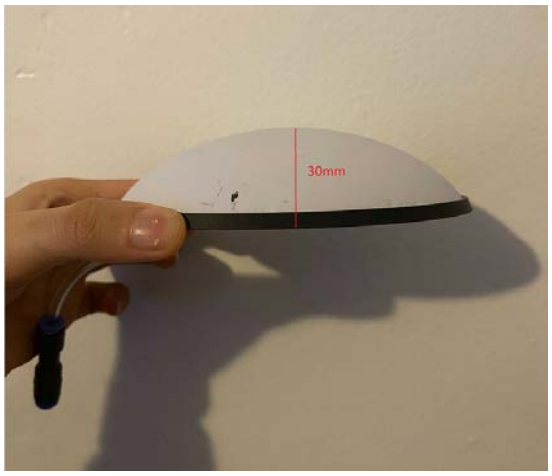


Figure 58: Inflated bubble module to max height, 30 mm

25. ⚠️ Detach any stuck edges by pinching the latex and pulling it upwards off of the acrylic plate to make sure it doesn't bond permanently. ⚠️
    a. ⚠️ If the latex is stuck to repositionable adhesive spray, it will be let go at this stage. ⚠️
    b. ⚠️ If the cyanoacrylate glue creeps under the acrylic and onto the latex, it is critical that the latex is detached before it fully dries. ⚠️
    c. ⚠️ Do not pull too hard as you may accidentally detach the latex from the intentionally glued edges of the acrylic plate. ⚠️

Figure 59: Pulling off latex that is stuck to the acrylic

26. You may choose to apply one more application of CA glue on the side opposite the bubble between the acrylic and sealing band (Fig 60)
    a. ⚠️ It's important to not scratch or get glue on the exposed acrylic surface. If glue does get on the surface, immediately remove with a cotton lens wipe. ⚠️

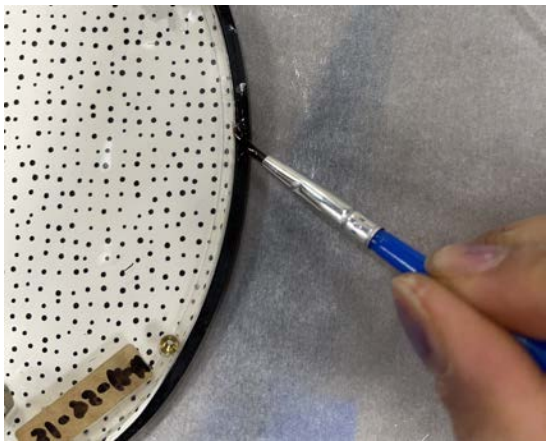


Figure 60: Applying final layer of glue between sealing band and acrylic

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 track down leaks, inflate and squeeze under water and look for tiny bubbles.

28. If you find a leak, deflate the bubble and brush CA glue into cracks between the latex and sealing band as done previously in Step 26, targeting the leaky location.
29. Document the new bubble module in your tracker, including links to any photos.
30. Cover the exposed acrylic window with painters tape to protect from dust and scratches.
31. Congrats, you made a bubble! After assuring the bubble is not leaking, keep the bubbles deflated and stored in a cool, dark area.

Figure 61: Completed bubble modules of various designs

BUBBLE GRIPPER FAB AND ASSEMBLY

See video: “Bubble gripper “finger” assembly, including bubble module and depth camera”

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
3. 2.5 mm allen key
4. 3.5 mm allen key
5. Deburring tool

Materials

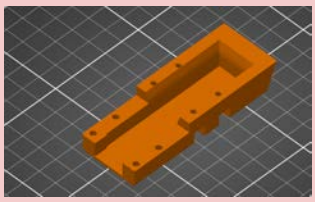
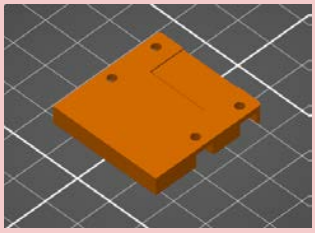
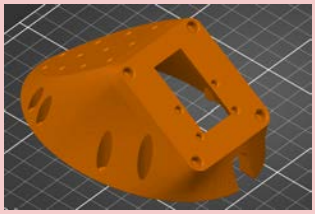
1. Plastic 3D printer filament
2. VHB double sided tape

Fasteners

3. M2 washers, qty 16 (98269A430)
4. M3 washers, qty 8 (93475A195)
5. M4 washers, qty 4 (98269A420)
6. M2 x 5 mm socket head cap screws, qty 16 (91290A012)
7. M2 x 10 mm socket head cap screws, qty 8 (91290A017)
8. M3 x 8 mm socket head cap screws, qty 8 (91290A113)
9. M4 x 14 mm socket head cap screws, qty 4 (91290A150)
10. M2 heat-set inserts, 2.9 mm installed length, qty 16 (94180A307)
11. M3 heat-set inserts, 3.8 mm installed length, qty 8 (94180A331)
12. Push-to-connect fitting clips, qty 2 (5779K433)

Components

1. 3D printed parts
    a. Pico_Case_Back, qty 2
    b. Pico_Case_Front, qty 2
    c. Bubble_Gripper_Body, qty 2
    d. Gripper_Finger_Mount, qty 2

	3D Printing (STL)	Image
Gripper Body Assembly	Pico Case Back.stl	
	Pico Case Front.stl	
	Bubble Gripper Body.stl	
	Gripper Finger Mount.stl	

2. Latex bubble modules (built in section "Bubble Module Assembly"), qty 2
3. Pico Flexx, qty 2
4. USB 3.0 Type A straight to Micro B left angle exit 1 meter long or less, qty 1
5. USB 3.0 Type A straight to Micro B right angle exit 1 meter long or less, qty 1
6. Anker slim USB Hub
7. Schunk WSG 32 or other gripper
8. USB 3.0 Extension

3D Printing of Gripper Body

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 on a Markforged X7, Onyx, Taz 6 and Prusa i3 MK3.

Print Setup

1. Print the Gripper_Finger_Mount (Fig 57) using the following settings:
    a. 100% infill
    b. 85 degree overhang angle for support material

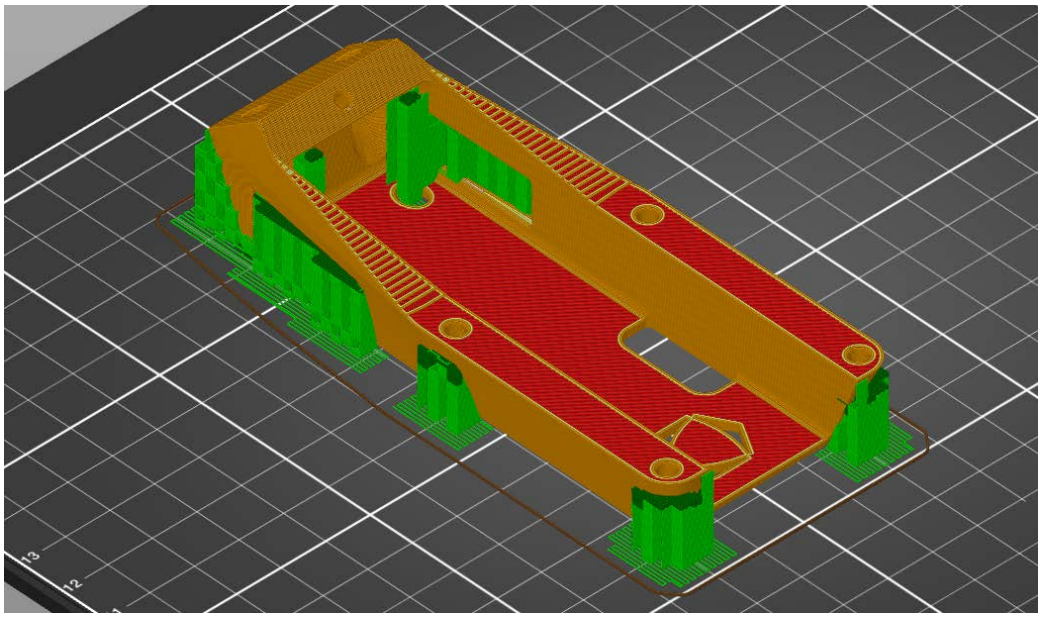


Figure 62: STL model of Part Gripper_Finger_Mount with support material in slicer

