Shells for Gretchen

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Project description

The project consists of the planning, construction, manufacturing, and testing of three components for the humanoid robot ‘Gretchen’.

1. Shells for the legs and hip, that must protect the motors, cables and belt system from collisions.
2. Gretchen’s Feet need a redesign for better walking abilities
3. Gretchens camera gimbal test platform needs a redesign to attach a new camera system.

Required time per task

Task	Planned hours	Real hours	Estimated progress	Hours percentage	Details
Overhead	10:00	13:00	100%	130%	Done
0 Hulls	90:00	89:55	100%	100%	Good estimation
0 Predesign	10:00	15:45	100%	158%	Done
0 Design	45:00	64:25	100%	143%	Done
0 Manufacturing	25:00	5:15	100%	21%	Done
0 Documentation	10:00	4:30	100%	45%	Done
1 Feet	20:00	18:25	100%	92%	1,5h less than expected
1 P	2:00	1:30	100%	75%	Done
1 D	13:00	11:15	100%	87%	Done
1 M	3:00	4:25	100%	147%	Done
1 Doc	2:00	1:15	100%	63%	Done
2 Camera	16:00	26:55	100%	168%	10,5h more than expected
2 P	3:00	2:35	100%	86%	Done
2 D	7:00	12:05	100%	173%	Done, 5 hours more than expected
2 M	4:00	8:45	100%	219%	Done
2 Doc	2:00	3:30	100%	175%	Done
Total	136:00	148:15	100%	109%	

Finished project renderings


brother

Shells

Requirements

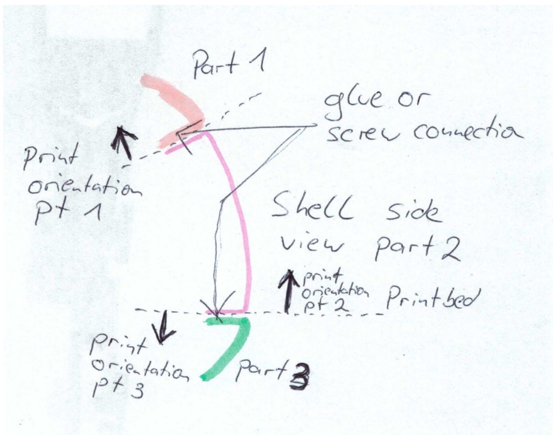
- The shells must be very thin, flexible light and should not add more than 200g to the system. (also to be cost effective)
- The shells shall be made of PLA (or equivalent 3D-printable plastics) and must be printable on common home/lab-quality printers (e.g. Ultimaker) in terms of size and resolution requirements.
- The shells shall be easy to assemble, remove and replace. Access to the motors or belts must be granted in less than 5 minutes of time, e.g. by easily accessible screws or snap mechanism.
- The shells must fulfill a certain degree of aesthetic design and shall underline a child-like appearance of the robot with non-specific sex.

Design studies

To achieve a design which meets all requirements, design studies are conducted. They are split into three parts: *3D printability, solutions for quick assembly, attachment points on the robot, stability, and aesthetics.*

3D printability

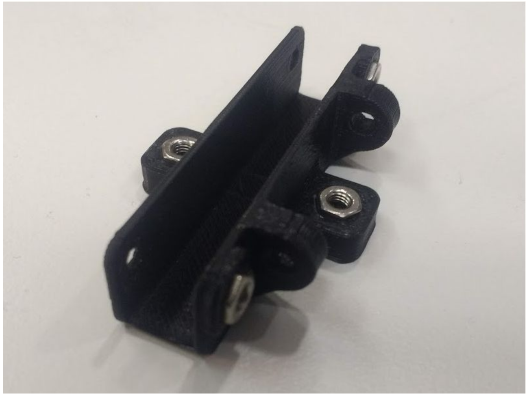
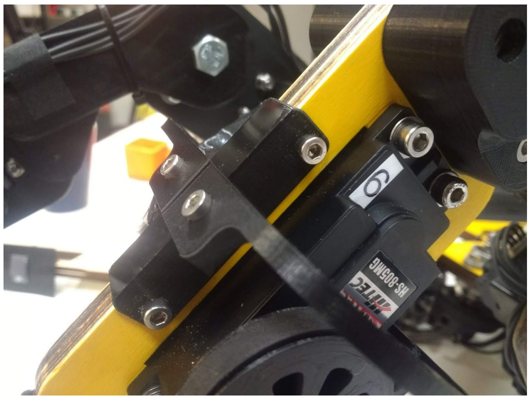
The shells will have a dynamic form, which can be challenging for 3D-printers. A solution could be to use PVA (water dissolvable) support structures which increases the print time and the cost of the parts. This method will be avoided if possible through design decisions. The shells will be split into multiple parts, which simplifies repairing small damages. All parts should have a flat ‘Lip’ which can lay flat on the print bed and which can be connected to other parts through glueing, screwing or zip-tieing them together. The zip-tie solution is simple enough for replacement, lightweight and robust.



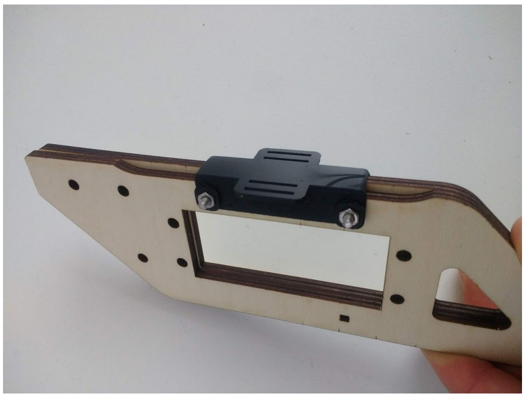
Quick assembly

The shells shall be easy to assemble, remove and replace. To achieve this, quick assembly connectors can be permanently attached to Gretchens body. They can use the existing holes which were earlier used to guide cables. The adapters will guide the cables and have a mechanism which allows for a robust connection to the shells which can quickly assembled. The mechanism can be implemented in multiple ways and four candidates are presented.

- **Screws:** A nut is inserted in the adapter which allows to attach a screw from the outside of the shell. The outside form of the adapter parts fits together so that a single screw can hold together everything.

  The tests show that simple connection parts can be designed and built which allow for quick and very robust assembly and disassembly.
  The shown adapters have the issue, that the embedded nuts would not hold tight by themselves and can fall out. This will be changed in the next revision.
  Pro: Very robust, no new parts, quick
  Con: Weight
  Conclusion: This solution was chosen since it fits the style of the rest of the robot and the additional weight is not too much
- **Velcro:** A Velcro band can hold the shells as shown in the image below.

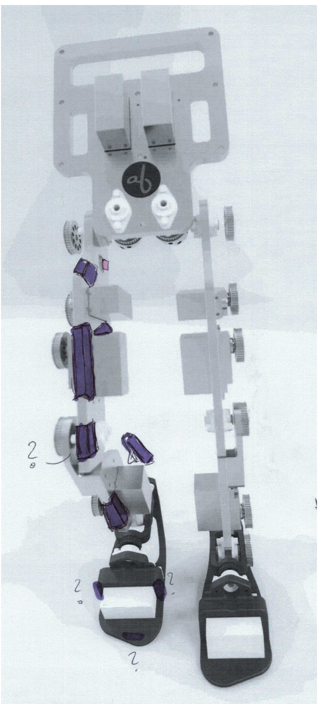
  
  
  
  

The tests show that the connection is stable enough for the requirements and that assembly and disassembly is extremely quick and easy. The screw connections are nevertheless more robust.
Pro: Lightweight, extremely quick
Con: New parts which are not standardized
Conclusion: This solution was not chosen since the newly required parts cannot be guaranteed everywhere and it is not as robust as screws

- **RC Car body clips:** The shells can be attached as the body of an rc car. The clips are accessible in the world and easy to use.
  Pro: Quick, easy, accessible
  Con: Visible from the outside, complex form for 3D-printer, can break
  Conclusion: Too complex, no prototype built

- **Hook + Rubber-band:** The shells are attached through a hook mechanism which would normally slip out again. To prevent it from slipping, a rubber-band pulls it either to the adapter or to another shell with the same mechanism, holding each other in place.
  Pro: No special parts
  Con: Complex forms for 3D-printer, testing required, rubber can get old
  Conclusion: Too complex, no prototype built

Attachment points on the robot

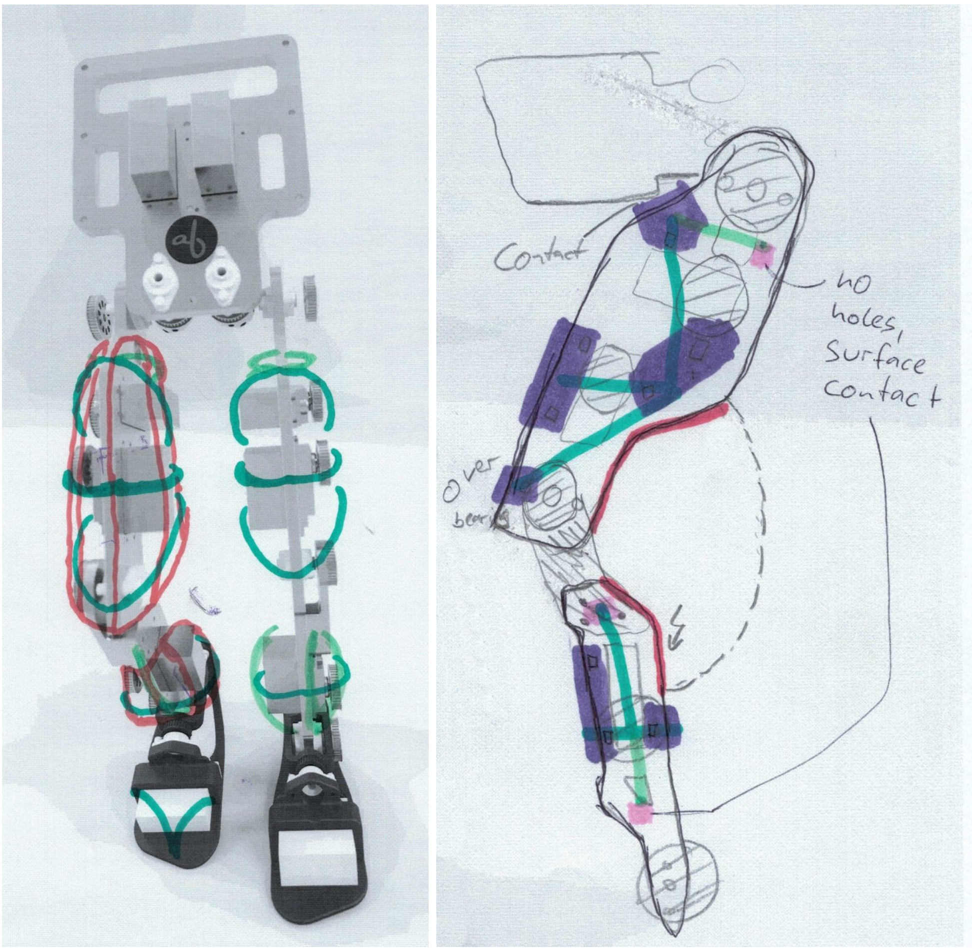


Gretchen’s legs were not designed with attachment points for shells in mind. However there are holes for cable management zip-ties. These holes will be reused to attach the shell adapters. The hole locations determine the attachment points.
In the figure below, possible attachment areas with the necessary holes can be seen in purple. Pink areas don’t have holes for screws but could be used as contact areas or adapters could be attached using zip-ties through big holes in the leg surface. Red sections cannot have additional material which overhang the wooden leg edge since when completely flexed, the upper and lower limb have contact in these areas. The green lines show

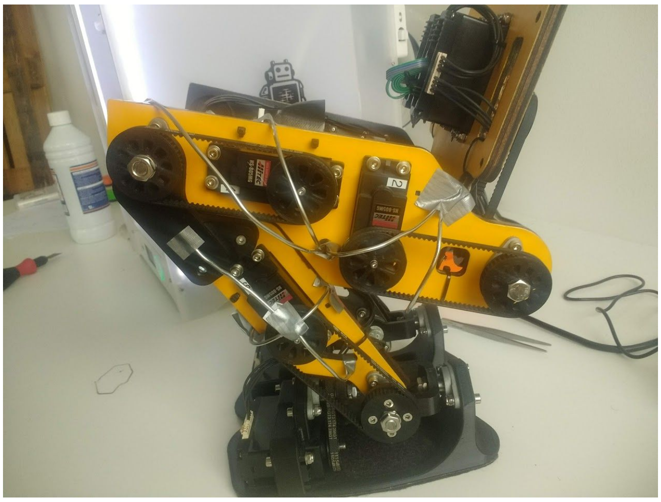
where robust connections can be constructed (more in the next paragraph).
Most adapters can be built in a U-form, going over the edge of the wood and being attached on the large wooden surface.

