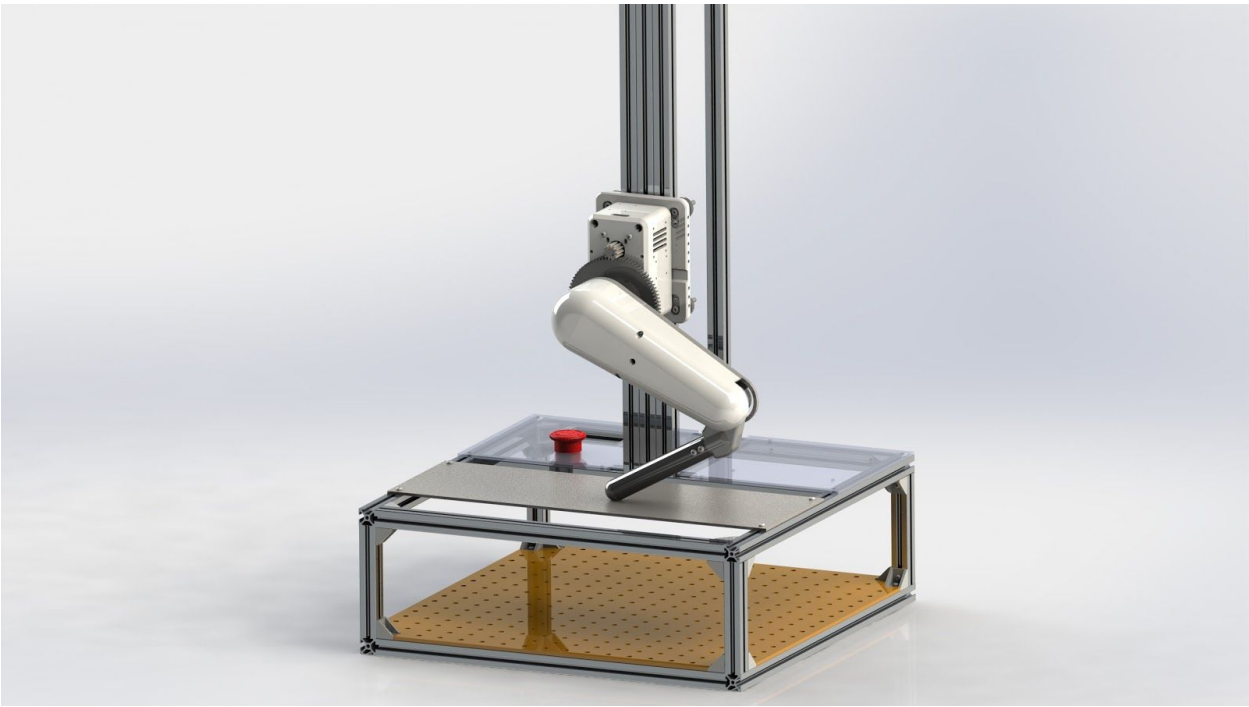
OpenLeg Open Source Biomimetic Robotic Leg

Assembly Guide



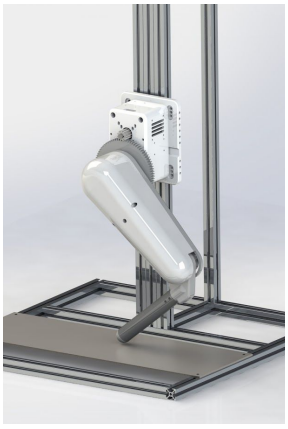
Author: Joseph Byrnes

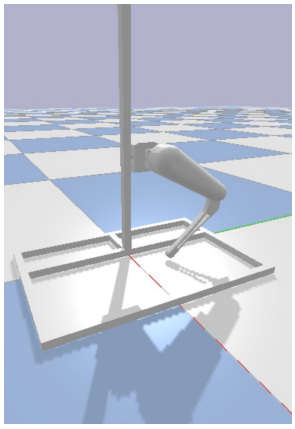
This guide is still a work in progress. Check the table of contents for what is already completed and what is yet to come.

Table of Contents

Project Overview

This manual will cover the assembly and use of the entire OpenLeg development platform. The OpenLeg project was created as my ECE senior design project at UIUC. The purpose of the project is to provide an open-source and low cost development platform for legged robotics.

Video of the project in action: https://www.youtube.com/watch?v=aXOSeKpADnk

Project source files at: https://github.com/JoeyByrnes/OpenLeg

Parts Needed

OpenLeg Part List		
Part Name	Quantity	Link
3D Printed Parts		(if applicable)
LegShell 3D Print	1	LegShell
LegCover 3D Print	1	LegCover
1.65mm_spacer 3D Print	2	Spacer
T5_30T_Pulley 3D Print	2	30T Pulley
T5_12T_Pulley 3D Print	1	12T Pulley
IdlerBentConnector 3D print	1	Idler Connector
LowerLegAdapter 3D Print	1	Lower Leg
LowerLegFoot1 3D Print	1	Foot
84T_SpurGear 3D print	1	84T Gear
Leg_To_Hip_Adapter 3D Print	1	Hip Adapter
Gantry 3D Print	1	Gantry
Hip 3D Print	1	Hip
Parts Needing Machining/Cutting		
Half inch hex shaft of length 58mm	2	Hex Shaft
Half inch hex shaft of length 94mm	1	See Above
5mm steel shaft of length 30mm	3	Steel Shaft
130mm Carbon Fiber Tube, OD 25mm, ID 23mm	1	Carbon Fiber
Custom 3mm to 2mm shaft key	1	
460mm Square sheet of pegboard	1	
460mm x 200mm ⅛ inch plastic sheet	1	
6in x 18in metal sheet (or 460mm x 150mm)	1	
460mm 2020 T-slot	4	2020 T-Slot
420mm 2020 T-slot	6	See Above
125mm 2020 T-slot	4	See Above
160mm 2020 T-slot	2	See Above
1000mm 2020 T-slot	1	See Above
1500mm 20mmx60mm V-slot	1	20x60 V-Slot
Electronics/Associated Parts		
AS5047D Magnetic Encoder	2	AS5047D

Diametrically magnetized magnet 6mm x 2mm	2	Magnet
6354 Size Motor	2	Motor
24v ODrive	1	ODrive
Hardware for the leg		
Half inch hex bearings	4	Bearings
Half inch hex shaft collars	2	Shaft Collars
Heavy Duty Half inch hex shaft collar	1	HD Shaft Collar
10mm wide,5mm bore idler pulleys	2	Idler Pulleys
M4 8mm screws (Screws for stand listed separately)	8	
M2.5 8mm Screws	4	
M4 30mm screws	6	
M3 35mm screws	3	
M3 square nuts	3	
12T Motor Pulley for T5 Belt, 8mm bore	1	12T XL Pulley
M4 x 45mm screw	2	
M4 x 10mm screw	4	
M4 Square nuts	10	
M3 20mm screws	7	
M2.5 5mm Screws	4	
M2.5 5mm Standoffs	4	
M2.5 nuts	4	
M4x35mm Screws	4	
11T motor pinion gear	1	11T Gear
24mm V-wheels	4	V_Wheels
M5x6mm Spacers	4	
M5x1mm Washers	4	
M5x50mm Screws	4	
M5 lock nuts	4	
Hardware for the development stand		
2020 T-slot Corner Bracket	46	2020 Hardware
M4x8mm Screws	112	See Above
M4 2020 T-slot Sliding Nuts	112	See Above

Electronics Overview

OpenLeg is primarily controlled by an ODrive along with and accompanying python script. The ODrive takes care of the difficult BLDC motor control and allows a position or torque to be commanded to each joint. The ODrive controls two high torque 60KV BLDC motors to drive the hip and knee joints.

OpenLeg uses magnetic encoders on each motor to allow for precise and accurate control. The encoders are capable of absolute output but currently the project only uses the quadrature output of the encoders and must be started in the same position each time for position control to be correct.

The Development stand houses two 12V 60A power supplies which are wired in series in order to provide 24V to the leg. The step on modifying one power supply to have a floating ground output is very important for the supplies to function properly when in series, do not skip this step.

Mechanical Overview

The leg is almost fully made out of 3D printed parts, with the exception of the knee motor pulley, a few belts, and the carbon fiber tube that makes up the majority of the lower leg.

All parts are designed to fit on a standard Prusa i3 printer or clone. Personally, I used the Afinibot A3 for printing most of my parts.

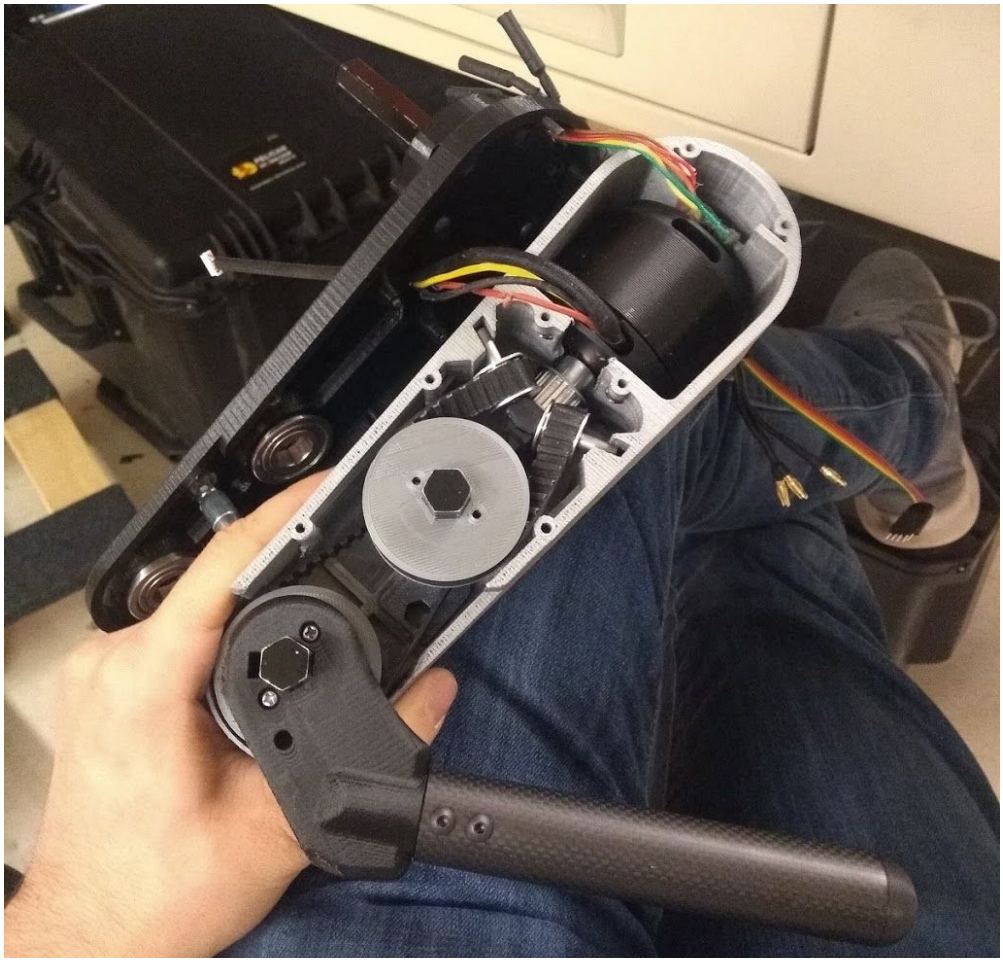
In the photos of my senior design project, all black and silver printed parts are PLA and all white parts are PETG. This was simply because of the resources I had available already. One part which holds the idlers inside the upper leg is printed in bridge nylon filament to make sure it was strong enough, but I have edited the part already so that it will probably work with PLA or PETG as well.

Assembly Intro

The following pages will jump straight into assembly of the leg and development stand. Since this project is still fairly new, there may be pieces left out that lead to confusion so please feel free to contact me at openlegproject@gmail.com or through Hackaday messages to ask any questions.

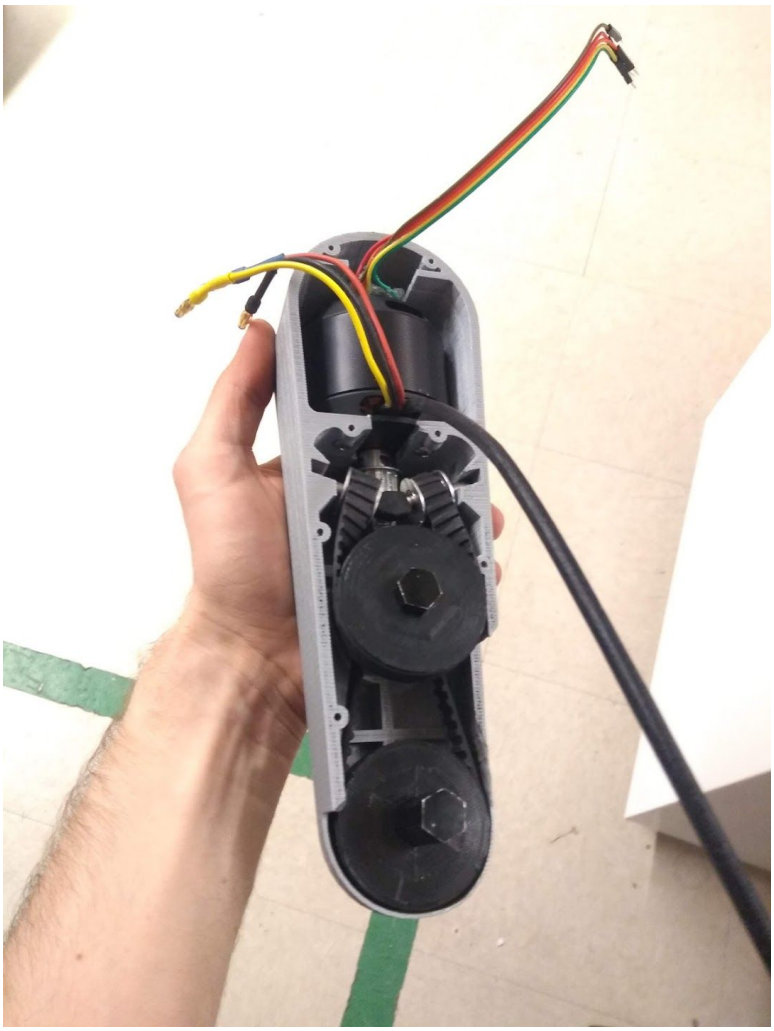
Disclaimer: While I try to make each step clear, this assembly guide is not guaranteed to be like your typical Lego instruction manual. If you get to a step and you're thinking something like *wait, shouldn't I be putting this on first, it doesn't mention it here* then you are probably right, go with your common sense, and always feel free to contact me and let me know there's something confusing in the guide.

