TABLE OF CONTENTS

Chapter 7: Software

Chapter 8: Conclusion

01

OVERVIEW

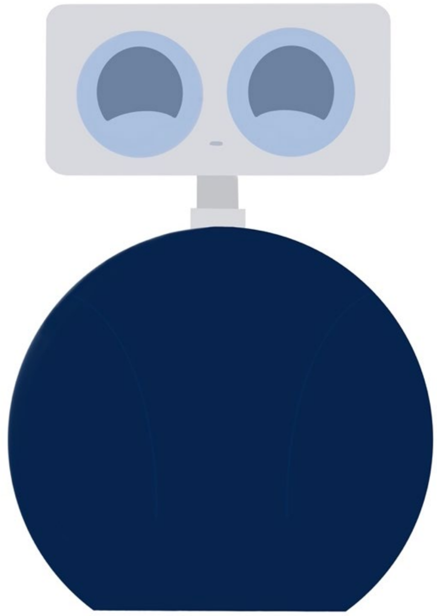
INTRODUCTION

Thank you for your interest in Ommie, the social robot that helps demonstrate and facilitate deep breathing exercises!

The purposes of this compilation are to document the process of building Ommie, provide useful resources and links, and note areas for future development in Ommie manufacturing. In this document, you will find instructions and photos based on the development of Ommie V1, constructed during spring 2024. This document will also include a BOM (Bill of Materials), motor configuration, software documentation and troubleshooting, and an FAQ for other troubleshooting and prototyping tips and tricks.

Some resources in this document link to external YouTube videos that can be useful for learning skills like soldering. We are not affiliated with the YouTube sources but recommend them for additional support. Most resources link to a Google Drive called Ommie Manufacturing Documentation. Please contact Rebecca Ramnauth (rebecca.ramnauth@yale.edu) for any questions or to request access to any materials described here.

Let's get started!



OMMIE ORIGIN

Everyone experiences distressing thoughts from time to time, but for some, these feelings can become overwhelming. Imagine a university campus common-room with hundreds of students passing through, each preoccupied with their own lives. Alex, a passionate student, is burdened by the stress of his impending assignments and exams. Traditional methods like therapy and medication either require more time than he can spare or are out of reach financially. His anxiety continues to grow, which affects his ability to focus on his studies and engage socially—winding himself in a cycle of worry and tension.

Alex's issue is far from unique. Anxiety levels are on the rise. In a 2020 CDC study, 25.5% of American adults exhibited anxiety disorder symptoms, three times higher than in the year prior at 8.1%[1]. Even before the COVID-19 pandemic, anxiety rates had risen by 30% between 2008 and 2018[2]. A 2007 study estimated that 31.1% of adults would experience an anxiety disorder in their lifetime[3]. Young adults, in particular, are severely affected. A 2021 National Collegiate Health Assessment reported that 37.4% of students had been diagnosed or treated for an anxiety

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[1] Centers for Disease Control and Prevention. (2020). Mental health, substance use, and suicidal ideation during the COVID-19 pandemic—United States, June 24–30, 2020. MMWR. Morbidity and Mortality Weekly Report, 69(32), 1049-1057.

[2] Goodwin, R. D., Weinberger, A. H., Kim, J. H., Wu, M., & Galea, S. (2020). Trends in anxiety among adults in the United States, 2008–2018: Rapid increases among young adults. Journal of Psychiatric Research, 130, 441-446.

[3] National Institute of Mental Health. (2007). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication.

disorder[4]. These impacts expand past mood, negatively affecting work/academic performance, social interactions, and overall mental health. Despite this, limited access to treatment and high costs have only heightened the issue.

Still, Alex's cannot be relieved. Enter Ommie, a novel socially assistive robot that supports deep breathing practices for the purposes of anxiety reduction. This practice of deep breathing (breathing while extending one's inhales, holds, and exhales) provided the perfect foundation for Ommie functionality to calm the autonomic nervous system. Ommie, situated in this university common room, would be available to guide users through a series of deep breaths by way of haptic interactions and audio cues—providing a potential avenue of relief for users like Alex.

Ommie's design is overly inviting, making help seem accessible to everyone. A spherical body with an acknowledging head, Ommie is soft and squishy for assisting breathing. Equipped with sensors and actuators, Ommie guides users through deep breathing exercises by providing gentle pulses and vibrations that mimic the natural rhythm of breathing. His soothing sounds provide further comfort and instruction. In one short session, Ommie could be able to dramatically reduce stress and anxiety in users.

While Ommie appears to be designed solely for students like Alex, its potential extends to any person who may need assistance. For children, adults, and the elderly of all backgrounds—students, working adults, parents, etc—the robot's ability for assistance is immediate and accessible.

Our plans for Ommie originated from a desire to make this behavioral mitigation overly attainable for any person seeking help. With such a growing crisis of anxiety today, there need to be new approaches since the current ones are lacking. We believe that Ommie's potential to bring help to users is unique and may aid in decreasing the anxiety rate long term. In sharing our story, we hope to inspire others to recognize the importance of available health resources and as an example of how researchers can design robots for behavioral practices for mental health. Our journey with Ommie is just the beginning as we continue to refine and improve this charming, socially positive companion.

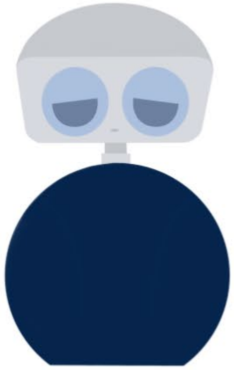
- Fiona Vitali

High School Intern

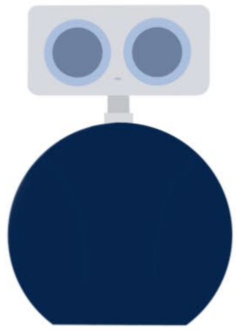
Summer 2024

[4] American College Health Association. (2021). National College Health Assessment III: Undergraduate Student Reference Group Executive Summary Spring 2021. Silver Spring, MD: American College Health Association.

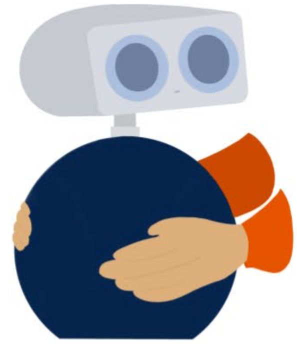
OMMIE FUNCTIONALITY



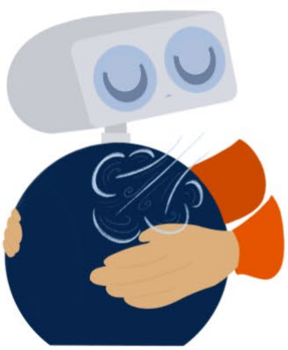
Sleeping



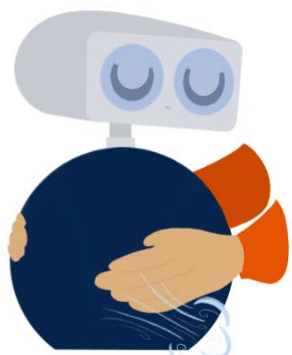
Ready to Begin



Starting a Session
(By rubbing the 'belly')

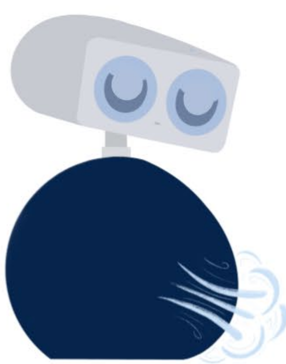


Breathe In

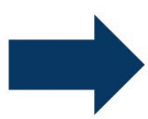


Breathe Out

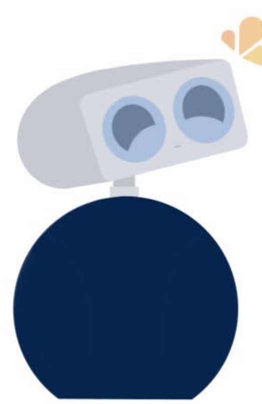
Continue Breathing In



Continue Breathing Out



Repeat As Needed



Let's Celebrate!

BILL OF MATERIALS

The Bill of Materials (BOM) lists all materials purchased for building Ommie. The materials are divided by the mechanism/sub-assembly that uses them. The last section contains fasteners, adhesives, and other securements.

Note that commonly used or safety items such as gloves, safety glasses, etc. and tools such as drills, or soldering irons were not included in the BOM. The first sheet includes required materials for basic, functioning Ommie, but a second sheet is included with additional sensors that could be added as well as alternate materials if certain materials are unavailable based on previous work.

See the Bill of Materials here Ommie Bill of Materials as well as in Appendix.

02

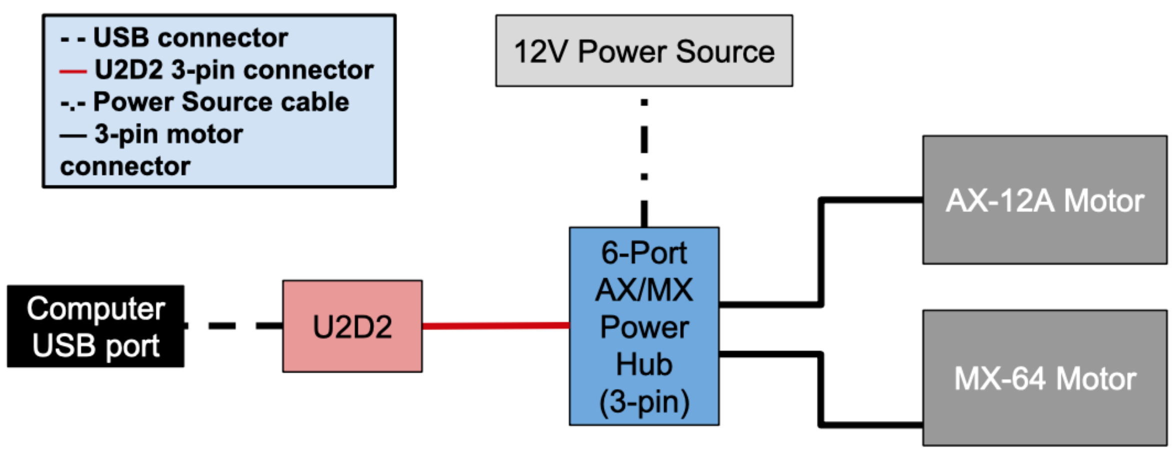
CONFIGURATION

MOTOR CONFIGURATION

Both motors are configured using the Dynamixel Wizard 2.0 application which can be downloaded here (Windows, Mac, Linux compatible):

https://emanual.robotis.com/docs/en/software/dynamixel/dynamixel_wizard2/

Before configuring the settings, the following electronics must be connected to power and communicate with the motors. This setup is schematized below. Note the two power sources: a standard USB 3.0 cable connection to a computer and an external power source.