Stability and Aesthetics.

For stability a robust skeleton between the attachment points is suggested. The connections can be built on the inner leg side as-well on the outer side.
In the figure below, possible connections between attachment points are shown in green. Additional ribs between the connections are shown in orange.



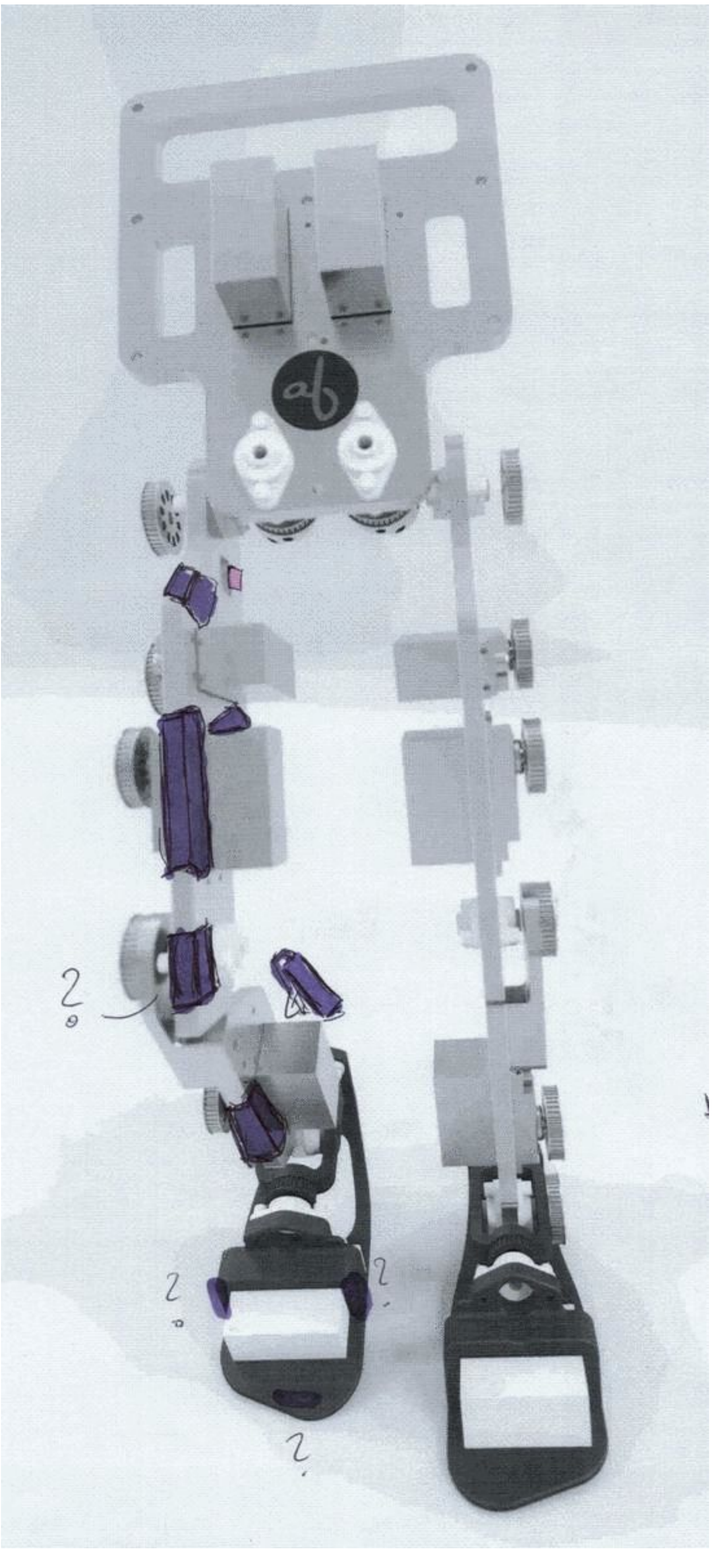
To get a better feeling for the aesthetics before designing everything in detail, a prototype skeleton was added directly to the outside of a Gretchen leg as shown in the figure below. It becomes obvious that enough clearance between the skeleton and the belt system is important. Also, the knee is not perfectly protected by the shown connections.

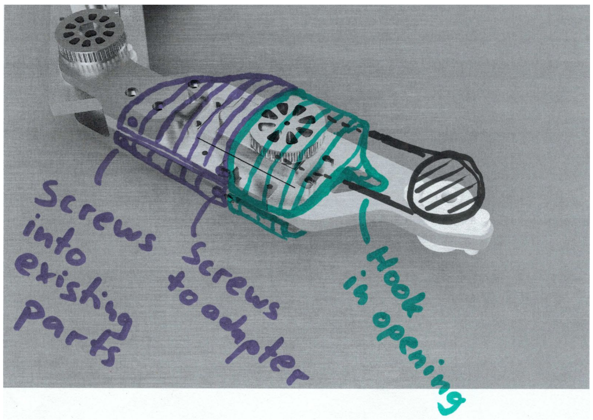
There is a tradeoff between aesthetics, robustness, weight, manufacturing effort and design effort. A solution can be functional design: The function of the part is most important and the can be added.
design follows. This solution would result in an open skeleton since a closure between the robust part is not absolutely necessary. In a second step, cosmetic parts or a soft skin (cloth)

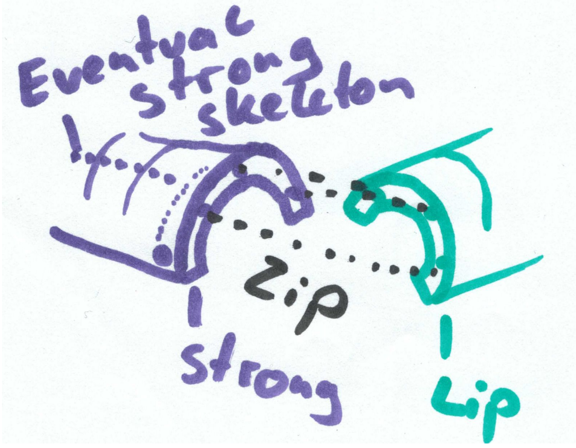
GIF of attachment points and skeleton

(sorry for everybody who wants to print or just has the pdf file)



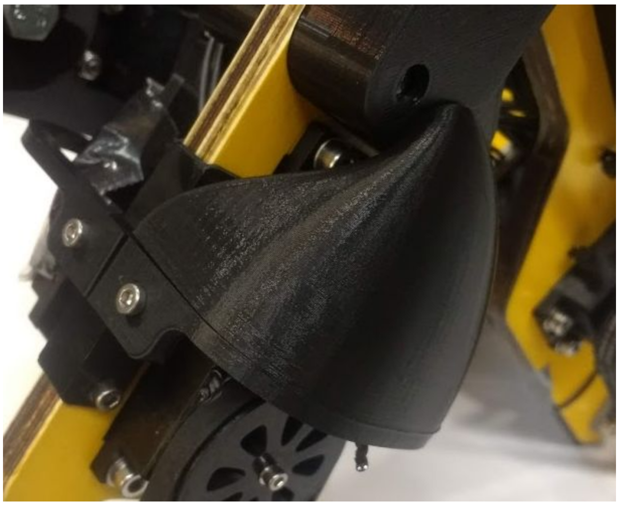
Designing the shells





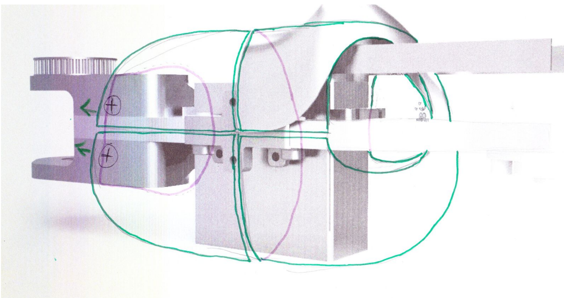
The shells should be constructed from two parts for easier printing. One part should have a strong section at the ‘bottom’ to connect to the leg and to the other part. The two parts can then be zip-tied together to reduce weight and complexity. To design the parts, the loft command of Fusion 360 with rails is used. To create 3D splines, the option has to be activated in the preferences (design) before.

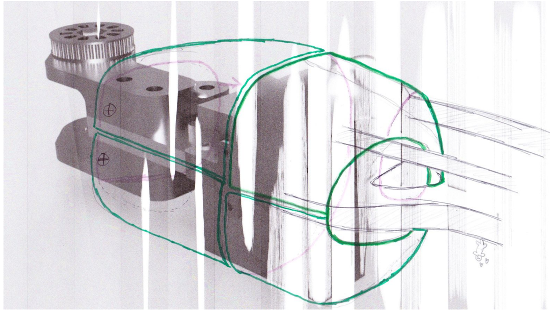
For the first test, a shell was designed without the final form. A photo is shown below:

