DROP: Hardware Setup

Albert H. Li

`alberthli@caltech.edu`

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This document contains the instructions for building the hardware setup used in the paper "DROP: Dexterous Reorientation via Online Planning." Feel free to email if you have any questions regarding the setup. If you find any part of this project useful, please cite our work using the following citation:

```
@article{li2024_drop,
    title={DROP: Dexterous Reorientation via Online Planning},
    author={Albert H. Li, Preston Culbertson, Vince Kurtz, and Aaron D. Ames},
    year={2024},
    journal={arXiv preprint arXiv:2409.14562},
    note={Available at: \url{https://arxiv.org/abs/2409.14562}},
}
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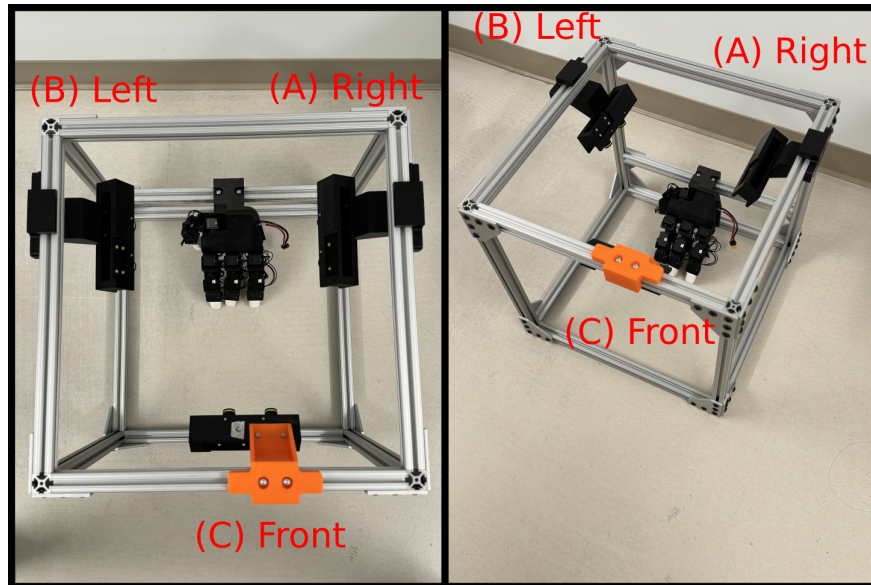

Figure 1: The full hardware setup (without wires to computer). The three cameras are labeled A, B, and C throughout for the right, left, and front positions respectively.

Contents

1 Parts List

The below table summarizes the required parts and notes. The files for the 3D-printed parts should be included in the same zipped directory as these instructions. Part costs were checked on the date listed at the top of this document, rounded up to the nearest dollar. The costs of the computer, 3D printing filaments, and tools like wrenches are **not** included.

The build uses screws of three sizes: 1/4-20", M2, and M3. You should have the correct corresponding Allen wrenches prior to beginning assembly.

Part	Qty	Total Cost	Notes
Computer	1	-	In our paper, we use a workstation with a Ryzen Threadripper Pro 5995wx CPU (for rolling out simulations) and an RTX 4090 GPU (used for running the keypoint detector). The main bottleneck for reproducing results will be the threadcount of your CPU. Each ZED camera needs a USB 3.0 port.
LEAP Hand	1	∼$1,800	Instructions+parts list at `leaphand.com`. The cost fluctuates based on whether you purchase tools or filament.
ZED Mini	3	$1,200	Link: `stereolabs.com/store/products/zed-mini`
18-in. 80/20	13	$133	Link: `mcmaster.com/47065T101-47065T554`
90° Brackets	20	$232	Link: `mcmaster.com/47065T267`. Comes with screws and nuts.
End Caps	4	$9	Link: `mcmaster.com/3136N2`
1/4-20x1/2" Screws	8	$8	Link: `mcmaster.com/92949A537`. For mounting cams + hand to enclosure. Cost is for 1 pack of 50.
