Realistic Movement of Robotic Hands

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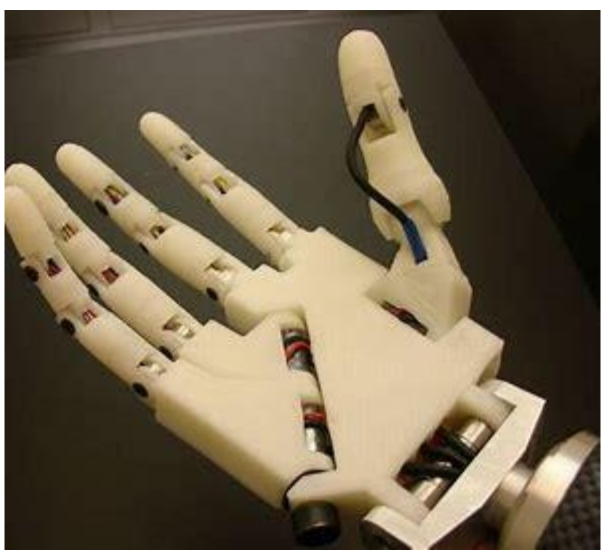
Goal

The goal of this project is to redesign an open-source robotic limb which was a section of the InMoov project designed by Gael Langevin.

Summary of InMoov Project:

The InMoov Project is an open-source 3D printed life-sized humanoid robot. This project is broken down into smaller sections starting with one finger moving to the hand, wrist forearm and so on. Specifically, up to the forearm was built before this project to give insight on robotic prosthetics. The prosthetic worked by using six large metal gear servos, (4 DS3235sg and 2 MS24) one of which was set in the wrist and the other five are used for operating the fingers. Other than the motors, the screws and the cord each part is 3D printed and glued together. The movement of the hand is caused by cords or 'tendon strings' which are anchored in the tips of the fingertips by superglue. Pulling on one end of the string will pull the finger into a closed position and pulling on the other end will pull the finger into an open position. These strings are to simulate a tendon-like system to give more natural movement. The tendon strings are then fed through the wrist and tied to five 3D printed disks which connect to the servo horns to connect the tendon strings to the motor. This lets the motors open and close the fingers by turning the disks to either the left or the right. Separately, the wrist is moved by a set of two 3D printed gears where one is glued to a servo horn and attached to the wrist servo directly. All the motors were then driven by an Arduino uno with a servo shield attachment and a power supply to power the motors directly.



The redesign can be broken down into two main challenges from the previous design. The first being the unpracticality of replacing the strings when broken. The motors in the previous design are oriented in different positions which caused many of the tendon strings to break. If a tendon string were to break the entire finger would have to be reprinted and replaced as well as the disk must be reoriented to avoid future breaks. Therefore, the first goal was to create a way to anchor and access the tendon strings by replaceable means. These means will consist of removable parts and a non-permeant anchor for the tendon strings. The second challenge was the linearity of the finger movement. The original model consisted of finger joints that only moved in one direction. This worked function wise but offered a lack of realism and a ridged robotic movement. The second goal of the project was to recreate specifically the Metacarpophalangeal joint in each finger to create and prove a more realistic multidimensional movement. To prove the movement smaller MG90S metal gear servos will be used, and an extra motor and tendon string will be added to each finger to attempt to create multi-axis movement.

List of Parts

MG90S Metal Gear Servos
Yonex Titanium Badminton String BG 65 TI
Overture PLA 3D Printer 1.75mm Filament

Thumb:
- Thumb Tip V2-1
- Thumb Tip V3-2
- Thumb Section 2 V1-1
- Thumb Section 3 V1-2
- Thumb Section 3 V2

Pointer:
- Pointer Finger Tip V6-1
- Pointer Finger Tip V7-2
- Pointer Section 2 V6
- Pointer Section 3 V4-1
- Pointer Section 3 V6-2
- Pointer Section 4 V3