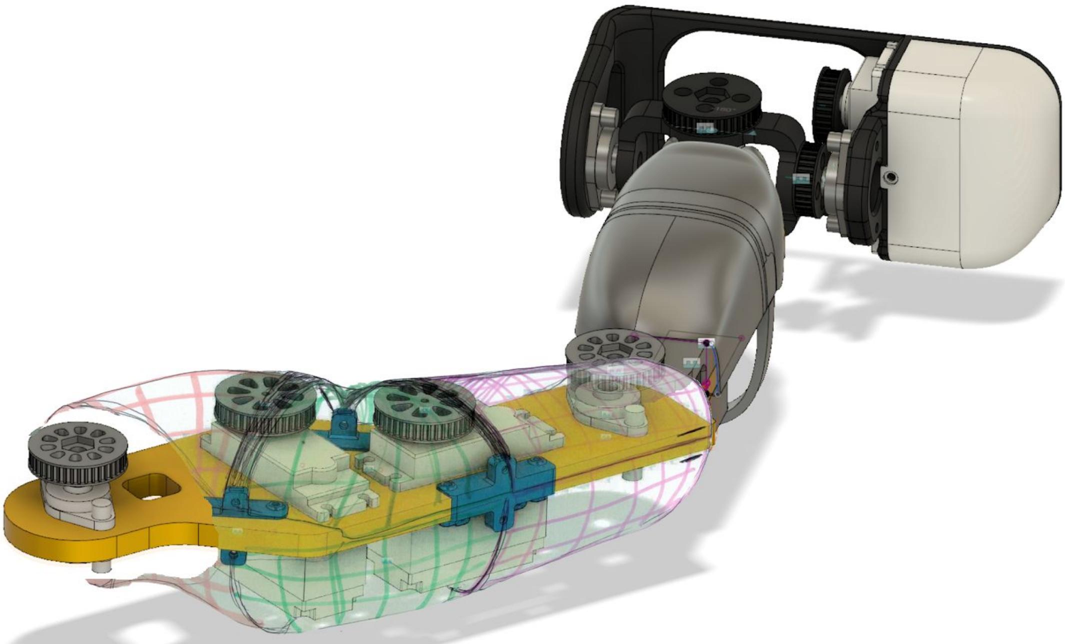


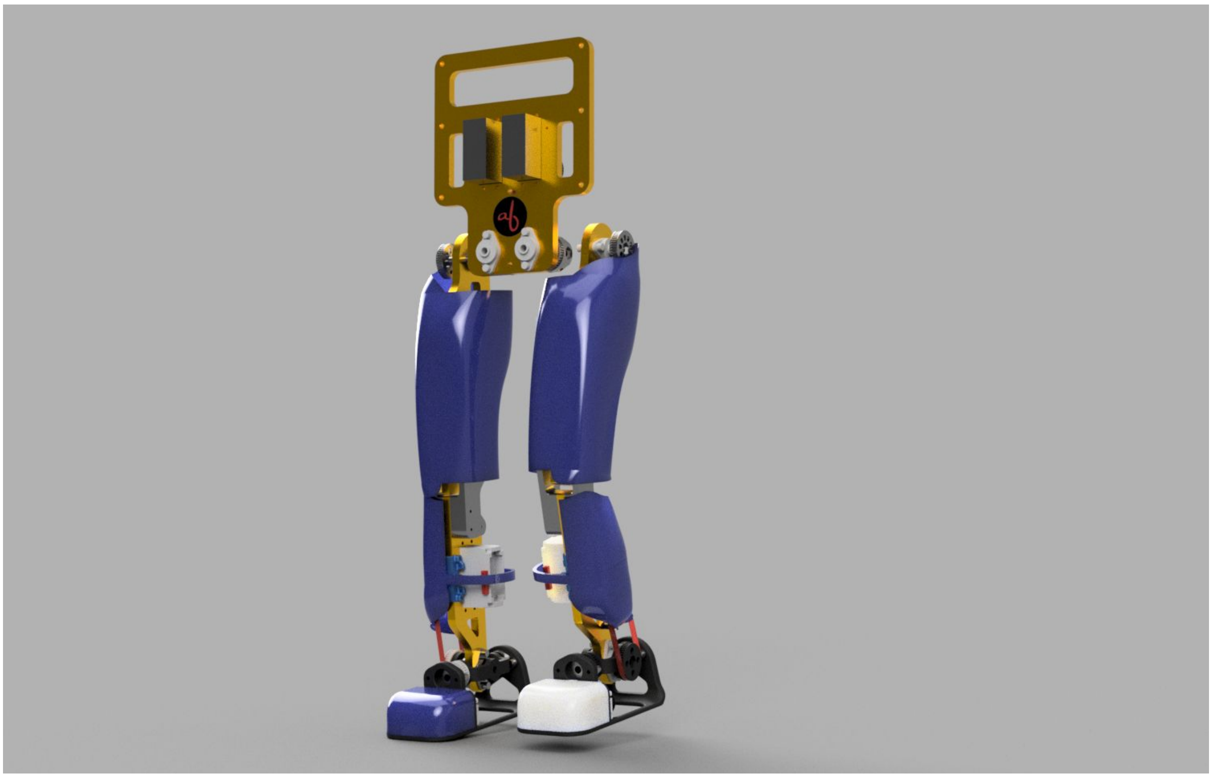
The test shows, that a real skeleton as described before might not be necessary, since the parts are very strong. Removing skeleton parts simplifies the design and manufacturing.

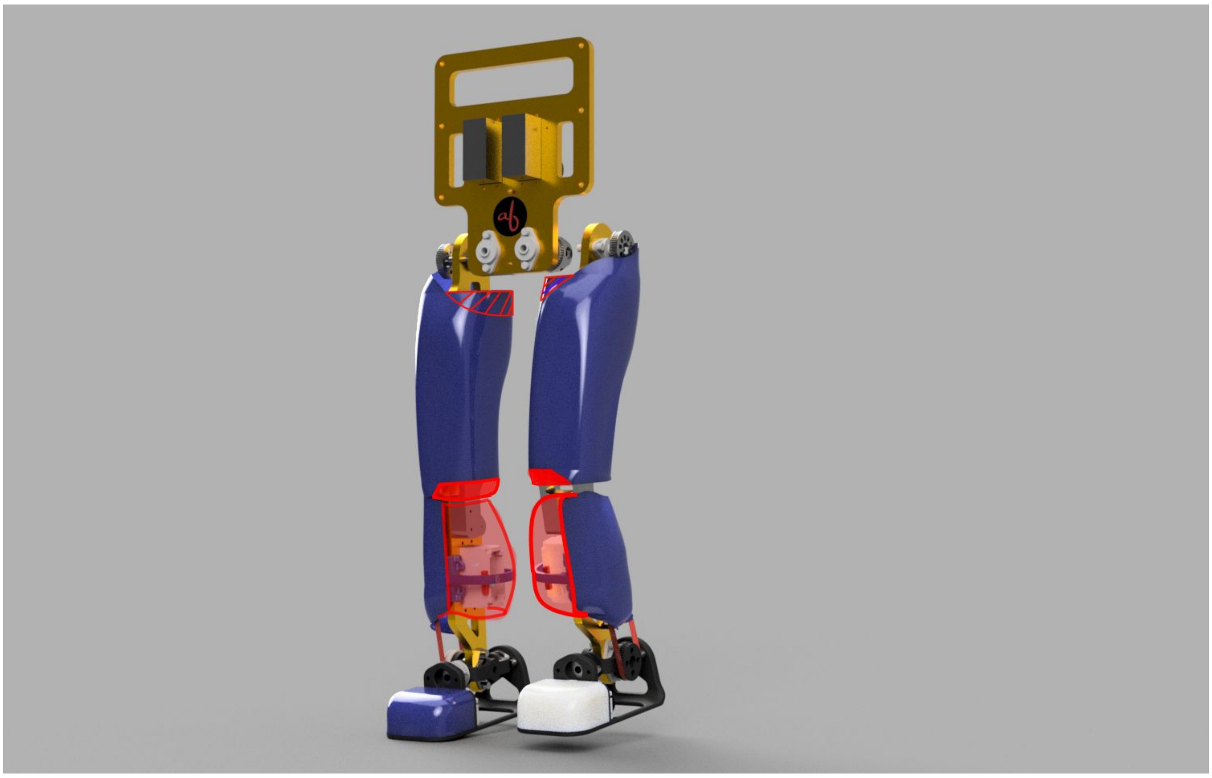
The following figures each show the design for 4 shell parts for the shank. Green lines are visible and pink lines are invisible lines. *In the second figure the printer had issues.*











Manufacturing and Assembly Guide

The shells consist of adapters, which are attached to the wooden legs directly and shells which can be easily and quickly be mounted on the adapters.

All screws, used for the shells are M3 size and all nuts are self securing nuts. The only required sizes are M3x10 and M3x30.

Required screws:

48 x M3 self securing nut
32 x M3 x 10
16 x M3 x 30

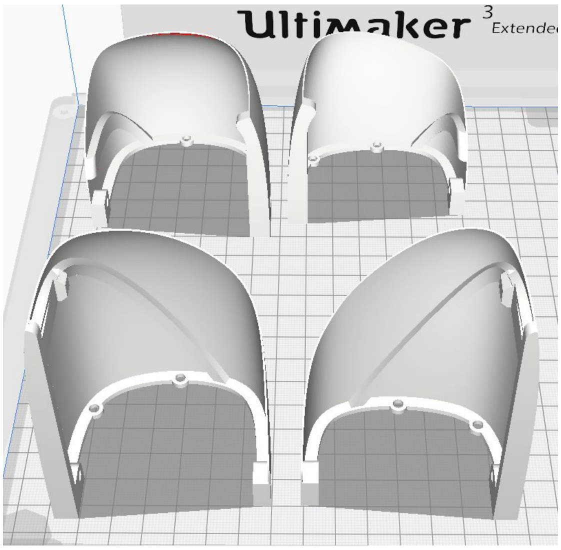
Manufacturing

All parts can be 3D Printed. Most parts are designed to be printable without support structure. One adapter has do be printed with support structure. This table shows how often a part is required. (M) means, that the part should be mirrored for the other leg. This can be done with the supplied file or in the slicer.

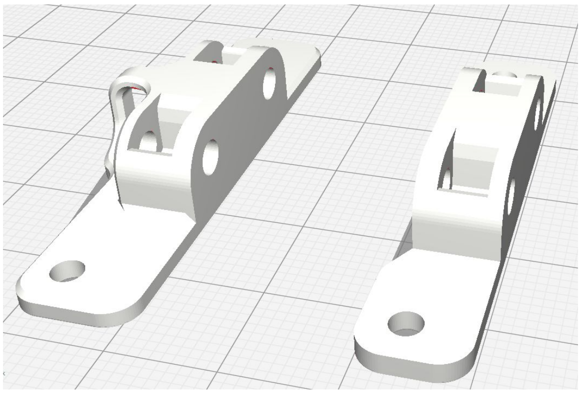
Name	Support structure	Amount	Resolution	Time per piece
shank_1_outer_upper	no	1 left, 1 (Mirrored) right leg	0.1 - 0.15mm	~3:20 (0.1mm)
shank_2_outer_lower	no	1 left, 1 (M) right leg	0.1 - 0.15mm	~3:20 (0.1mm)
shank_3_inner_upper	no	1 left, 1 (M) right leg	0.1 - 0.15mm	~3:20 (0.1mm)
shank_4_inner_lower	no	1 left, 1 (M) right leg	0.1 - 0.15mm	~3:20 (0.1mm)
shank_adapter_back	no	4, (2 left, 2 right) no need to mirror	0.15 - 0.2mm	~ 0:25 (0.15mm)
shank_adapter_front	no	4, (2 left, 2 right)	0.15 - 0.2mm	~ 0:25 (0.15mm)
thigh_1_inner_upper	no	1 left, 1 (M) right leg	0.1 - 0.15mm	~ 5:00 (0.1mm)
thigh_2_inner_lower	no	1 left, 1 (M) right leg	0.1	~ 5:00 (0.1mm)
thigh_3_outer_upper	no	1 left, 1 (M) right leg	0.1 - 0.15mm	~ 5:00 (0.1mm)
thigh_4_outer_lower	no	1 left, 1 (M) right leg	0.1	~ 5:00 (0.1mm)
thigh_adapter_back	no	2 normal, 2 mirrored (1 each per leg)	0.15 - 0.2	~0:25 (0.15mm)
thigh_adapter_front	yes, PVA with dual extrusion	1 left, 1(M) right leg	0.15 - 0.2	~1:40 (0.15)

The printing orientation of the pieces is important, for strength and for printability (avoid overhangs). In the following, figures show the correct orientation:

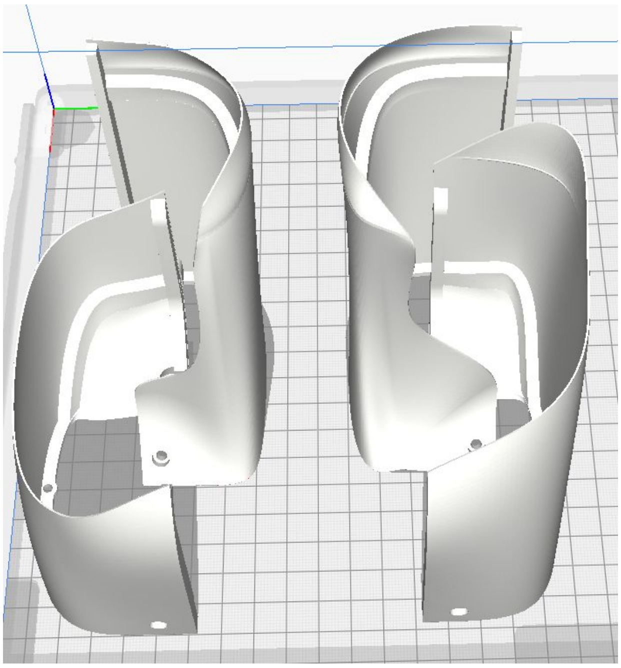
Shank Shells



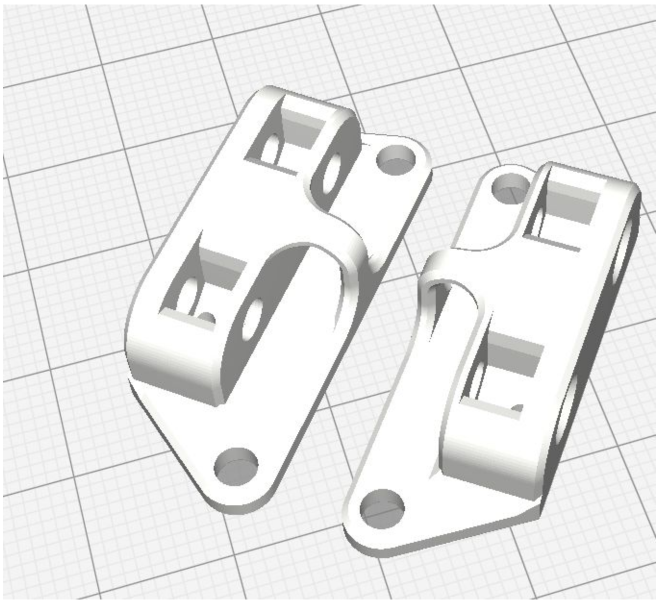
Shank Adapters

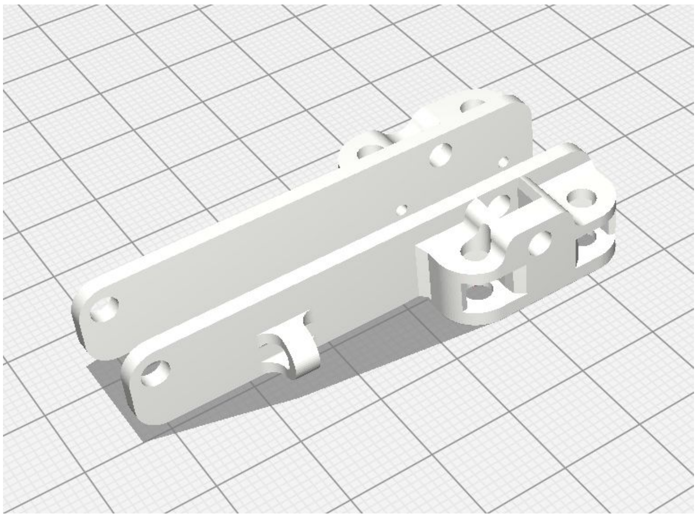


Thigh Shells

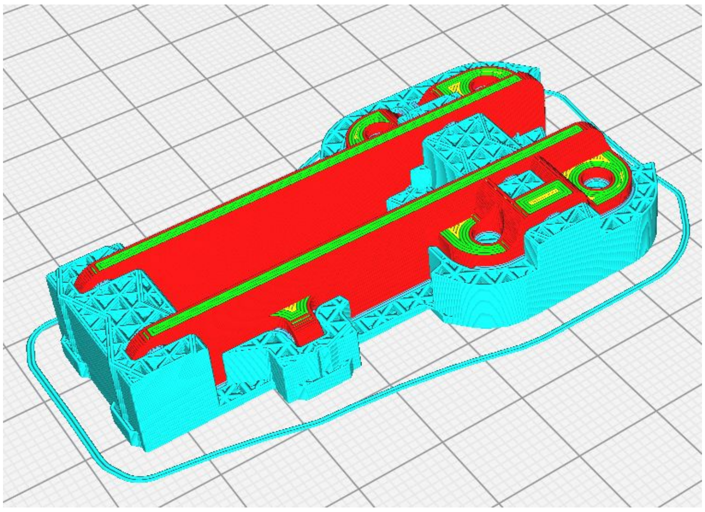


Thigh Adapters



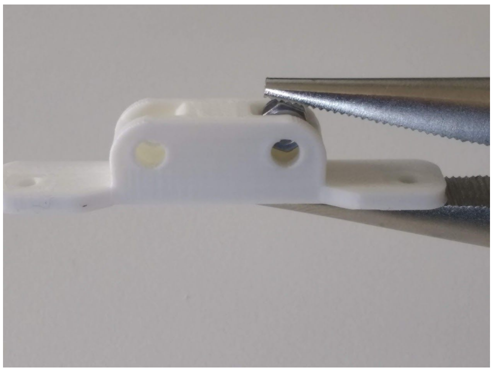


Important: This adapter has to be printed with support material!



Assembling the adapters

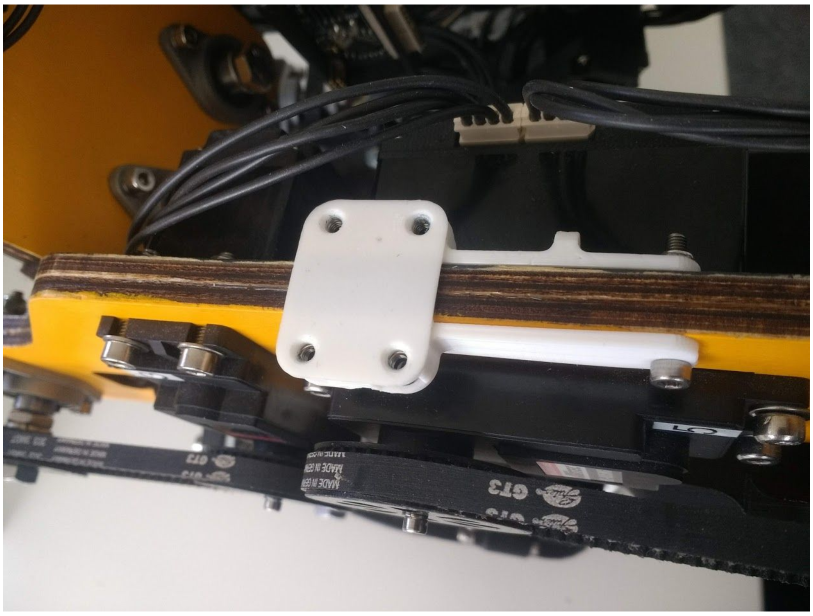
All adapters have recesses for inserting self securing M3 nuts. The nuts have to be press-fit into the adapters. To do so, lay the nut in the recess and use pliers to press them in. It should make a satisfying click.

IMPORTANT: The direction of the nuts is very important! The outside (from where the screw will come) has to be the hexagonal side of the nut and the (blue) securing ring has to be inside. So on the left picture above, the shell will be attached from the left side. If you don't follow this, the torque will be too high when assembling and the nuts can loosen themselves in the adapters.

The front thigh adapter requires 5 nuts to be inserted, all other adapters require only two. The adapters are assembled from both sides of the wooden leg with two M3 x 30 screws and two M3 nuts each.

Thigh front adapter



Shank front adapters

Thigh back adapters

Multiple adapters

Note, that the Thigh back adapter is not symmetric but has a longer side. This side is higher up the leg, when gretchen is standing.

Shank Back

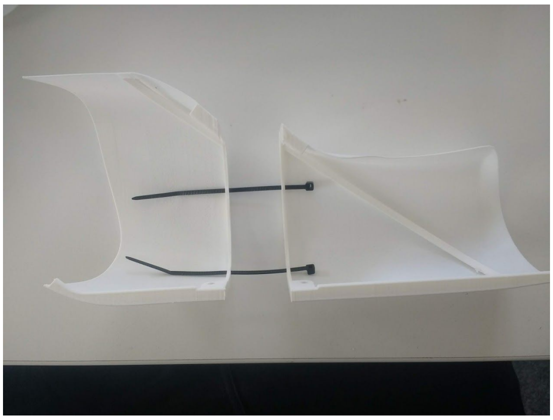
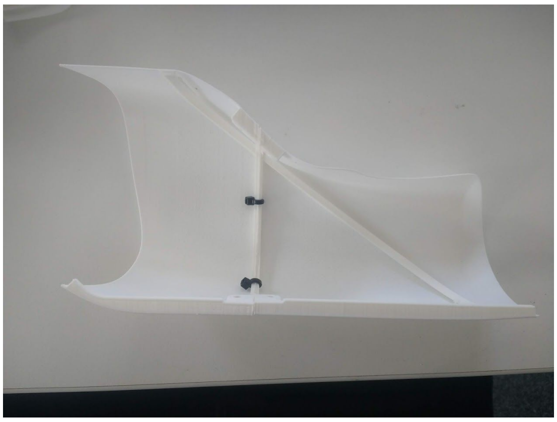
The shank adapter has two holes for assembly but the leg has only one of them. It has to be drilled with a 3mm drill. To find the correct spot, pre-assemble the adapter and mark the spot with a sharp tool.

Cables

Most adapters have loops for cable management. They are meant to be used with zip ties. If the orientation of a loop is not helpful for the task, you can use two zip ties as in the picture to secure the cables in place.

Assembling the shells

The upper and lower parts of the shells can be combined, using zip ties. This is easy, quick and lightweight. It stabilizes the structure but is still optional.

The each shell side (combined from two parts) is secured in the adapters by 4 M3x10 screws. They can be inserted from the inside without holding any nut from the other side.

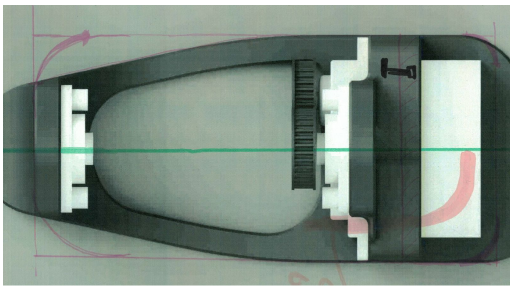
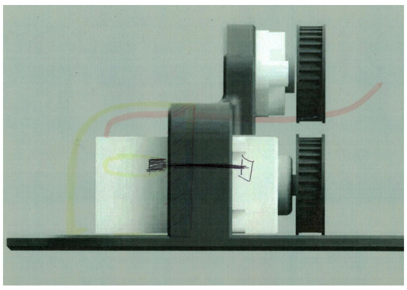
Strength

The shells are lightweight through their thin skin but through the skeleton like support inside, they are very strong. Tests showed, that static forces as in the picture up to 10kg are not an issue.

Feet

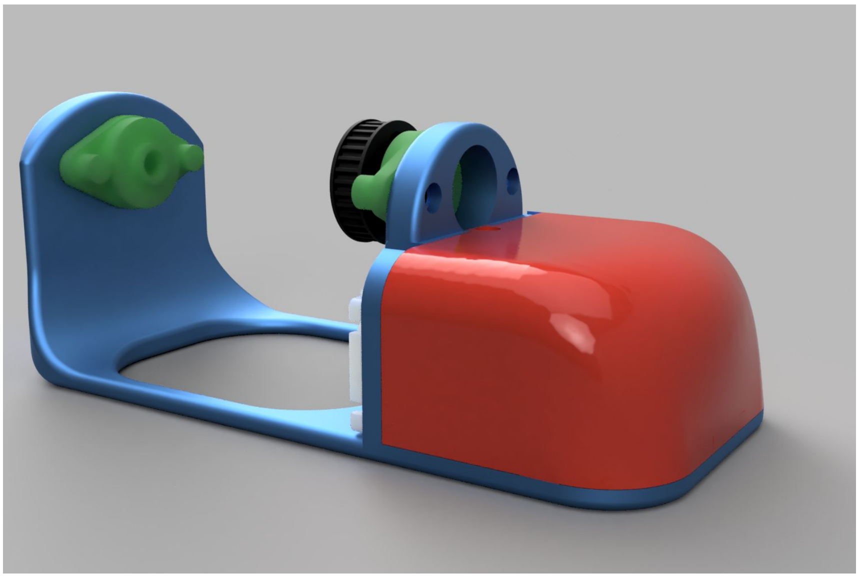
Requirements

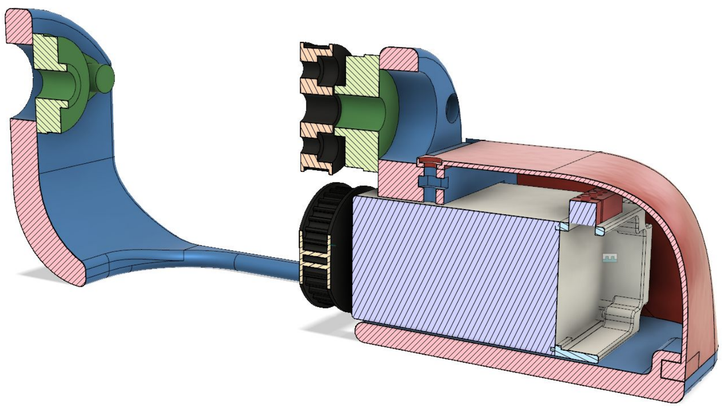
- Adjust the soles (feet) to meet the simulation constraints in friction and shape, in order to ease the transfer of simulation results.
- The foot shall be symmetric
- The heel shall not stick out as in the previous version but end straight
- shells for the motor in the front (top with screws, front with hook)

First drawings for redesigning the foot, a front cap (yellow in figure 2) should be attached with a single screw and locking mechanisms otherwise. The cable of the motor (orange) should fit under the cap and have a channel to come out. For easier printability, both feet will be identical and completely symmetric.