1/4-20 Nuts	8	$12	Link: `mcmaster.com/6000N501`. For screwing the 1/4-20 screws into the 80/20. Cost is for 2 packs of 4.
Heated Inserts	6	$28	Link: `mcmaster.com/94180A333`. For threading into cam housings. Cost is for 1 pack of 100.
M3x10 Screws	6	$13	Link: `mcmaster.com/91290A115`. For attaching cam housings to cam mounts. Cost is for 1 pack of 100.
M2x10 Screws	12	$8	Link: `mcmaster.com/91292A833`. For attaching cams to housings. Cost is for 1 pack of 100.
M3x16 Screws	4	$12	Link: `mcmaster.com/91290A120`. For screwing the hand to the hand mount. Cost is for 1 pack of 100.
Hand Mount	1	-	3D printed.
Camera Mount	3	-	3D printed.
Cam Housing Left	2	-	3D printed.
Cam Housing Right	1	-	3D printed.
Hand Shim	1	-	3D printed.
Front Cam Shim	1	-	3D printed.
Cube	1	-	3D printed.
Cube Faces	1	-	This is just a color-printed piece of paper.
TOTAL		∼$3455	

2 Assembly Instructions

We will now explain how to construct the frame used for all experiments. We assume that all parts have been 3D printed and the LEAP hand has already been assembled as per the instructions at `leaphand.com`.

1. **Construct the frame.** This step requires (i) the 18-in. 80/20 bars, (ii) the 90° brackets, and (iii) the nuts and bolts that come with the brackets. The process for assembling the frame is self-explanatory, based on the pictures of the front and back view shown below. Note that when tightening the bolts, the relative positions of the bars may shift. Make sure that the bars are flush against each other and the floor after tightening all bolts.
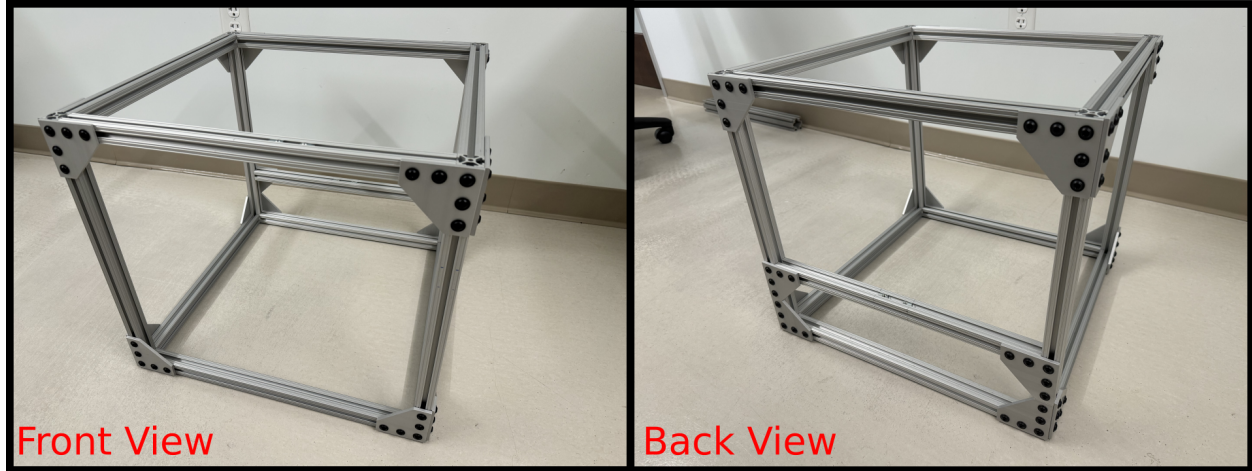

Figure 2: The front and back views of the frame. Note that the corner columns of the frame are vertical 18 inch 80/20 bars. This means that the widths of the frame are 20 inches, but the height is only 18 inches. Observe that in the back plane of the frame, there are 3 horizontal bars. The bar in the middle is installed such that its supporting 90° brackets are flush with the brackets of the bottom of the frame. This is where the hand will be installed.