Note that the 3-pin cable that comes with the U2D2 that is connected between the U2D2 and the Power Hub is a unique cable and other 3-pin cables that come with the motors do not connect with the U2D2 properly. If the cable is incorrect, the U2D2 may consistently fail during the “Scan” step described below.

Opening Dynamixel Wizard 2.0, click the cogwheel to access the settings. Select Protocol 1.0 and 2.0, ensure the right computer port is selected, and select all baud rates. These settings are set to locate the motors and lead to a longer scanning time. Once they are configured, the baud rate range can be decreased to speed up the scanning time to connect and recognize the motors.

Click the icon to start scanning. Alternatively, you may click the “Device” tab on the top menu and then select the “Scan” option. If scanning fails, check the wire connections and power connections. Both power sources must be connected! The U2D2 will change from a red light to flashing pink and green lights if communication is successful.

The motor settings are in the subsections below. Don’t change the other settings.

Body Motor: MX-64 Dynamixel Motor Settings

Click on the specific setting and use the interfaces on the right side of the interface to adjust the settings.

ID: 1 (Decimal: 1, Hex 0x01)
Baud Rate: 1M bps = 2M (1+1) (Decimal: 1, Hex: 0x01)
Return Delay Time: 10 [μsec] (Decimal: 5, Hex: 0x05)

Head Motor: AX-12A Dynamixel Motor Settings

Click on the specific setting and use the interfaces on the right side of the interface to adjust the settings.

ID: 2 (Decimal: 2, Hex 0x02)
Baud Rate: 1M bps = 2M / (1+1) (Decimal: 1, Hex: 0x01)
Return Delay Time: 10 [μsec] (Decimal: 5, Hex: 0x05)

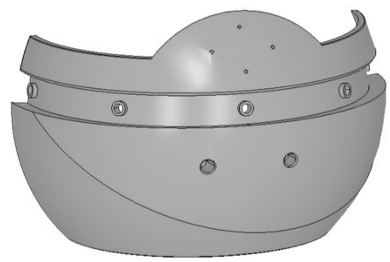
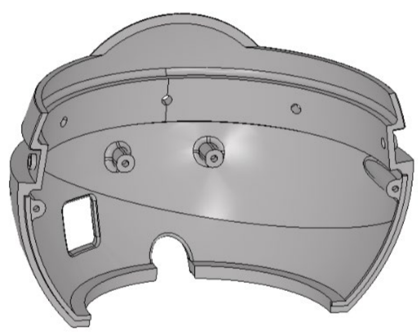
To test the motors, press the “Torque” setting in the upper right menu and click the +90 or -90 buttons. This will move the motors 90 degrees CW or CCW. The rotation will be visible and audible and will be more visible if the motor adaptor plates are attached to the motors.

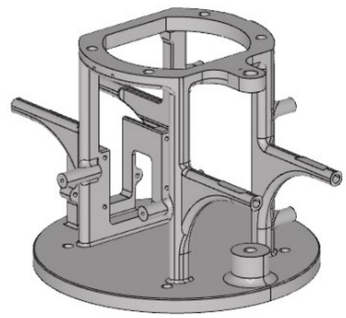
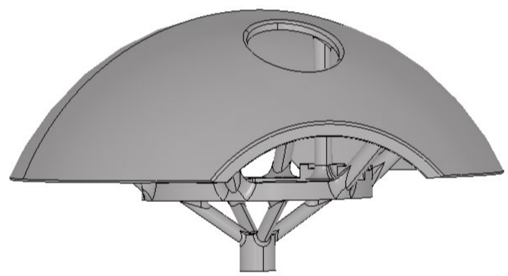
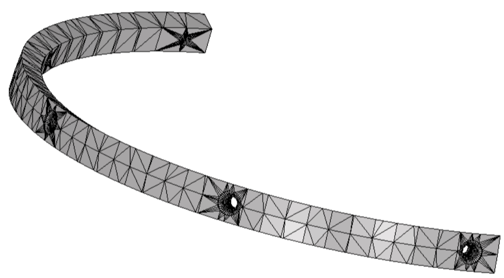
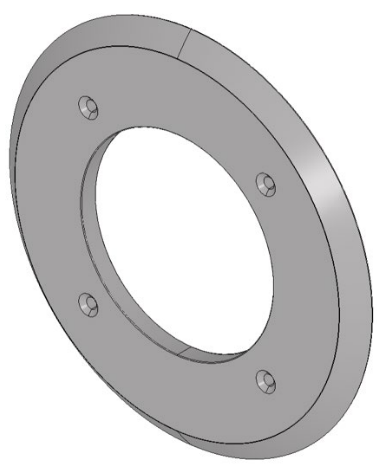
03

3D PRINTING

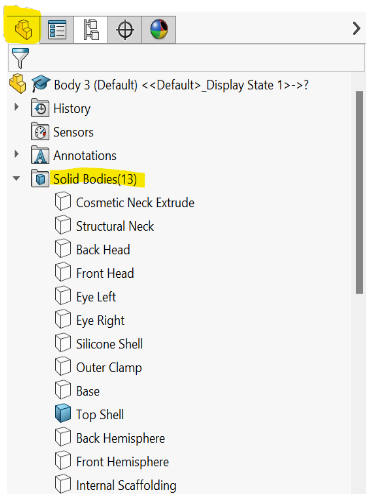
BODY, LINK, & MOTOR ADAPTORS

The files mentioned in these sections can be found in Part_Files in the 2_Ommie_Manufacturing_Documentation Google Drive. The parts mentioned in the "Ommie Body, Link, and Motor Adaptors" section can be found in the Body folder under "Part Files." Prepared STL files can also be found in the aforementioned folder. Ommie's Body consists of the following parts:

Front Hemisphere	
Back Hemisphere	

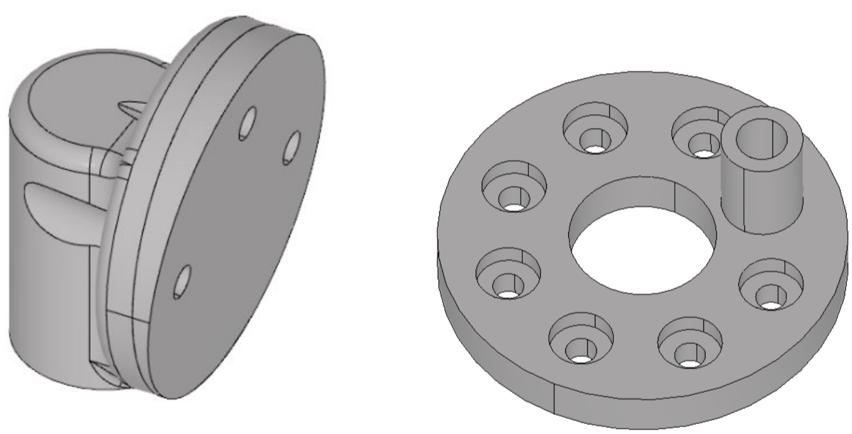
Internal Scaffolding	
Top Shell	
Clamps	
Bottom Plate**	

**The bottom plate was included in the first iteration of Ommie but discontinued in later versions, because it was an additional piece that was not required to support Ommie's functionality.



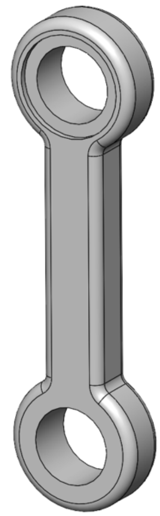
If changes are made to the CAD file, the different body pieces can be exported by using the "Solid Bodies" feature found on the left-hand menu in the Feature Manager Design Tree.
The screenshot on the left comes from the Solidworks file for the Body CAD. Under the highlighted Solid Bodies tab, the Top Shell solid body has a blue cube next to the name of the solid body. This means that this body is visible in the workspace. Notice how the other bodies have a clear cube next to the names of the bodies. This means they are not visible on the workspace. To export the "Top Shell" file, go to File > Save As > edit File Name and File Type. (.STL/.STEP most commonly used for printing)

There are two motor adaptors: the head motor (AX-12A) adaptor and the body motor (MX-64) adaptor. They are pictured below. How to connect these adaptors to the motors will be described in the "Assembling Ommie" section (subsections: "Linkage and Motor Assembly" and "Head and Neck Assembly").



Left: head motor adaptor; Right: body motor adaptor

Ommie's breathing mechanism is a single degree of freedom mechanism with one 3D-printed lever bar or link.



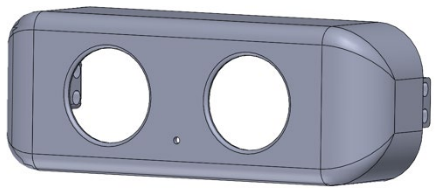
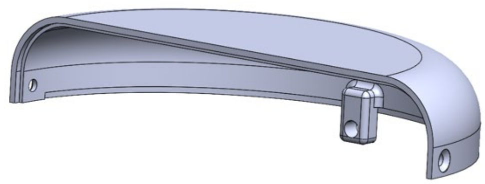
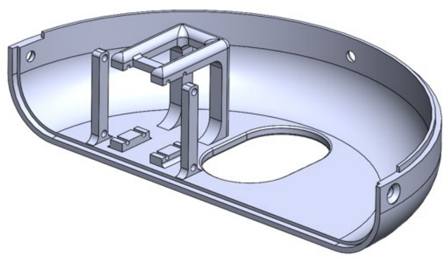
Link for breathing mechanism

MANUFACTURING: Print all parts using MJF (Multi Jet Fusion) with PA12 or SLS (Selective Laser Sintering) with PA12 25% Mineral Filled material using external services such as Protolabs or Shapeways. Because these parts are printed using special powder material, they must be printed using external services.

NOTES ON PAST MANUFACTURING: All of the pieces except the head motor adaptor were printed using an external 3D printing service. In the first version of Ommie, they were printed through a service called 3D Hubs (now Protolabs Network) using MJF printing with PA12 (the standard material choice). The head motor adapter was printed at the Yale CEID, available to Yale students, using SLA (resin) printing on a Formlabs 3D printer. In the second iteration, Protolabs was used for all of the pieces but SLS printing was used with a partially mineral-filled material. The MJF process was originally chosen for strength properties and precision of the print. When evaluating our parts with Protolabs staff, they pointed out a couple potential problems: coarse faceting and dimensional warping. Coarse faceting can be addressed by checking the resolution of the exported files or providing STEP files. Dimensional warping can be addressed by process and material changes. We were recommended to switch to SLS and use a reinforced material, the PA12 with a 25% mineral fill. We did not notice significant issues with surface finish, dimensional warping, or compromised strength of the material making the change from MJF to SLS. Therefore, the cost of the printing process becomes a more significant consideration for the printed parts.