2. Print the bubble case and pico flexx case parts at 20% infill, no support material necessary

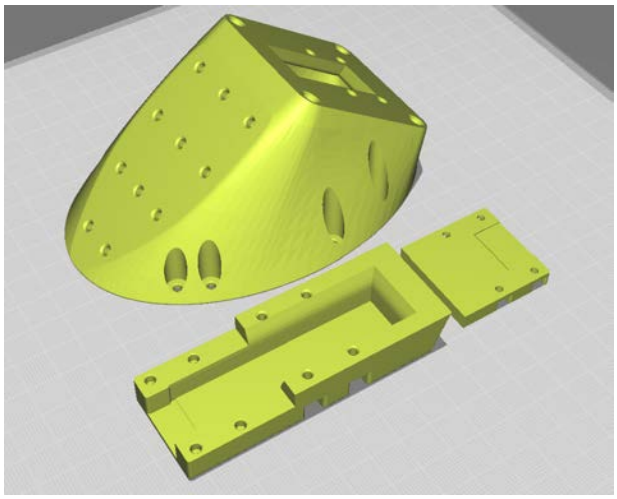


Figure 63: STL model of parts Bubble_Gripper_Body, Pico_Case_Front, and Pico_Case_Back laid out in the slicing software with no support material needed

Assembly

1. Go to a ventilated area that is designated by your institution to be used for fumes.
2. Use a soldering iron with a heat-set insert tip to Insert four M3 heat-sets into the following positions on each Bubble_Gripper_Body.

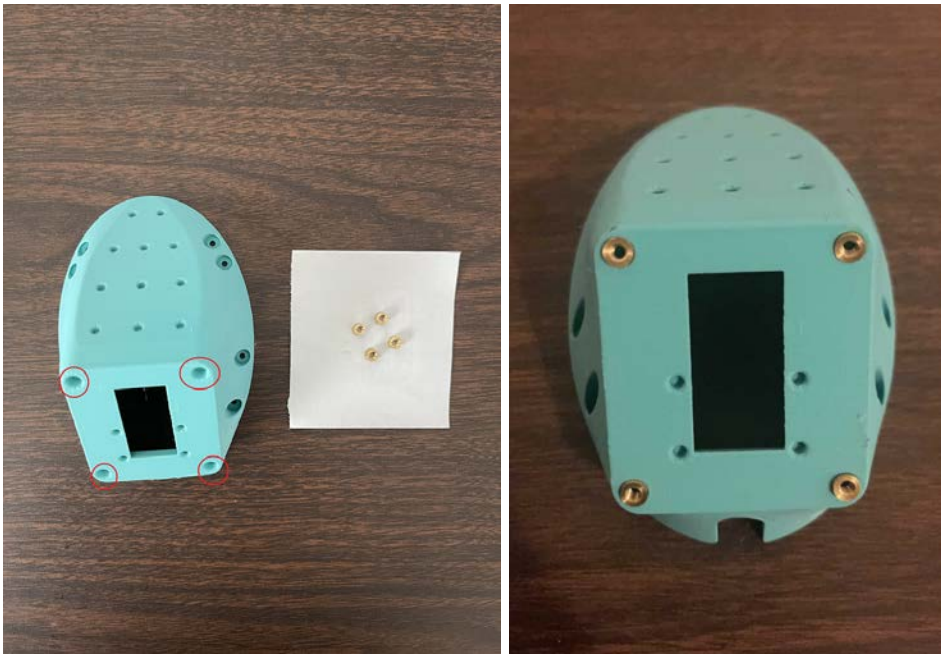


Figure 64: M3 heat-set insertion for part Bubble_Gripper_Body. Locations circled in red.

3. Insert four M2 heat-set inserts into the following positions on the Bubble_Gripper_Body.

Figure 65: M2 heat-set insertion for part Bubble_Gripper_Body

4. Insert four M2 heat-sets in the following position into each Pico_Case_Back part.

Figure 66: M2 heat-set insertion for part Pico_Case_Back

5. In each of the Gripper_Finger_Mount parts, clear out the following holes using a deburring tool, reamer or knife.

Figure 67: Removal of stray plastic in the holes of part Pico_Case_Front

6. Insert a Pico Flexx into Pico_Case_Back part. You should angle it in and then snap it in place. It should be placed in the following orientation and butt up tightly against the upper surface (Fig 68).
    a. Make sure to not touch the lens or emitter window of the pico flexx.

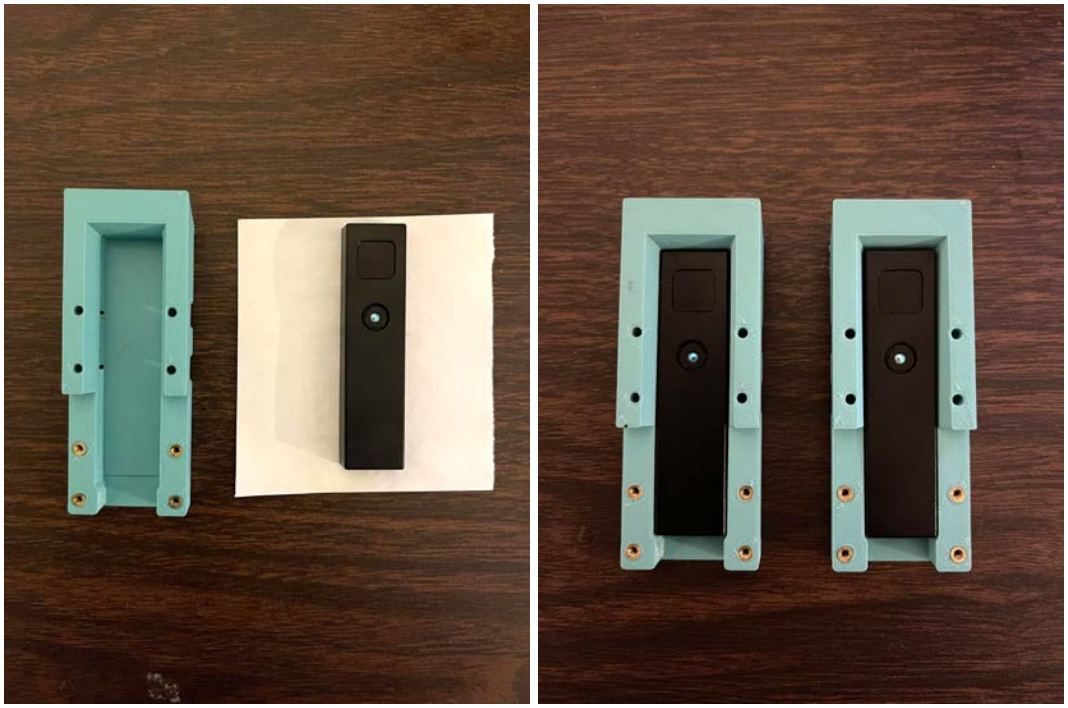


Figure 68: Pico Flexx inserted into part Pico_Case_Back

7. Insert each USB into a pico flexx in the Pico_Case_Back assembly (Fig 69).
    a. Attach the right angle USB to the picoflex in the Pico_Case_Back assembly.
    b. Attach the left angle USB to the other picoflex in the Pico_Case_Back assembly.