2. **Insert the end caps.** Simply install the 4 end caps on the 4 bottoms of the enclosure. This ensures that the entire assembly can sit/slide smoothly on the supporting surface instead of scratching it.
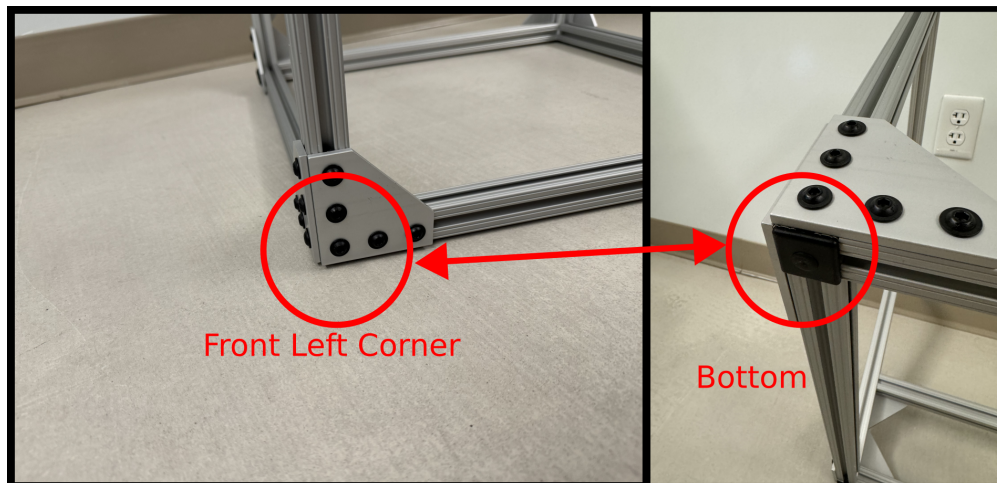

Figure 3: The four end caps should be installed below each of the 4 corners of the frame. Shown here is one such corner.

3. **Attach the LEAP hand to the hand mount.** This step requires the 4 M3x16 screws. In practice, you can just screw the bottom two screws in to make it more convenient to take the mount off if maintenance needs to be done on the hand.
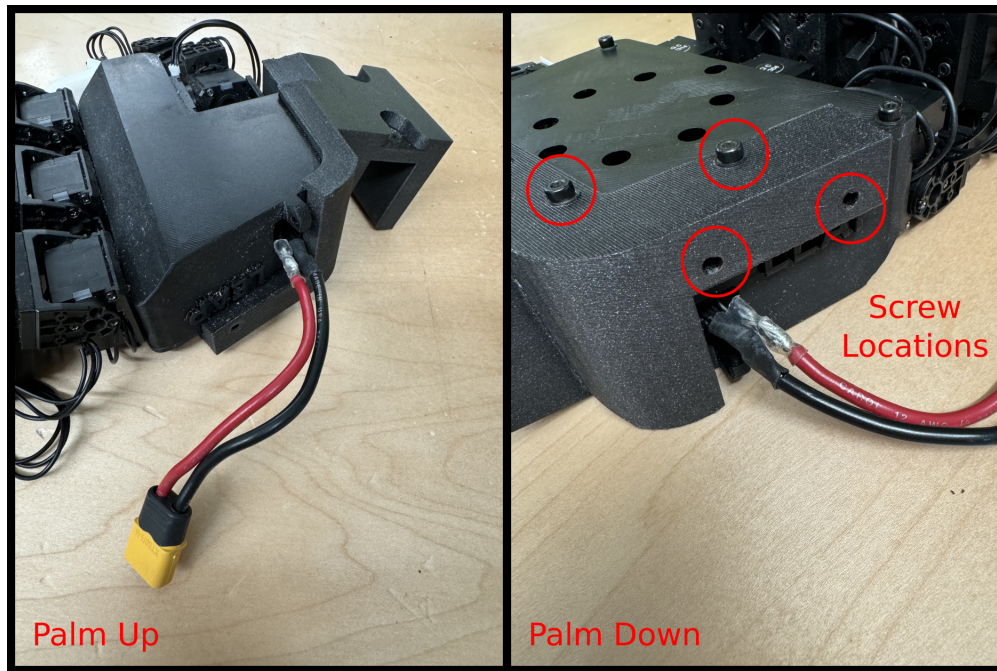

Figure 4: The hand should be slid into the mount as shown. The 4 screw locations are revealed on the back of the hand, near the power wires. While we expose 4 holes, in practice, we only use the 2 on the back of the palm to make maintenance easier.