HEAD & NECK

Ommie's Head is made of three parts:

Front Head	
Top Head	
Bottom Head	

Ommie's Head parts are located in the Head folder under "Part Files." Formlabs files are included (.form), as previous iterations of Ommie have used white resin. A Solidworks CAD file is included for editing and exporting to other file formats. See "Areas for Improvement" under "Closing Remarks" for notes on issues encountered with Ommie's Head and Neck.

Ommie's Neck is a single piece that slides onto the threaded rod. It functions more as an aesthetic cover and a tunnel for the wires from the head to be funneled discreetly into the body. It is pictured on the left.

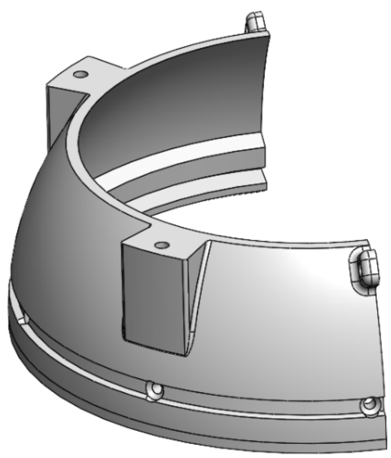
MANUFACTURING: Print head and neck parts with white resin material using external services such as Protolabs or Shapeways. FDM (Traditional 3D Printing with PLA/ABS) and/or SLA (resin) printing may also be available at makerspaces and on-campus facilities. Using those services can reduce the cost of manufacturing, so be sure to consider those options if they are available.

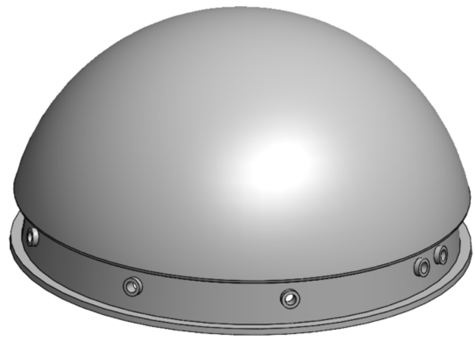
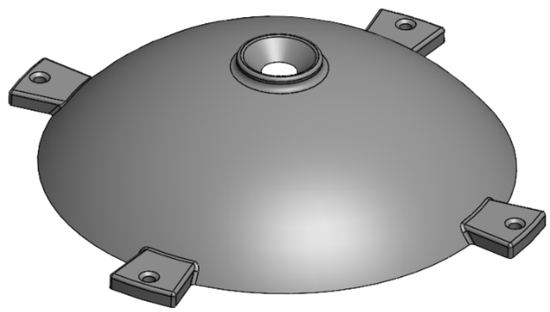
NOTES ON PAST MANUFACTURING: In the first version of Ommie, all the head and neck parts were printed at the Yale CEID using resin printing. In the second version of Ommie, all the head pieces were printed at the Yale CEID, and the neck piece was printed using a FDM 3D printer with PLA. The pieces were spray painted.

One note that will also be included later in the "Areas of Improvement" subsection is that heated inserts can be difficult to insert into the resin and, on average, cracks the resin. A different material may need to be considered for the head, but make sure to consider factors such as surface finish (especially since the Head is a key user-facing component), strength, and cost among other factors. The neck being printed in PLA did not affect its function as a cover for the rod and pathway for wires, but printing the Head in PLA would affect its surface finish, durability, and heat resistance.

SILICONE MOLD

The silicone mold is used to create the silicone shell that goes over Ommie's body parts to add some structure and smoothen the breathing motion. It is comprised of four parts:

Side Mold A	
Side Mold B	

Inner Mold	
Top Mold	

The CAD file and .STL files are located in the Silicone Mold folder under "Part Files."

MANUFACTURING: Print silicone mold parts with PLA material with a 20% infill using external services such as Protolabs or Shapeways. See "Notes on Past Manufacturing" for more details on the material choice. While minor warping is acceptable for all other pieces, the precision of the silicon mold is important for producing the silicone mold, so printing quality and settings may be factors to consider during manufacturing. FDM (Traditional 3D Printing with PLA/ABS) and/or SLA printing may also be available at makerspaces and in campus facilities. Using those services can reduce the cost of manufacturing, so be sure to consider those options if they are available.

MANUFACTURING NOTES: In the first Ommie model, the mold parts were externally printed using PLA material with a 20% infill to reinforce the print. In the second model, the mold was printed using resin printing at the Yale CEID. The PLA mold worked well, although one of the pieces had to be reprinted due to notable dimensional warping. Consider what printing and material is available to you to use a durable and stronger material for the mold. The mold parts were printed in an opaque material, and in the future, if there is no other redesign, the parts should be printed in a clear material to aid with shell manufacturing.

04

SILICONE SHELL

SHELL MANUFACTURING

As aforementioned, the silicone shell goes over Ommie's body parts to add structure and smoothen the breathing motion. It is important to make a shell that is relatively uniform in thickness and pliable.

To make the silicone shell, the following materials are needed: Dragon Skin™ 10 Slow Part A, Dragon Skin™ 10 Slow Part B, Silicone Thinner™, mold release spray, a shake table (used the Labnique™ Oribtal Shaker), and a graduated measuring cup. Separate utensils must be used for each of the silicone rubber components. One utensil **cannot** be used to take out both parts.

To keep the space tidy and reduce clean-up time, it is highly recommended to clear the workspace, tape down a large sheet of paper, foil, or thin plastic, and have many napkins and pairs of gloves. Tape a sheet of material on the shake table as well. Wear an apron and/or old clothes to prevent liquid silicone from getting on clothing. Tie hair back and remove loose accessories. If liquid silicone gets on tables or equipment, let it cure and peel it off. Liquid silicone may come off clothing if uncured with alcohol. All surfaces can also be wiped down with dish soap and water.

The silicone shell is assembled in two phases: one for the base and one for the lid curve.

MANUFACTURING NOTES:

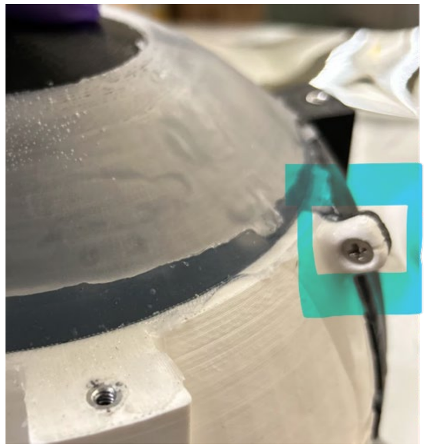
- This process takes time and may span over a few days.
- Duct tape was used for the taping described below.
- Printing the mold in an opaque material made it challenging to determine whether the silicone was spreading or whether the mold was filled since silicone can get messy. It can also appear that the gap seems filled, but upon letting the silicone cure, it turns out the silicone mixture was still settling, so the entire gap was not filled.
- On the bright side, Dragon Skin™ will stick to itself, so if only part of the silicone shell is cured and the lid curve is thin or there are other issues, the cured silicone shell can be cut. Use the mold assembly and more silicone into the regions that need more silicone to fix or add to the shell.

- If the 3D-printed pieces are not fitting together, one of the parts may be notably warped from printing and may need to be reprinted.
- To make sure the bowl is sitting properly in the 3D-printed shell and not unevenly, assess how the screws fit in the holes and how the slight gap between the shell and the bowl appears.
- The shake table will be used in intervals to help the silicone rubber spread around the circumference of the mold bowl and move down in the assembly. This helps create a uniform shell with less air bubbles.
- The shake table used to create Ommie was borrowed from another lab on campus, so check campus labs/facilities to see if this equipment is available for borrowing.
- Mold release spray is not required, but it notably helps with easily removing cured silicone from the 3D-printed mold (which can otherwise be a challenging task with a lot of pulling and other tools involved to pry off the cured shell).
- The silicone shell is complete when the entire shell is covered in a thick layer. If there isn't a hole in the center, the Dragon Skin can be easily cut with scissors to make a hole in the silicone shell.

- First, a 0.012" diameter, 1-inch long needle was used for the syringe, but the needle length was too long. Then a graduated syringe of a similar diameter hole without a needle was used, and the holes in the top mold were drilled out to accommodate the syringe.

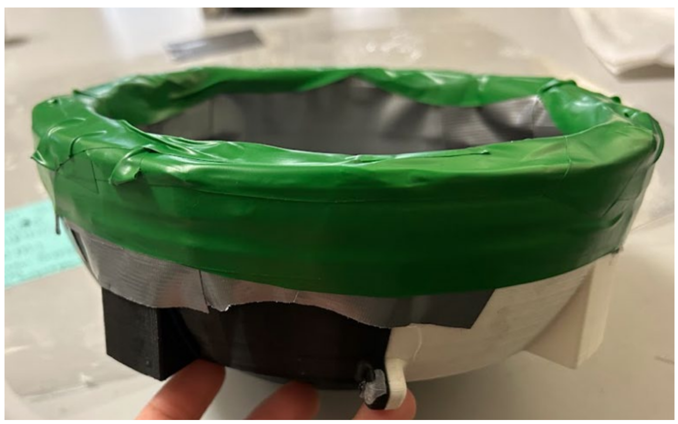
SILICONE SHELL: BASE

1. Spray mold release spray on Side Mold A and Side Mold B and the Inner Mold.
2. Align the Side Molds A and B together. Connect them by screwing in 6-32 ⅜" Phillips screws in the protruding hole connections on the Mold A and B pieces pictured below.



3. Turn the connected shell so that the shell is in an open-bowl orientation. Place the mold bowl in the shell. Line up the holes in the mold bowl with the holes in the shell. Screw 6-32 ⅜" Phillips screws into the holes. Make sure the bowl is sitting properly in the shell and not unevenly.

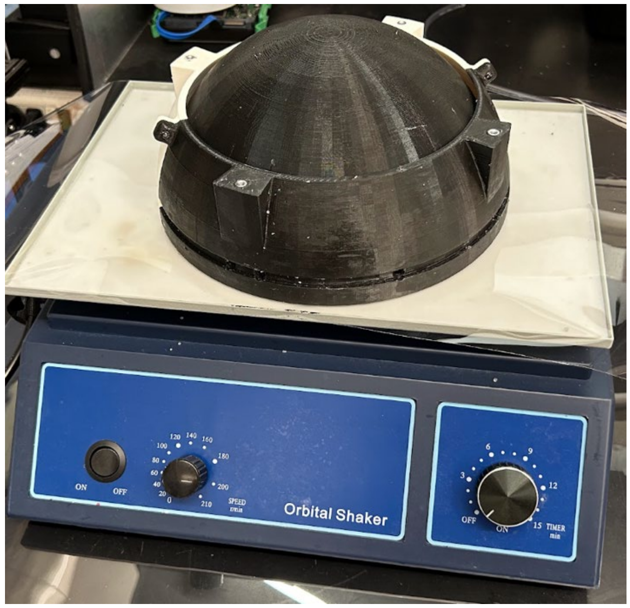
4. Tape the bottom of the base assembly covering all possible cracks and gaps. Be generous– you don't want silicone to be pouring out of your mold!