The figure below shows the foot with colorful materials to better visualize them in the 3D environment. They will be produced in more fitting colors.





Section analysis of the first new foot design. The motor fits snugly under the cap and the cap is secured by a hook in the tip of the cap.

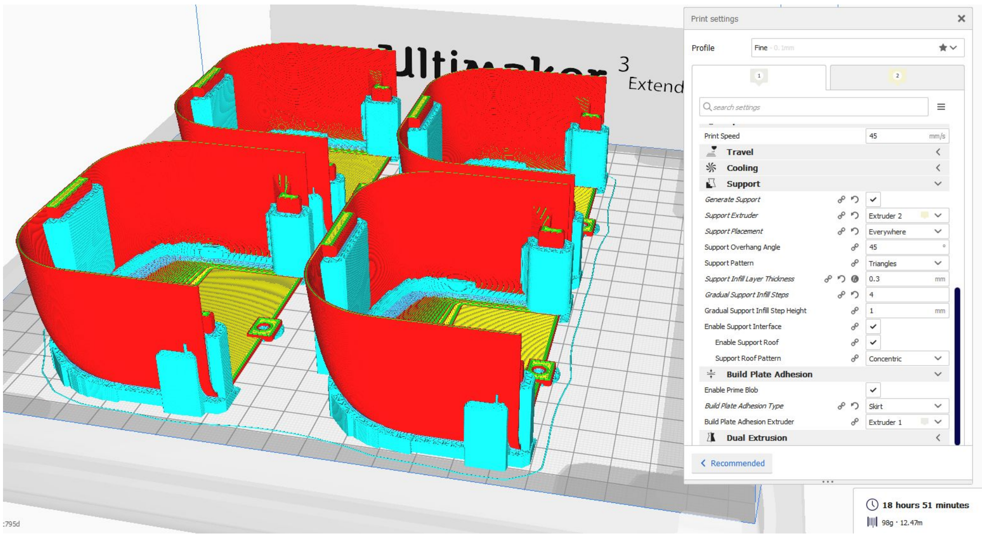
This first version was 3D-printed and tested, there are several small issues which are reviewed in the second and probably final revision.

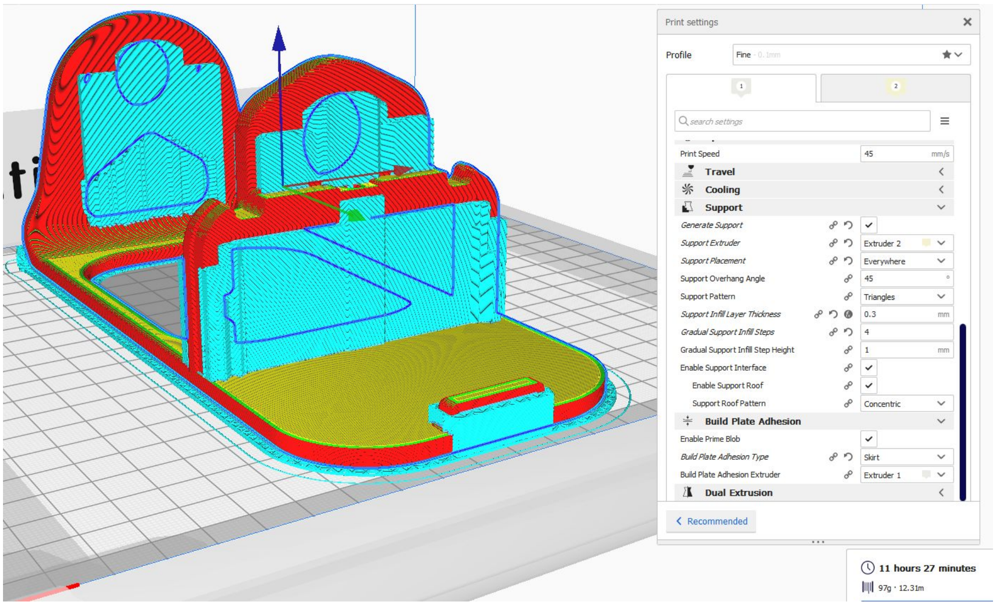
- The clearance for the motor gear is too small
- The tolerance between the cap and the foot is too tight in almost all areas, where the two parts meet.
- The round heel does not look good when 3D printed. The geometry shall be changed to fit the manufacturing process.
- The sides of the cap are not secured. A ring to fit over the screwheads shall be added.

In the second revision the issues above were fixed.

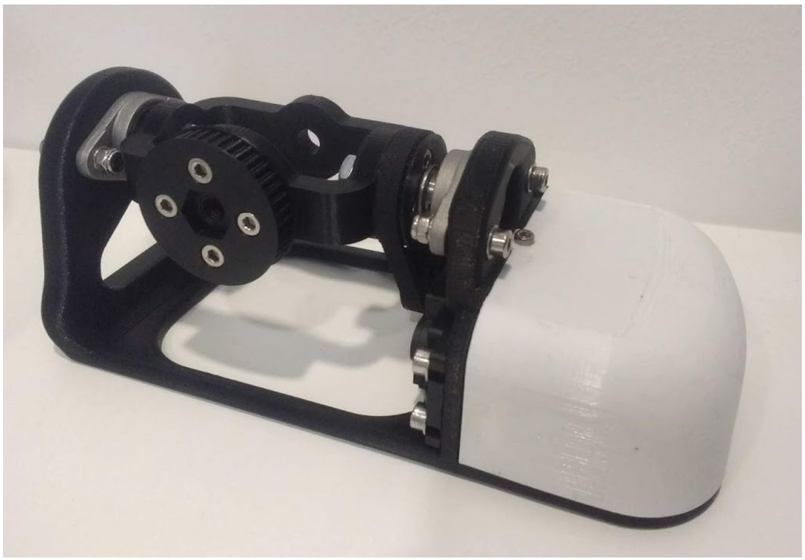
When printing the parts, the foot itself is printed with 0.2mm layer height, the cap can be printed with 0.1 - 0.15mm height and 20% infill.

Both parts should be printed with PVA support structure. The support infill step feature saves time and material (4 steps every 3 mm) and a support roof was added.





The fully assembled new version of the foot is shown below with motor and the protective shell. The foot is more bulky but as required closer to the simulated foot.



All requirements are met and the part is finished.

Camera Gimbal

Requirements

- Adjust the camera gimbal for the new type of camera as selected by Wally Chung and Jacob Yu from AIBrain Korea.

The Playstation 4 Camera was selected to be mounted onto the camera gimbal. It is much wider than the previous camera and so the mount has to be stretched.

There are two possible issues with the solution, which were discussed before starting the project:

- The camera is heavier, so that the gimbal might be not stiff enough for smooth operation. It could happen that it wiggles with rotation around the z axis.
- The previous gimbal had all rotation axis going through the camera chip. With having a stereo camera, not both chips can go through the z axis.

To dismantle and measure the camera chip the camera was ordered.

As the camera arrived, there showed up more issues:

- The camera cable is not a USB cable but a proprietary PS4 cable
- The camera cable is very stiff and not extendable, its resistance will change depending on the position
- The case of the camera is not easily openable without the danger of destroying it
- The dimensions of the camera are five times bigger than the old camera which is an issue for the stability of the gimbal.

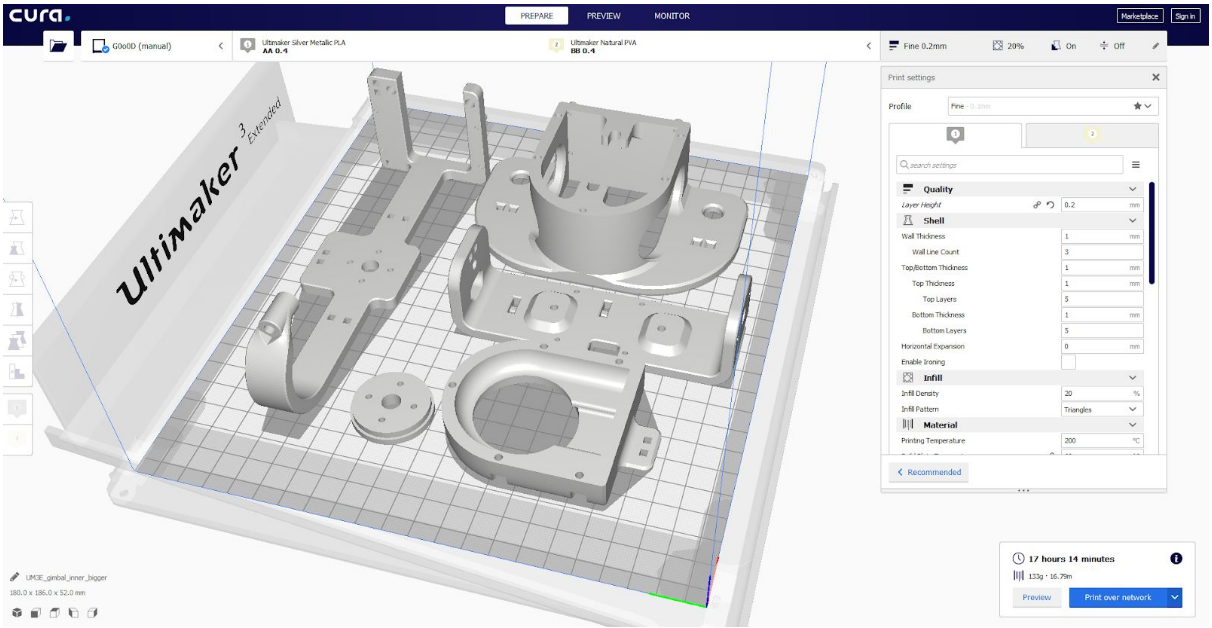
The camera will be sent back and alternatives can be the two following cameras:

- https://store.structure.io/buy/structure-sensor
- https://click.intel.com/intel-realsense-depth-camera-d435i-imu.html

The issues above are not present in the mentioned cameras.

The Intel realsense d435i was chosen, since it’s small and has a good ROS integration. All parts of the camera gimbal were redesigned to fit the new camera. The usb-c cable brought the challenge, that it comes out from the short side of the camera. This increases the actual width. To make enough space for the cable, the middle part is bent on the side.