4. **Attach the LEAP hand.** Take the long hand shim and datum it against either of the 90° brackets. Then, pushing the hand mount against the shim, screw it into the slide nuts that should already be exposed. This might require a bit of guesswork to align the nuts with the screw holes in the hand mount. Once the mount is installed, the shim can be removed.
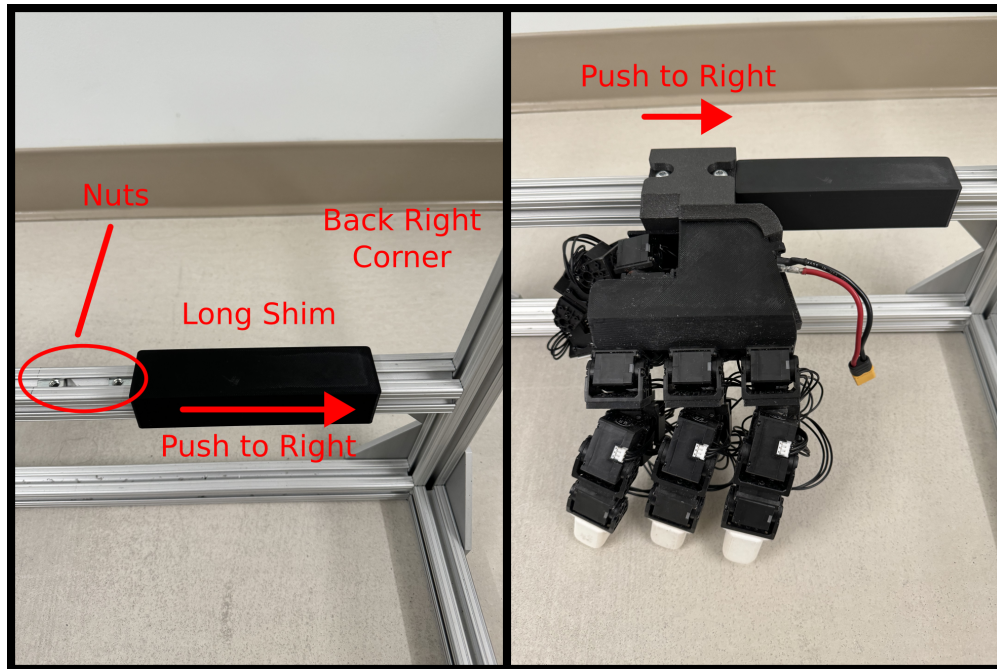

Figure 5: To install the hand, first place the shim on the back rail and push it to the right. In this position, drop the nuts into the rail in preparation for screwing in the hand mount. Then, place the mount on the rail and push it against the shim to correctly locate it on the frame. While pushing, screw the mount into the nuts.

5. **Attach the camera mounts.** There are 3 3D-printed camera mounts. The two mounts on the side are directly datumed against the corresponding 90° brackets.

   The front camera mount is asymmetric and should be installed using the short camera shim. Facing the enclosure as shown in the below picture, datum the shim against the bracket on the right. Then, datum the camera mount against the shim, and like the hand mount installation, screw in the mount while pressing against the shim. Afterwards, the shim can be removed.