5. Pour 50 mL of Dragon Skin™ 10 Slow Part A and 50 mL of Dragon Skin™ 10 Slow Part B into a graduated measuring cup. Pour 10% of that combined amount (10 mL) of Silicone Thinner™ into the graduated measuring cup. Stir for thirty seconds. **NOTE:** The measurements written above do not reflect the amount of silicone needed to make an entire silicone shell. This step will need to be repeated 3-5 times, but the entire batch cannot be made all at once. This is because the mixture begins to cure as time passes, so smaller amounts are better to work with. Approximately equal parts of A and B must be mixed. Follow the instructions on the backs of the silicone containers. Silicone Thinner™ is added as a percentage of the total volume. Guidelines for Silicone Thinner™ usage can be found on the Smooth-On website.

6. Place the base assembly bowl side down on the shake table. Begin pouring the silicone mixture on the mold assembly, guiding the mixture with a utensil (plastic knife or popsicle stick recommended) into the gap between the bowl and the connected shell and scraping

excess or overflowing mixture into other areas of the gap with less mixture. At regular intervals about every 15-20 mL poured, turn on the shake table at a medium to high frequency for about a minute to help spread out the material.



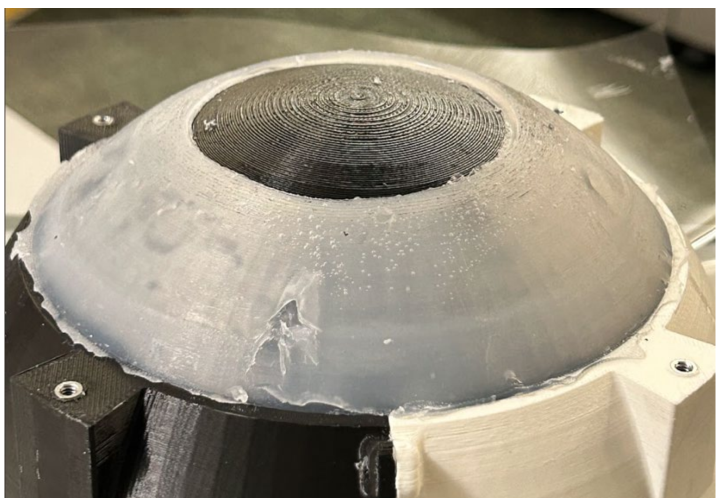
7. Repeat steps 4-5 as needed to fill the gap in the base assembly. Let cure for 4-5 hours.
8. Check whether the gap has been filled by visual inspection or poking a popsicle stick into the gap. **Do not take apart the base assembly.** If not filled, repeat 4-5 as needed, adjusting the silicone measurements as needed.
9.

SILICONE SHELL: LIP CURVE

To make the lid curve or top part of the silicone shell, the mold lid and a syringe will be needed along with the other materials used for the base. Long needles and small diameter needles will restrict the silicone flow rate making it extremely difficult to get silicone into the mold. The holes in the mold lid may be drilled slightly to accommodate a bigger diameter needle, but be careful not to make the hole too big, as that will also be a location where silicone will ooze out which should be limited.

1. Spray mold release spray on the mold lid.
2. Check syringe flow rate and how the needle fits in the four small holes. Adjust syringe and/or mold lid as described above and as desired.
3. Attach the mold lid to the top of the base assembly using 6-32 ⅜" Phillips screws as tightly as possible.

4. Generously tape the seam between the mold lid and the base assembly to prevent silicone leakage. Set the full mold assembly on the shake table.
5. Create the mixture as described in step 4 of the Silicone Shell: Base procedure.
6. Fill the syringe and inject the silicone mixture into the mold using the four small holes on the mold lid. Some silicone can also be poured into the larger, central hole.
7. At regular intervals about every 15-20 mL poured, turn on the shake table at a medium to high frequency for about a minute to help spread out the material.
8. Repeat 5-7 as needed. When silicone is leaking from the four holes and may be coming over the top of the central hole, let the assembly cure for 4-5 hours.
9. Check the lid curve by removing the mold lid. If the lid curve has variation in thickness (thinner top region) or is not fully formed (see photo below), remove misshapen regions, reattach the mold lid, and follow 4-7 as needed.



05

SWEATER

MATERIALS NEEDED

Here is a detailed guide for creating a sweater for your Ommie robot, including the necessary fabric, materials, and patterns.

1. **Fabric:** Choose a stretchable, soft fabric such as knit or fleece to accommodate the robot's spherical shape and ensure a snug fit. You'll need about 1/2 yard of fabric and an additional 1/2 yard for the lining, if desired. For the present iteration of Ommie, we used cotton jersey for both the outer and lining of the sweater.

   Below, we discuss the pros and cons of the various fabrics we prototyped with.

   a. *Knit* fabric provides flexibility and stretch, ensuring a comfortable fit. However, it is susceptible to fraying with continued use and washing.

   b. *Fleece* also provides flexibility, stretch, and a smooth yet soft texture. This is the preferred fabric choice for the robot as it is often associated with children's' blankets and can endure wash and wear for relatively longer than other options. Yet, we note that selecting a thicker fleece may result in added bulk to the sweater, making the seams more apparent and dampening the robot's motion.

   c. *Cotton jersey* is soft, breathable, and slightly stretchy. However, it has less stretch than knit fabric and may not conform as snugly to the spherical shape.

   d. *Spandex* or *Lyra* is highly stretchy, form-fitting, and durable. However, it can be more difficult to sew and may require specialized sewing techniques.

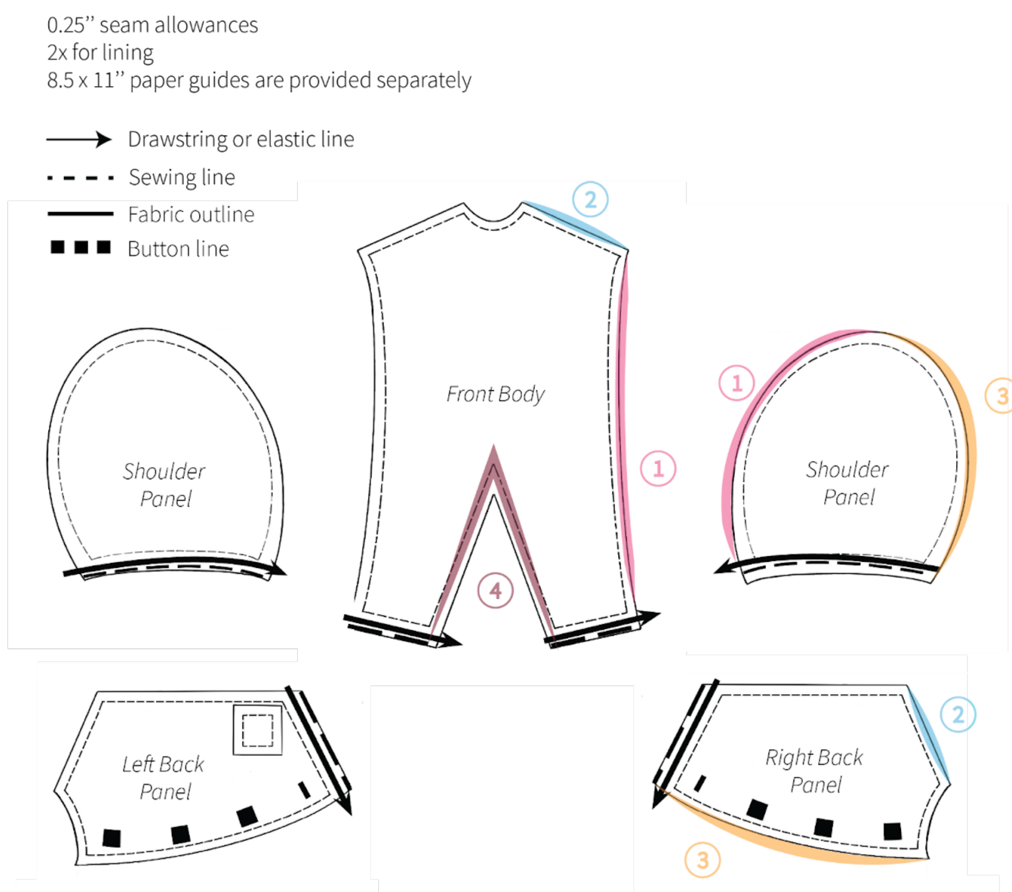
   Note that the thickness of the selected fabric may reduce the legibility of the breathing motion.

2. **Band**: A 1/4-inch-wide elastic band or drawstring to ensure the sweater stays in place around the robot's base. You'll need about 5 inches in elastic or 10 inches in drawstring material, including allowance for tying the draw string.

3. **Sewing Supplies**:
   a. Sewing machine or needle and thread: For assembling the sweater.
   b. Pins: To hold the fabric in place while sewing.
   c. Fabric scissors: For cutting the fabric patterns accurately.
   d. Measuring tape: To measure the robot and fabric pieces accurately.
   e. Fabric marker or chalk: For marking the fabric according to the pattern.

4. **Fasteners**: For securing the sweater on the robot, use either Velcro or snap buttons. This allows for easy removal and adjustment. We do not recommend using a zipper as this may result in bunching of the fabric.

5. **Fabric Patterns:** We supply patterns on 8.5 x 11'' paper so that it can easily be printed. These patterns can be found here: [Sweater]() as well as in the Appendix. Below is the sewing guide.



ASSEMBLY INSTRUCTIONS

1. **Pin the Fabric Pieces**: Pin the fabric pieces together according to your pattern, ensuring that the right sides of the fabric are facing each other.
2. **Sew the Seam**s: Using a sewing machine or needle and thread, sew the pinned seams together. Ensure you leave openings where necessary.
3. **Attach Elastic Band**: Sew the elastic band around the openings (like the bottom hem) to help the sweater stay in place. If using a drawstring, you can thread the string after sewing.
4. **Add Fasteners**: Attach Velcro or snap buttons to secure the sweater on the robot. Place them at strategic points to ensure a secure fit.

FINAL TOUCHES

1. **Try It On**: Place the sweater on the robot to check the fit. Make any necessary adjustments to ensure it fits snugly but comfortably.
2. **Finishing Seams**: Trim any excess fabric and finish the seams to prevent fraying.