The new camera (Intel Realsense D435i) is heavier than the old one so a ball bearing between the bottom and middle part is included to make the connection more stable.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PREPARE
PREVIEW
MONITOR
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Sign in
Ultimaker Silver Metallic PLA
AA 0.4
Ultimaker Natural PVA
BB 0.4
Fine 0.2mm
20%
On
Off
Ultimaker 3 Extended
Print settings
Profile
Quality
Layer Height
Shell
Wall Thickness
Wall Line Count
Top/Bottom Thickness
Top Thickness
Top Layers
Bottom Thickness
Bottom Layers
Horizontal Expansion
Enable Ironing
Infill
Infill Density
Infill Pattern
Triangles
Material
Printing Temperature
Recommended
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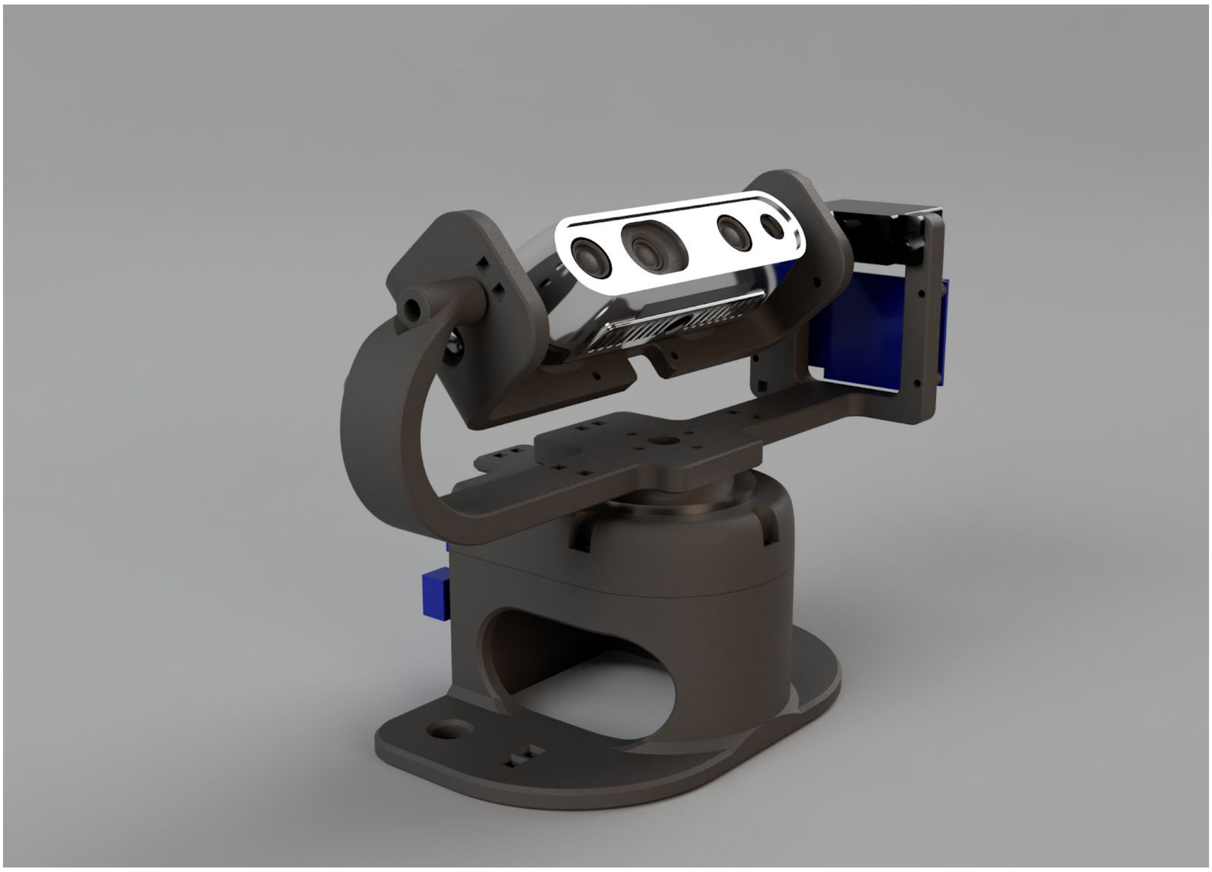
133g · 16.79m
Preview
Print over network
UM3E_gimbal_inner_bigger
180.0 x 186.0 x 52.0 mm

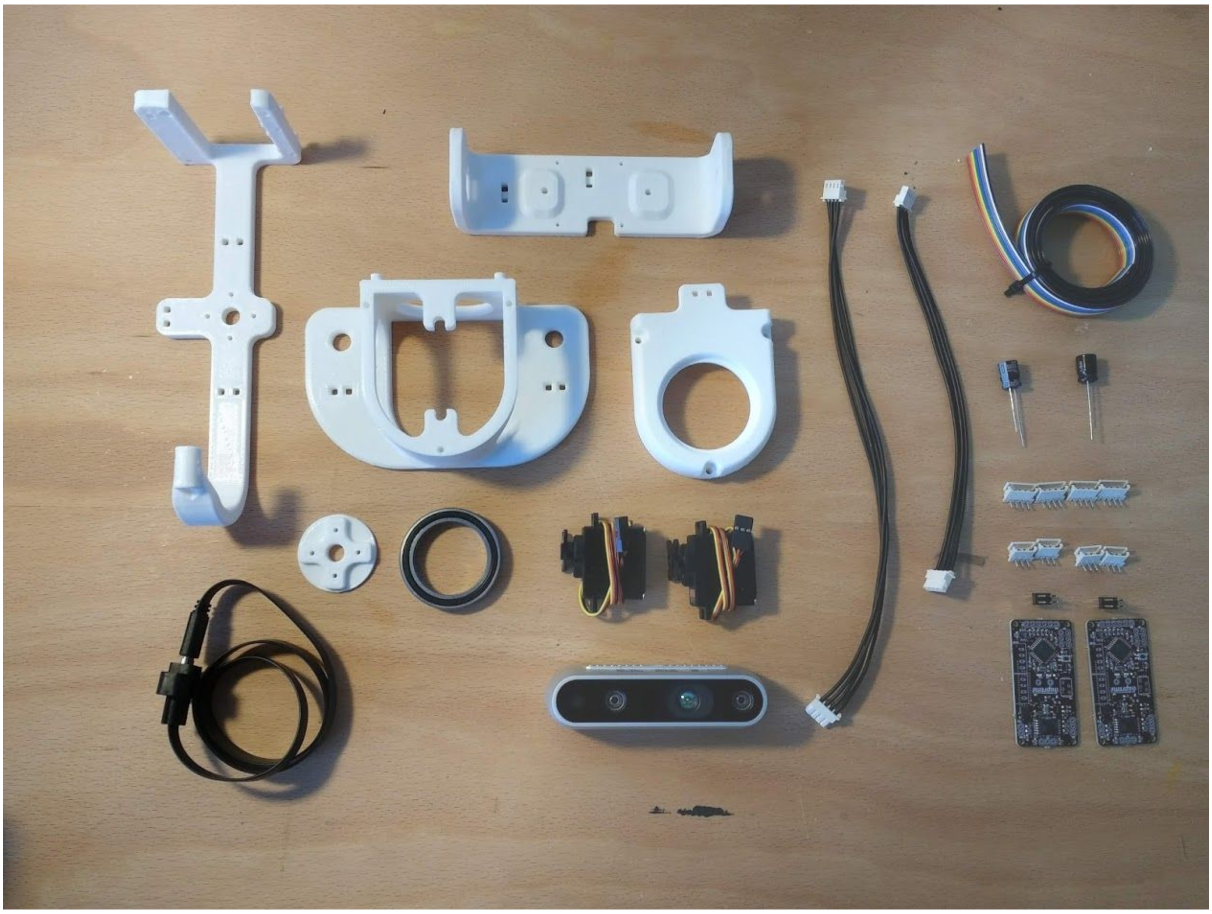


Required Screws

Article	in one Gimbal	in 3 Gimbals	Usage
M2 x 6	8	24	Sensorimotor board mount
M2 x 10	2	6	Upper Servo horn mount
M2 x 12	4	12	Lower Servo horn mount
M2 Nut	2	6	Upper Servo horn mount
M3 x 10	5	15	Base assembly & Intel camera assembly
M4 x 16	4	12	Servo mount
M4 x 30	1	3	Upper gimbal assembly
M4 Nuts (Unsecured/ Secured)	5	15	Servo mount & Upper gimbal assembly

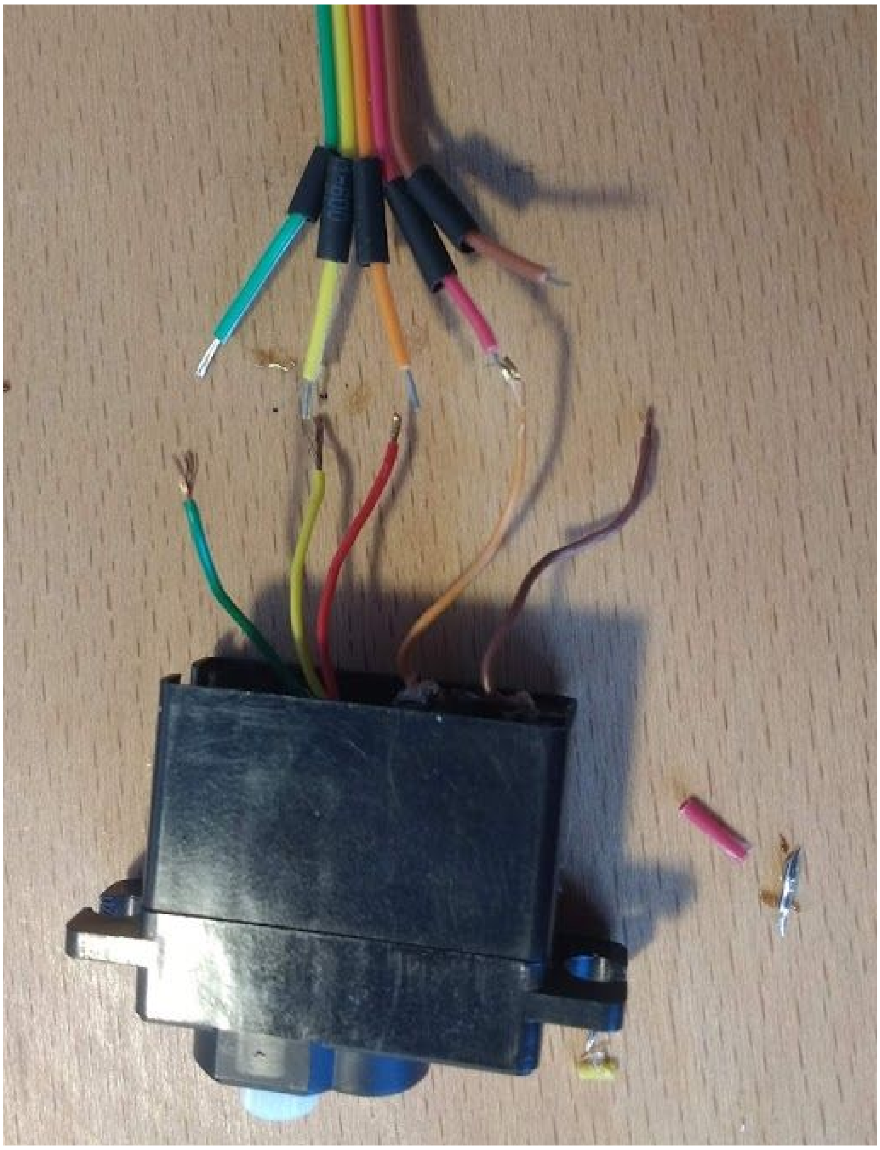
Required other parts

USB 3.1 C-Type extension
2 x Hitec HS81 Servo
Intel Realsense d435i
2 x Sensorimotor boards (with each 2 x 3 pin molex connector and 2 x 4 pin molex connector, 220uF 35V capacitor, and 2x3 pin header)
2 x robotis dynamixel 4p 240mm cable
2 x cable extension with 3 pin molex connectors, using crimps
1 x 42mm (outer) x 30mm (inner) x 7mm (height) ball bearing



Assembly Guide

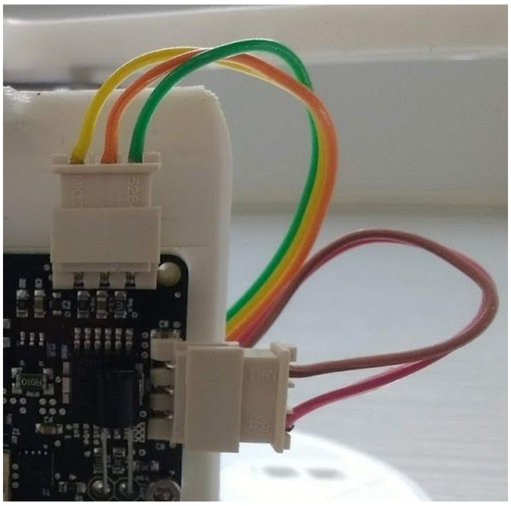
Prepare the motors to be used with the sensorimotor boards.