Figure 69: Right and Left USB cables inserted into Pico Flexxes

8. Using a deburring tool, reamer or knife, carefully clean out all holes in both parts Pico_Case_Front.

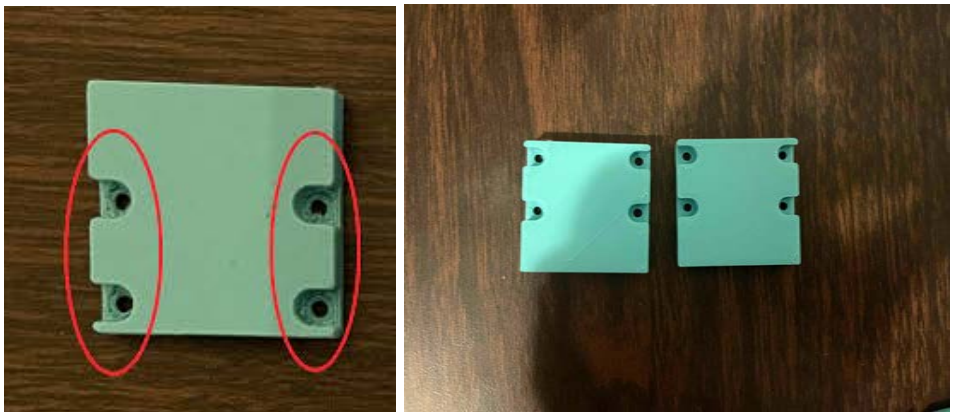


Figure 70: Clean out holes circled in red for part Pico_Case_Front.

9. Insert four M2 washers and fasten four M2 x 5 mm socket head cap screws in each Pico_Case_Front part and screw onto part Pico_Case_Back using a 1.5 mm allen key.

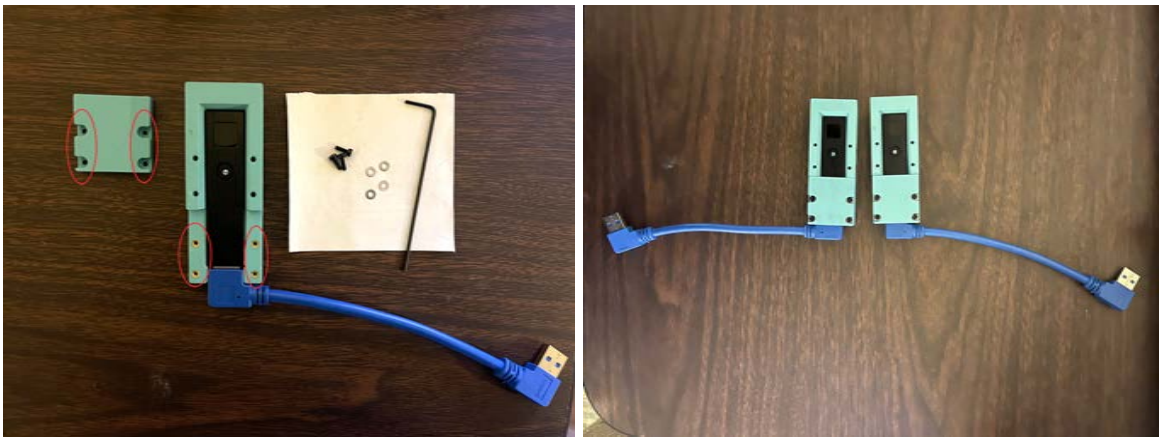


Figure 71: Mounting of part Pico_Case_Front onto Pico_Case_Back to secure the pico flexx.

10. Insert four M2 washers and fasten four M2 x 10 mm socket head cap screws in the following positions on Pico_Case_Back into each Bubble_Gripper_Body part using a 1.5 mm allen key

Figure 72: Mounting of part Pico_Case_Back onto Bubble_Gripper_Body

11. Attach Bubble_Gripper_Body to Gripper_Finger_Mount.
    a. Slide the USB in first through the opening of Gripper_Finger_Mount as seen in Fig 73.
    b. Repeat for the other assembly.

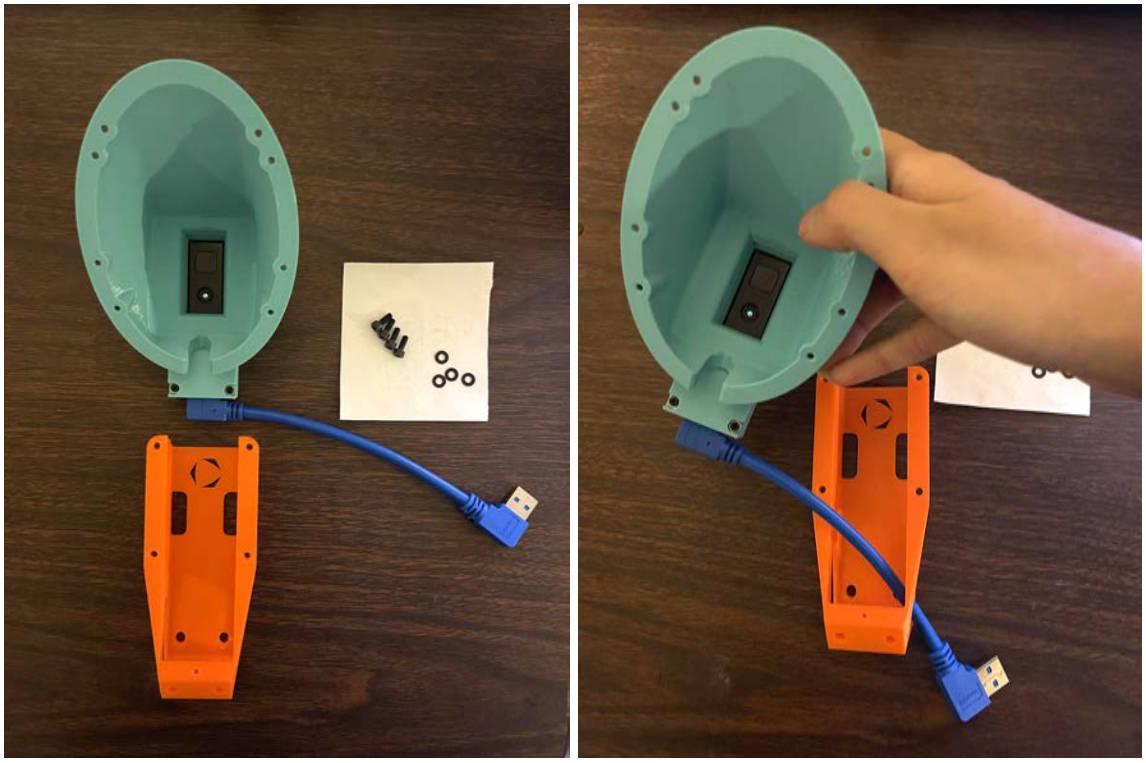


Figure 73: USB cable inserted through the opening of Gripper_Finger_Mount

12. Insert four M3 washers and four M3 x 8 mm socket head cap screws into each Bubble_Gripper_Body part and attach it to Gripper_Finger_Mount using a 2.5 mm allen key following a torque pattern.