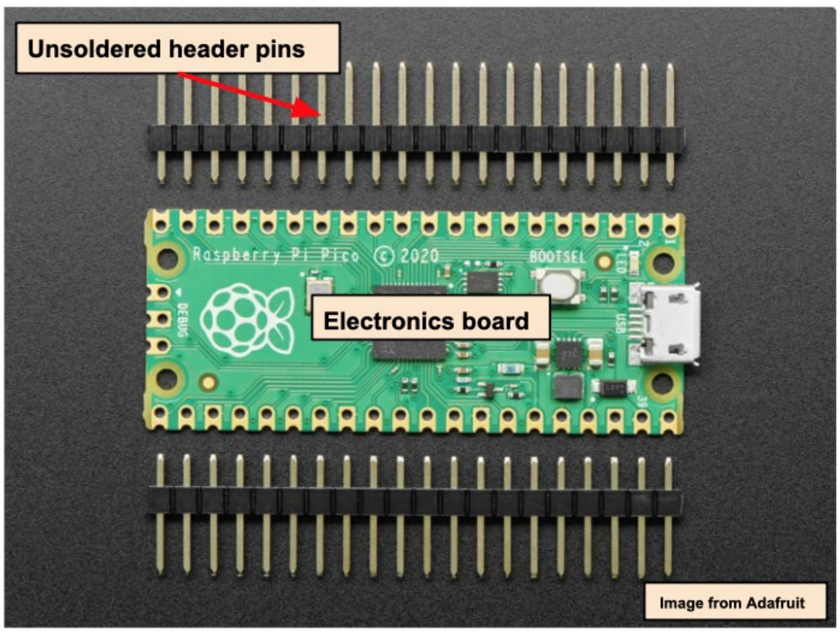
06

ASSEMBLY

ASSEMBLING OMMIE

The following sections are roughly in the order in which they should be carried out unless otherwise stated (important for the head and breathing mechanism assemblies).

SOLDERING ELECTRONICS

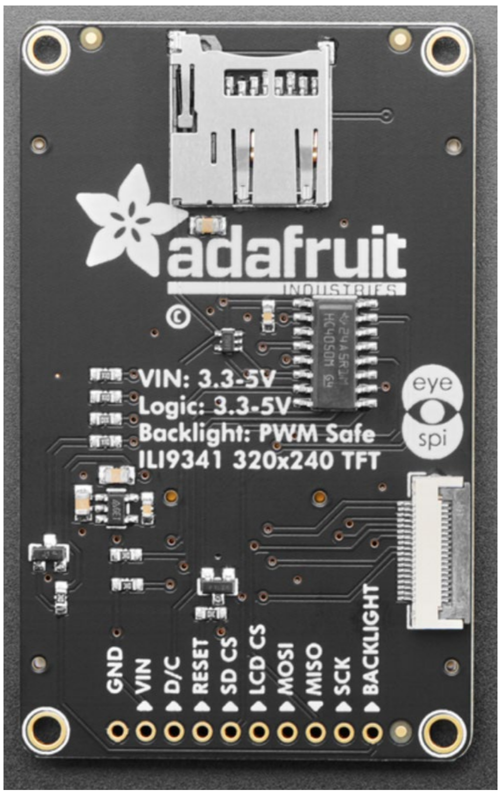


The picture above shows an unsoldered electronics board. The header pins come in a long strip with the electronics board.

Count out the number of header pins needed and break off that amount from the strip, but do not break them into individual pins. Note that one side of the header pin is longer than the other. The longer side will be where “female”-connection wires can be connected, so make sure the pins are soldered such that the electronics board be mounted as needed. Use proper ventilation and be safe while working with solder at high temperatures. This video explains how to solder electronics: HOW TO SOLDER! (Beginner's Guide) - HackMakeMod.

SCREENS' WIRE SOLDERING

Ommie has two eyes, two screens. The [Adafruit 240 x 320 2.2" TFT w/ILI9341 screen] will be used for explaining below, but the code and pins can be adapted if other screens are used. The colors used in the subsequent photos are also noted below and are useful for differentiating the different connections.



Guide: Screens' Pin → Color

GND → Black
VIN → Red
D/C → Blue
RST (Reset) → Yellow
LCD CS or CS → Orange
MOSI → White
SCK or SLCK → Green

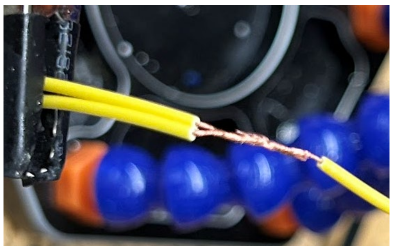
The same type of screen is used for each of Ommie's eyes. This means that there is overlap between the pin connections between screens that is taken advantage of in the wire soldering by soldering together two wires with a third wire to make a Y-shape that connects both screens to the Adafruit T-Cobbler Plus which is connected to the Raspberry Pi. All pins will use this Y-shape except the LDCS pin which will have a separate wire for each of the screens, one wire for the "left" eye and one for the "right." In total, 8 pins are used. These pins are noted in the "Screens Mounting and Wiring" section.

For the prongs of the Y, the wires connecting directly to the GND, VIN, D/C, RST, MOSI, and SCK pins, use two 7.8 in (20 cm) wires for each respective pin (remember to differentiate the colors). For the vertical of the Y, the wire connecting to the Adafruit T-Cobbler Plus, use the 11.8 in (30 cm) wire.

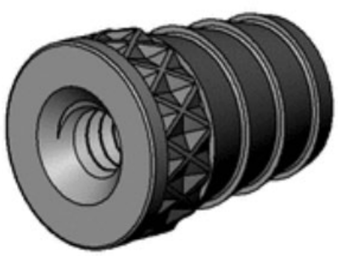
Strip one inch off one end of the standard copper F-F jumper wires (noted in BOM) using the 20 AWG (0.80 mm) notch on a wire cutter. Twist the ends of the shorter wires together, then twist the end of the longer wire with the twisted shorter wires. It should look like the first picture below. A stand with flexible arms and alligator clips is used to help hold the wires in place and is really useful.

Solder the wires together using a soldering iron and rosin-core solder for electronics with ~1.8-2.2% flux in it. Follow advice and instructions from the "Soldering Electronics" section. See the second picture below.

Slip about an inch of heat shrink tubing over the soldered joint. Use a heat gun to apply uniform heating to shrink the tubing over the joint. See the third picture below.



ADDING HEATED INSERTS



Heated inserts are cylindrical metal pieces that are internally threaded. They can be inserted into 3D prints to add threads to a piece to use screws as a fastener. Using heated inserts can be preferred over printing parts with 3D-printed threads for stability. A soldering iron is needed to insert heated inserts. Here is a video that explains how to use heated inserts: How To Install Heat Set Inserts in 3D Prints - BV3D: Bryan Vines. (Image on left from McMaster-Carr)

The BOM lists three different brass tapered heated inserts: 4-40 0.219", 6-32 0.15", 6-32 0.25". Let's break that down. Looking at the first insert, the 4-40 refers to the screw type and thread–a 4-40 screw is a #4 screw with 40 threads per inch, and the length of the insert is 0.219".

The 6-32 0.15" insert is for the holes on the front and back body pieces that are around the middle of Ommie's body where the clamp is tightened.

The 6-32 0.25" insert is for the holes in the head.

The 4-40 0.219" insert are for the other body holes in the front and back body pieces that connect to the internal scaffolding and connect the front and back body pieces to each other. For the 4-40 screws, press the heated inserts into the holes from the inner face of the 3D printed parts as shown below.

NOTES: Around 550-600° F was used for adding the heated inserts, but it is recommended to check online for temperature recommendations depending on the material that the inserts are being inserted into.

STRUCTURAL NECK ASSEMBLY

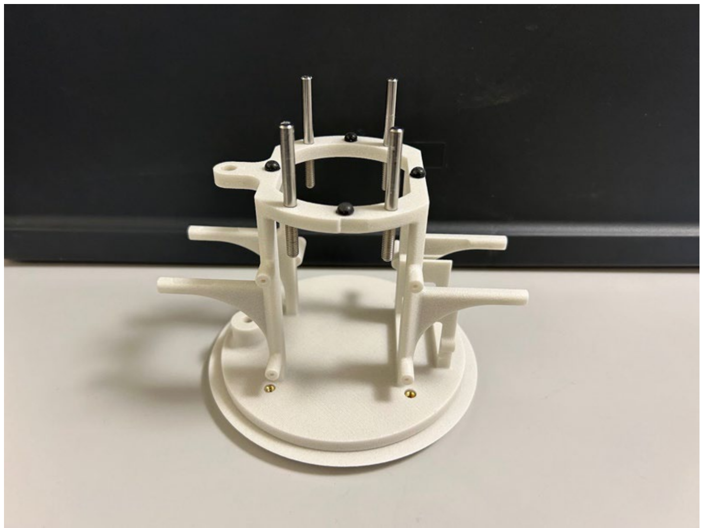
Take the 1/4"-20 thread size 8" long threaded rod and slide it into the protruding hole on the internal scaffolding. Hammer the rod lightly to get it into the hole on the bottom of the scaffolding.

Screw two 1/4”-20 nuts onto the threaded rod. These are used to support the 3D-printed neck piece, and their exact location along the structural neck will be adjusted during the “Head Assembly” section.

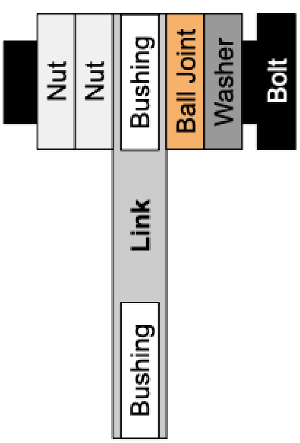
BREATHING MECHANISM ASSEMBLY

Ommie’s breathing mechanism is a single degree of freedom mechanism actuated by the body motor. There is a single link that moves up and down as a result of the motor’s rotation, and that regulated up-and-down motion causes Ommie’s spherical shell to expand and contract to simulate breathing.

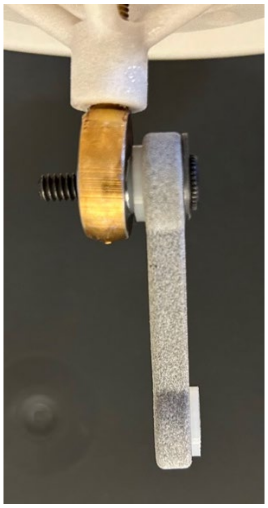
To the internal scaffolding, screw in the 18-8 stainless steel studs that are threaded on one end in the holes on the top and attach the small bumpers as shown below.



Screw the 1/4"-28 thread ball joint in the hole in the center of the top shell body piece. It will be difficult to screw in due to the tight tolerances required for the mechanism, so do not worry if it is difficult! For Ommie, the ball joint functions as a hole for the shoulder joint that holds the single link on one end. Therefore, the ball on the ball joint must be stationary. This is achieved by using super glue on the ball, being careful not to get glue on the inside of the hole. A popsicle stick is useful for glue application, and it can be used to move the ball in different directions to expose the unglued portions of the ball for gluing. The ball may be easier to move with glove-covered hands. Try to keep the ball as level with the horizontal as possible. Otherwise, the link will be at an angle, and it will be difficult to connect it to the motor. **Allow the super glue to cure completely before moving onto the next step.** Follow curing directions for the super glue used.