If you're planning to make this project, I suggest contacting me to ask about any known bugs/unfinished designs that you will want to know about going into it.



Assembled Lower and Upper Leg with Cover Unscrewed

Upper Leg Assembly



Assembled upper Leg without cover

Parts needed for upper leg:

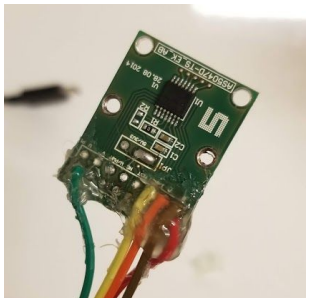
- **1x *LegShell* 3D Print**
    - (PLA or PETG are sufficient for this)
- **1x *LegCover* 3D Print**
    - (PLA or PETG are sufficient for this)
- **2x *1,65mm_spacer* 3D Print**
    - (PLA or PETG are sufficient for this)
- **2x *T5_30T_Pulley* 3D Print**
    - (Use nylon if possible to last longer, I used PLA for Senior Design though)
- **1x *T5_12T_Pulley* 3D Print**
    - (Use nylon if possible to last longer, I used PLA for Senior Design though)
- **1x *IdlerBentConnector* 3D print**
    - (Use nylon if possible, I used Bridge Filament for Senior Design)
- **1x 6354 Size Motor**
    - I Suggest using the 50Kv Motor from FreeRCHobby - https://frchobby.en.alibaba.com/product/60468141915-803101590/New_Sealed_MP6354_Kv230_Motor_for_Electric_Skateboard.html

      Contact me for ordering if you'd like, It might align with an order I'm already coordinating
- **1x AS5047D Magnetic Encoder development board**
    - I purchased this part from Digikey - https://www.digikey.com/product-detail/en/ams/AS5047D-TS_EK_AB/AS5047D-TS_EK_AB-ND/5125788
    - If you're making multiple legs you may find it more cost effective to put the encoder on your own pcb, it only requires two capacitors in addition to the IC.
- **4x Half inch hex bearings**
    - I bought these from VEX - https://www.vexrobotics.com/bearings.html
    - These and the hex shaft are overkill but they were a last minute change to be safe after the set screws on a 5mm shaft kept rotating. One benefit is that these work well with 3D printed parts, and the 5mm shaft required metal pulleys.
- **2x Half inch hex shaft of length 58mm**
    - I bought this from VEX - https://www.vexrobotics.com/shaft-stock.html
    - You will have to cut the shaft to the length required, I used a horizontal band saw
- **1x Half inch hex shaft of length 94mm**
- **2x Half inch hex shaft collars**
    - I bought these from VEX - https://www.vexrobotics.com/shaft-collars.html
    - Make sure to buy the standard size, not the high strength ones

- **1x Heavy Duty Half inch hex shaft collar**
    - I bought this from AndyMark. If you plan to use the 3D print provided as is then you will need the same one, not the one from VEX - https://tinyurl.com/y46wyf65
- **2x 10mm wide,5mm bore idler pulleys**
    - I bought these from Amazon - https://www.amazon.com/gp/product/B07BPHRSN5/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&psc=1
- **2x 5mm steel shaft of length 30mm**
    - I bought the shaft from Amazon - https://www.amazon.com/gp/product/B01MTKNWZB/ref=ppx_yo_dt_b_asin_title_o01_s01?ie=UTF8&psc=1
    - You will have to cut the shaft to length. I do not suggest trying to use a saw, it would take forever. I suggest using a dremel with a cutting wheel.
- **4x M4 8mm screws**
    - These are for holding the motor in. Any screw length that holds well and doesnt hit the motor coils is fine
- **4x M2.5 8mm Screws**
    - These are for holding on the encoder. 8mm is just an estimate, anything around that should work fine, there is plenty of room for the screw to extend out of the holes.
- **3x M4 30mm screws**
    - These are for holding the upper leg to the adapter and 84T Spur gear.
- **3x M3 35mm screws**
    - These are for tensioning the idler pulleys on the first stage of the transmission in the upper leg.
- **3x M3 square nuts**
    - These are for the M3 x 35mm screws to thread through.
- **1x Diametrically magnetized magnet 6mm x 2mm**
    - This magnet is for the encoder. I purchased mine from DigiKey - https://www.digikey.com/product-detail/en/radial-magnet-inc/9049/469-1075-ND/6030786
    - Make sure the magnet is diametrically polarized, not axially polarized.
- **1x 12T Motor Pulley for T5 Belt, 8mm bore**
    - I purchased a pulley made for XL belt instead of T5 because I could not find an affordable T5 belt that would arrive fast enough. Here is the link to the belt I used- https://www.amazon.com/gp/product/B0747HLH9T/ref=ppx_yo_dt_b_search_asin_title?ie=UTF8&psc=1
    - If you can source a T5 12mm pulley that would be ideal, but the XL works well as the pitch is very close.

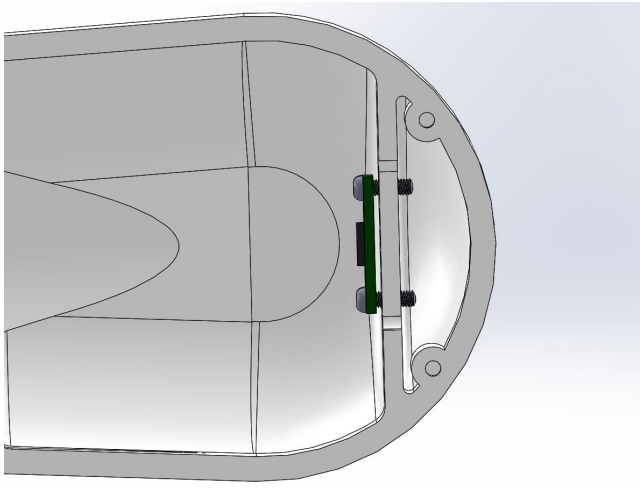
Upper Leg Assembly Step One:

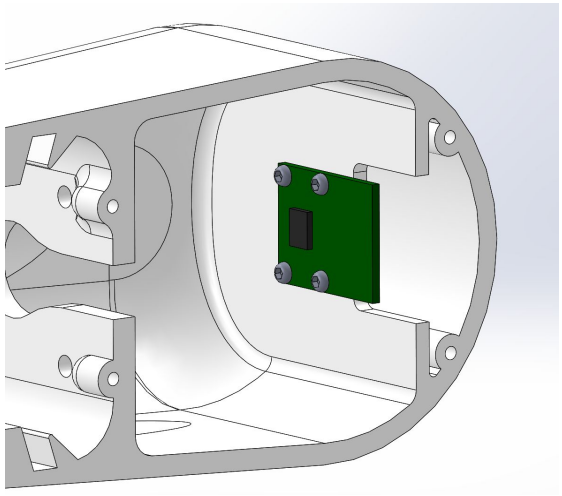
First, solder wires to the encoder of about 30cm in length. Connect wires to the A, B, 5V, and GND pins.



Connect the encoder to the Leg Shell using 4 M2.5 screws. (M3 can be forced through the dev board as well). The Leg Shell is made for M3 holes to thread in, M2.5 screws will need locknuts on the end.

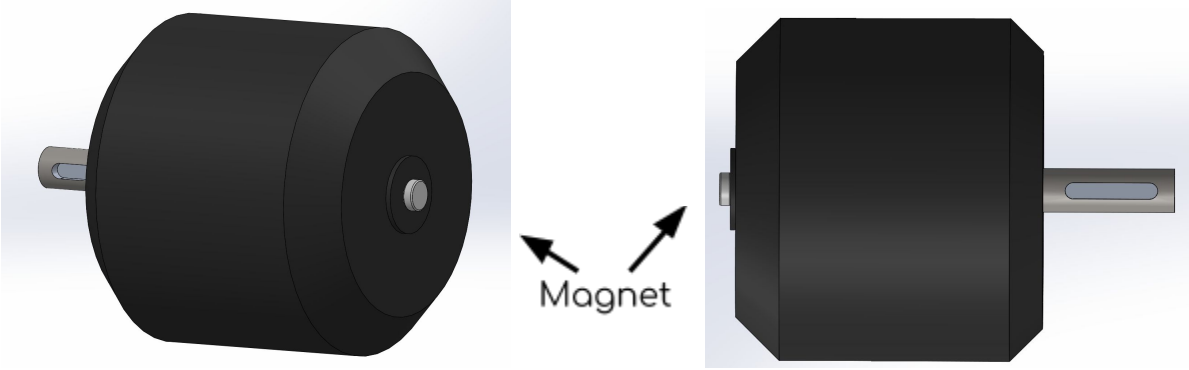
ATTENTION: The spacers are not shown, but you will need to space the PCB away from the shell by about 1.5mm to 2mm for it to be at the proper distance from the magnet. The Encoder IC should be about 0.5mm to 1mm from the magnet.





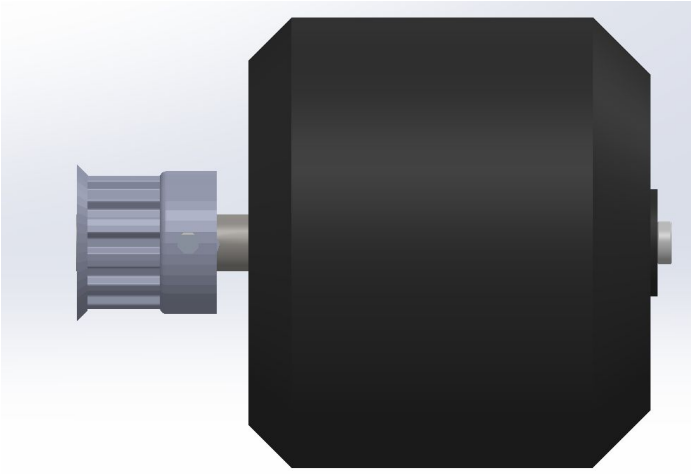
Upper Leg Assembly Step Two:

Glue the magnet to the back of the motor in the center using Super Glue or epoxy.



Upper Leg Assembly Step Three:

Attach the metal 12T pulley to the Motor Shaft, Align one of the set screws with the keyed part of the shaft for a good hold.

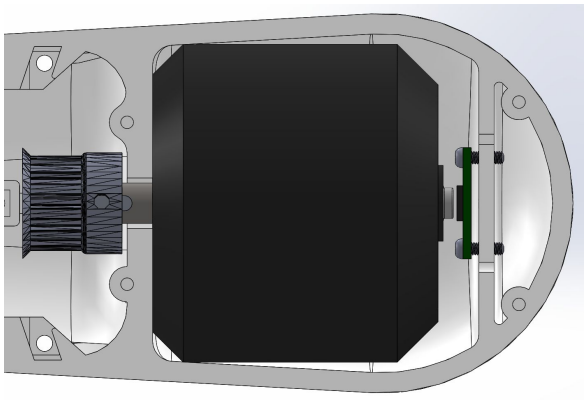


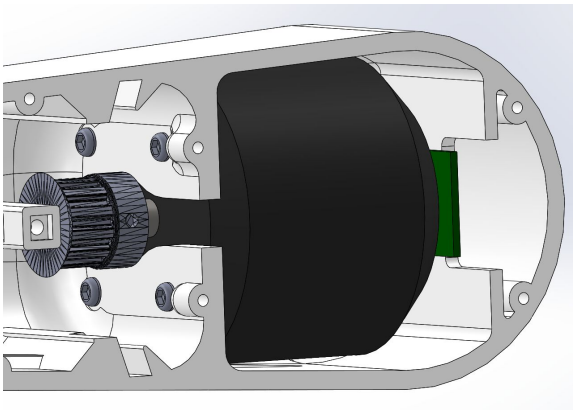
The pulley I used is not a T5 Pulley but it worked very well anyway. If you have access to a T5 pulley, I would of course suggest using the T5 instead.

The distance between the face of the motor and the pulley can be adjusted to line up with the idler pulleys later in the assembly.

Upper Leg Assembly Step Four:

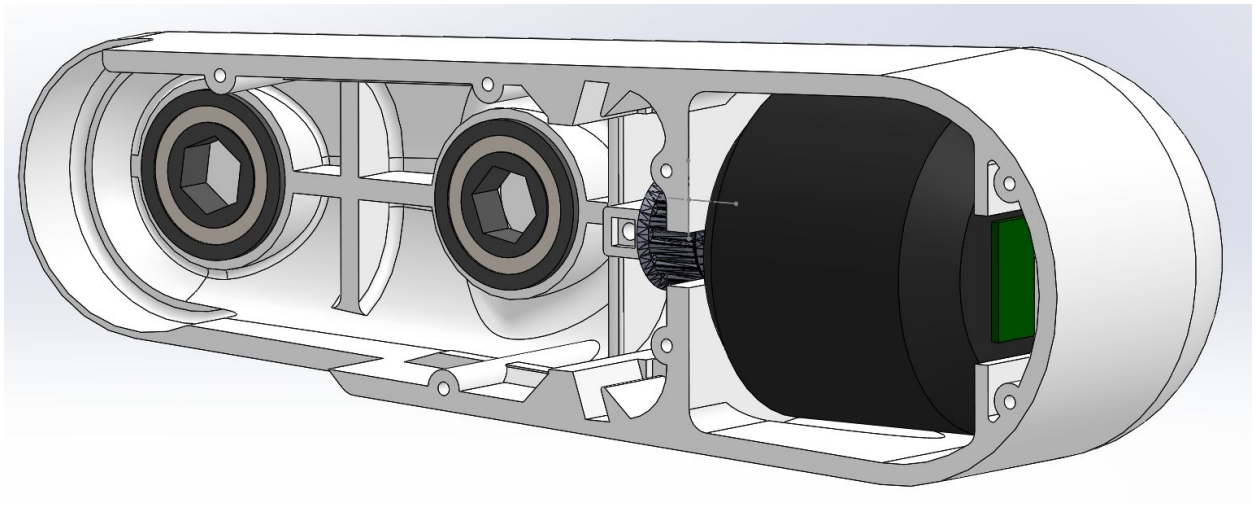
Connect the motor to the Leg Shell using four M4 by 8mm Screws. Make sure that the wires coming from the motor are facing out of the Leg shell opening.