   It is assumed for all mounts that you have placed the nuts in the rails before attempting to fix them to the frame, similar to the installation of the hand onto the frame.
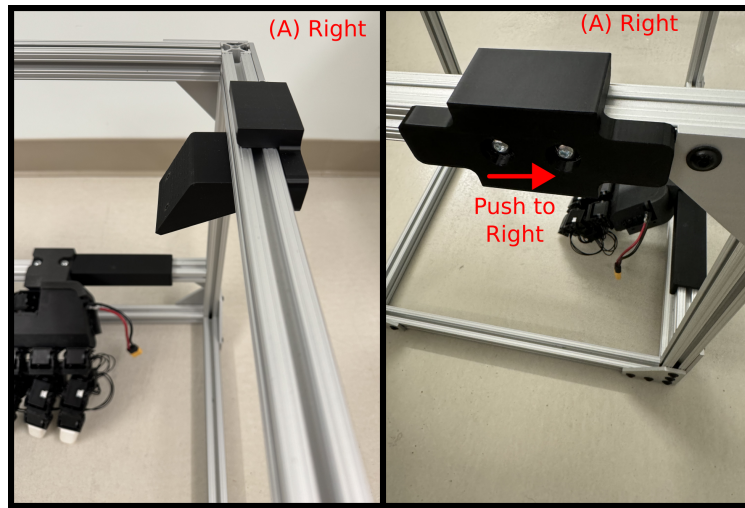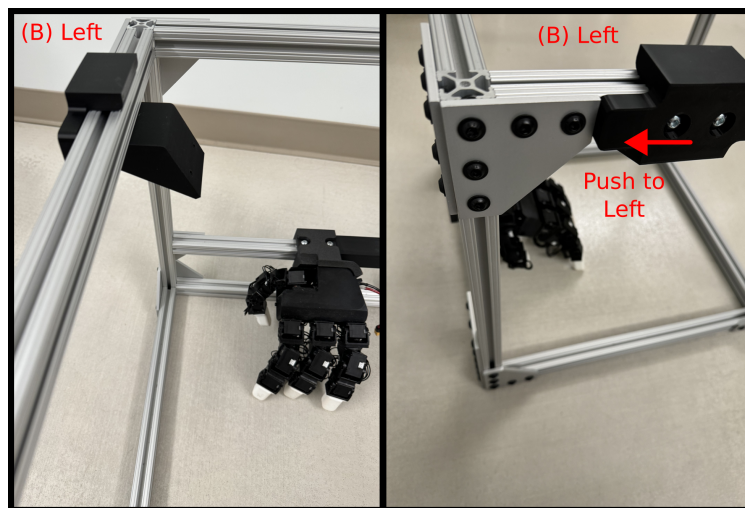

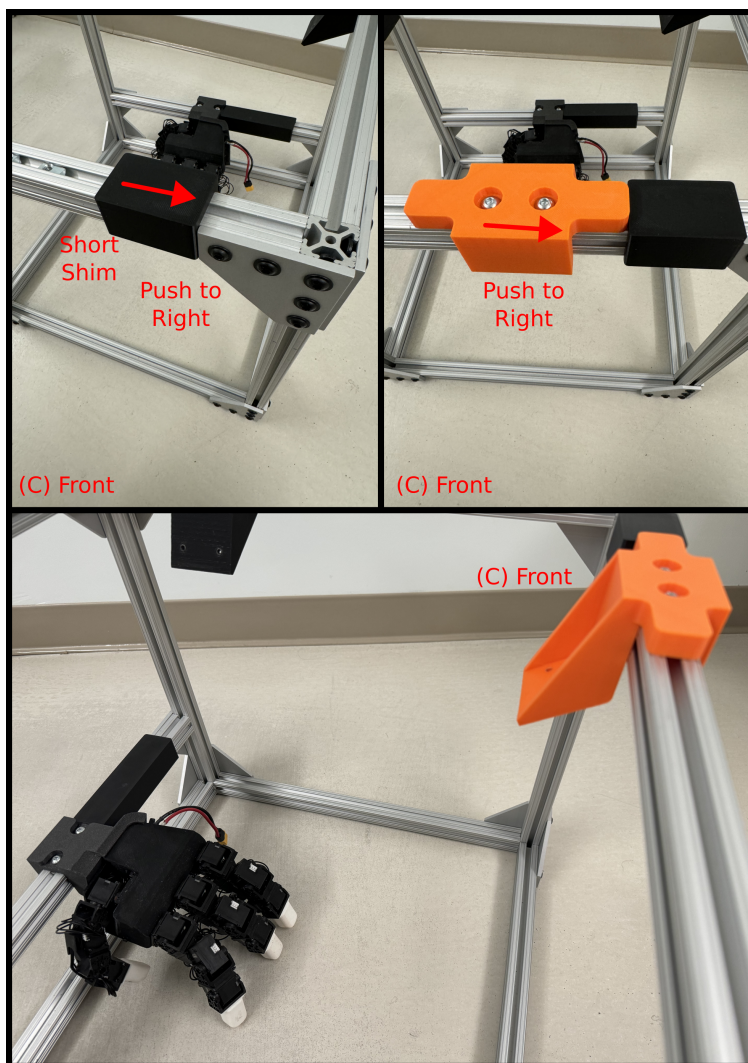Figure 6: Right cam mount.

Figure 7: Left cam mount.

Figure 8: Front cam mount.

6. **Install the heated inserts in the camera housings.** There are 3 camera housings, but they are **not** all identical. The left and frontal camera use the **left** housing model, while the right camera uses the **right** housing (this is a mirror of the other part).