Middle:
- Middle Finger Tip V1-1
- Middle Finger Tip V1-2
- Middle Section 2 V1
- Middle Section 3 V1-1
- Middle Section 3 V1-2
- Middle Section 4 V1

Ring:
- Ring Finger Tip V1-1
- Ring Finger Tip V1-2
- Ring Section 2 V1
- Ring Section 3 V1-1
- Ring Section 3 V1-2
- Ring Section 4 V1

Pinky:
- Pinky Finger Tip V1-1
- Pinky Finger Tip V1-2
- Pinky Section 2 V1
- Pinky Section 3 V1-1
- Pinky Section 3 V1-2
- Pinky Section 4 V1

List of Protype Versions

Finger Tip V1
Finger Tip V2
Finger Tip V3-1
Section 3 TEST
Section 3 V1
Section 3 V2-1
Thumb Tip V2-2
Thumb Tip V3-2
Thumb Section 2 V1-1

Finger Tip V4-1
Finger Tip V5-1
Finger Tip V6-1
Finger Tip V3-2
Finger Tip V4-2
Finger Tip V5-2
Finger Tip V6-2
Finger Tip V7-2
Section 2 V1
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Section 2 V3
Section 2 V4
Section 2 V5
Section 2 V6
Section 3 V3-1
Section 3 V4-1
Section 3 V2-2
Section 3 V3.1-2
Section 3 V3.2-2
Section 3 V4-2
Section 3 V5-2
Section 3 V6-2
Section 4 V1
Section 4 V2
Section 4 V3
Thumb Tip V1-1
Thumb Tip V2-1
Thumb Tip V1-2
Thumb Section 2 V1-2
Thumb Section 3 V1
Thumb Section 3 V2

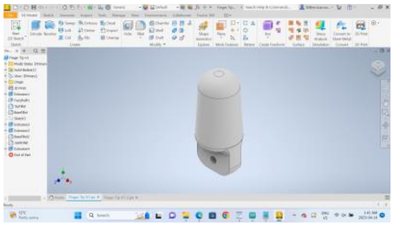
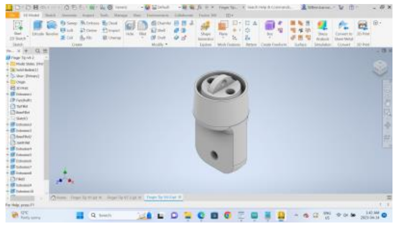
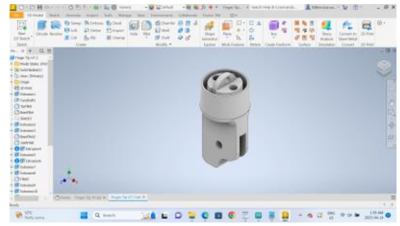
Middle Scale V1
Ring Scale V1
Pinky Scale V1

Budget

MG90S Metal Gear Servos in Packs of 8 Yonex Titanium Badminton String BG 65 TI Total	24 9g servo (3 X 8 pcs = 3 X 34.99) - $ 104.97 1 badminton string spool - $25.45 before tax/shipping - $130.42

Design Process

The robotic hand followed a step-by-step design process where a general sketch of a skeletal human hand, with measurements, was used to design a rough undetailed design. These designs were then 3D printed and tested for fitment and possible improvements. The next version of each part starts identical to the last then changes are saved as the next version. The version number only increases after the new design is printed and the changes are made physical. This makes multiple changes easily recorded in the Inventor file itself. The version numbers start at V1 and increase till a split is made in the design where the version number becomes V3-1 and V3-2. The first number indicates the version number and the second indicates the split subsection, being either 1 or 2. TEST indicates the one version that was not printed which was a trail of certain functions needed to make section 3 V1. Section 3 also introduced V3.1-2 and V3.2-2 which were two V3s made in tandem to test a very slightly different design. Finally, Scale shows the versions that had no other changes other than size scaling of the final versions of the pointer finger. The design process was implemented in a timeline with 5 stages to yield a significant result at the end of each stage.