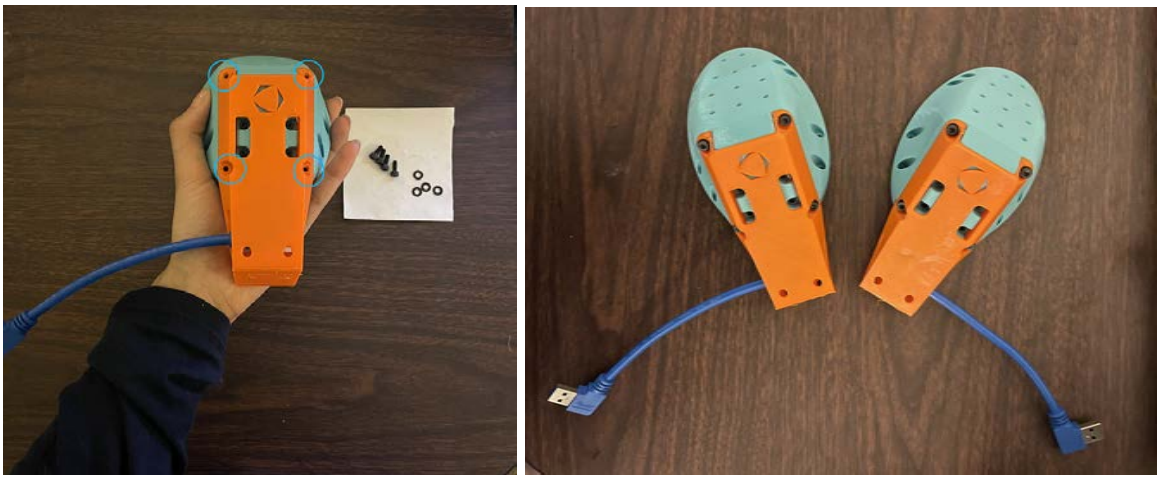


Figure 74: Mounting of part Gripper_Finger_Mount on to part Bubble_Gripper_Body

13. Attach the tube fitting clip with a thread forming screw to the hole in each Gripper_Finger_Mount using a screwdriver. The alignment 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 usb cable (Fig 75).

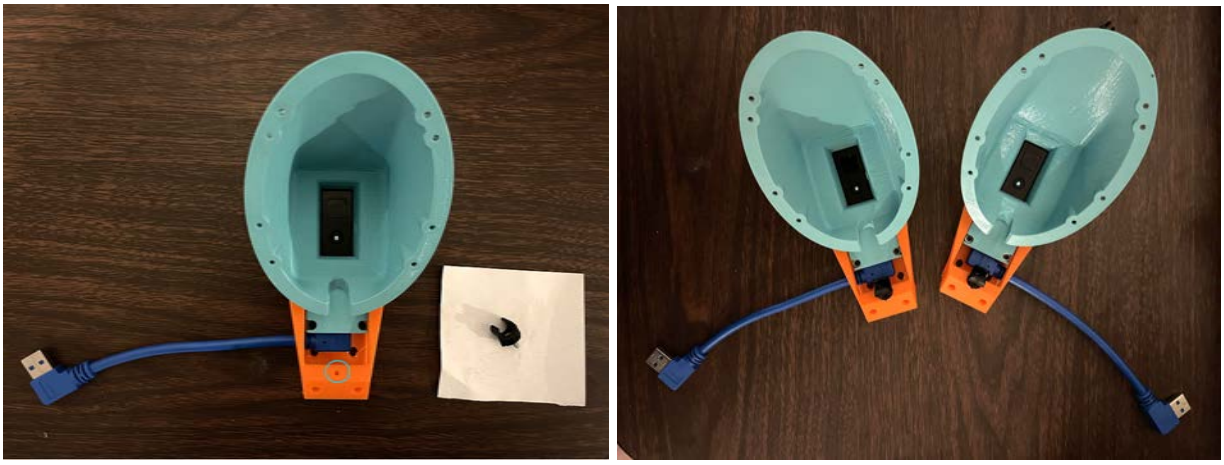


Figure 75: Alignment clip screwed onto part Gripper_Finger_Mount

14. Push the push-to-connect fitting into the clip onto each Gripper_Finger_Mount.

Figure 76: Push-to-connect fitting inserted into the clip

15. Insert four M2 washers and four M2 x 5 mm socket head cap screws into each Gripper_Finger_Body and use an 1.5 mm allen key to attach the bubble module assemblies from section Bubble Module Assembly - shown in figure 77.

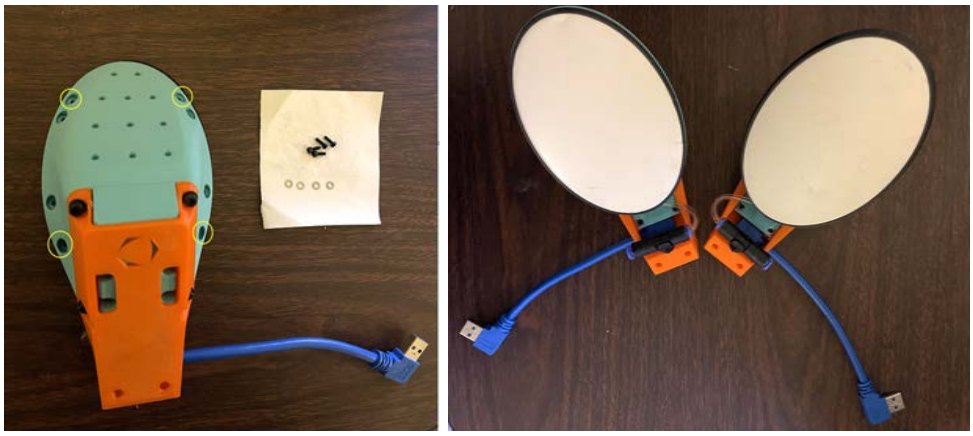


Figure 77: Bubble modules mounted onto Bubble_Gripper_Body.

16. If desired, to attach the bubble gripper assembly to Schunk WSG 032 gripper, insert two 4 mm washers and two M4 x 12 mm socket head cap screws into each Gripper_Finger_Mount and mount securely to the Schunk using an M3 allen key.
    a. Using the provided CAD, the Gripper_Finger_Mount can be modified to fit your grippers as well.
17. VHB tape the USB hub to the gripper.
18. Attach the USB 3.0 extension to the USB hub and your laptop.
19. Plug the two USBs into the hub.

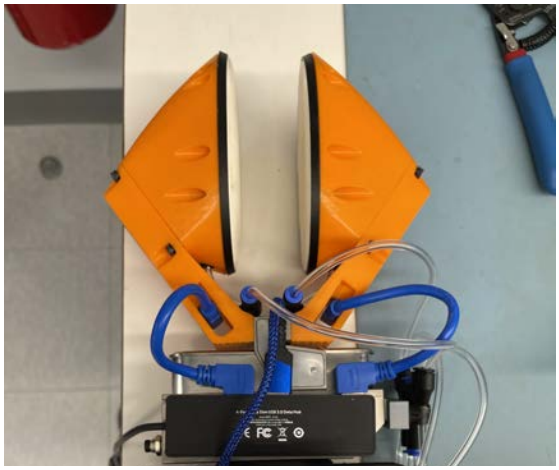


Figure 78: Bubble gripper assembled onto schunk

PRESSURE SENSING SYSTEM

The pressure sensing system consists of a microcontroller and two pressure sensors that are connected to the pair of Soft-Bubble gripper fingers. 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 compact, lightweight system can be mounted directly onto the robot's end effector if desired.