The purpose of the 6 heated inserts is to allow installation of metal threads in plastic 3D-printed parts. The locations where the heated inserts should be installed is different on all 3 housings. The pictures below show the where the inserts should be installed on each housing. To install them, press down on the insert using a soldering iron slowly until the top edge of the insert is flush with the surrounding plastic.
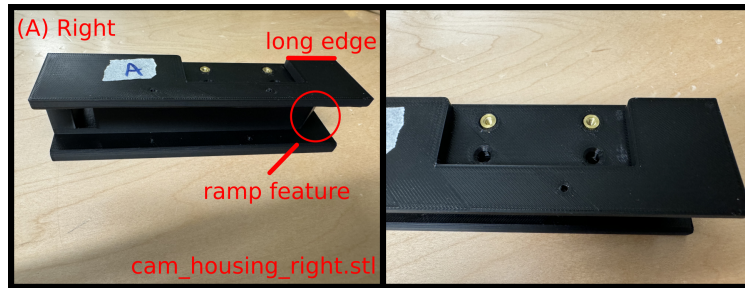

Figure 9: Right heated inserts. Note that this mount comes from `cam_housing_right.stl`. Pay close attention to the features called out in the figure to choose the correct holes to install the inserts into.
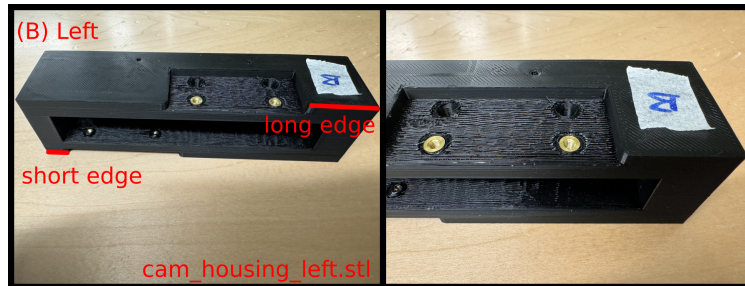

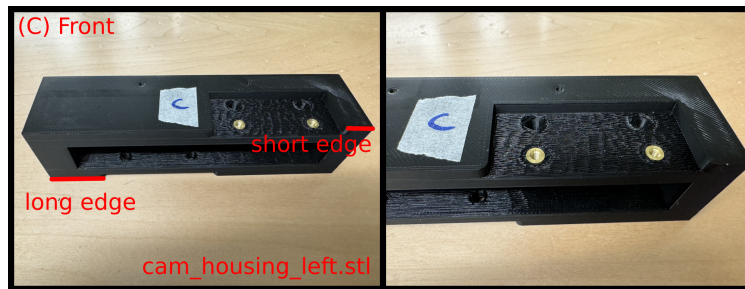Figure 10: Left heated inserts. Note that this mount comes from `cam_housing_left.stl`.