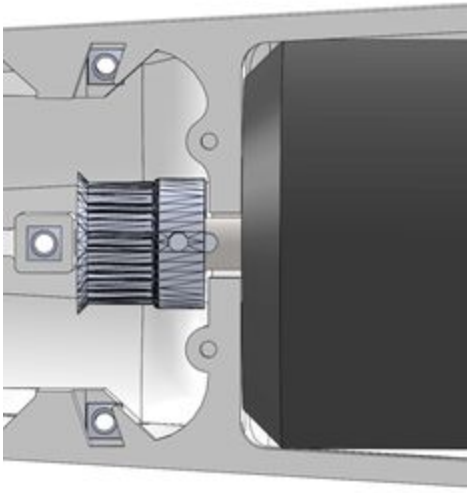
Upper Leg Assembly Step Five:

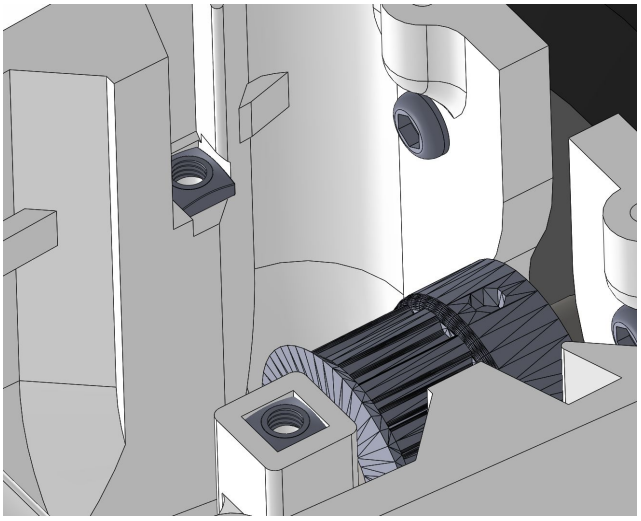
Insert two of the hex bearings into the Leg Shell. The bearings should be a press fit and may require using a clamp, assembly press, or mallet to get them in.



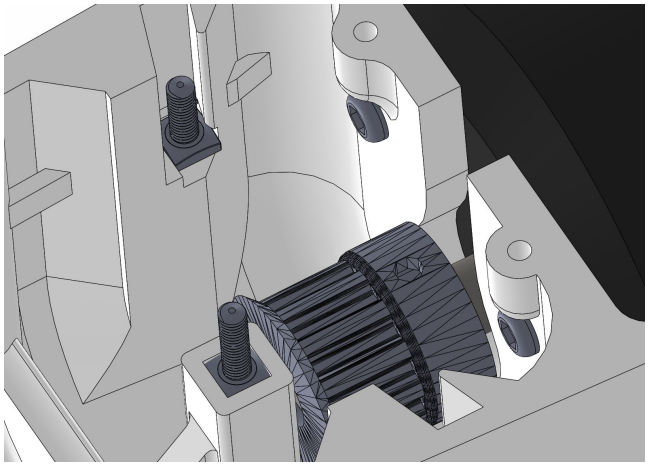
Upper Leg Assembly Step Six:

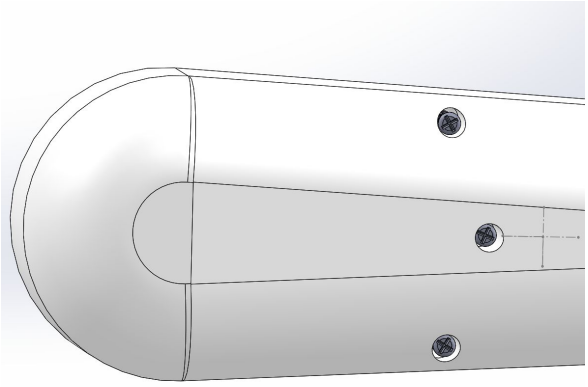
Insert the three square M3 nuts into the locations in the Leg Shell shown below. The shell is designed for the nuts to be heated and pressed into place while slightly melting the plastic around them so that they hold in place well.





Next, screw the 35mm long M3 Screws into the nuts from the outer side of the leg shell as shown below. These screws will be how you tension the belt between the motor pulley and the first shaft.

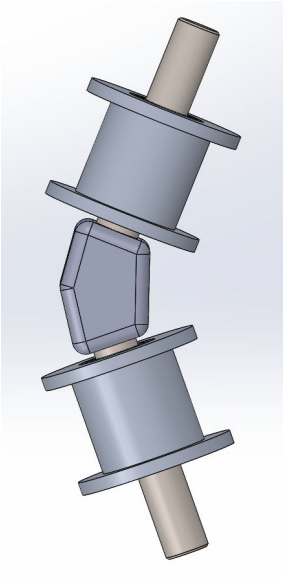


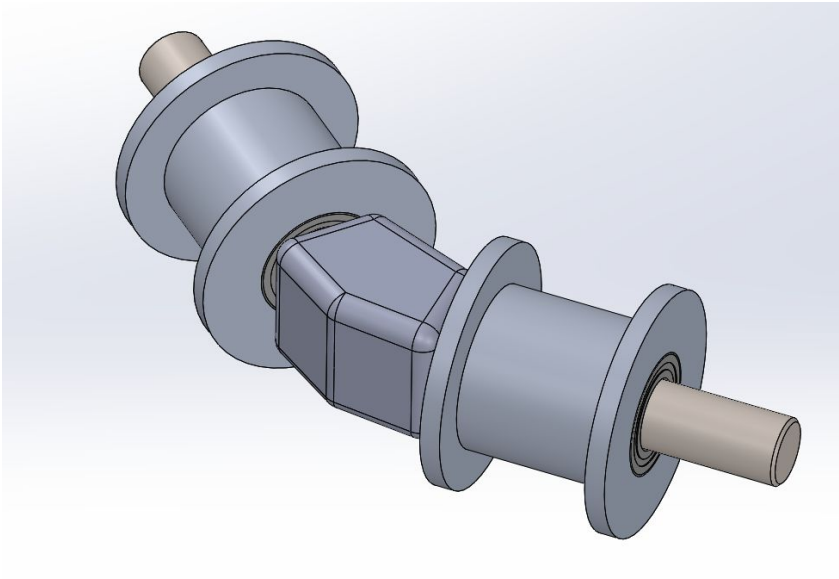


Upper Leg Assembly Step Seven:

Create the Idler Pulley Sub-Assembly

- Cut two pieces of 5mm Steel Shaft to a 30mm length
- Insert the shaft pieces into each side of the *Idler Bent Connector*
- Slide the Idler Bearings onto the two shaft pieces as shown below
- I suggest putting glue in the holes of the Idler Bent Connector before putting in the shaft so that they do not fall out later.

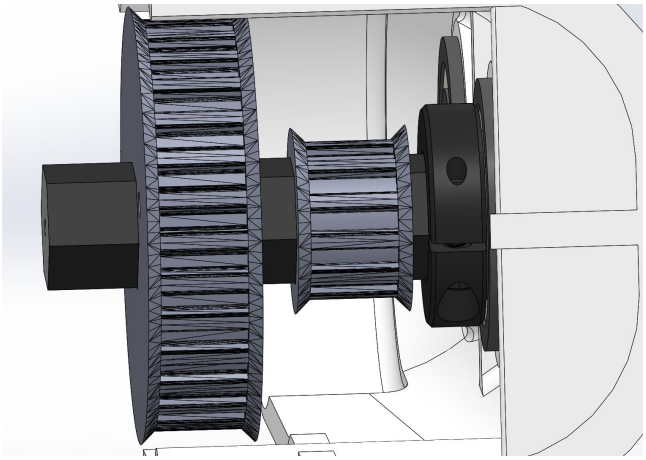


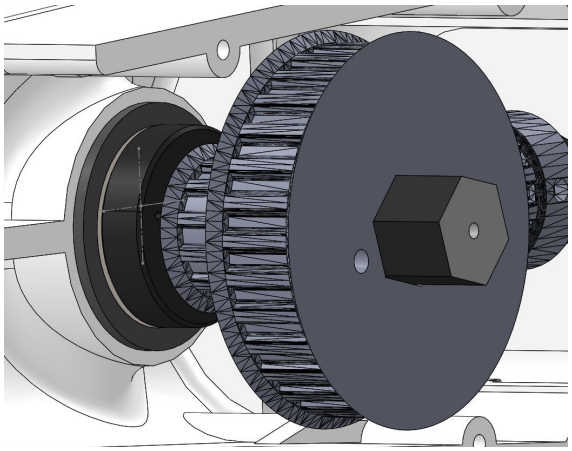


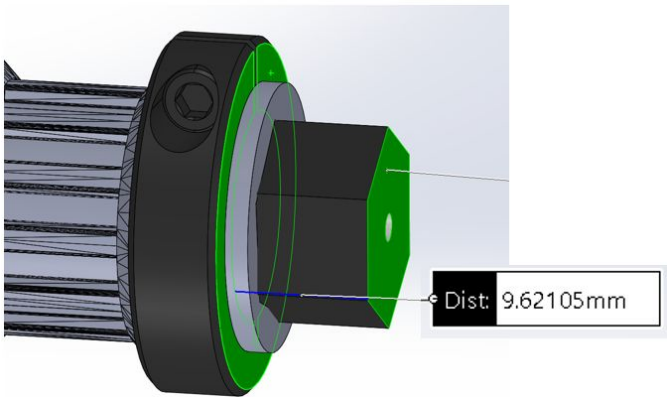
Upper Leg Assembly Step Eight:

Create the first stage pulley sub-assembly

- Cut a Piece of hex shaft to 58mm
- Clamp the shaft collar about 9.5mm from the end of the shaft as shown below
- Slide on the 12T Printed Pulley and the 30T printed pulley in the order shown below
- Add the 1.65mm spacer next to the shaft collar. This goes on the side that will face the bearing.



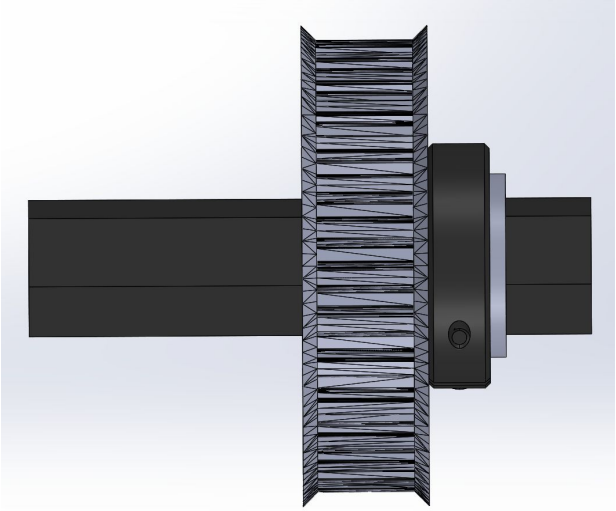


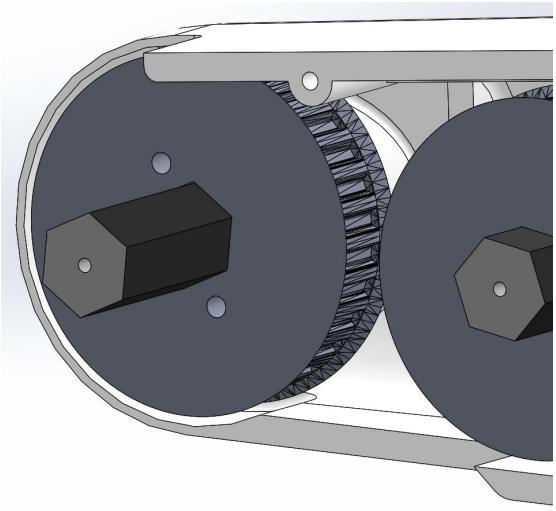


Upper Leg Assembly Step Nine:

Create the second stage pulley sub-assembly

- Cut a Piece of hex shaft to 58mm
- Clamp the shaft collar about 9.5mm from the end of the shaft as shown below
- Slide on the 30T printed pulley on the side shown below
- Add the 1.65mm spacer next to the shaft collar. This goes on the side that will face the bearing.

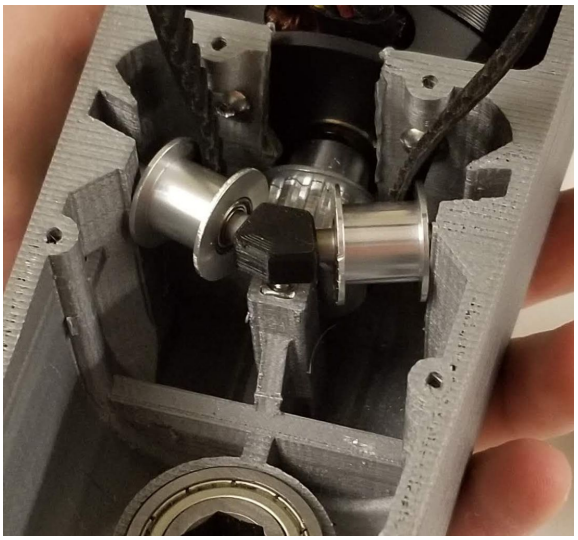
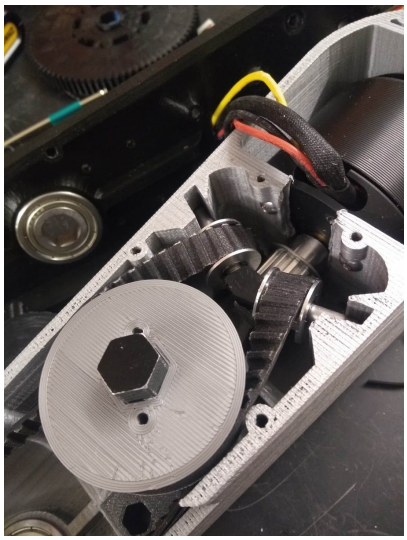
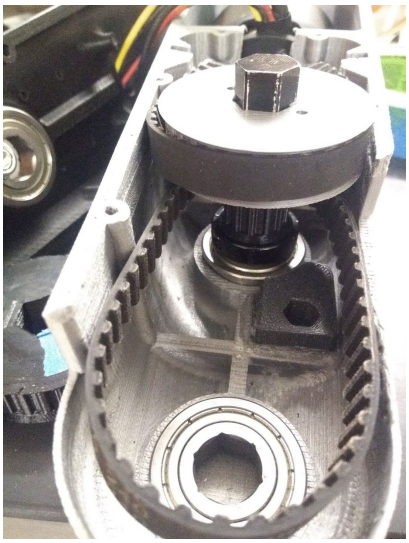
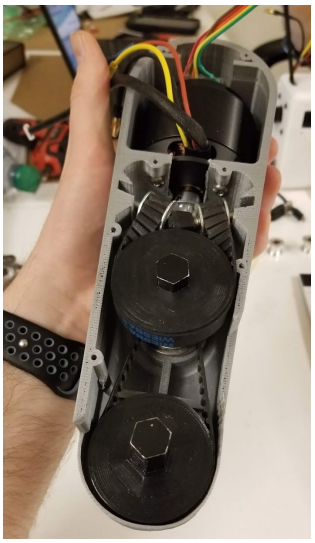




Upper Leg Assembly Step Ten:

Insert the sub-assemblies from the previous steps into the leg.