See video: "Pressure sensing electronics assembly"

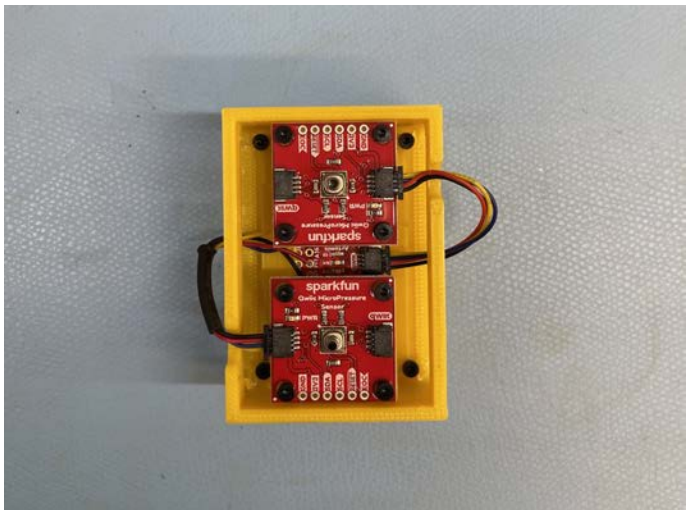


Figure 79: Pressure Sensing System

Before You Start

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

Tools

1. 1.5 mm Allen key
2. Temperature controlled soldering iron
3. Bench top fume absorber
4. Solder scour pad with metal brass wire
5. Wire stripper/cutter
6. Vise
7. Pliers

Materials

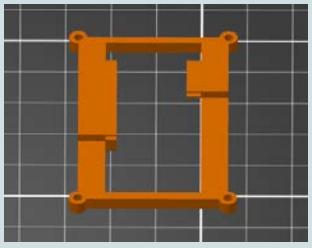
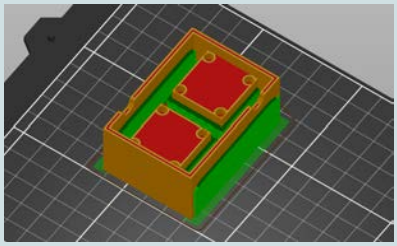
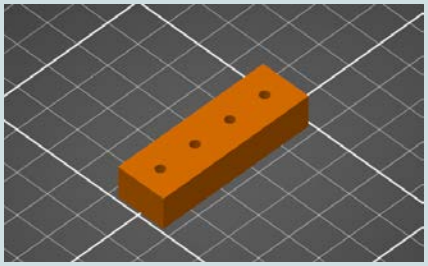
1. PLA filament (1 kg spool)
2. Push-to-Connect Tube Fitting for Air, Wye Connector (4 mm Tube OD) (5225K85)
3. 2 mm ID, 4 mm OD Soft PVC Plastic Tubing (5233K112)

Fasteners

1. M2 heat-set inserts, 2.9 mm installed length, qty 12 (94180A307)
2. M2 x 5 mm socket head cap screws, qty 12 (91290A012)

Components

1. 3D printed parts
    a. Microcontroller fixture, qty 1
    b. 3D printed pressure sensor system mount, qty 1
2. USB Cable A to C, qty 1
3. SparkFun RedBoard Artemis Nano, qty 1 (DEV-15443)
4. SparkFun Qwiic MicroPressure Sensor, qty 2 (SEN-16476)
5. 50 mm Qwiic Cable, qty 1 (PRT-14426)
6. 100 mm Qwiic Cable, qty 1 (PRT-14427)
7. Push-to-connect fitting clips (5779K433)

	3D Printing (STL)	Image
Pressure Sensor System	Microcontroller Fixture.stl	
	Pressure Sensor System Mount.stl	
	Tube Connector Fixture.stl	

Assembly

1. Cut off 20 mm off one end of the 100 mm Qwiic cable (Fig 80).

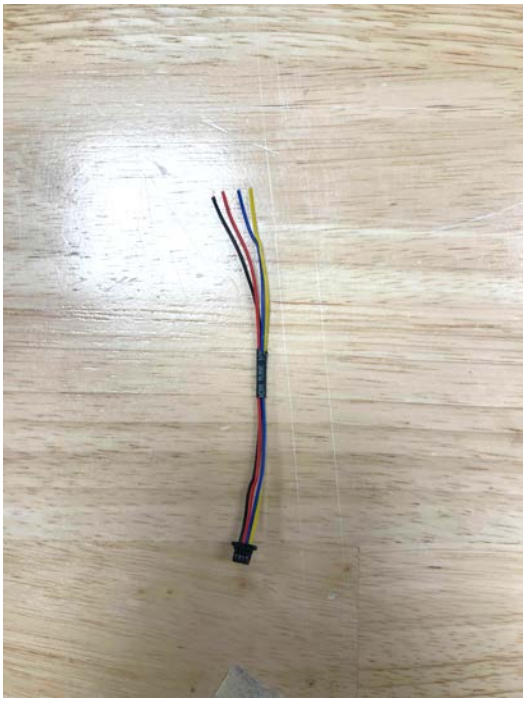


Figure 80: One connector end of the 100 mm Qwiic cable is cut off.

2. Peel apart the yellow, blue, red, and black wires.

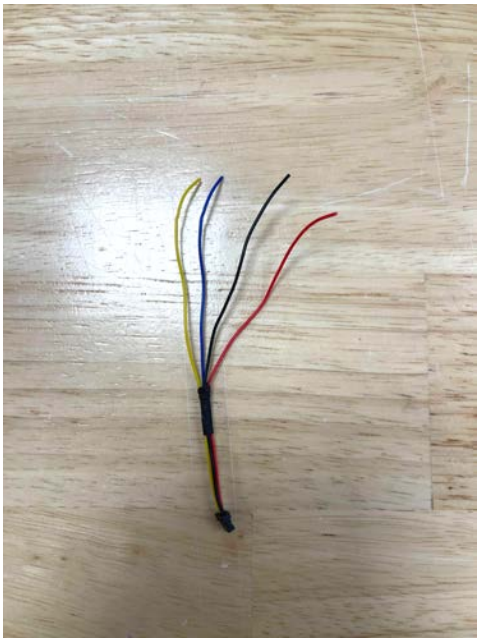


Figure 81: The four wires are peeled away from each other.

3. Using a wire striper, strip off 5 mm of the wire insulation for each wire (Fig 82).
    a. ⚠️ Be careful to not rip off the actual wire inside of the casing. ⚠️
    b. Fan out the copper strands in each wire and twist them together for strength

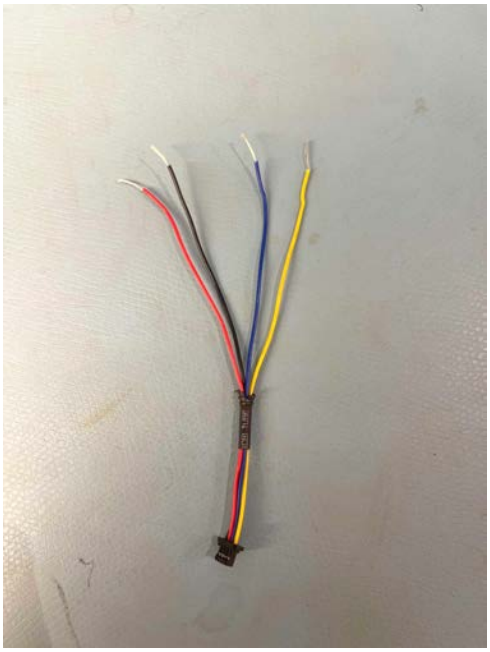


Figure 82: The wire stripper is used to strip off 5 mm of casing for each wire

4. Turn on the soldering iron and ventilation.
5. A close view of the microcontroller (SparkFun RedBoard Artemis Nano) is seen in Fig 83. Highlighted are the pins the Qwiic cable cut in Steps 1-3 will be soldered to where the respective colors of the wire are called out by colored arrows on Fig 83.
    a. Solder the wires to the pins based on the following:
        i. (QWIIC cable, red wire) <—> 3.3V (Artemis nano)
        ii. (QWIIC cable, black wire) <—> GND (Artemis nano)
        iii. (QWIIC cable, blue wire) <—> Pin 13 (Artemis nano)
        iv. (QWIIC cable, yellow wire) <—> Pin 11 (Artemis nano)