Timeline

Stage 1:

- Test SG90 metal gear servos
- List of parts for budget
- Reach out to genesis robotics
- Start initial design of pointer finger

Stage 2:

- Finish design of pointer finger
- Build / 3D print pointer finger
- Test movement of pointer finger
- Redesign and repeat till refined

Stage 3:

- Design of thumb
- Build / 3D print thumb
- Test movement of thumb
- Redesign and repeat till refined

Stage 4:

- Scale pointer finger to make middle, ring, and pinky finger
- Build / 3D print middle, ring, and pinky finger
- Design palm and palm constraints
- Test movement of all Fingers
- Redesign till finished product

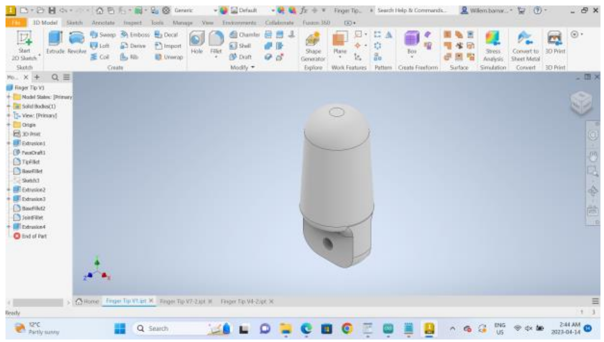
Stage 5:

- Design of wrist
- Build / 3D print wrist
- Test movement of wrist
- Redesign and repeat till refined
- Incorporate into existing InMoov forearm system

Change Log

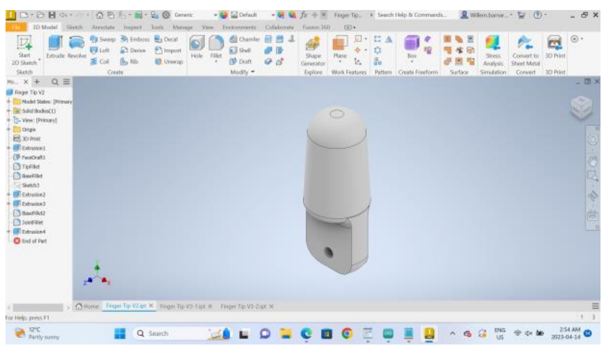
Finger Tip

Finger Tip V1



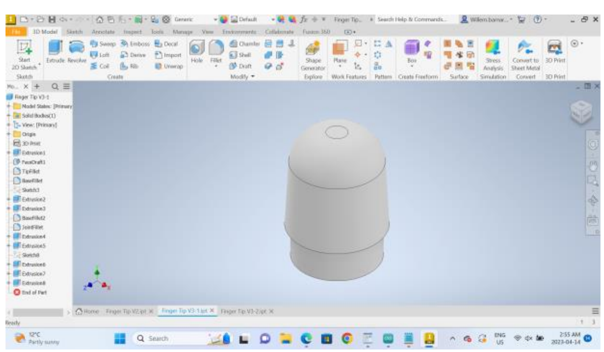
Initial design is based on skeletal fingertip while joint draws inspiration from linear InMoov finger joints. This model does not have many of the necessary features since it focusses on testing joint fitment.

Finger Tip V2



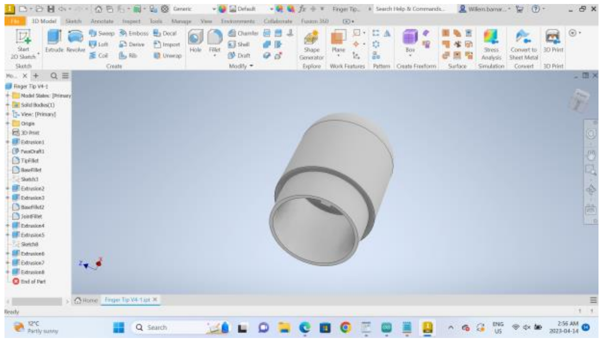
First change to the fingertip added 5mm to the joint extrusion to give space for the finger to move freely while still lining up the join holes.