To do this, take out the servo board and extend the internal cables as shown in the picture. If you don't have the same colors, just remember which cable connects to which pin on the sensorimotor board. Use shrinkwrap to isolate the soldered connections.

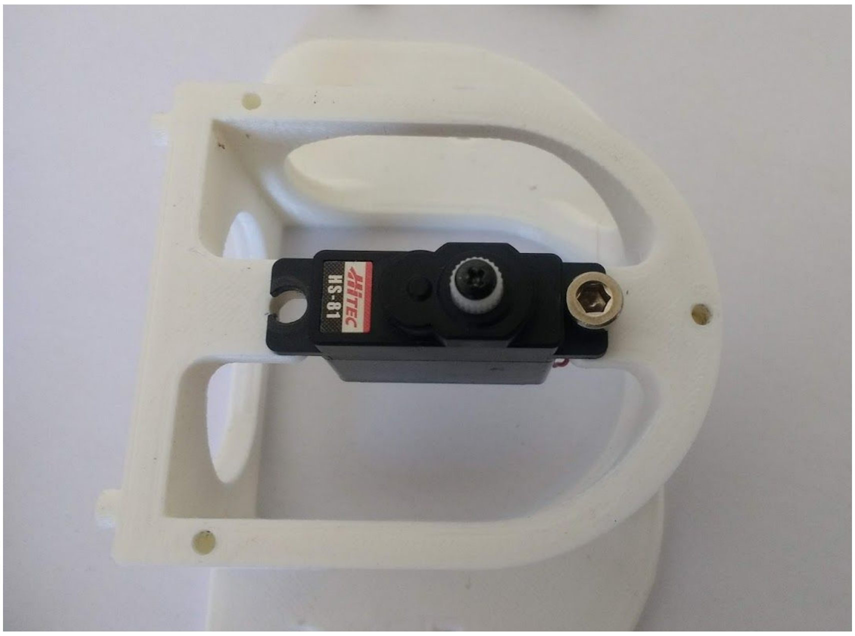
On the other end, two 3 pin molex connectors are added. One with the two motor wires and one with the three potentiometer wires. This step requires using crimps for the connectors. The step is described in the main gretchen documentation:
https://github.com/aibrainag/Gretchen/blob/master/documentation/documentation.adoc#cable-confection

The correct order of wires can be seen in this picture, if the motor internal connections are as in the picture above:

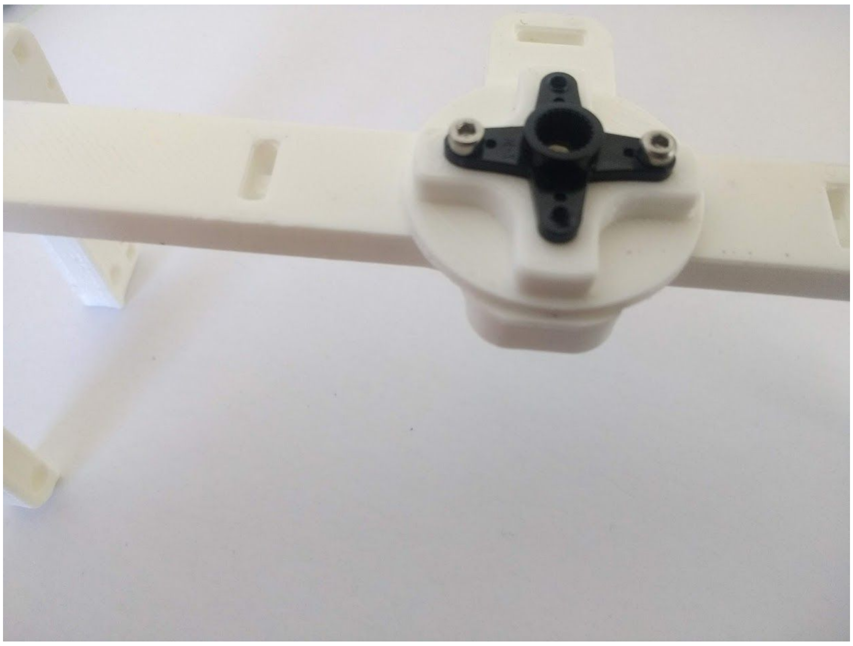


The 5 cables won’t fit through the old opening. Cut the lid to make space for the new cables:

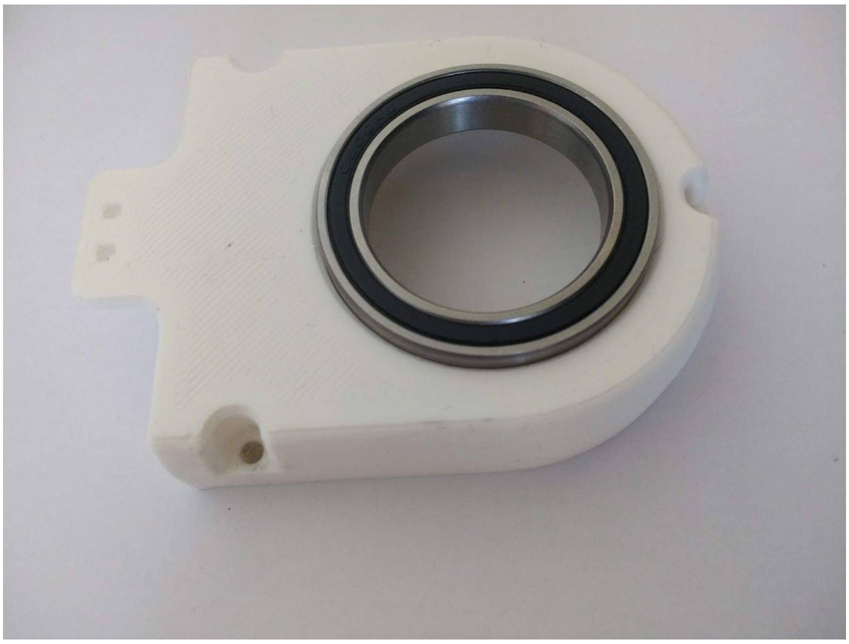
Use the M4 x 16 screws with nuts to put a Servo in the base part. It is easier to assemble the front screw to the servo with a loose nut first, then put it into the base part and assemble the second screw. The screws should be a bit loose, so that the motor can self align when the upper part is added later.



Assemble the middle part of the gimble, which consists of two 3D printed parts and the x-horn of the servo. The holes of the horn should be carefully widened to 2mm with a fitting drill. If no drill is at hand, the screws delivered with the servo can also be inserted and removed to widen the hole. This is shown in the image below on a different horn (required in a later step).

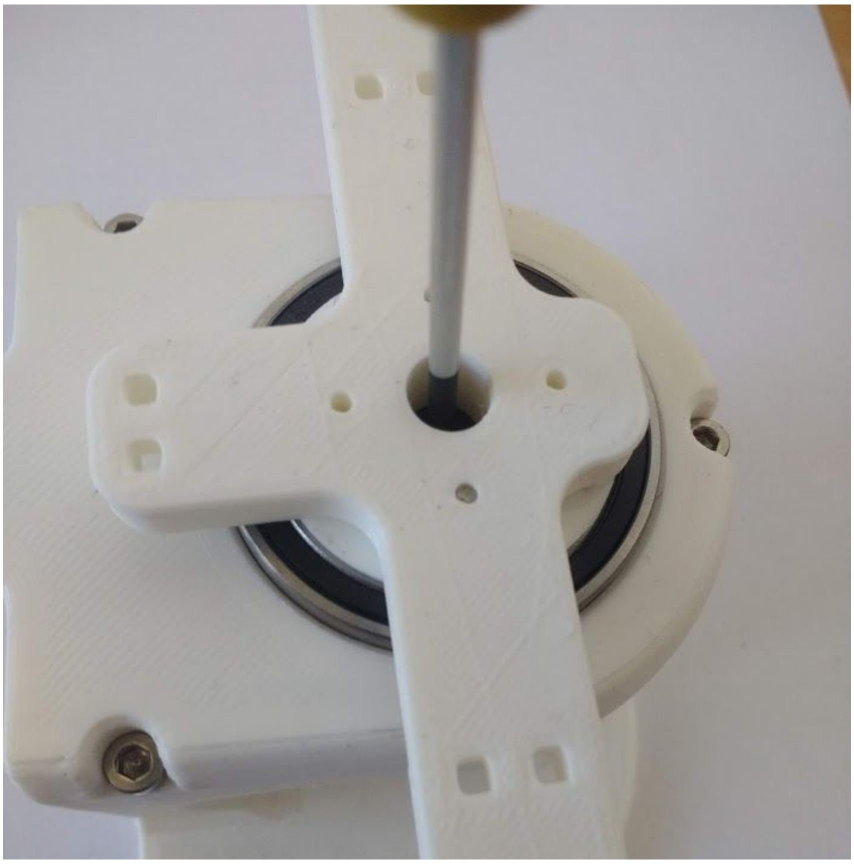


Pressfit the 30x42x7 bearing (6806 2RS / 61806 2RS) to the 3D printed part. Push until it can't move anymore. It requires some force.