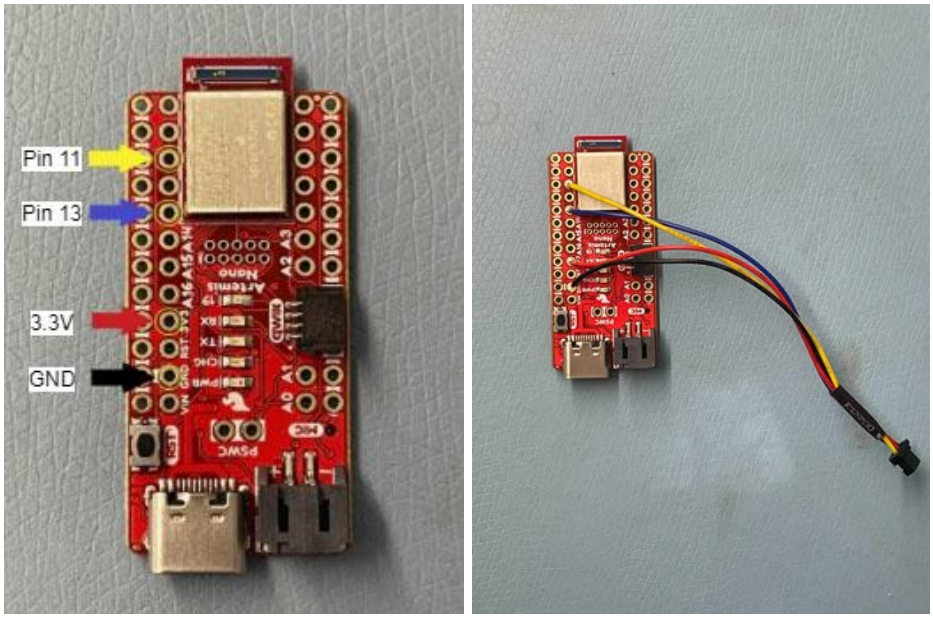


Figure 83: Each colored wire is soldered to the pins as marked by colored arrows.

6. Cut off the excess exposed wire to prevent electric shorting.

Fig 84:

7. Slide the microcontroller assembly into the 3D printed microcontroller fixture in position shown in Fig 85.
    a. ⚠️ Be careful to not rip off wire soldered to the board. ⚠️

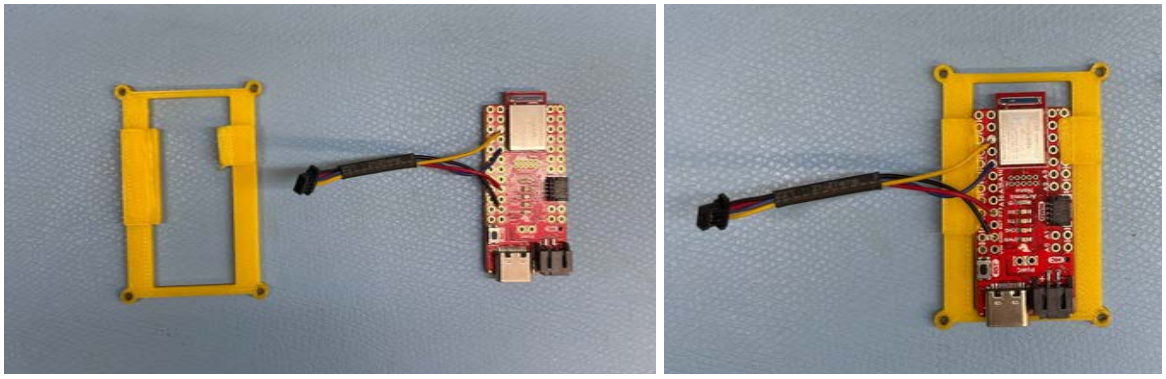


Figure 85: The microcontroller inserted into the microcontroller fixture.

8. Attach the 50 mm Qwiic cable to the Qwiic connector highlighted in red in Fig 86 on the microcontroller.

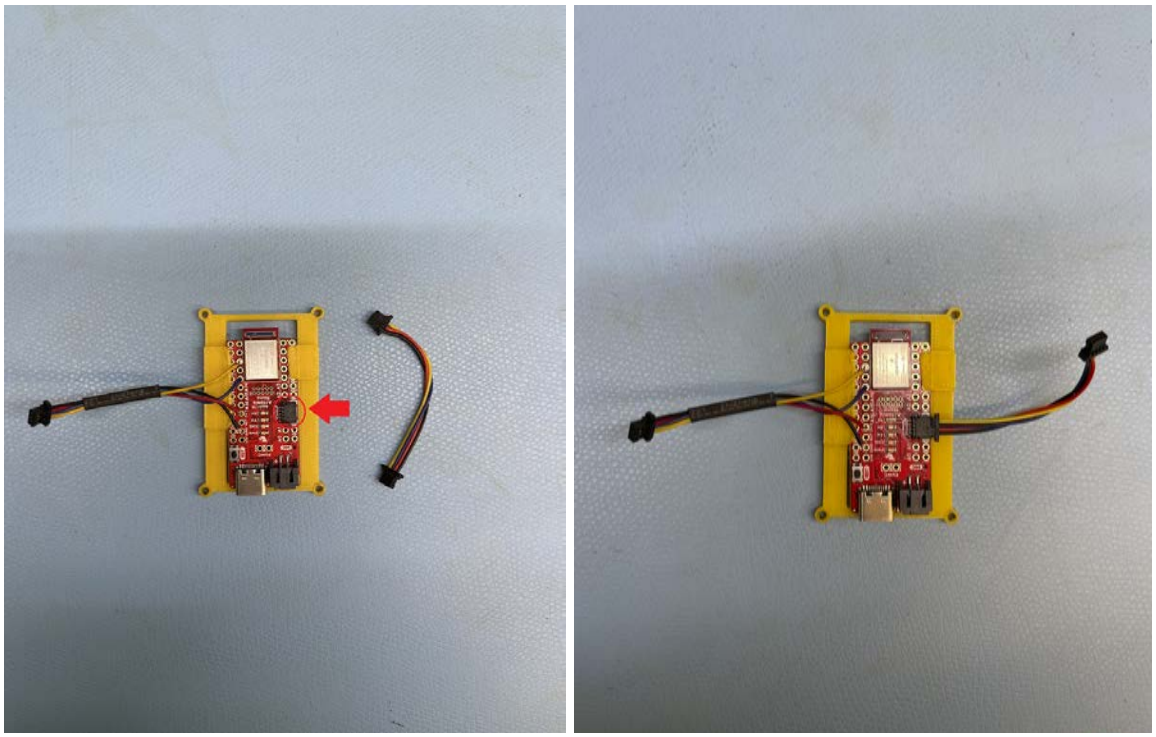


Figure 86: The 50 mm Qwiic cable is attached to the Qwiic connector on the microcontroller.