Finger Tip V3-1



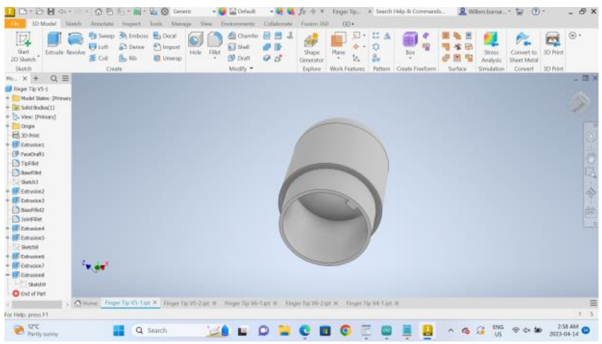
Next, I split the fingertip into two separate sections. The split is 15mm from the top of the fingertip. A lip is also added to connect the two pieces.

Finger Tip V4-1



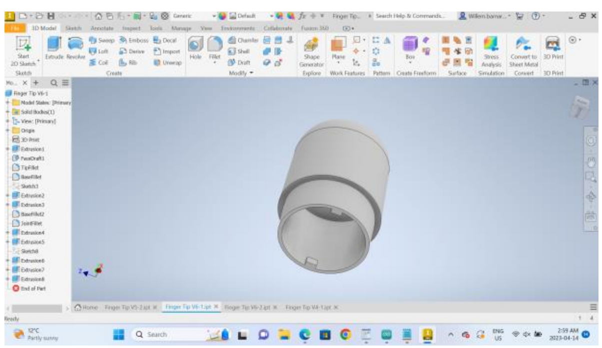
A locking tab is added to pair with the slot locking mechanism on Finger Tip V4-2. Tab is 0.5mm by 1.5mm by 1mm.

Finger Tip V5-1



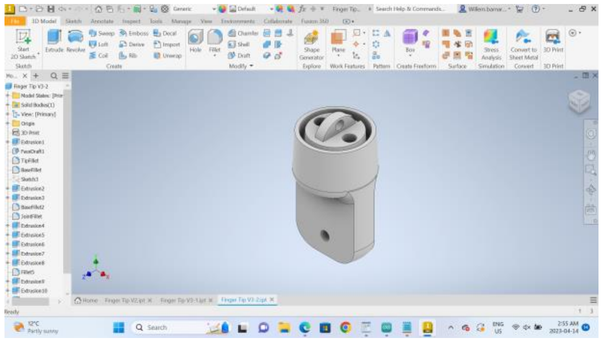
Locking tab is improved by extending inwards 0.75mm instead of the previous 0.5mm changing parameters to 0.75mm by 1.5mm by 1mm

Finger Tip V6-1



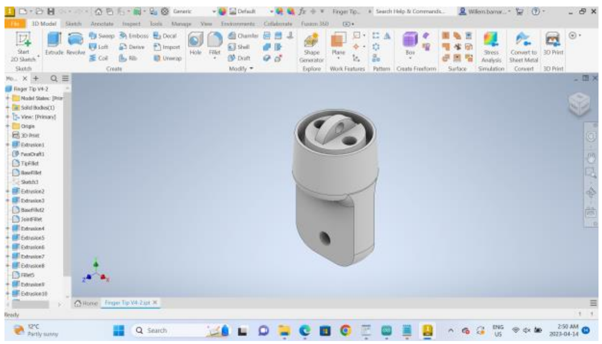
The second locking tab is added on opposite sides to give a more secure and even lock. This is the final change to this part.