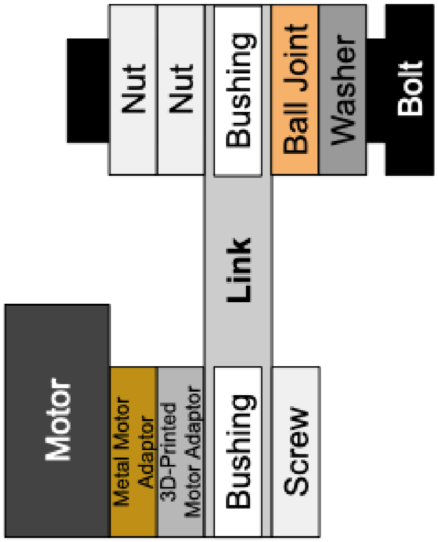
The single link was 3D printed as described in the section "Ommie Body, Link, and Motor Adaptors." The plastic bushings go into the holes on the ends of the link. A shoulder bolt goes through the linkage and connects with the ball joint. The other elements are labeled on a schematic diagram to the left. Pictures are included below the schematic for reference.

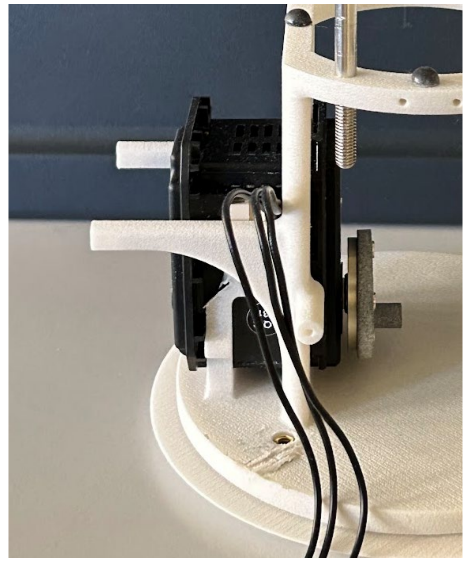


Now the top shell must be connected to the internal scaffolding. The top shell has holes along the inner circle above the ball joint, and these holes slide over the stainless-steel threaded studs that were screwed in earlier. Because of the tight tolerances, it is much easier to hammer in the top shell over the threaded studs. It is recommended to pull off the top shell and hammer it back on the studs a few times to make it easier for the top shell to slide up the threaded studs by introducing a slight amount of wear.

Skip ahead to the "Motors' Mounting, Electronics, and Wiring: Body Motor" section. After completing the body motor section, return to this section.

After mounting the body motor, the motor adaptors need to be connected. Dynamixel provides a motor adaptor, small hex screws, and a three-pin connector. Before connecting the adaptors, disconnect the three-pin connector from the 3-pin power hub. It can be helpful to remove the top shell temporarily to have more space for adjusting the motor, but it is not necessary. Push the included metal motor adaptor plate onto the gear on the motor. Screw the 3D-printed motor adaptor on top of the metal adapter with the included hex screws. In the picture below, the two plates are shown. The cylindrical extrusion on the 3D-printed plate should be at the bottom of the plate.





The link can now be connected to the motor. Slide the top shell back on if it was removed, and push the link with the bushing on it against the cylindrical extrusion. The extrusion will fit snugly against the bushing. Use an 8-32 1/4" Phillips round head screw to secure the link to the 3D-printed body motor adaptor. The linkage can be tested as described in the "Motor Configuration" section. Alignment issues can occur, so check the following: motor mounting, ball joint hole levelness, and whether the bumpers are inhibiting the linkage from reaching the cylindrical extrusion.

HEAD ASSEMBLY

Put the silicone shell over the top shell and neck cover before continuing with the head assembly. It can be kept raised and out of the way by using one of the body clamps and threading it through the two of the holes on the silicone shell.

Skip ahead to the "Motors' Mounting, Electronics, and Wiring: Head Motor" section. Complete the head motor section, the "Screens' Mounting and Wiring" section, and the "Speaker Mounting and Wiring" section. After completing these sections, return to this section. The Raspberry Pi/T-Cobbler mounting and wiring is not necessary to complete the previous sections, but the wiring is mentioned in each section, and it can be carried out after all the other electronics are mounted.

The head motor adaptor, head motor, speaker, and bottom head piece should all be attached to Ommie now. The screens should be glued to the inside of the front head piece.

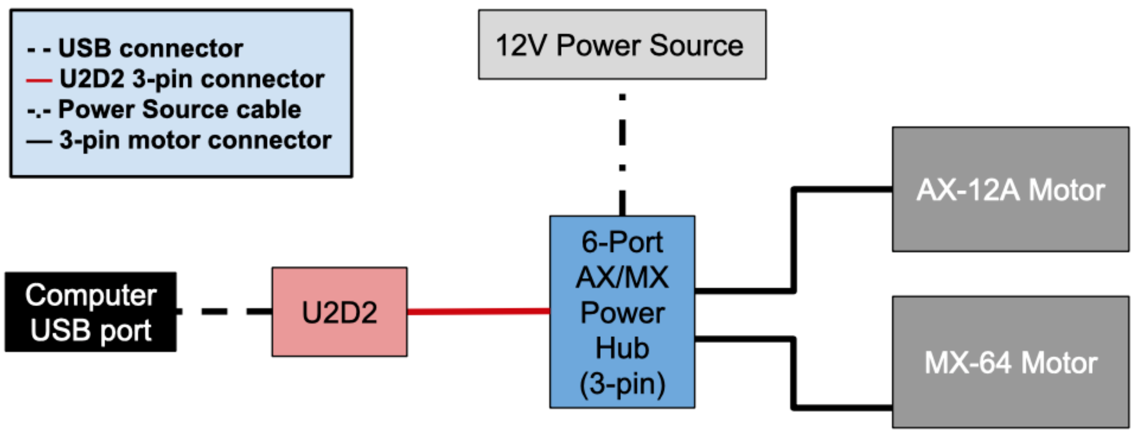
Attach the front head piece to the bottom piece using 6-32 ⅜" screws. Attach the top head piece to the rest of the assembly using the aforementioned screws. The head is now assembled.

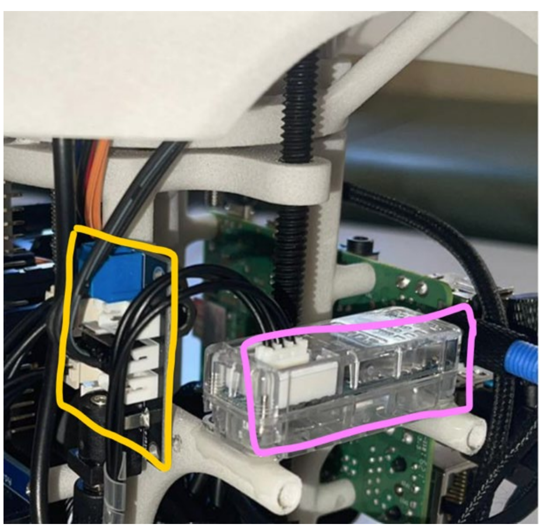
MOUNTING & WIRING ELECTRONICS

MOTORS' MOUNTING, WIRING, & ELECTRONICS

Before working through this section, configure and test the motors as described in the "Motor Configuration" section. Spiral sleeving, electric tape, and Velcro can be used with cable management among other materials.

The motors should be mounted in their mounting cartridges. The female three-pin connectors both connect to the 3-pin power hub which is connected to the U2D2. The schematic below is also in the "Motor Configuration" section and shows the different wires connected.





As stated in the "Motor Configuration" section, the U2D2 and the 6-port 3-pin power hub are required to power and control the motors. The U2D2 is mounted on the internal scaffolding using hot/super glue on the indented posts of the scaffolding closest to the structural neck threaded rod. The power hub is screwed into the post perpendicular and to the left of the U2D2 in this orientation using 2-56 5/16" screws. This is pictured left.

MOTORS' MOUNTING: BODY MOTOR

It can be helpful to remove the top shell temporarily to have more space for adjusting the body motor (MX-64), but it is not necessary. Connect the included three-pin connector to the body motor before mounting the motor. Angle the motor as pictured on the right. Push the motor at an angle to slot it into place. Use the 2-56 5/16" screws on the front corners of the motor to screw the motor into the internal scaffolding.

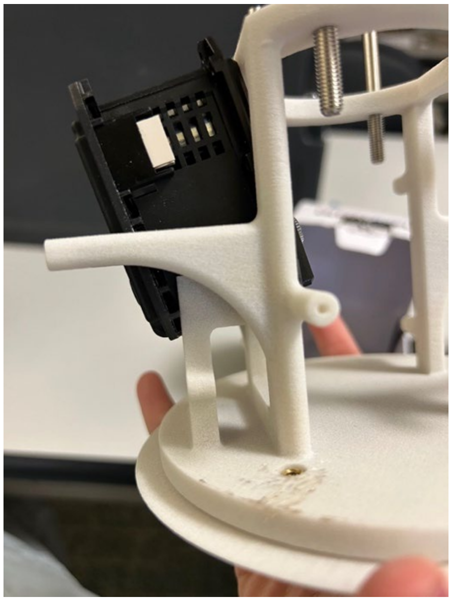
The internal scaffolding on the right features right angle boundaries that have been removed in the updated CAD. Wiring follows the instructions and schematic in the previous section.

MOTORS' MOUNTING: HEAD MOTOR

The head motor is mounted simultaneously with attaching the bottom head piece to Ommie. Take the head motor (AX-12A) adaptor and slide or screw it on the top of the structural neck rod. Connect the three-pin connector to the head motor. Take the head motor and slide it into the head motor holder. Use the 2-56 5/16" screws to fix the bottom head piece with the motor to the structural neck.

NOTE: Do **not** screw these screws in all the way! This will cause an overload error on the motors when trying to run them later. This error is visible when checking the motors using the Dynamixel Wizard software and seemed to be caused by screwing in the screws in the head motor all the way. This arrangement is shown in the photo below.

The three-pin connector is also threaded through the 3D-printed neck and connects to the 6-port power hub. If the motor is loose in the holder or the adaptor does not hold well, glue may be used to help keep the parts together.

SCREENS' MOUNTING & WIRING

The screens can be mounted by hot gluing them to the inside of Ommie's front head piece. Take caution in lining up the screens before gluing them as it is very difficult to take off the screens without damaging them. You can check the alignment of the screens by ensuring that only the screen is visible and not the circuit board of the screen when flipping over the head piece and looking at the screen placement. Screen mounting is an area for further development to eliminate the need for hot glue.