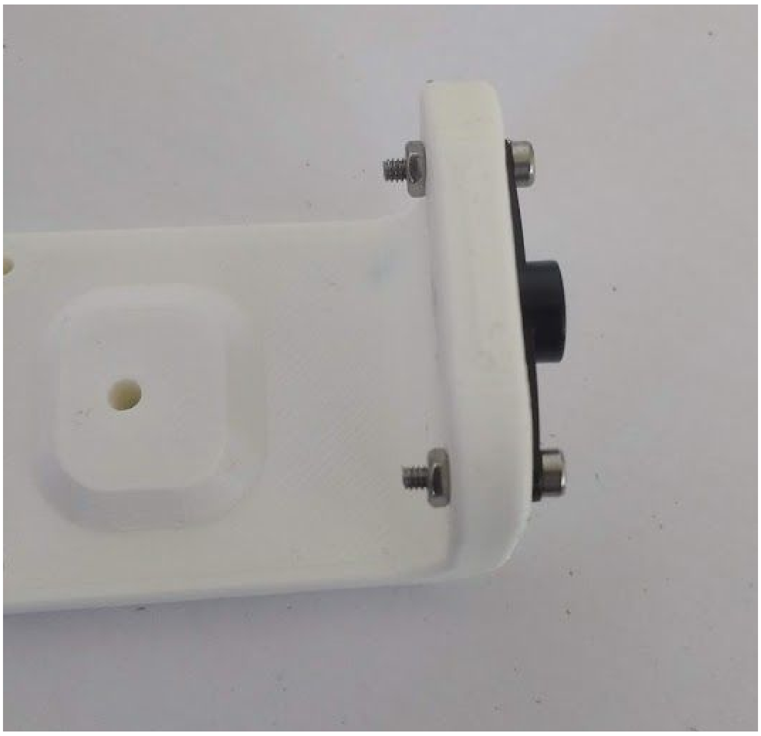


Assemble the two base parts with 3 M3 x 10 screws

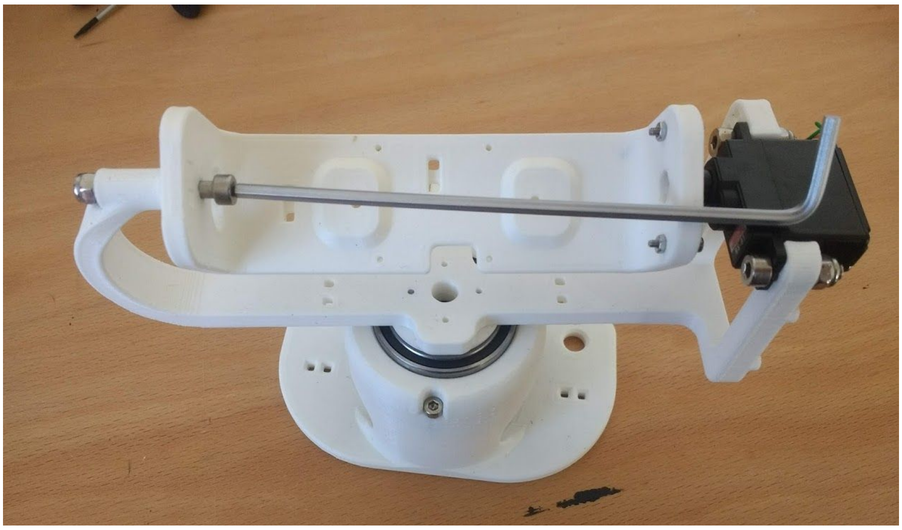
Attach the middle gimbal part to the servo. The servo should be movable in ~90° in both directions.



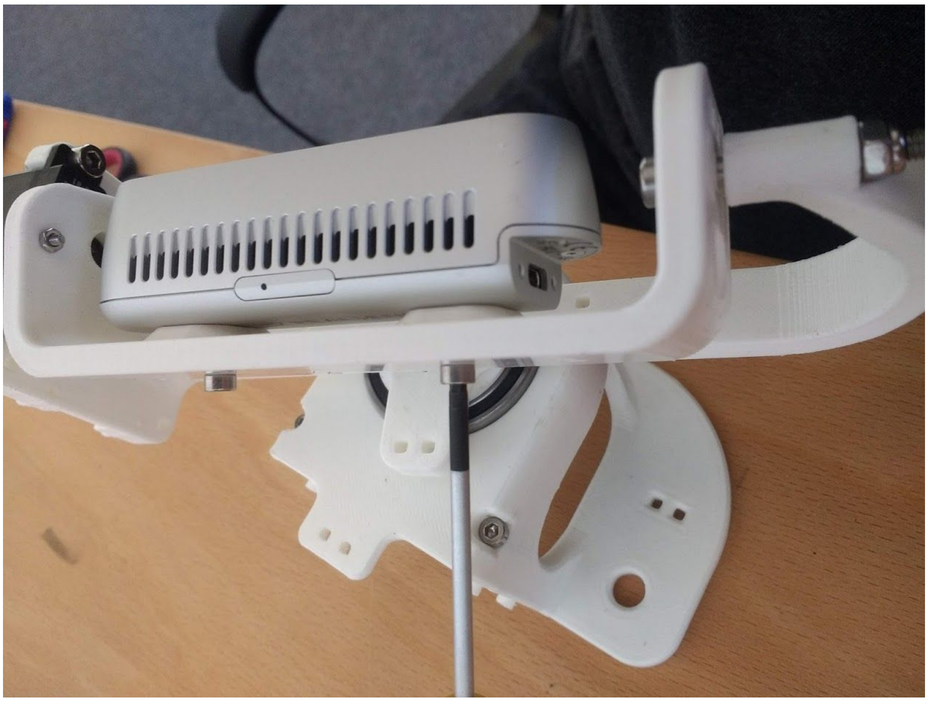
Attach the straight horn to the inner gimbal part. This requires widening the holes as described before. The M2x10 screws are used with the nuts.



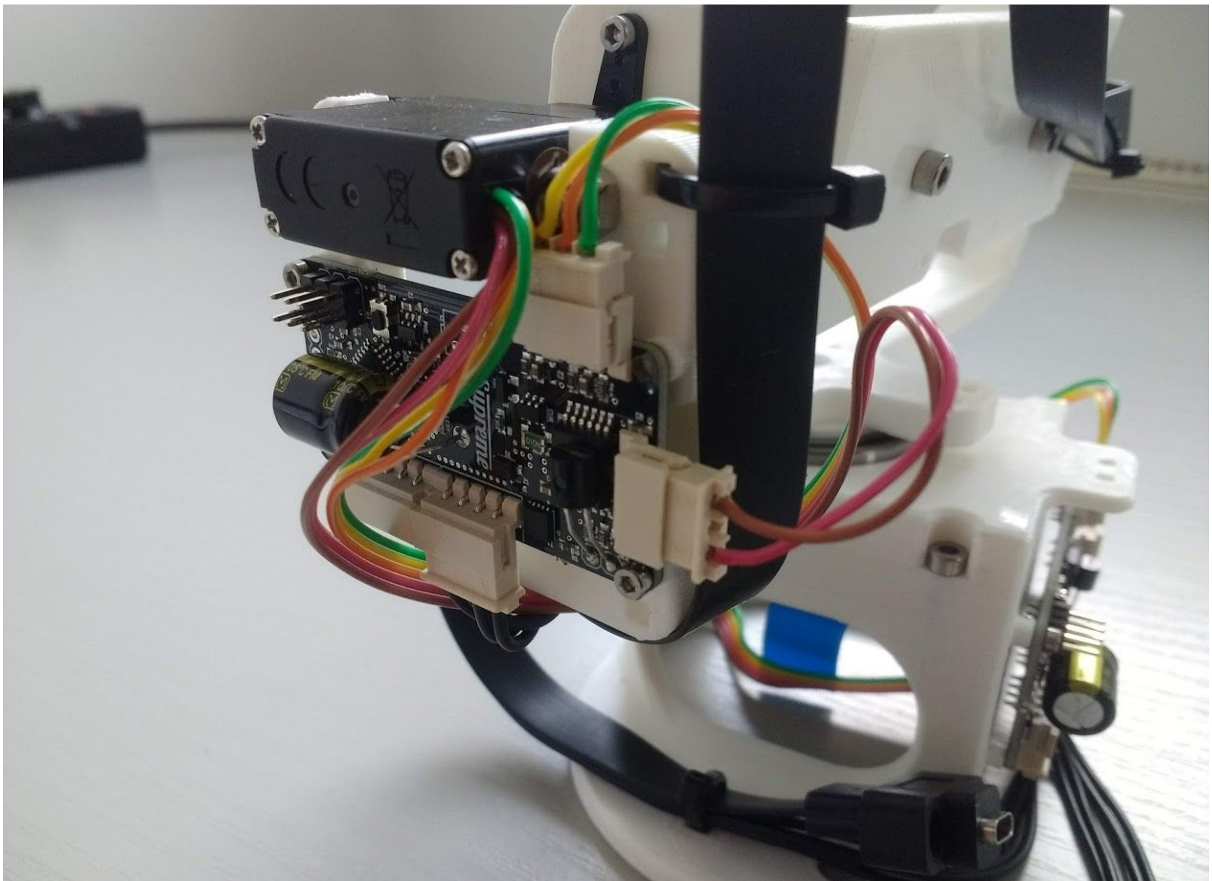
Assemble the inner gimbal part to the middle gimbal part with the M4x30 screw. Use a ball head imbus screwdriver to reach the screw. The Nut can be self-securing or normal, depending on your usage.

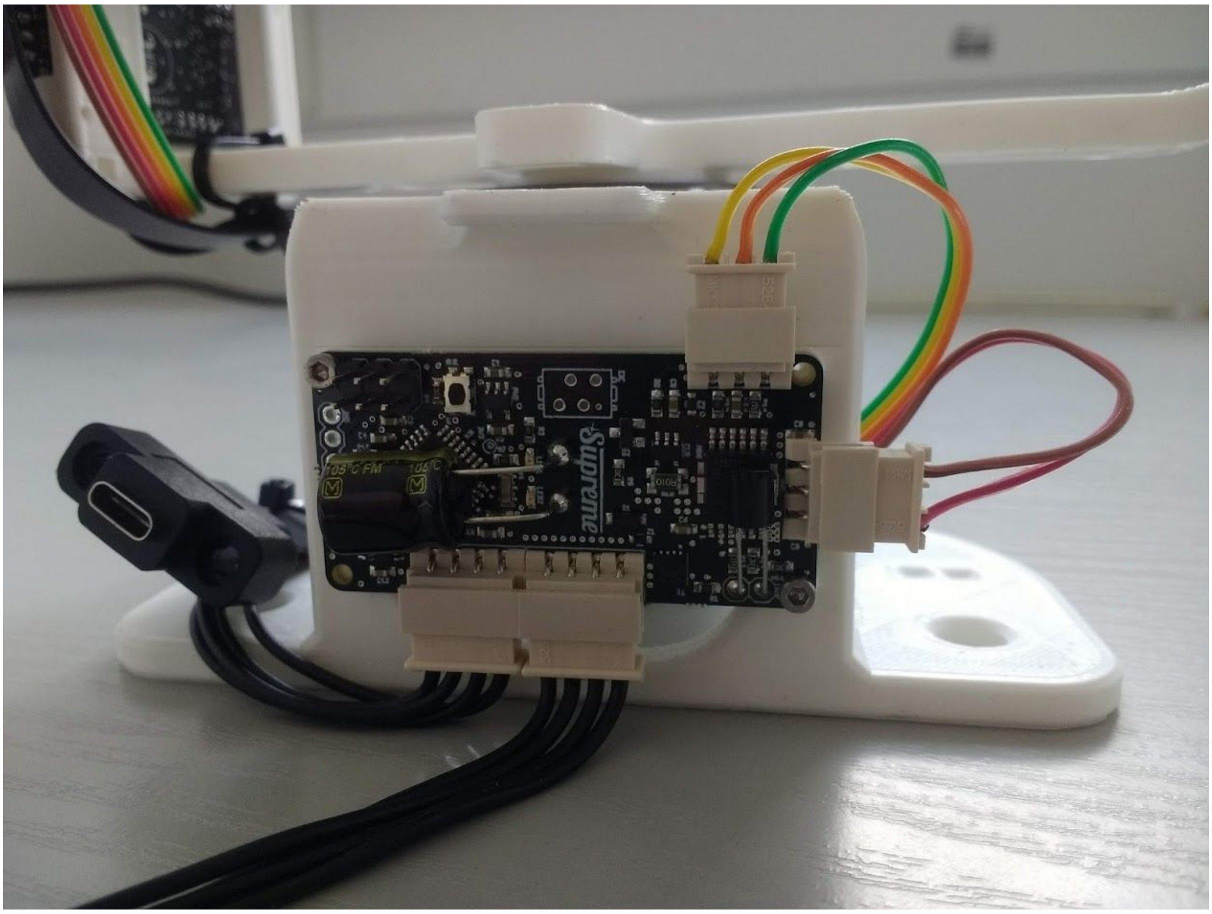


Assemble the Intel Realsense d435i to the gimbal with 2 M3x10 screws.



Assemble the Sensorimotor boards as described in the Gretchen documentation. The firmware also has to be flashed to the boards as described in the documentation. Connecting the cables with the 3 PIN Molex connectors is optional but helps maintenance through modularity. The boards should be screwed to the Gimbal in the shown places. 2 x M2 screws per board are enough to hold them in place.





The cables can be held in place with zip ties. The USB 3.1 Type C cable is the most difficult one as it is stiff in one direction and has to be bent into the correct directions to be able to flex.