Finger Tip V3-2



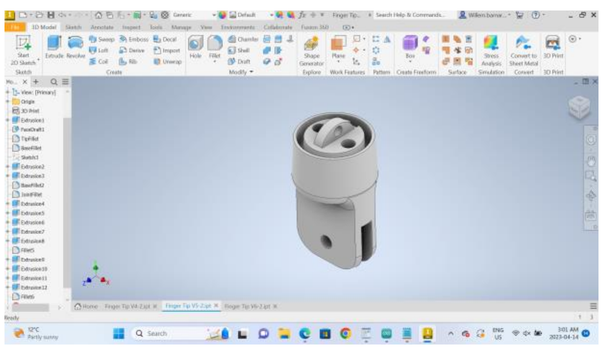
Slot locking mechanism is added which is an extrusion down and then an extrusion to the left to create a physical lock. An anchor is also added for the string to loop around to prevent slipping.

Finger Tip V4-2



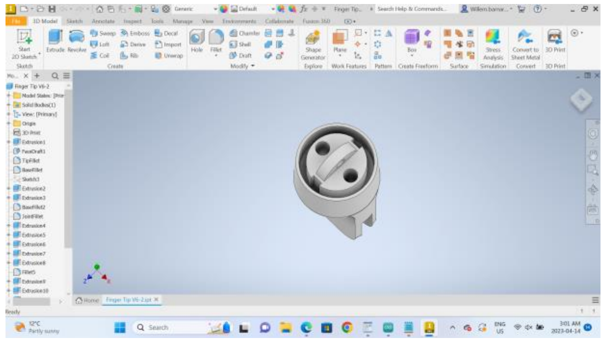
Joint hole is changed to a 2.5mm diameter to use section of filament as pins.

Finger Tip V5-2



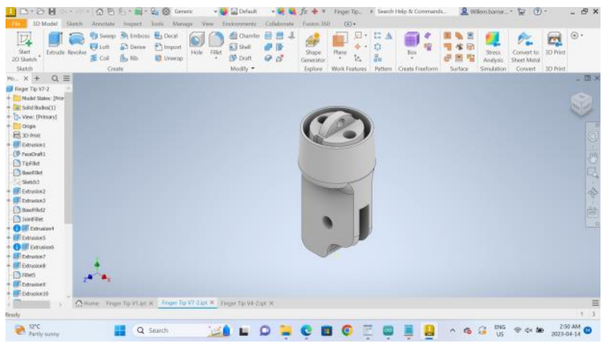
Section on joint is removed so the tendon strings are not being restricted when attempting to close finger. This makes it so a 90-degree angle is possible with the first joint.

Finger Tip V6-2



The second slot locking mechanism is added on the opposite side so we the fingertip is turned counterclockwise the fingertip locks securely in place.

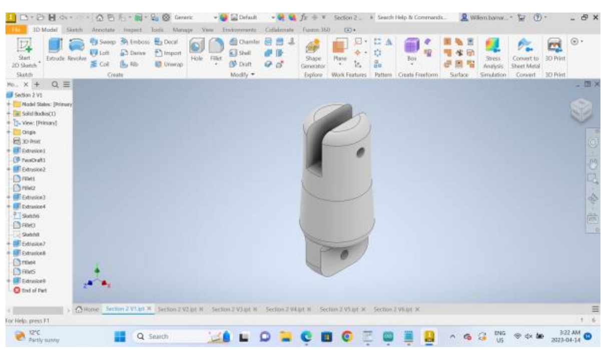
Finger Tip V7-2



The back half of the joint is extended by 5mm to add a physical constraint so the finger will not bend too far backwards.