- Start by getting the first stage belt around the motor shaft. If the pulley on the motor shaft is not too far from the motor the belt can be slid around it.
- Then insert the Idler sub-assembly. Keep the screws tensioning the idler sub-assembly loosened.
- Insert the first stage pulley sub-assembly. Put the second stage belt around the 12T pulley before inserting so that it is ready for the next step.
- Wrap the belt over the idlers and around the 30T pulley as shown below.
- Insert the second stage pulley sub-assembly. The belt is supposed to be tight. You will have to get the belt from the 12T pulley around the 30T pulley of the second stage and then insert the shaft into the bearing.

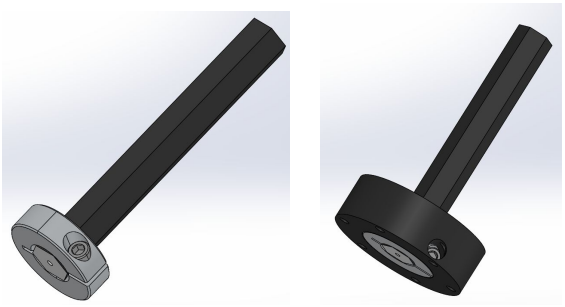
Upper Leg Assembly Step Eleven:

Prepare the cover with the Bearings.
Note: This will not be put on until after the lower leg assembly is finished and put onto the upper leg.


Upper Leg Assembly Step Twelve:

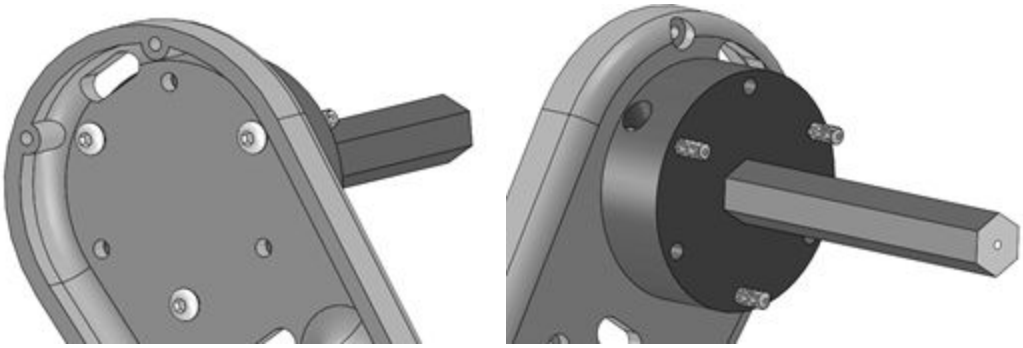
Prepare the hip shaft assembly.

- Connect the heavy duty shaft collar to the end of the the 94mm shaft. The collar should be flush with one end.
- Slide the shaft through the Leg to Hip Adapter print as shown below. If you'd like to be able to loosen the collar later you can line up the screw with the hole in the print. However, you probably will never do this. The collar will be very difficult to push into the print, this is on purpose so that it is a very rigid connection. Use an arbor press, clamp, or vise if you can.



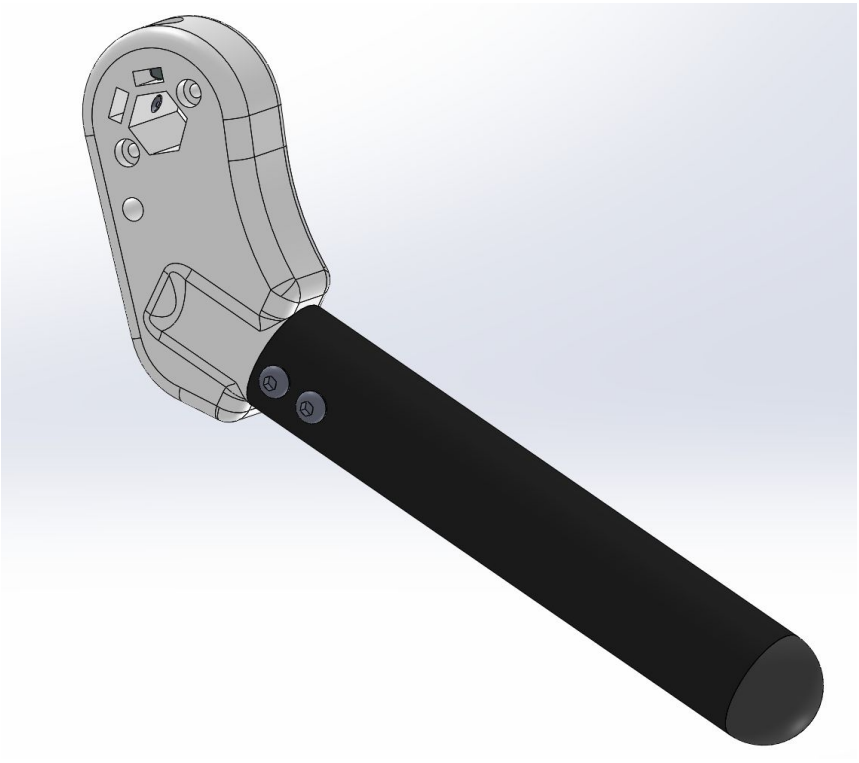
Upper Leg Assembly Step Thirteen:

Connect the leg cover to the hip shaft assembly. Use three M4x30mm screws. The screw heads face the inside of the leg shell as shown below. Insert them into three of the six holes spread out evenly as shown below. The other three screws will be put in later from the other direction when the gear is put on. (So that the two screw holes in the leg cover are still accessible for now)



All done with this assembly for now! Move on to the lower leg and then we will return to connecting the two.

Lower Leg Assembly:



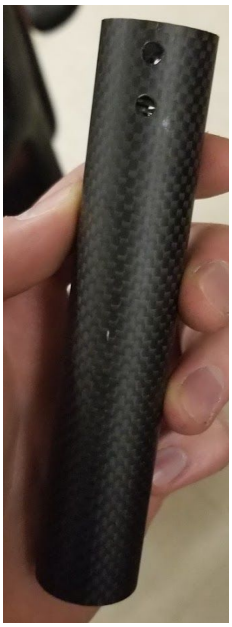
Parts needed for lower leg:

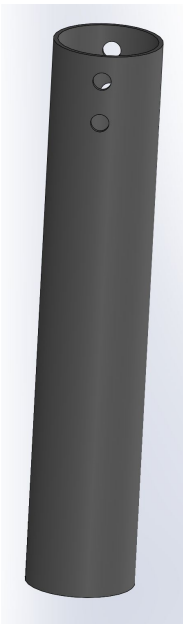
- **1x *LowerLegAdapter* 3D Print**
  - (PLA or PETG are sufficient for this, Nylon would be better)
- **1x *LowerLegFoot1* 3D Print**
  - I suggest using TPU for this part. If you can't get your hands on some flexible filament I suggest somehow trying to cover whatever you use in a rubber material
- **1x Carbon Fiber Tube of length 130mm, OD 25mm, ID 23mm**
  - I bought this tube on HobbyKing and cut it to length - https://hobbyking.com/en_us/carbon-fiber-round-tube-500x25x23mm.html
- **2x M4 x 45mm screw**
  - These screws are for strengthening the lower leg adapter, the length does not have to be exact
- **4x M4 x 10mm screw**
  - These screws are for connecting the carbon fiber tube to the lower leg adapter
- **6x M4 Square nuts**
- **1x 5mm steel shaft of length 30mm**

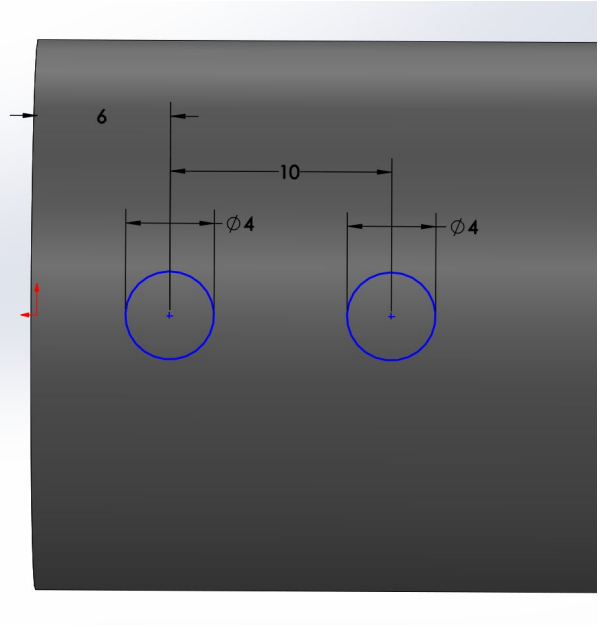
Lower Leg Assembly Step One:

Prepare the carbon fiber tube

- Cut the tube to a length of 130mm, look up how to cut carbon fiber tube if you haven't done it before
- Drill the two 4mm holes through the tube. The holes should be centered on the side of the tube, the holes are 10mm apart from each other and the first hole is 6mm from the end. Refer to the pictures below.



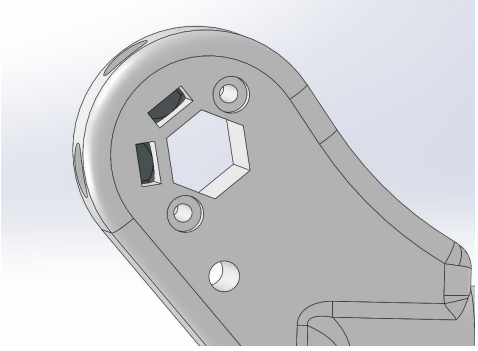




Lower Leg Assembly Step Two:

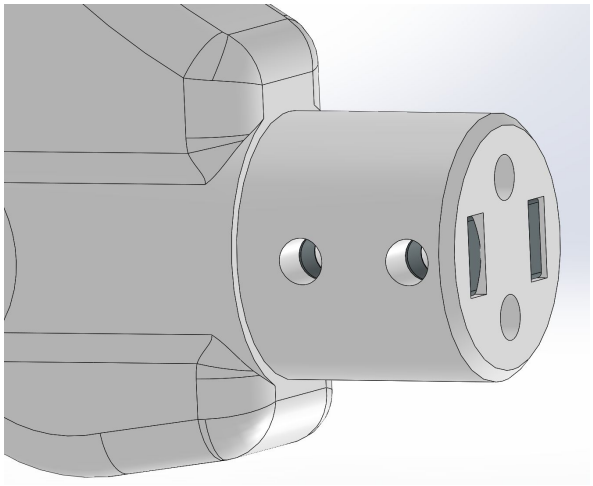
Insert the six M4 square nuts into the lower leg adapter 3D print

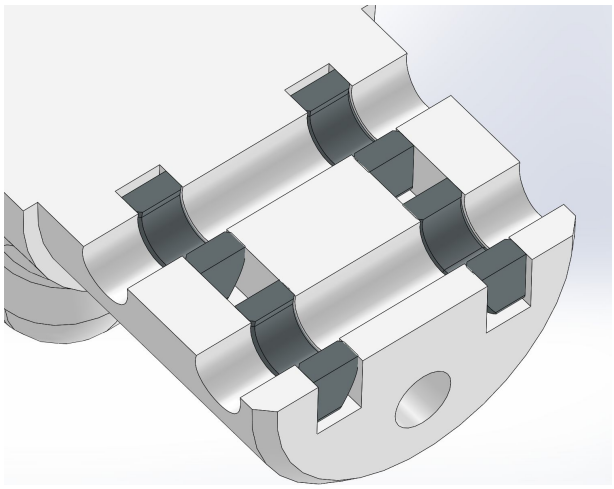
The first two nuts get slid into the side of the adapter until they line up with the holes as in the picture below



The next four nuts get slid into the circular part of the adapter until each one lines up with its respective hole. Slide in the deeper nuts first and use something like a hex key to push them until

they line up with the holes, once aligned, slide in the next nut until it lines up with its hole, be sure not to push it too far!

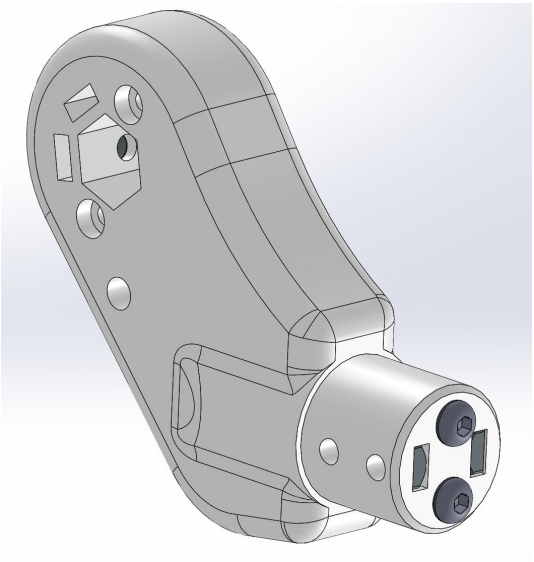


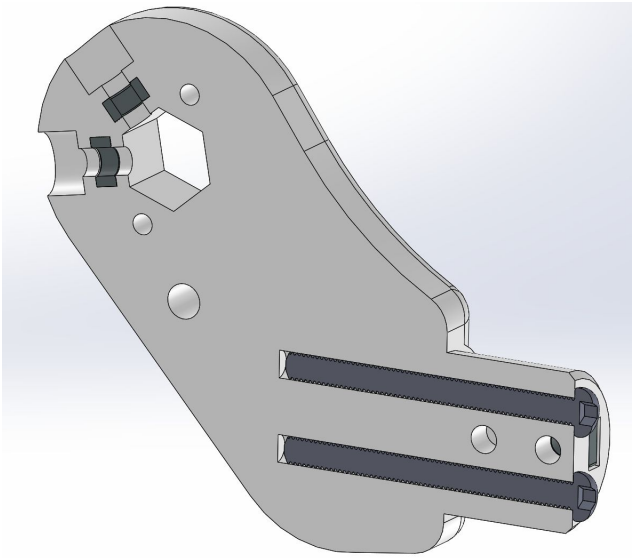


(Second picture is a section view to show nuts better)

Lower Leg Assembly Step Three:

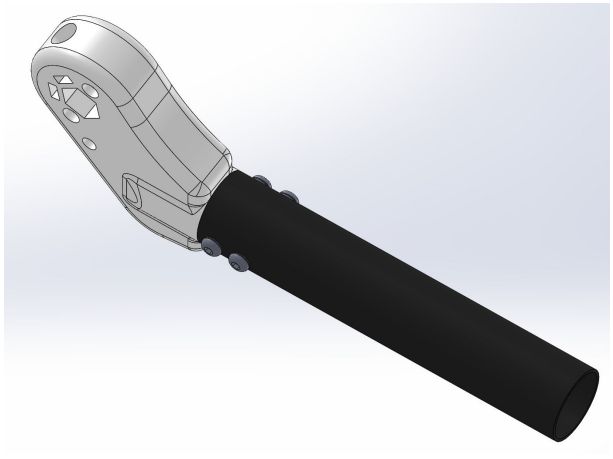
Screw in the two M4 x 45mm screws to the circular face of the adapter. These screws are for strengthening the plastic adapter.