9. Remove the support material from the 3D printed pressure sensor system mount (Fig 87).

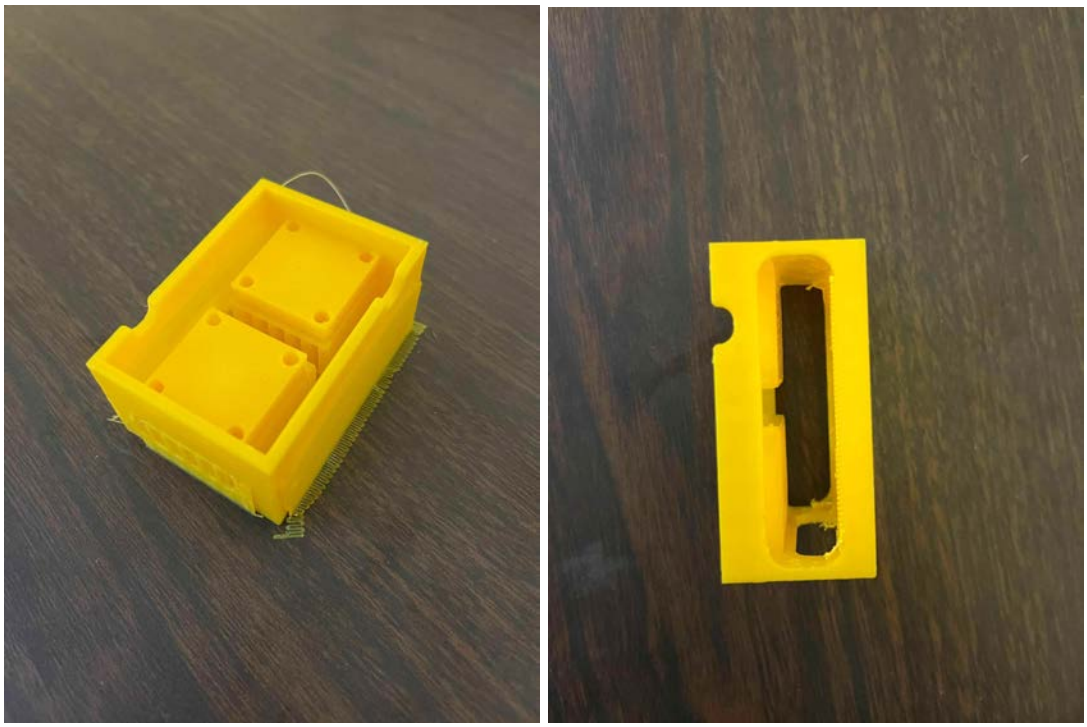


Figure 87: The support material is removed from the interior of the mount.

10. Using a soldering iron with a tip for M2 heat-sets, insert the 12 heat-sets into the pockets defined by the red circles in Fig 88.

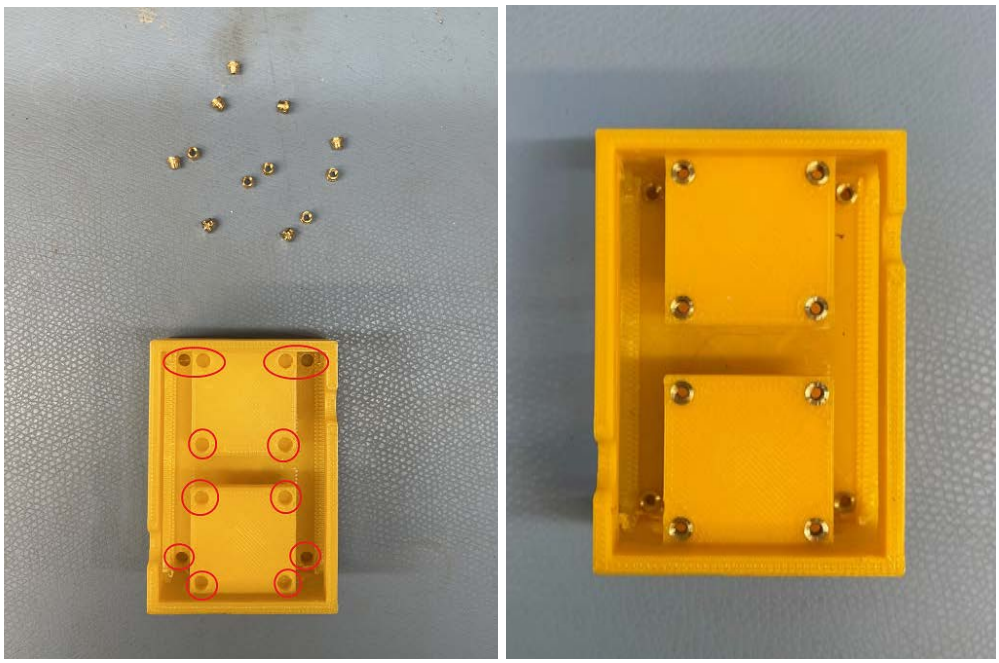


Figure 88: Heat-sets are inserted into the 12 pockets.

11. Insert the microcontroller fixture into the pressure sensor system mount. The USB connector should be facing the opening as shown on the side wall in Fig 89.

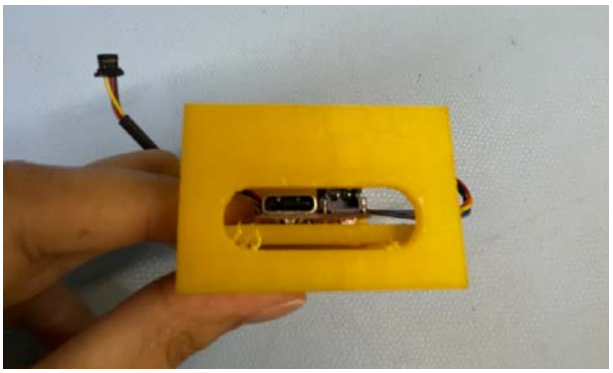


Figure 89: Microcontroller fixture is inserted with USB connector facing side opening.

12. Using four M2 x 5 mm socket head cap screws and a 1.5 mm allen key, screw the fixture to the mount starting with one corner and going in a torque pattern (Fig 90).
    a. Do not tighten until all screws are applied.

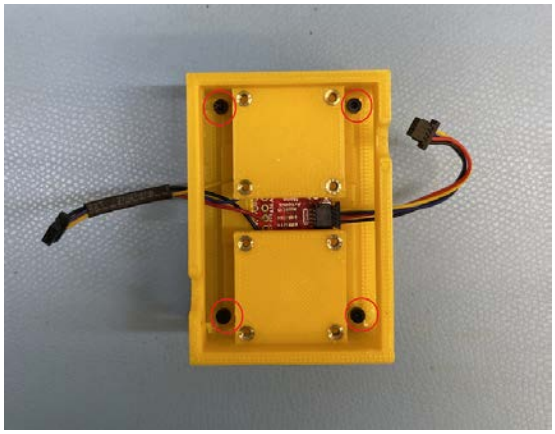


Figure 90:: Microcontroller fixture is screwed onto the pressure sensor mount

13. Place the two pressure sensors in the position shown in Fig 91.

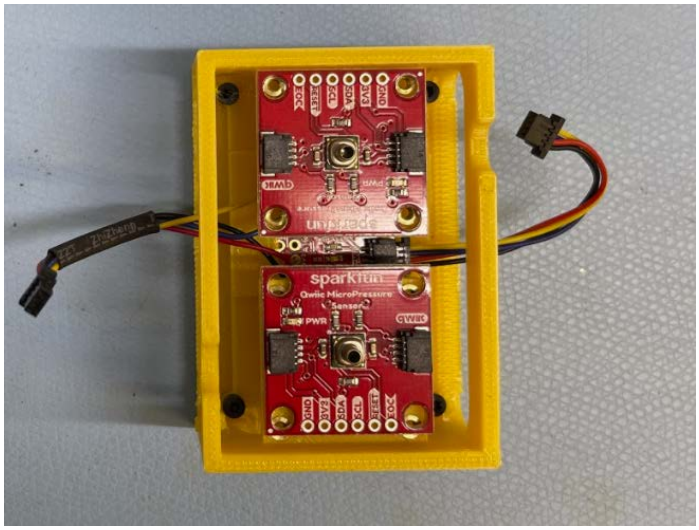


Figure 91: Pressure sensors are placed on the pressure sensor mount in the orientation shown

14. Using four M2 x 5 mm socket head cap screws, screw the pressure sensors to the mount, starting at one corner and going in a torque pattern (Fig 92).
    a. Do not tighten until all screws are applied.