Figure 11: Front heated inserts. Note that this mount comes from `cam_housing_left.stl`. However, the location of the inserts is **not** the same as in the left housing! Pay close attention to the locations of the short and long edges called out in the figures to pick the correct holes in which to install the heated inserts.

7. **Screw the cameras into the housings.** Once the inserts have cooled, we can screw the cameras into the housings. Each ZED Mini has 4 screw holes. Carefully follow the pictures below to correctly orient each camera, as they are not all installed in the same orientation.

Figure 12: The edge containing the port on the camera should always be aligned with the edge of the ramp of the camera housing. Install each camera as shown here.

Figure 13: Right camera housing installation.

Figure 14: Left camera housing installation.

Figure 15: Front camera housing installation.

8. **Attach the housings to the camera mounts.** Finally, we can simply screw the housings into the mounts using the 6 M3x10 screws. Do so by aligning the threads of the heated inserts with the through holes of each mount.
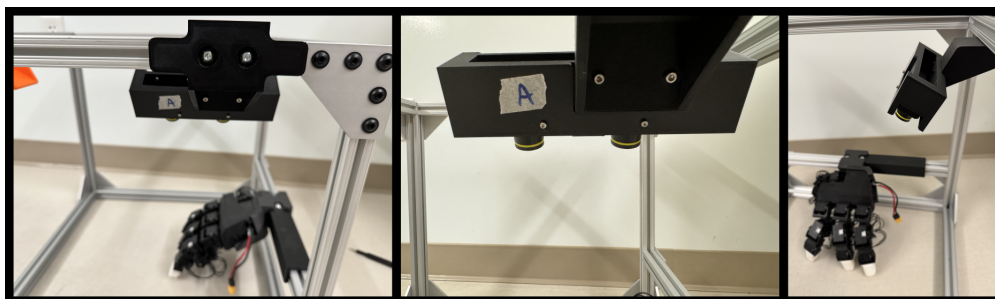

Figure 16: Right camera installation.

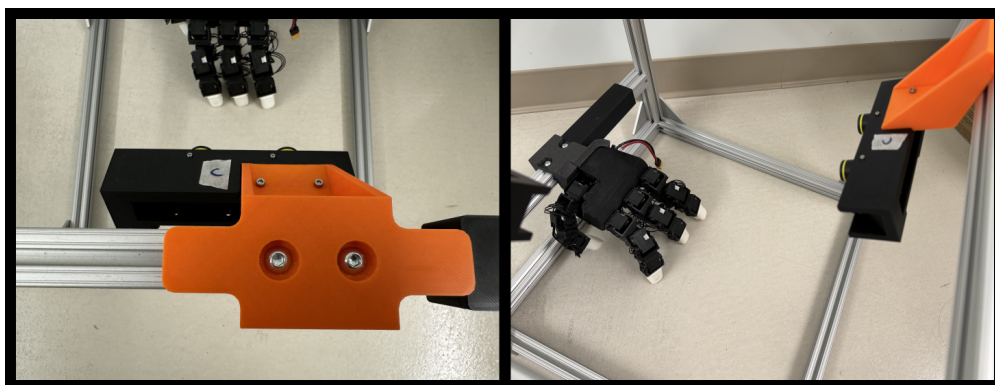Figure 17: Left camera installation.