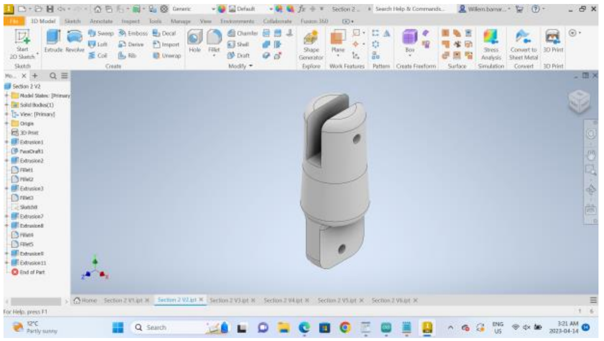
Section 2

Section 2 V1



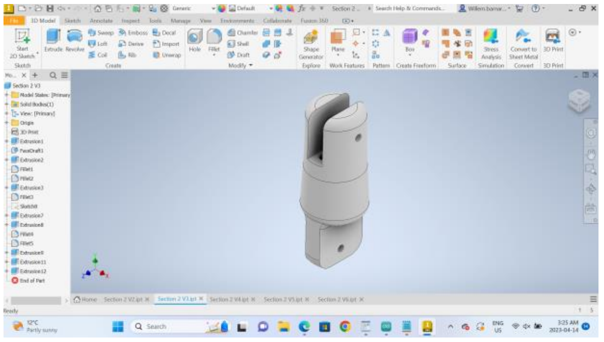
Section 2 started as a fitment test with Finger Tip V1 to show the fitment of the linear joint.

Section 2 V2



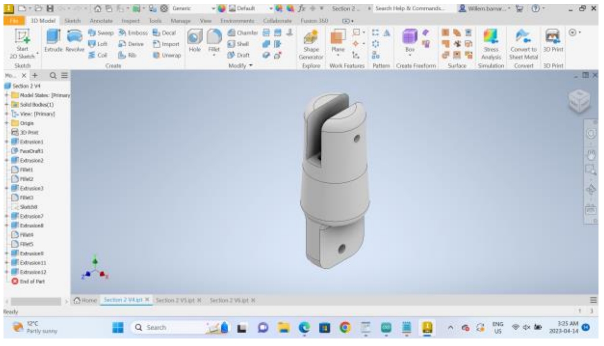
The fitment was adjusted by adding 5mm to the second joint extrusion and adding 2mm to the female side of the first joint giving clearance to the male end.

Section 2 V3



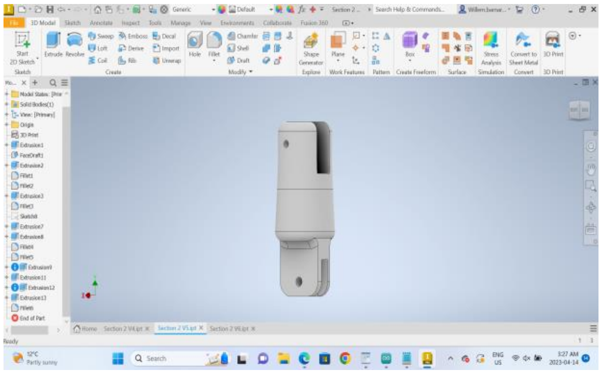
Joint holes are resized to be 2mm in diameter from 2.5mm which hindered the addition of filament pins. The holes for the tendon strings are added as well.

Section 2 V4



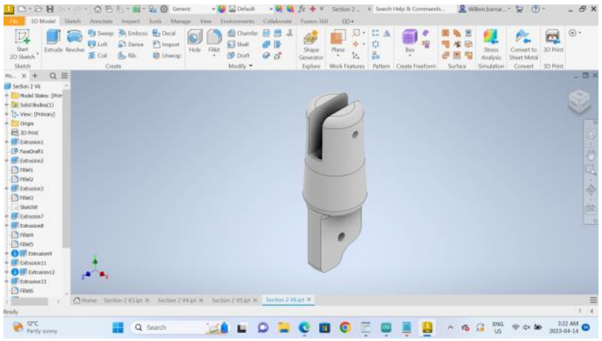
The male end of the second joint changed the hole size back to 2.5mm in diameter but the female size remained the same to create a friction fit lock with the 1.75mm filament pins due to 3D printer squish.

Section 2 V5



A section is cut out of the male end of the second joint to give freedom of movement so a 90-degree angle can be created at that joint.