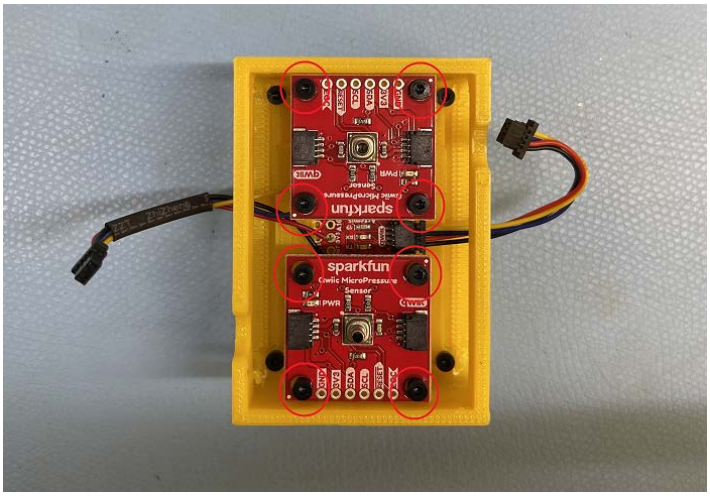


Figure 92: Pressure sensors are mounted securely onto the pressure sensor mount

15. Connecting the pressure sensors (Fig 93):
    a. Pressure Sensor 1 is assigned to the Qwiic cable that was connected to the controller in Step 6. Insert the free end of the Qwiic cable into the pressure sensor 1.
    b. Pressure Sensor 2 is assigned to the Qwiic cable that was soldered onto the microcontroller. Insert the free end of the Qwiic cable into pressure sensor 2.

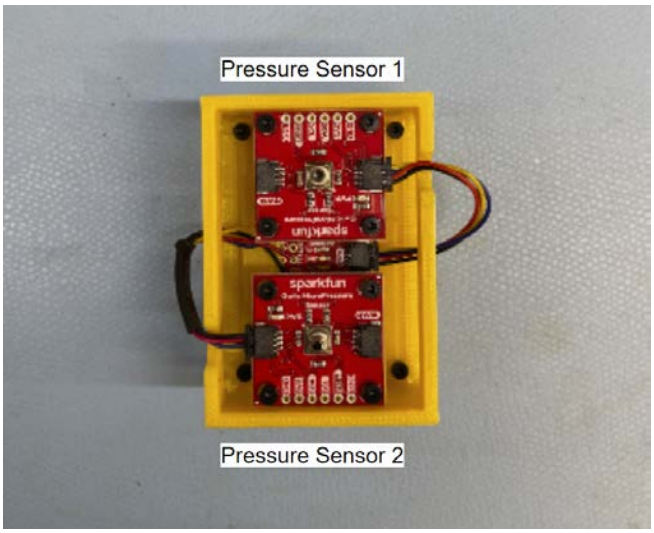


Figure 93: Qwiic cables are connected to the respective pressure sensor

16. Mount the pressure sensing system onto the robot end-effector using VHB tape (Fig 94)

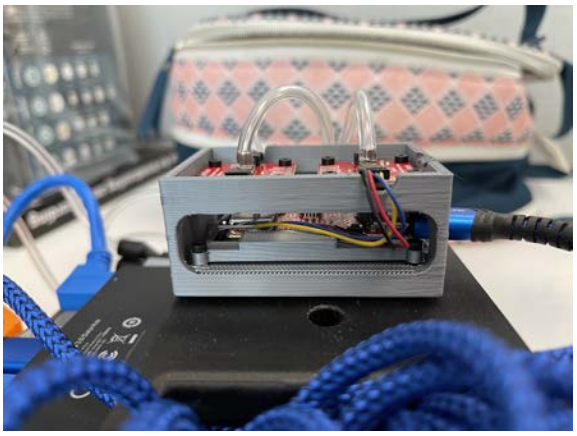


Figure 94: Pressure sensing system mounted onto the robot end effector

17. Insert the USB C cable end into the connector on the microcontroller and the USB A end into the USB hub (Fig 95).
18. Screw four push-to-connect fitting into the connector bracket and attach it to the gripper.
19. Cut two pieces of tubing (one for each bubble), 8 inches long. Apply the compressed air duster onto both ends of the tubing and insert one end into each wye connector and one end into each bubble's bubble fitting-tubing assembly specified in Figure 95.
20. Cut two pieces of tubing (one for each pressure sensor), 8 inches long. Apply the compressed air duster onto one end of the tubing and insert it into the wye connector. Repeat for the other piece of tube with the other Y connector. Insert the other end (the side with no compressed air duster applied) onto the pressure sensor shown in Figure 95.
21. Cut two pieces of tubing, 3 inches long, and apply the compressed air duster to both ends. Insert one end to the wye connector and the other end to the push-to-connect fitting with shut off valve for air on the end with no check-valve symbol (Fig 95).

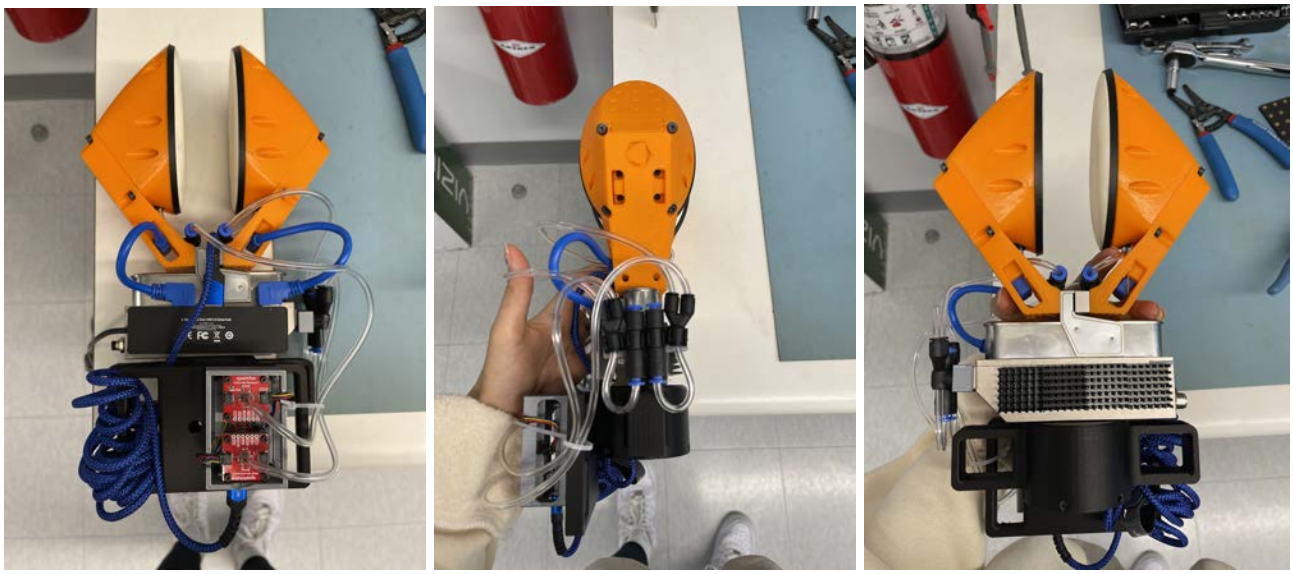


Figure 95a, 95b, 95c: Final Soft-Bubble gripper assembly with pressure sensing system

22. Congrats you have successfully made the pressure sensing system!