The following pins need to be connected with female-to-female wires from the screens' pins to the Adafruit T-Cobbler's pins. The colors used in the subsequent photos are also noted below and are useful for differentiating the different connections. See the "Screens' Wire Soldering" section for information on the wires needed.

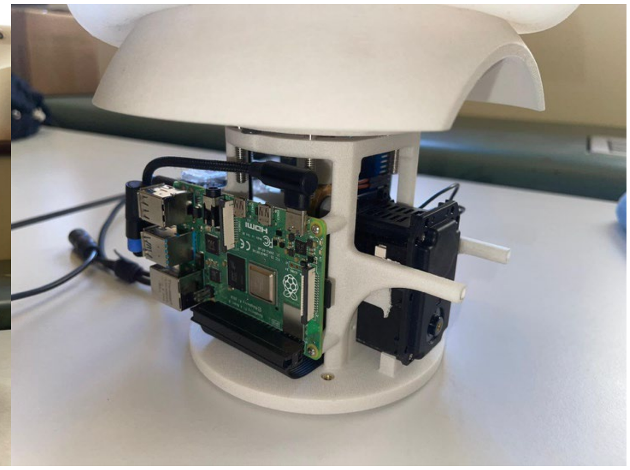
Guide: Screens' Pin → Adafruit T-Cobbler Pin → Color
GND → Ground: 25 → Black
VIN → 3V3: 17 → Red
D/C → GPIO 22: 15 → Blue
RST (Reset) → GPIO 18 (PCM_CLK): 12 → Yellow
LCD CS or CS → GPIO 7 (CE1) AND 8 (CE0): 24 AND 26 → Orange
MOSI → GPIO10 (MOSI): 19 → White
SCK or SLCK → GPIO 11 (SCLK): 23 → Green

The wires are connected such that the wires are threaded from inside the head, down the neck, and into the body, avoiding interference with the linkage. This is pictured below. This step is done in the "Head Assembly" section.

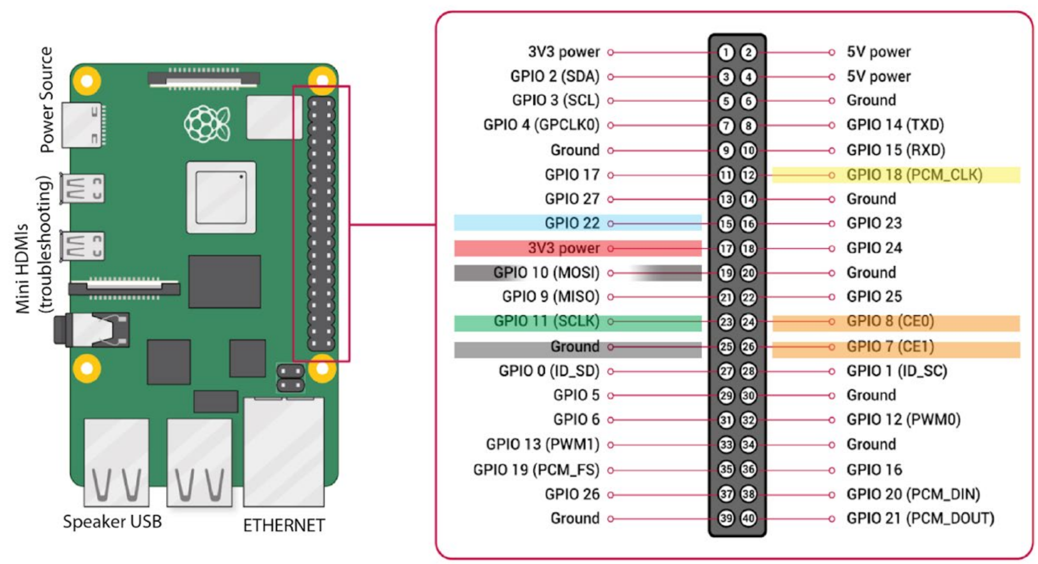
RASPBERRY PI 4B/5 MOUNTING

An Adafruit T-Cobbler Plus is used for organization and increasing access to the GPIO pins inside Ommie. The pins on the Adafruit T-Cobbler Plus are the same as the pins on the Raspberry Pi. The Adafruit T-Cobbler Plus is mounted with 1-72 ¼" screws into small holes on the internal scaffolding on the side adjacent to where the U2D2 is glued.

The Raspberry Pi is also mounted on one side of the internal scaffolding with four holes that are the corners at the Raspberry Pi. The mounting for both of these pieces are included below. A ribbon cable included with the T-Cobbler is used to connect the Raspberry Pi to the T-Cobbler. Once this connection is made, jumper wires can be connected directly to the T-Cobbler for use. It is easier to test and troubleshoot sensors and screens on the T-Cobbler when it is unmounted, because of how the header pins face inward on the T-Cobbler.



The pinout diagram below comes from the Raspberry Pi website for the Raspberry Pi 4 Model B which is similar to the Raspberry Pi 5. The pinout diagram is annotated to reflect Ommie's wiring. Note that the GPIO (General-Purpose Input/Output) pins on the right side of the circuit board are a visualization of the wiring described in "Screens' Mounting and Wiring." Besides the screen wiring, the Raspberry Pi 4 has three other required connections: power, the speaker USB, and Ethernet. The Ethernet cable should be connected after the body pieces are all assembled. The other USB ports and mini-HDMI ports can be used for troubleshooting. The Raspberry Pi also requires an SD card with Ommie's files on it which will be described in more detail in the "Software" section.



SPEAKER MOUNTING

The speaker is mounted using Velcro tape inside the head on the bottom piece next to the AX-12A motor carriage. The speaker's wire is also threaded from inside the head, down the neck, and into the body, avoiding interference with the linkage.

The speaker's USB cable is connected to one of the Raspberry Pi's USB ports as labeled in the previous section.

FINAL ASSEMBLY

With all the electronics mounted and the head assembled, there are a couple more steps left for a fully assembled Ommie.

1. Align and hold together the front and back hemispheres. The back hemisphere goes on the side of Ommie where the Ethernet port of the Raspberry Pi is, because there is a hole for the Ethernet cable to be inserted in.

2. Use 4-40 ½" screws to connect the body pieces together and to the internal scaffolding. There are six screws total, four to connect the hemispheres to the internal scaffolding and two to connect the hemispheres to each other on the sides. It is recommended to do the side screws first.

3. Fit the silicone shell over the connected hemispheres and align it, so that the holes line up with the screw holes along Ommie's center.

4. Take the body clamps and align them along Ommie's center on top of the silicone shell. If they fit awkwardly, flip the body clamp and try to align and press them again. Use 6-32 ⅜" Phillips screws to connect the body clamps to the body. There are five holes on both of the hemispheres. Start with the center hole and move outward, loosening or tightening screws as needed to compensate for alignment or dimensional warping issues with the body clamps.

5. Put the sweater on Ommie ensuring that the Ethernet port hole and the three snap clasps are in the back.

The Ethernet cable can now be inserted and the full assembly can be tested after the software is completed. To take Ommie apart, remove the sweater and screws and pull up the silicone shell. When reassembling, alignment is the most significant factor to pay attention to. To access the components in the head, take off the top head piece by unscrewing the 6-32 ⅜" Phillips screws that attach the top head piece to the rest of the head.

07

SOFTWARE

SCRIPTING

The Ommie codebase for ROS (Noetic, Ubuntu 20.04) as of the writing of this document can be found at **https://github.com/rramnauth2220/ommie**. The repository can be downloaded into the ~/catkin_ws on an external computer and/or Ommie's Raspberry Pi.

BEHAVIORAL CONTROLS

The robot is primarily controlled via a Raspberry Pi, either directly in Python or with the Robot Operating System (ROS). This system controls all I/O components, including the screens (via I2C protocol), capacitive touch sensor (via GPIO), speakers (via USB), and motors (via a Dynamixel U2D2 board converting USB to TTL signals).

We currently have several robot behavioral states and transitions that combine these I/O components using a finite state machine. These behaviors include:

- **Sleep**: Randomizing between three “sleep breaths" types with audio coos and drooped eyes. This sleep state was designed to make the robot feel powered on and alive, even if it was not actively engaging in deep breathing.
- **Wake up**: A transition behavior with audio and eye animations. The robot begins with a coo and slowly squints its eyes open.
- **Idle**: This state involves micro-eye movements while waiting to start a breathing exercise. This behavior supports the continued perception of the robot's agency and prevents users from feeling like the robot is frozen or staring while waiting to begin the deep breathing interaction.
- **Breathing**: Moving the body upwards and downwards with closed eyes and audio chimes. This state can be triggered via wireless SSH or scheduled for autonomous movement using specific breathing parameters (e.g., breath length, number of breaths, etc.). We designed the system to be customizable to allow the robot to perform any variation of deep breathing.
- **Celebration**: Looking up at the user with joyful eyes and sounds before, for example, returning to a sleep state. We implemented this state as a way of providing a reward. This reward results in helping the user acknowledge their success in completing deep breathing, and portraying that the robot is happy and supportive of the user doing so.

SETTING OMMIE'S OS:

Installing ROS Noetic on Raspbian

1. Remove any ROS configurations, especially if you're reusing an SD card

   $ sudo apt-get purge ros-*

2. Remove the previous ROS dependencies

   $ sudo apt-get autoremove

3. Remove the old catkin workspace

   $ sudo rm -rf ~/ros_catkin_ws

4. Set up your computer to accept software from packages.ros.org

   $ sudo sh -c 'echo "deb http://packages.ros.org/ros/ubuntu $(lsb_release -sc) main" > /etc/apt/sources.list.d/ros-latest.list'

   $ sudo apt install curl # if you haven't already installed curl

   $ curl -s https://raw.githubusercontent.com/ros/rosdistro/master/ros.asc | sudo apt-key add –

   $ sudo apt-key adv --keyserver hkp://ha.pool.sks-keyservers.net:80 --recv-key C1CF6E31E6BADE8868B172B4F42ED6FBAB17C654

   $ sudo apt-key adv --keyserver hkp://keyserver.ubuntu.com:80 --recv-key C1CF6E31E6BADE8868B172B4F42ED6FBAB17C654

5. Make sure your Debian package is up to date

   $ sudo apt-get update

   $ sudo apt-get upgrade

6. Install bootstrap dependencies

   $ sudo apt install -y python3-rosdep python3-rosinstall-generator python3-wstool python3-rosinstall build-essential cmake

7. Those dependencies also require

   $ sudo apt install python3-catkin python3-catkin-lint python3-catkin-pkg python3-catkin-pkg-modules python3-catkin-tools

8. Initialize ROS dependencies

   $ sudo rosdep init

   $ rosdep update

9. Create the new catkin workspace

   $ mkdir -p ~/ros_catkin_ws

   $ cd ~/ros_catkin_ws

10. Fetch ROS packages. Replace **ros_comm** with **desktop** if you wish to install GUI tools like Rviz, Rqt and robot-generic libraries.