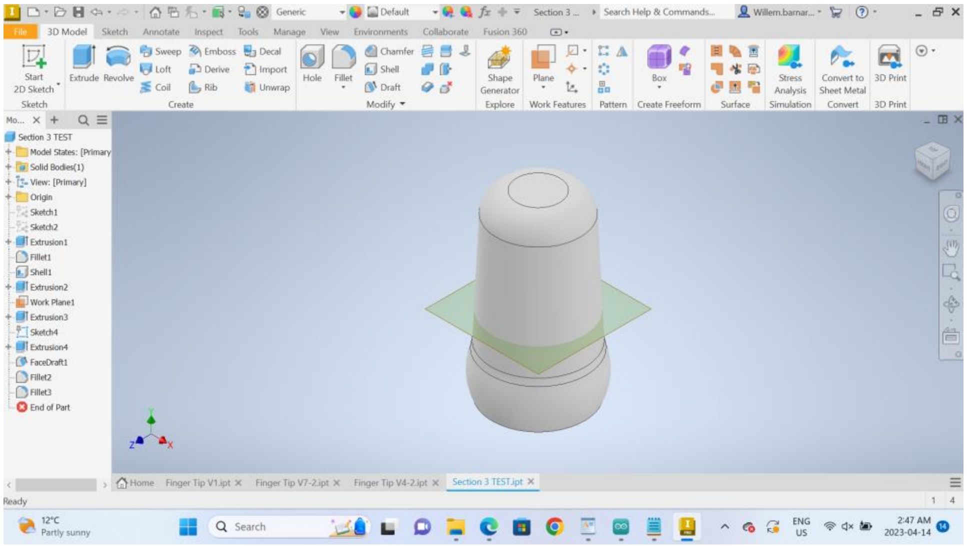
Section 2 V6



The physical constraint is added by extruding the back half of the male end of the second joint by 5mm. Also, the top of the back hole for the tendon string is filleted to give a smooth movement.

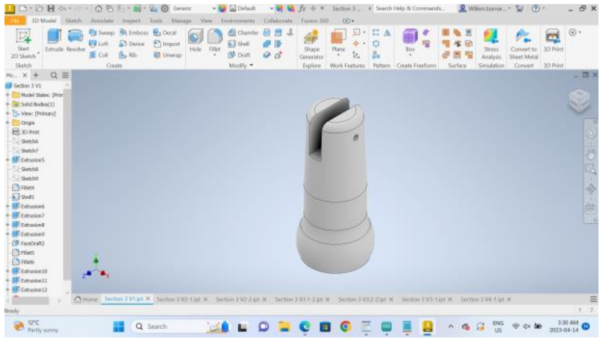
Section 3

Section 3 TEST



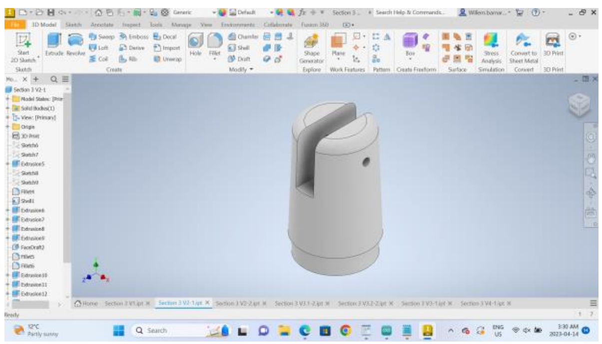
This model was not 3D printed. It was a means to practice making a sphere and a shell that will fit together to create a ball joint. Then after those are made a cylinder must be extruded on either side to create the rest of the finger.

Section 3 V1



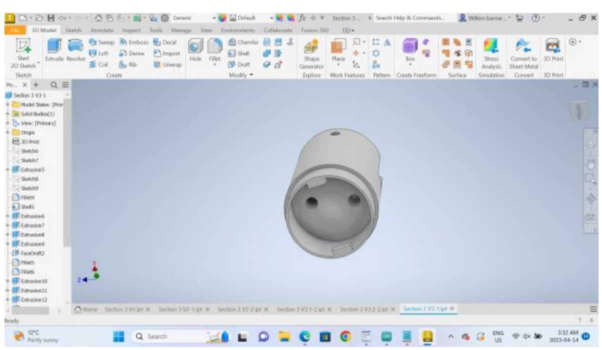
This is the first version of section 3 that was 3D printed and was used to test the fitment of the second linear joint and the ball joint with Section 4 V1 and Section 2 V4.