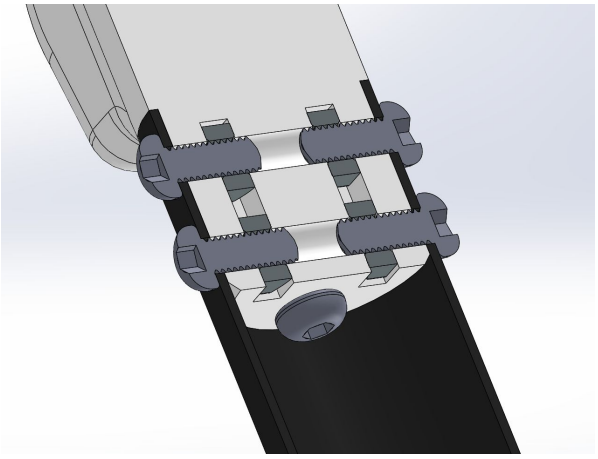




Lower Leg Assembly Step Four:

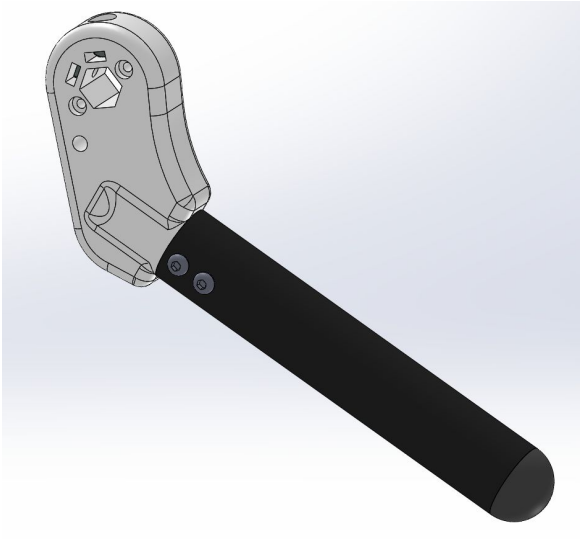
Attach the Carbon Fiber Tube to the lower leg adapter using four M4 by 10mm screws. I suggest using thread locker on these.

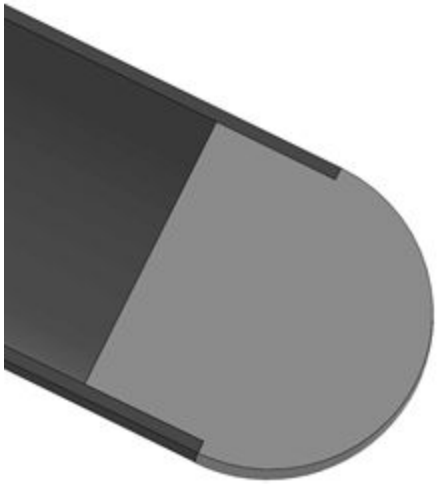




Lower Leg Assembly Step Five:

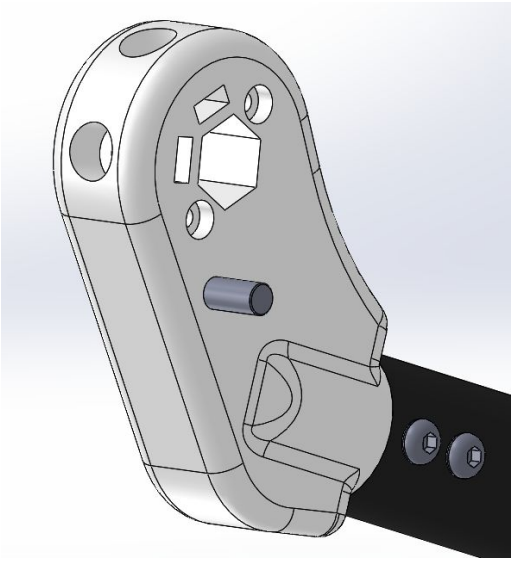
Insert the foot 3D print into the end of the carbon fiber tube. This should be a press fit. If the foot is too loose and slips out, try wrapping tape around the part that inserts into the tube until it causes a tight fit. Alternatively, you could glue the piece in but that wouldn't let you easily prototype new feet in the future.

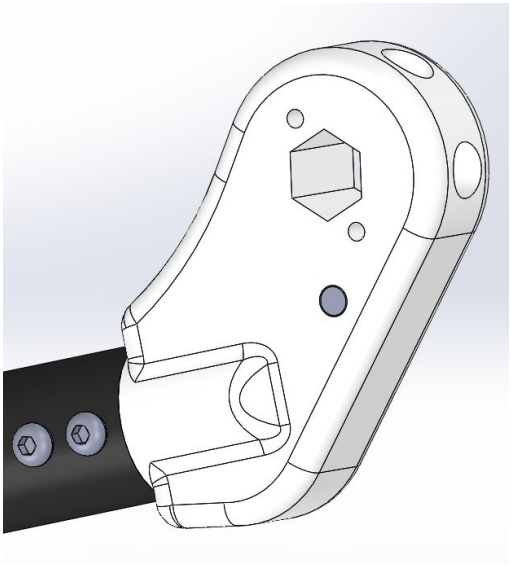




Lower Leg Assembly Step Six:

Press in the 5mm shaft to the side of the adapter. This should be a very tight press fit. This shaft acts as a hard stop in conjunction with the cut-out in the leg cover so that the lower leg does not crack the leg shell of the upper leg.





All done with the lower leg assembly! That was fast! Now let's connect it to the upper leg.

Connecting the Lower and Upper Leg Assemblies:

Parts needed for connecting the upper and lower leg:

- **1x *84T_SpurGear* 3D print**
    - (Use nylon if possible to last longer, I used PLA for Senior Design though)
    - OR - purchase the metal gear that this is based on from VEX - https://www.vexrobotics.com/1-2-hex-bore.html (84 Tooth Aluminum Spur Gear) It's slightly different but if you're making this project I trust you to figure out how to make it work. (It would be better than printing but too expensive for me to decide to use considering the print works well too).
- **1x *Leg_To_Hip_Adapter* 3D Print**
    - (PLA or PETG are sufficient for this)
- **3x M4 30mm screws**
    - These are for holding the upper leg to the adapter and 84T Spur gear. They are to reduce backlash by not allowing any of the 3 components to rotate independently due to play on the shaft.
- **7x M3 20mm screws**
    - These are for holding the cover to the shell.
    - For a very strong hold you can also thread in M4 Screws since the screws just thread into the 3D printed part. I suggest doing this if you will be taking them in and out multiple times.

Step 1:

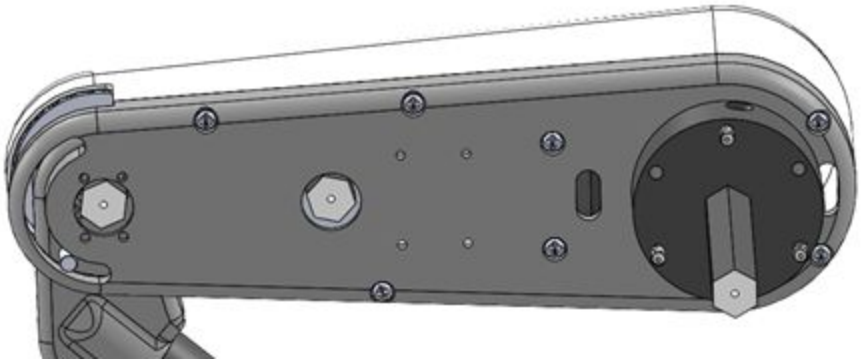
Slide the lower leg adapter onto the shaft of the second pulley stage as shown in the pictures. Be sure to line up the holes in the adapter with the holes in the pulley

Step 2:

Insert the screws that hold the lower leg adapter to the 30T Pulley. These screws are for reducing backlash. They ensure that the lower leg adapter and the pulley rotate the same amount regardless of whether each of them has any play on the shaft.

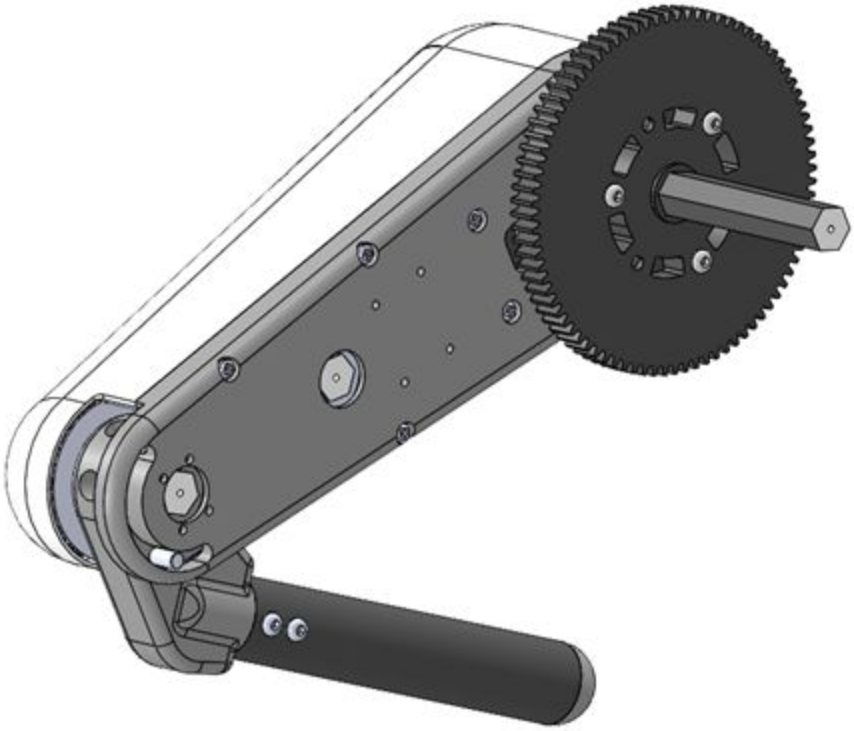
Step 3:

Connect the leg cover assembly. Make sure the motor wires and encoder wires are coming out of their respective holes in the cover.



Step 4:

Connect the 84T Spur gear as shown below. Slide the gear over the hip shaft with the small spacer extrusion facing away from the leg. Use three M4x30mm screws to hold the gear on, through the three unused holes in the leg to hip adapter.



The knee joint is complete! Not much fun with only one joint though, In the next section we will walk through building the hip joint.

Hip and Gantry Assembly:

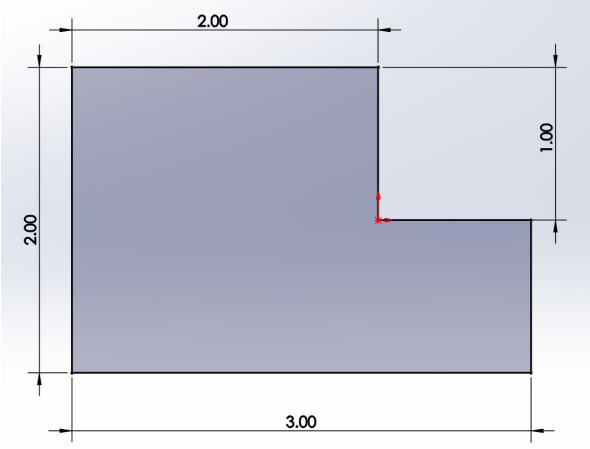
Parts needed for the hip

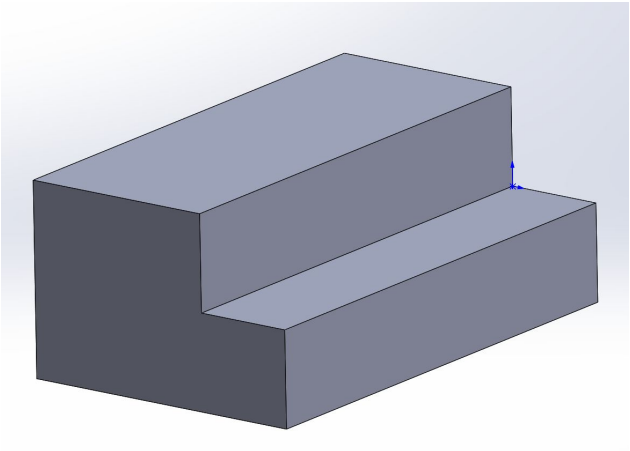
- **1x *Gantry* 3D Print**
  - (PLA or PETG are sufficient for this)
- **1x *Hip* 3D Print**
  - (PLA or PETG are sufficient for this)
- **1x AS5047D Magnetic Encoder development board**
  - I purchased this part from Digikey - https://www.digikey.com/product-detail/en/ams/AS5047D-TS_EK_AB/AS5047D-TS_EK_AB-ND/5125788
- **1x 6354 Size Motor**
  - I Suggest using the 50Kv Motor from FreeRCHobby - https://frchobby.en.alibaba.com/product/60468141915-803101590/New_Sealed_MP6354_Kv230_Motor_for_Electric_Skateboard.html
- **4x M2.5 5mm Screws**
  - These are for holding on the encoder.
- **4x M2.5 5mm Standoffs**
  - These are for holding on the encoder.
- **4x M2.5 5mm x 0.5mm washers**
  - These are for holding on the encoder.