Figure 18: Front camera installation.

9. **Make the cube.** To do so, we recommend cutting out all 6 faces separately and carefully aligning them with the faces of the 3D-printed cube use clear packing tape.

At this point, the physical setup of the system is complete, and we are ready to connect the cameras and hand to a computer!
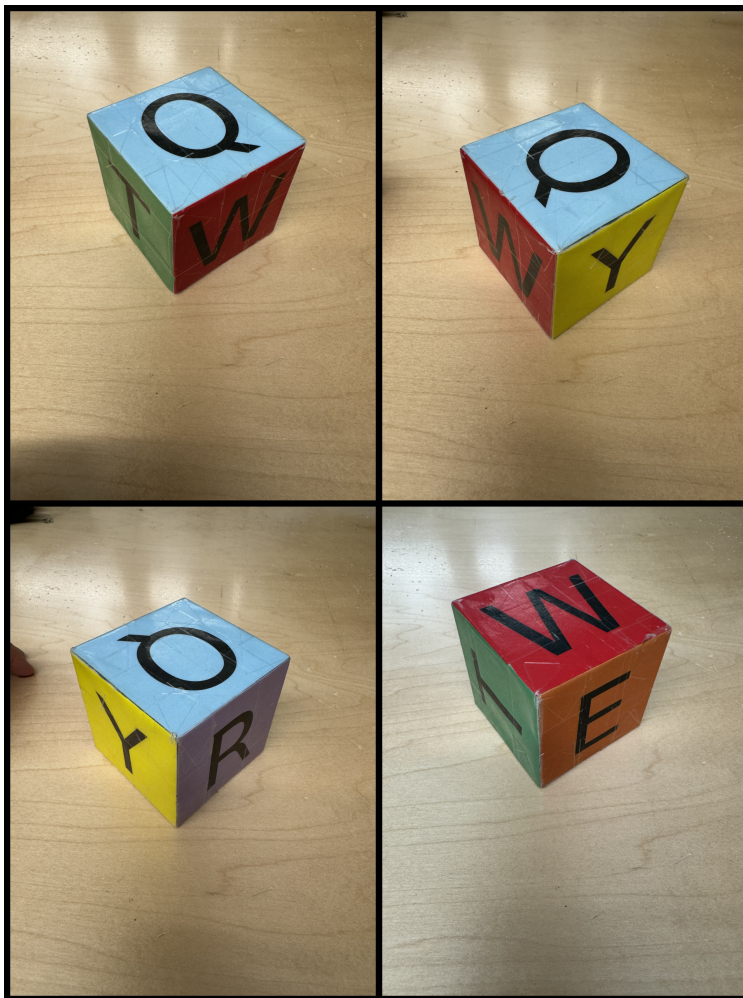

Figure 19: Four views of the cube that should allow you to recreate it.

3 Final Setup

After assembling the experiment rig, there are a few final details, warnings, and tips.

- Each ZED camera has a unique serial code. You can either use the installable ZED utility `ZED_Explorer` or the python ZED SDK to figure out each camera's serial number. Afterwards, the `zed_mini_params.yaml` file located at this link should be populated with the correct numbers.

- When connecting the cameras, note that the USB cables provided by Stereolabs are **not** bidirectional. There should be arrows etched into the USB-C side of the cable, and these should be on the same side as the camera lenses. Additionally, we found that the ZED Minis were very sensitive, and the cable often needed to be wiggled a few times before the camera could be properly seen by the computer.

- When plugging the cameras into the computer, try to make sure that they are plugged into separate USB buses, otherwise the cameras may compete with each other and cause lag. Similarly to the above, you can unplug and replug the USB cable back in the port if you are having issues seeing the camera. We have often also found success when switching the port that each camera is plugged into.