    $ rosinstall_generator ros_comm --rosdistro noetic --deps --wet-only --tar > noetic-ros_comm-wet.rosinstall

    $ wstool init src noetic-ros_comm-wet.rosinstall

11. Resolve dependencies

    $ cd ~/ros_catkin_ws

    $ rosdep install -y --from-paths src --ignore-src --rosdistro noetic -r --os=debian:buster

12. We need to install these packages (python 3.6.5^) from the src folder manually. The following command loops through each directory and install the python package.

    $ cd src && for d in genmsg genpy gencpp geneus gennodejs genlisp ; do (cd "$d" && sudo pip3 install -e .); done && cd ..

13. Build the catkin workspace

    $ sudo ./src/catkin/bin/catkin_make_isolated --install -DCMAKE_BUILD_TYPE=Release --install-space /opt/ros/noetic -j4

14. ROS is now installed. Source the new workspace.

    $ echo "source /opt/ros/noetic/setup.bash" >> ~/.bashrc

Additional Considerations:

- Install wstool from pip if the apt installed one is giving “command not found”:

  $ sudo pip install --force-reinstall -U wstool

- Install some more python packages to be able to compile the ROS workspace

  $ sudo apt-get install python-empy python-nose python-catkin-pkg

Remotely moving Ommie PI files from local PC to the space on the Raspberry Pi.

[local] $ scp -r ommie/ommie_pi pi@192.168.X.XXX:ros_catkin_ws/src

[pi] $ cd ~/ros_catkin_ws

[pi] $ catkin_make

[pi] $ source devel/source.bash

Before executing, ensure the ROS configurations for each device, whether you are using an external computer of simply Ommie's onboard computer, are correct.

 Check env | grep ROS for details

- The ROS_MASTER_URI on the laptop should be itself
- The ROS_IP on the external compute should be itself

 When you *SSH* into Ommie, check the env | grep ROS for details

- The ROS_MASTER_URI on the robot should be that of the external computer
- The ROS_IP on the robot should be Ommie's IP

08

CONCLUSION

CLOSING REMARKS

Good work! You now have Ommie's physical and electronic components assembled as they were assembled in the Spring 2024 version of Ommie.

Below are listed some areas of improvement, and of course, Ommie can be customized to accommodate additional sensors and expressions for different projects. For software and maintenance, see the resources linked below. Thank you for your support!

AREAS FOR IMPROVEMENT

While Ommie is fully functional using the instructions above and the resources linked below, there are areas that can be improved to aid with maintenance.

Here are some main points:

- Head and Body Motor Cartridges: improving the insertion and replaceability of motors
- Material Choices for 3D-printed parts: optimize for cost, durability, and relevant properties related to the electronics and parts that interface with the 3D prints
- Silicone Mold Design and Manufacturing Process: Improving visibility during the process to reduce trials and repetition required to manufacture mold, improving manufacturing for the top lid stage
- Screen Mounting and U2D2 Mounting: eliminating use of difficult to remove solutions like hot glue and incorporating solutions to replace parts

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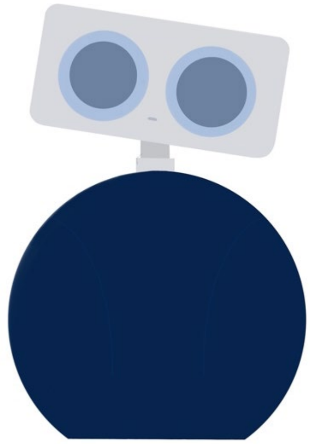

APPENDIX

A. Full Bill of Materials

	Name & Link to Part	Unit Cost	# of Units	Total Cost	Notes
Speaker	Mini External USB Stereo Speaker	$12.50	1	$12.50	
Motors	U2D2 - ROBOTIS	$32.10	1	$32.10	
	6-Port 3-Pin Series Power Hub	$10.95	1	$10.95	
	DYNAMIXEL AX-12A - ROBOTIS	$49.90	1	$49.90	
	DYNAMIXEL MX-64AT - ROBOTIS	$369.90	1	$369.90	
	Stainless Steel Decorative Round Head Phillips Screws 2-56 Thread Size, 5/16 Long	$3.84	1	$3.84	
Wire Connections	Assembled Pi T-Cobbler Plus - GPIO Breakout	$7.95	1	$7.95	
	Heat Shrink, Black, 0.19" ID Before Shrinking	$4.62	1	$4.62	
	Spiral Sleeving: 1/16" ID, Clear, 10 FT	$3.27	1	$3.27	
	120pcs 20 cm Breadboard Jumper Wires Assorted Kit,10cm 15cm 20cm 40cm 50cm 100cm Optional Dupont Wire 11.8 inch Male to Female Male to Male Female to Female Multicolored Ribbon Cable	$6.98	1	$6.98	
	120pcs 30cm Breadboard Jumper Wires Assorted Kit,10cm 15cm 20cm 40cm 50cm 100cm Optional Dupont Wire 11.8 inch Male to Female Male to Male Female to Female Multicolored Ribbon Cable	$8.99	1	$8.99	
Onboard Computer	Raspberry Pi 4 Model B - 8 GB RAM	$75.00	1	$75.00	
	Raspberry Pi 5 - 8 GB RAM	$80.00	1	$80.00	
	USB 3.0 Male to Female Extension Data Cable Left and Right Angle	$7.99	1	$7.99	
	90 Degree USB 3.0 Adapter	$7.99	1	$7.99	
	Passivated 18-8 Stainless Steel Pan Head Phillips Screw 1-72 Thread, 1/4" Long	$9.53	1	$9.53	
	Passivated 18-8 Stainless Steel Pan Head Phillips Screw 1-72 Thread, 3/8" Long	$10.31	1	$10.31	
	Rapthor Rechargeable 12V 6500mAh / 5V 13000mAh DC Battery Pack with Charger for Heated Jacket	$38.89	1	$38.89	portable charger outside Ommie

	Micro HDMI to HDMI Cable 1FT 2 Pack, Nylon Braided Micro HDMI Cable Support 3D/4K@60Hz 18Gbps/2160P/1080P	$13.99	1	$13.99	
Screens	2.2 18-bit color TFT LCD display with microSD card breakout [EYESPI Connector] : ID 1480	$24.95	2	$49.90	
Neck	High-Strength Steel Threaded Rod 1/4"-20 Thread Size, 8" Long	$12.79	1	$12.79	
Body: Silicone Mold	Dragon Skin 10 Slow - Trial Size	$33.12	1	$33.12	
	Smooth-On Silicone Thinner	$19.99	1	$19.99	
	Mann Release Technologies Ease Release 200 14 fl. oz.	$19.57	1	$19.57	
Body: Breathing Mechanism	Ultra-Low-Profile Shoulder Screw 1/4" Shoulder Diameter, 5/8" Shoulder Length, 10-24 Thread	$6.44	1	$6.44	
	Lubrication-Free Ball Joint Rod End Carbon Fiber Insert, 1/4"-28 Thread	$6.44	1	$6.44	
	Lubricant-Filled Nylon Plastic Washer for 1/4" Screw Size, 0.322" ID, 0.562" OD	$6.01	2	$12.02	
	18-8 Stainless Steel Threaded on One End Stud 10-32 Thread Size, 2" Long	$5.06	4	$20.24	
	Load-Rated Adhesive-Back Bumper Polyurethane, 1/4" OD, 0.35 lbs. Maximum Load	$1.34	4	$5.36	
	Ultra-Low-Friction Dry-Running Sleeve Bearing Flanged, PTFE, for 3/16" Shaft Diameter, 1/4" Long	$6.38	4	$25.52	
	Light Duty Dry-Running Nylon Sleeve Bearing Flanged, for 1/4" Shaft Diameter and 3/8" Housing ID, 5/16" Long	$0.69	4	$2.76	
	8-32 Thread, 1/4" Long Passivated 18-8 Stainless Steel Pan Head Phillips Screw	$9.25	1	$9.25	
Body: Sweater	Sweater materials (fabric, fasteners, etc.)	$15.00	1	$15.00	
3D Printed Components	3D printed head (top-head, bottom-head, face -- SLA, Formlabs standard resin)	$369.00	1	$369.00	Protolabs
	Head Motor Adapter (SLS, PA 12 25% Mineral Filled)	$46.78	1	$46.78	Protolabs
	Internal Scaffolding (SLS, PA 12 25% Mineral Filled)	$369.06	1	$369.06	Protolabs
	Top Body Shell (SLS, PA 12 25% Mineral Filled)	$425.62	1	$425.62	Protolabs
	Back Body Shell (SLS, PA 12 25% Mineral Filled)	$480.91	1	$480.91	Protolabs

	Base Body (SLS, PA 12 25% Mineral Filled)	$112.15	1	$112.15	Protolabs
	Body Motor Adaptor (SLS, PA 12 25% Mineral Filled)	$42.06	1	$42.06	Protolabs
	Front Body Shell (SLS, PA 12 25% Mineral Filled)	$486.53	1	$486.53	Protolabs
	Body Shell Clamp (SLS, PA 12 25% Mineral Filled)	$143.46	2	$286.92	Protolabs
	Neck Cover (FDM, PLA 20% Infill)	$9.32	1	$9.32	Protolabs Network (Hubs.com)
	Link (Lever Bar) (SLS, PA 12 25% Mineral Filled)	$43.66	1	$43.66	Protolabs
	Silicone Mold (Side A, Side B, Inner Mold, Top Mold -- FDM, PLA 20% Infill, Economy)	$167.50	1	$167.50	Protolabs Network (Hubs.com)
Fasteners and Securements	Brass Tapered Heat-Set Inserts for Plastic 6-32, 0.15" Installed Length	$16.81	1	$16.81	
	Brass Tapered Heat-Set Inserts for Plastic 6-32, 1/4" Installed Length	$16.81	1	$16.81	
	Brass Tapered Heat-Set Inserts for Plastic 4-40, 0.219" Installed Length	$21.05	1	$21.05	
	Passivated 18-8 Stainless Steel Phillips Flat Head Screw 100 Degree Countersink, 6-32 Thread, 3/8" Long	$15.96	1	$15.96	
	Passivated 18-8 Stainless Steel Pan Head Phillips Screw 4-40 Thread, 1/2" Long	$14.35	1	$14.35	
	Gorilla Glue Epoxy Adhesive	$8.97	1	$8.97	
	Gorilla Dual Temp Mini Hot Glue Gun Kit with 30 Hot Glue Sticks	$11.39	1	$11.39	
			Total Cost	**$3,937.95**	

B. Sewing Patterns: Left Back Flaps

C. Sewing Patterns: Right Back Flaps

D. Sewing Patterns: Front Body

E. Sewing Patterns: Left Shoulder Panel

F. Sewing Patterns: Right Shoulder Panel