- **4x M2.5 nuts**
    - These are for holding on the encoder.
- **4x M4 8mm screws**
    - These are for holding the motor in. Any screw length that holds well and doesnt hit the motor coils is fine
- **1x Diametrically magnetized magnet 6mm x 2mm**
    - This magnet is for the encoder to know what angle the joint is at. I purchased mine from DigiKey - https://www.digikey.com/product-detail/en/radial-magnet-inc/9049/469-1075-ND/6030786
    - Make sure the magnet is diametrically polarized, not axially polarized.
- **4x M4 Square nuts**
    - These are for holding the hip to the gantry
- **4x M4x35mm Screws**
    - These are for holding the hip to the gantry
- **1x 11T motor pinion gear**
    - I bought this from VEX - https://www.vexrobotics.com/20dp-motorpinions.html
- **1x Custom 3mm to 2mm shaft key**
    - This a custom made part to adapt the 3mm keyway in the motor shaft to the 2mm keyway in the pinion gear. I used a 2 axis mill to make this. I made it slightly oversized so that when the gear is pressed over it it is a press fit and does not require retaining rings. I milled it out of a larger steel key stock.
- **4x V-wheels**
    - I got these from ZYLTech - http://www.zyltech.com/zyltech-20-series-wheel-pulley-bearing-for-2020-aluminum-extrusion-v-slot-compatible/
- **4x M5x6mm Spacers**
    - For properly spacing the gantry from the linear rail
- **4x M5x1mm Washers**
- For properly spacing the gantry from the linear rail4
- **4x M5x50mm Screws**
    - For holding the V-wheels to the gantry
    - 50mm is only needed if you plan to attach a belt to the gantry to measure the height of the leg on the development stand, If you do not, they can be shorter.
- **4x M5 lock nuts**
    - For holding the V-Wheels to the gantry

Hip Assembly Step One:

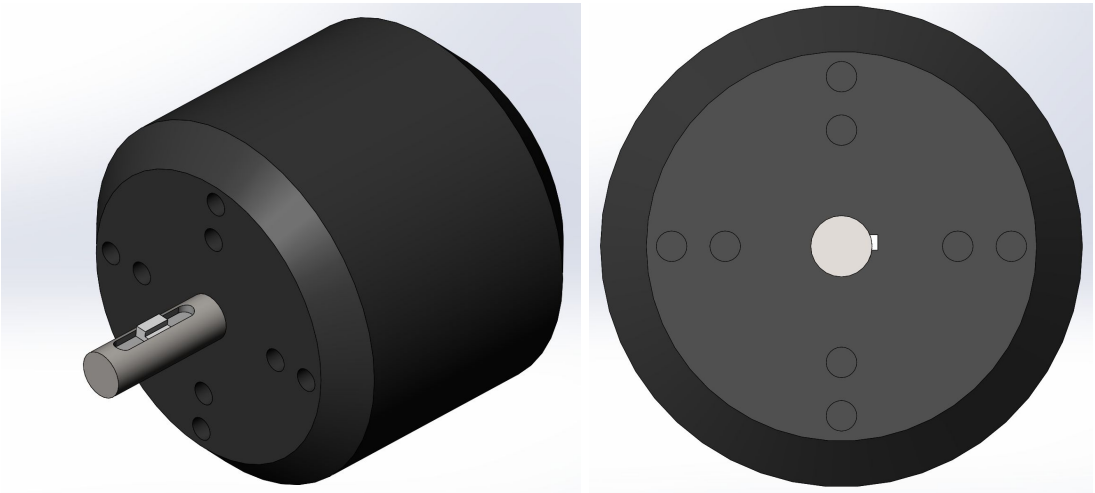
Create the 2mm to 3mm key for the motor shaft and insert the key onto the shaft





(Distances in mm) Make the key about as long as the keyway. These distances are estimated, When I made mine I milled it slightly oversized and the grinded it until the gear just fit by using a mallet to hit it onto the shaft.

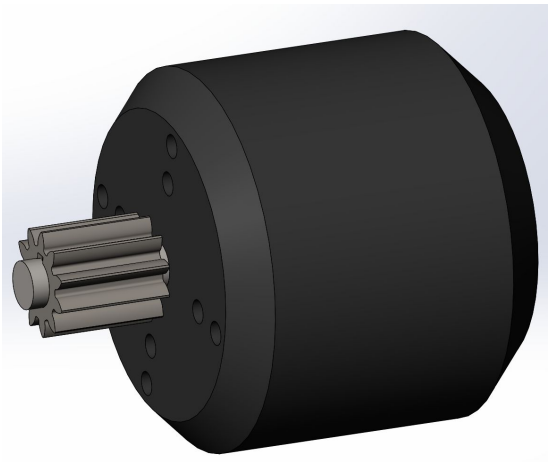
Press the key into the motor shaft using vice grips or pliers.

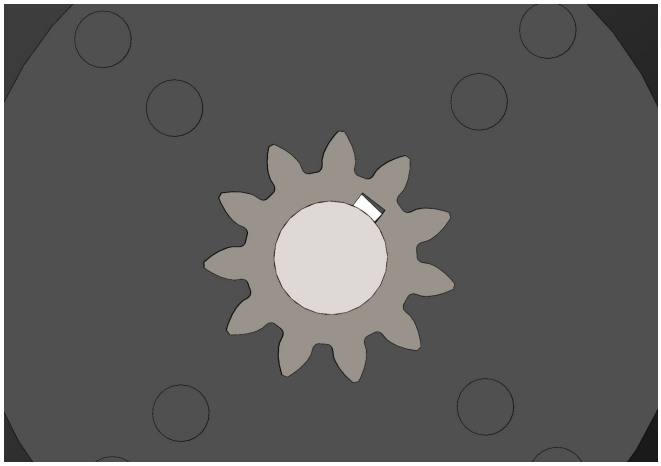


If you'd like to change the shape of the key to be a T shape instead of an L shape feel free to, I used an L shape because it was easier and the fact that the key was not centered on the shaft made the gear hold its place better.

Lower Leg Assembly Step Two:

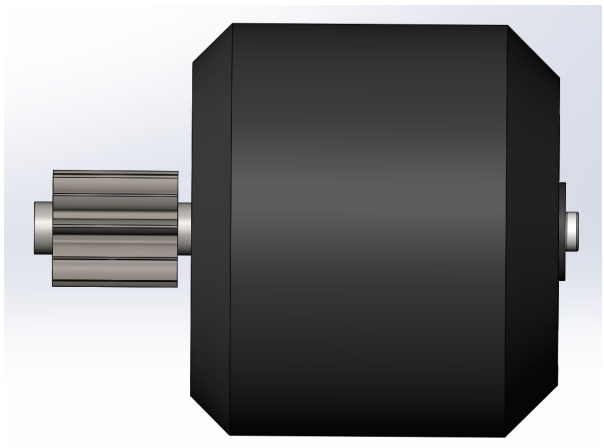
Install the pinion gear on the motor shaft. You will have to use a mallet or press if you have made the key to a press fit tolerance. If not, you will need retaining rings on each end of the gear. The 11T gear is wider than the 84T gear so there's not exact distance it has to be from the face of the motor.

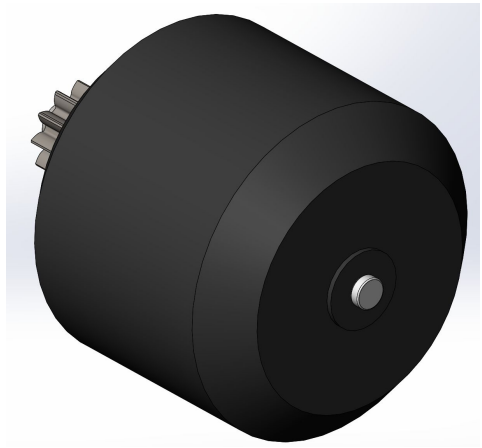




Hip Assembly Step Three:

Super glue or epoxy the magnet to the center back of the motor, same as for the previous motor. If you have to hammer the pinion onto the shaft make sure you do that step first.





Hip Assembly Step Four:

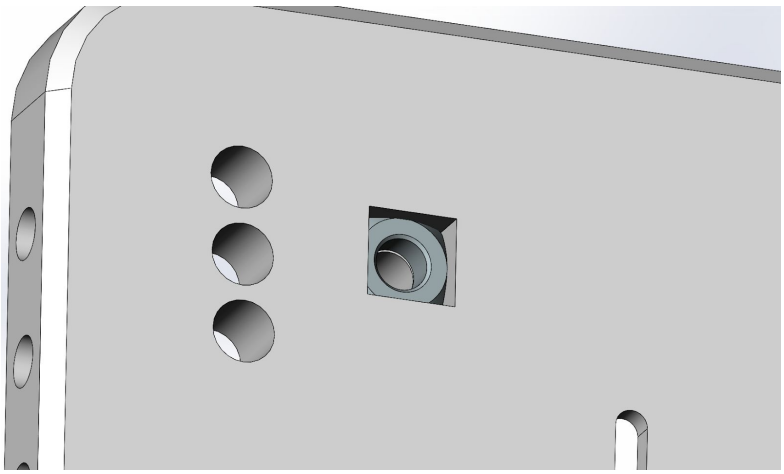
Attach the motor to the Hip 3D print using four M4x8mm screws as shown below. The Hip print has slots to adjust the gear center to center distance later if needed.

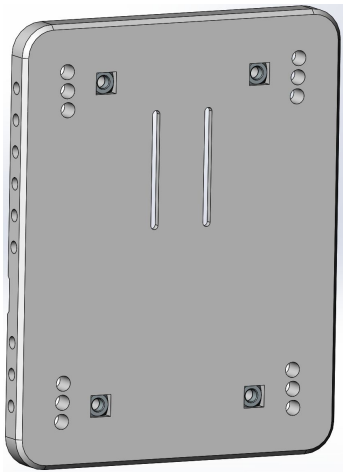
Hip Assembly Step Five:

Insert the two hex bearings into the Hip 3D print as shown below.

Hip Assembly Step Six:

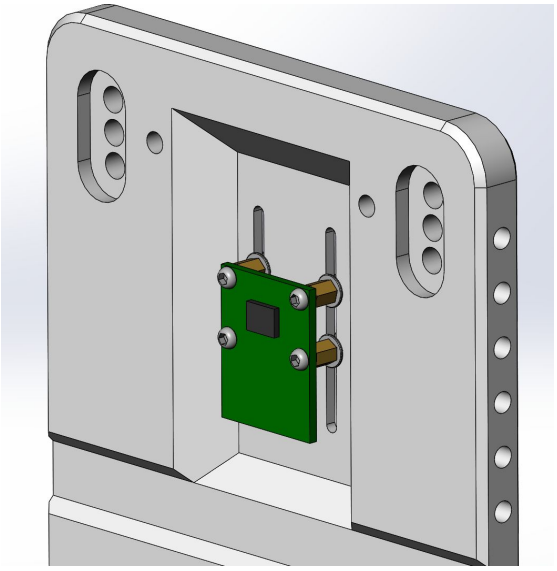
Press the four square M4 nuts into the Gantry 3D print as shown below. The print is designed for the nuts to be heated before being pressed in to slightly melt the plastic around them for a good hold.

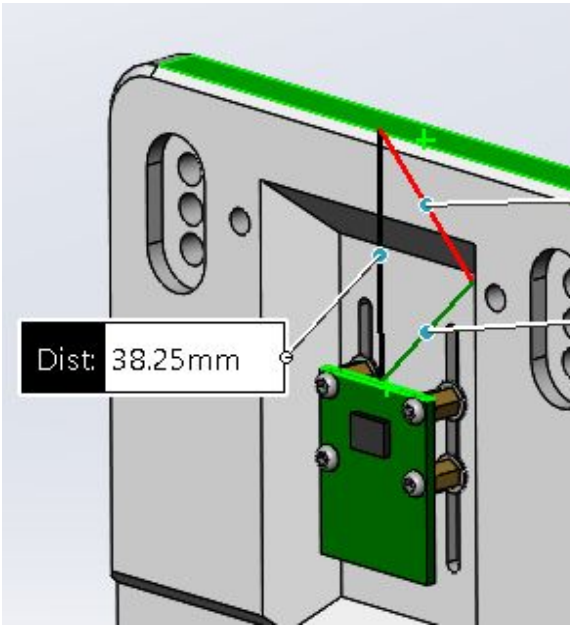




Hip Assembly Step Seven:

Attach the encoder to the Gantry 3D print using four M2.5x5mm standoffs, four M2.5x4mm screws, four M2.5 washers, and four M2.5 nuts. If you have the motor slid as far up on the hip as the slots allow, then the top face of the encoder should be 38.25mm from the top face of the Gantry as shown below. The same wires as the first encoder must be broken out (A, B, 5v, GND).



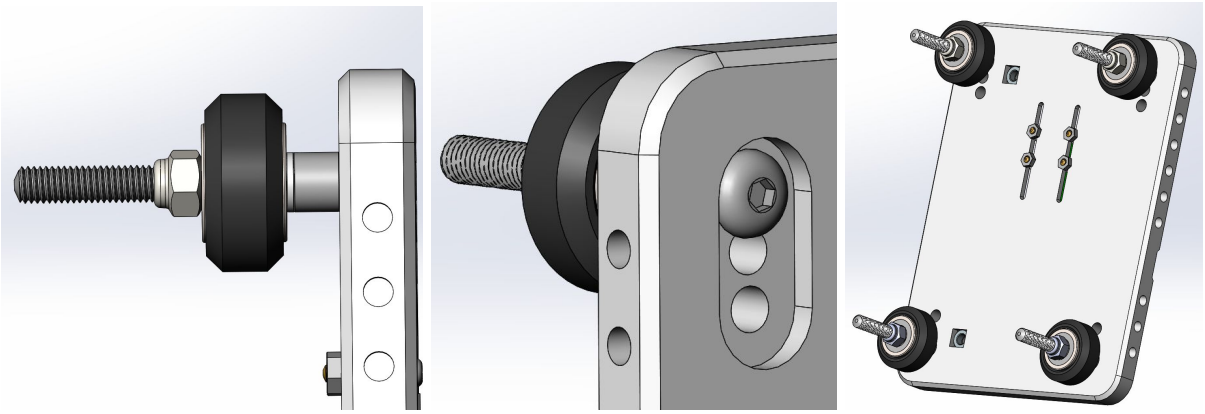


Hip Assembly Step Eight:

Attach the V-wheels to the Gantry as shown below. For this we will need the following:

- Four M5x50mm Screws
- Four 6mm M5 Spacers
- Four 1mm M5 washers
- Four M5 locknuts
- Four v-wheels

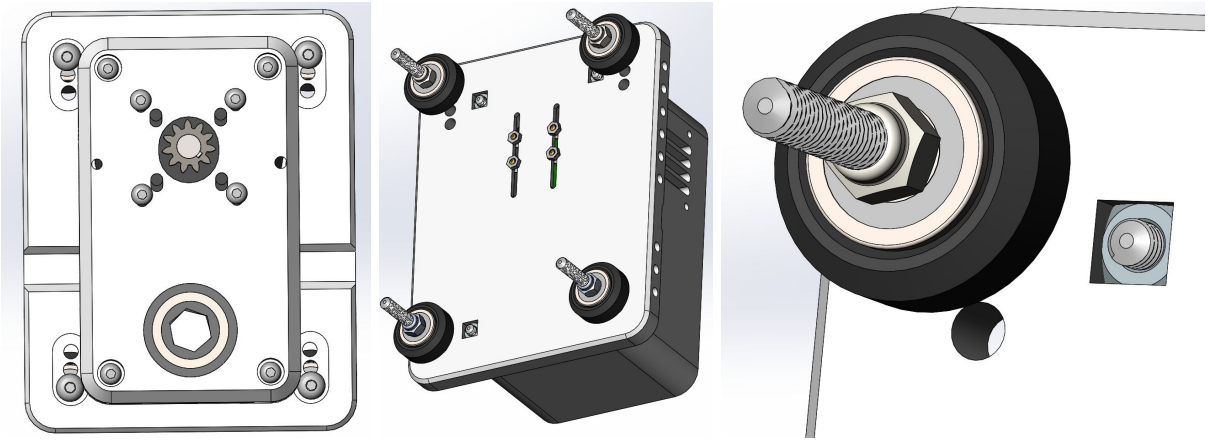
The 6mm Spacer goes on first, then the Washer, the v-wheel, and the locknut. If you want to use a 7mm spacer that's fine too, it is just less common to find at a hardware store so I used 6mm with a washer.



The three hole choices you have are for adjusting the spacing to get the right fit around the v-slot extrusion. The outer holes (the ones I used) are what the distance should be if everything is manufactured properly.

Hip Assembly Step Nine:

Connect the Hip Assembly to the Gantry assembly using four M4x35mm screws as shown.



Connecting the Leg to the Hip and Gantry:

- **1x Half inch hex shaft collar**
    - I bought these from VEX - https://www.vexrobotics.com/shaft-collars.html
    - Make sure to buy the standard size, not the high strength ones

Slide the hex shaft of the leg assembly through the bearings in the hip assembly. Before the shaft is all the way in, place the shaft collar where the shaft will come out of the second bearing so that the shaft slides into the shaft collar (much easier to do with the gantry detached from the hip).

When the shaft is through the shaft collar, tighten the shaft while making sure that there is no play back and forth axially on the shaft.

That's it! The leg is mechanically complete! If you plan to use it with the development stand continue to the next section.

Development Stand Assembly: (Mechanical Only)

Parts needed for Development Stand:

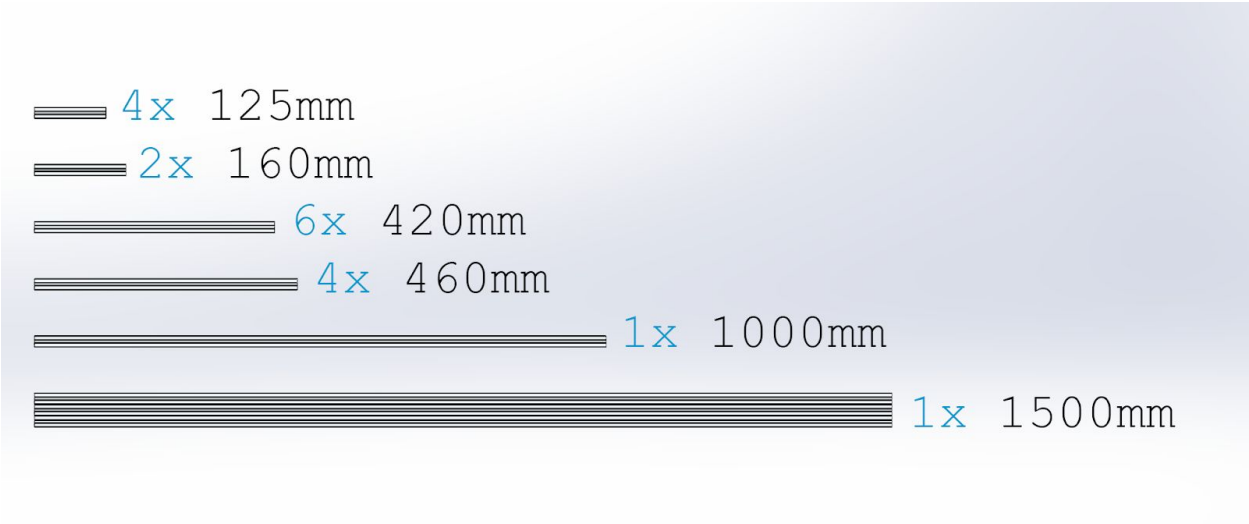
I got the T-slot and other 2020 hardware at ZYLTech - http://www.zyltech.com/store/aluminum-extrusion-hardware/2020-t-slot/

- **4x 460mm 2020 T-slot**
- **6x 420mm 2020 T-slot**
- **4x 125mm 2020 T-slot**
- **2x 160mm 2020 T-slot**
- **1x 1000mm 2020 T-slot**
- **1x 1500mm 2060 V-slot**
    - (Note: this is 20mm x 60mm V-Slot, not T-slot)
    - I got this from Amazon - https://www.amazon.com/V-Slot-Linear-Rail-1500mm-Length/dp/B00YCOQOUU/ref=sr_1_1?keywords=v-slot+linear+rail+1500mm+60mm&qid=1568693556&s=gateway&sr=8-1
- **46x 2020 T-slot Corner Bracket**
    - This would be the best amount. However I used less for cost reasons, I'll let you decide where to leave them out if you use less. I also 3D printed some of mine to save cost.
- **112x M4x8mm Screws**
    - This number will depend on how many corner brackets you choose to use
- **112x M4 2020 T-slot Sliding Nuts**
    - This number will depend on how many corner brackets you choose to use
    - Called Hammer Nuts at ZYLTech
- **1x 460mm Square sheet of pegboard**
    - This will be for mounting the power supplies to.
- **1x 460mm x 200mm Sheet of ⅛ inch plastic, Polycarbonate or ABS**
    - I had to use Acrylic for this because it's what I had. Acrylic is very brittle though.
    - Keep in mind you will need a laser cutter or water-jet cutter or router for this part, if you don't have access to one of these and don't want to cut it by hand then you might want to get creative with this part.
- **1x 6in x 18in metal sheet.**
    - Ideally this would be 460mm instead of 18in but I used what I could find at a hardware store in the US for this.

The mechanical assembly of the development stand is fairly straightforward so this section will mostly consist of renders of the final product rather than incremental steps showing it built up.

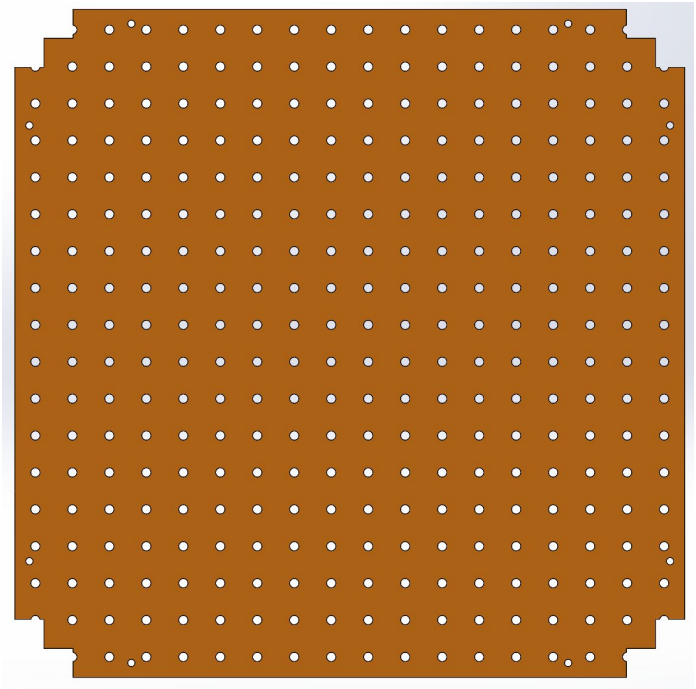
I do not remember the order that I assembled the pieces in, nor would I claim that there's any one best way to assemble them anyway.

Start with cutting all of the 2020 T-slot pieces as shown below



Prepare the pegboard

The pegboard is 460mmx460mm, note the extra holes drilled near the corners for mounting it to the Frame. These holes should be 10mm from the edges and fit an M4 screw.

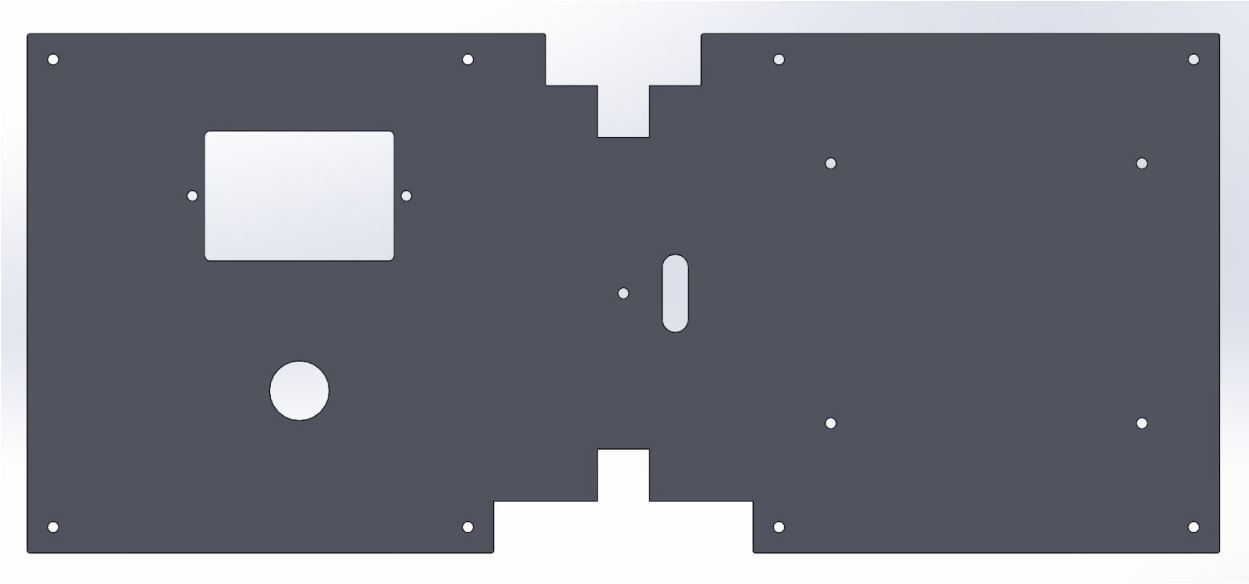


Prepare the Metal Plate

Drill four holes in the plate for mounting to the frame. If you are using an 18inch plate, the holes must be 9.95mm from the right and left side shown below to match up with the frame.

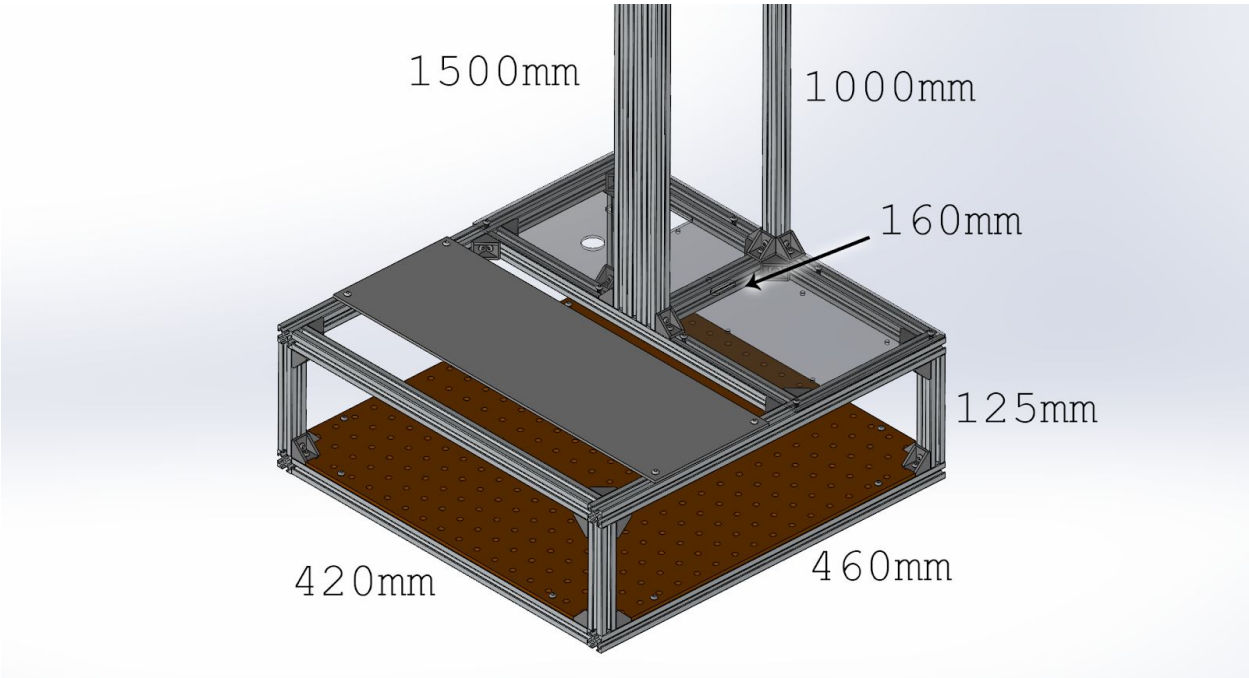
Prepare the Plastic Plate for holding the electronics:

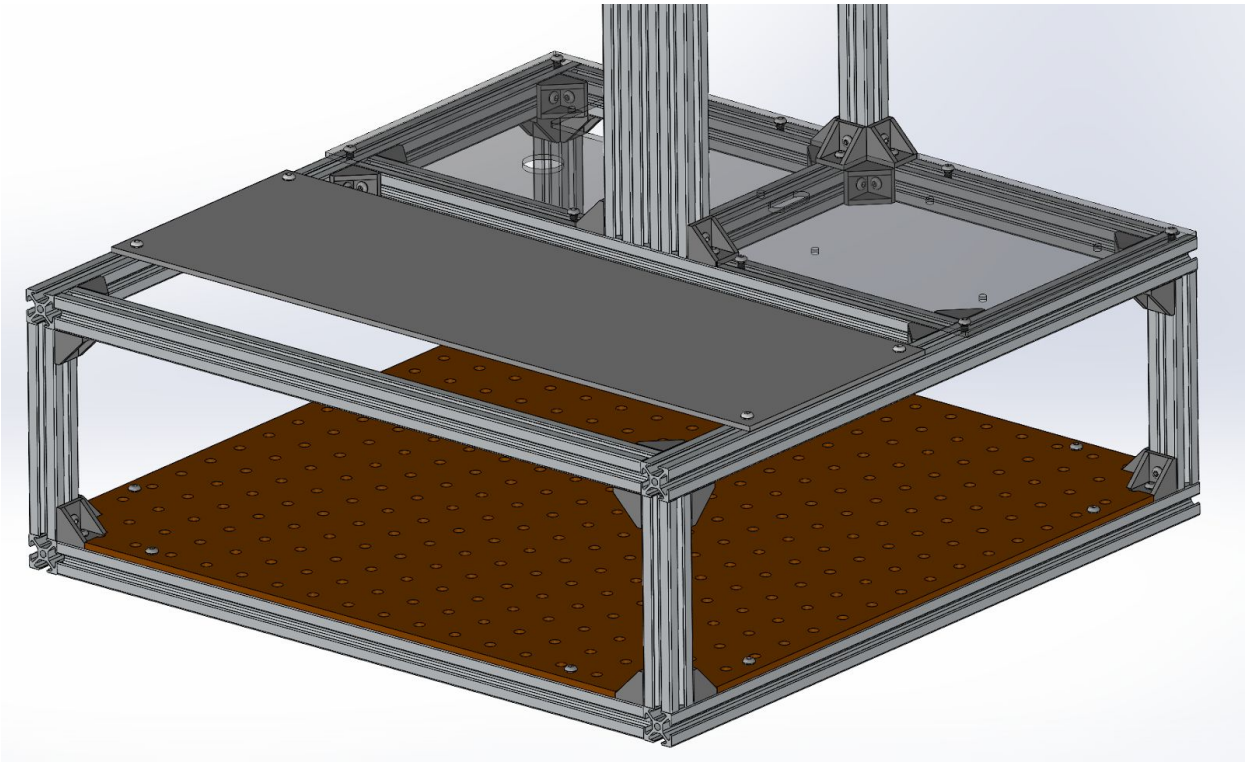
Using the Plastic Cover STEP file on GitHub, cut the following shape out of a plastic sheet approximately ⅛ inches thick.

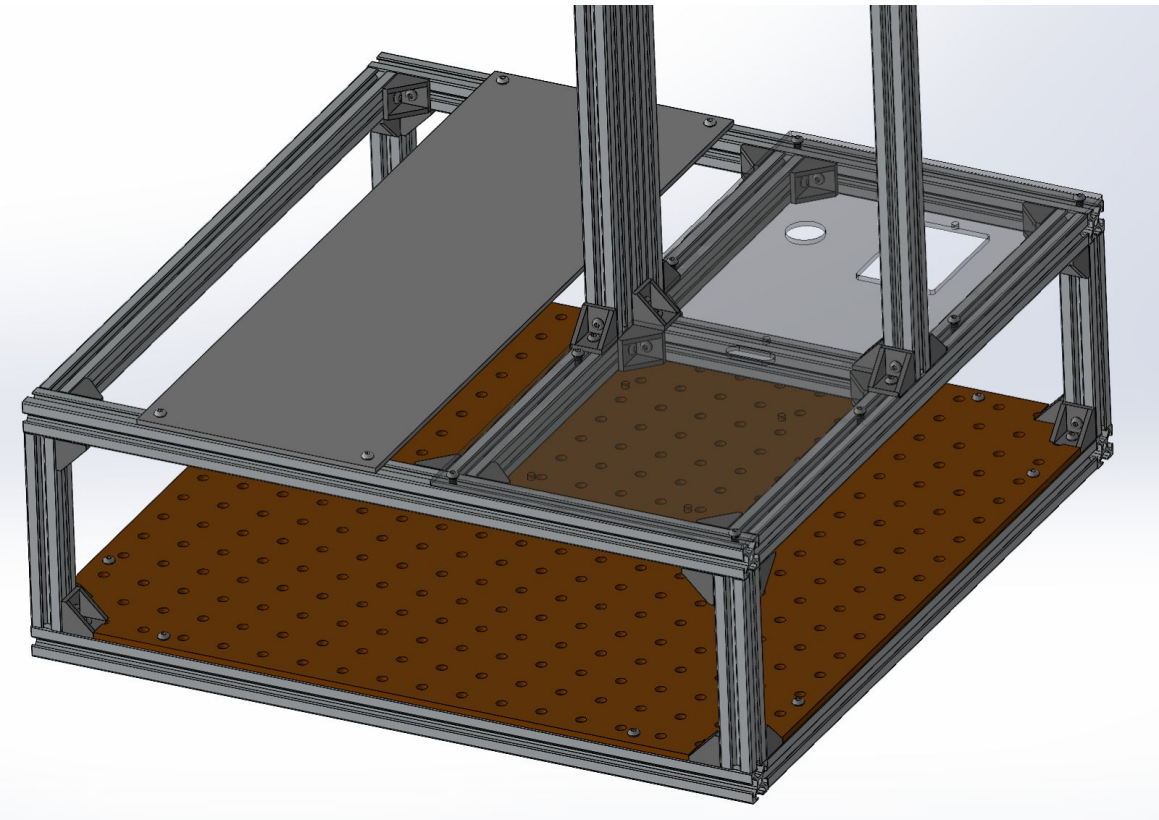


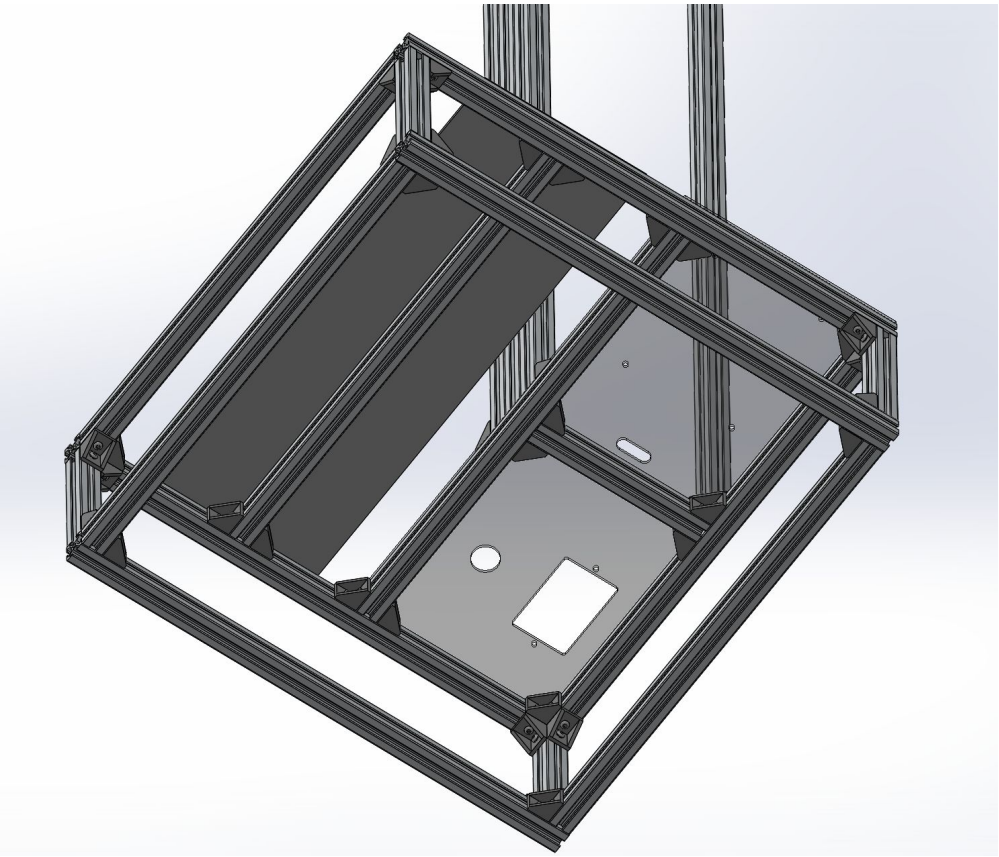
Using the hardware listed in the parts needed section, assemble the following Frame.

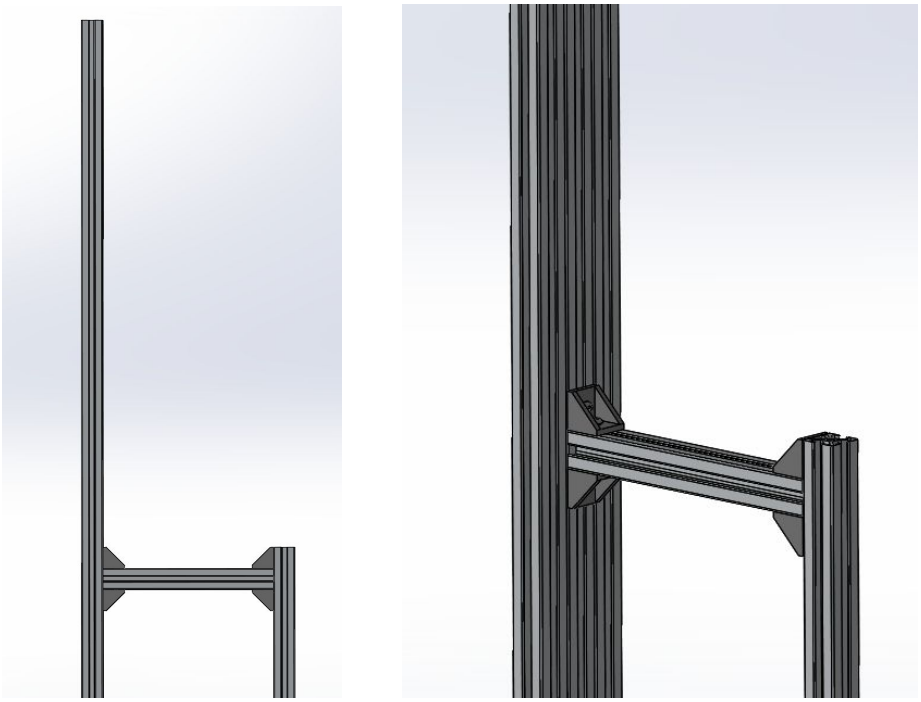
If you have gotten to this step and would prefer a step by step guide here, let me know and I will be happy to make one.



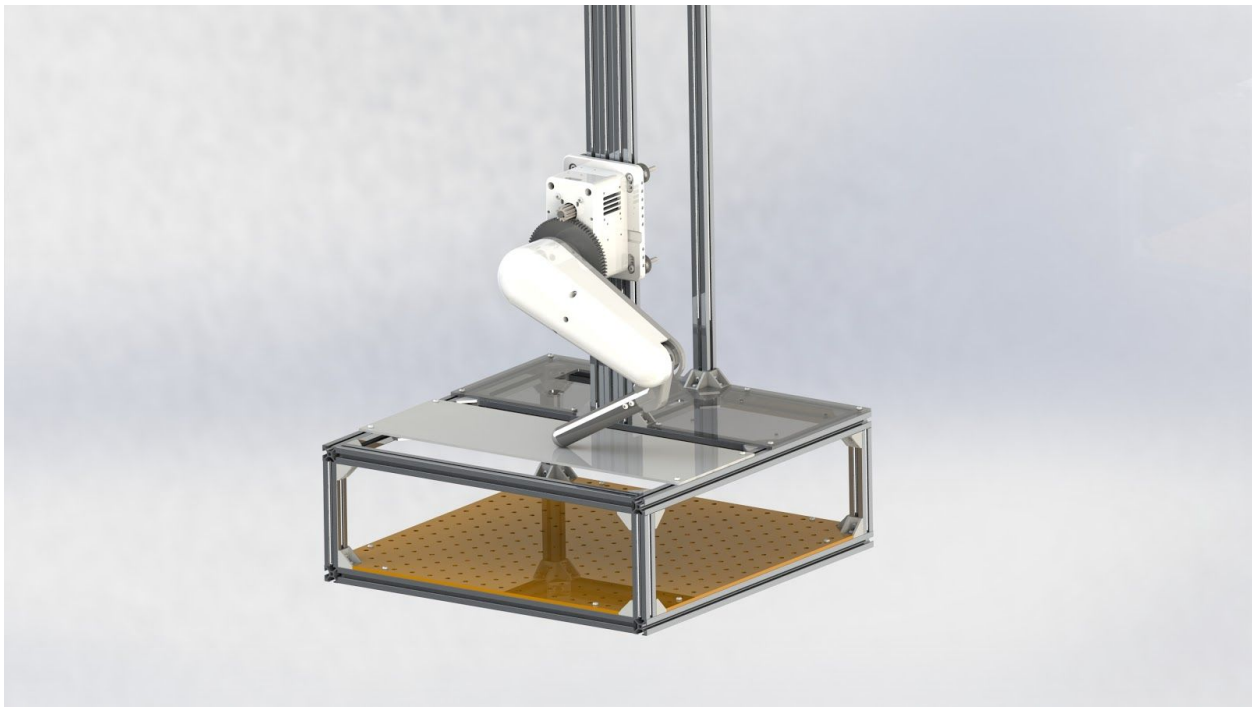








Your Assembly should now look something like this:



Congratulations! You have finished the base mechanical assembly of the project! Now you're ready to create the electronics and wire everything. That section of the guide will be coming soon.