Section 3 V2-1



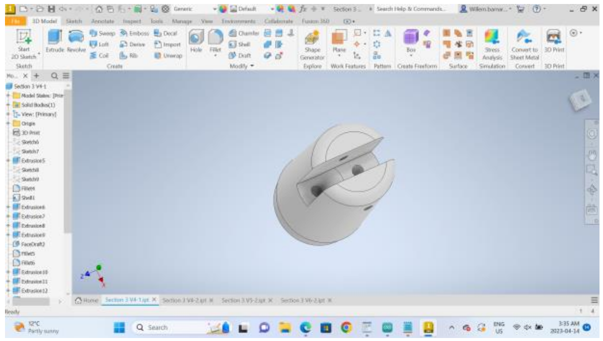
Section 3 was then split up into two pieces 30mm from the top. A lip was then added to connect the two pieces.

Section 3 V3-1



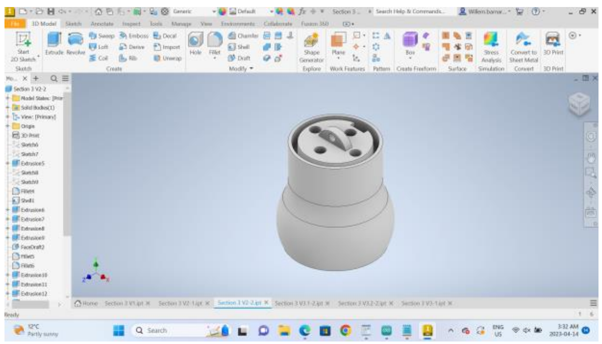
The two locking tabs are added on the lip to pair with the locking mechanism on Section 3 V5-2. The tabs are offset by 15-degrees so when the piece is rotated in the opposite direction to lock it will be square.

Section 3 V4-1



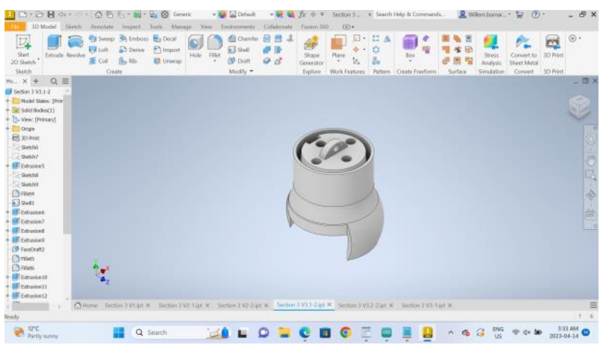
A 4mm fillet is applied to the top hole for the tendon strings to give a smoother movement with the physical constraint from Section 2 V6.

Section 3 V2-2



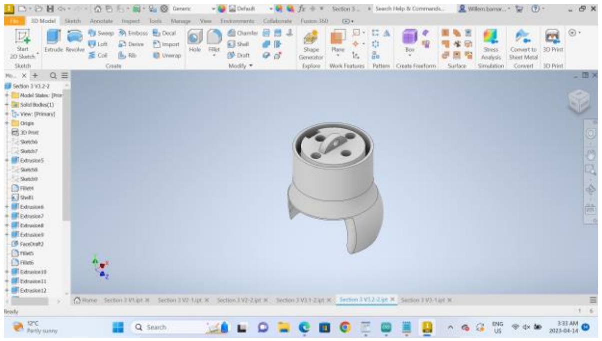
The second piece added the slot locking mechanism and anther anchor like Finger Tip V3-2. But this version added new holes for the left and right movement for the ball joint that would be anchored in this section.

Section 3 V3.1-2



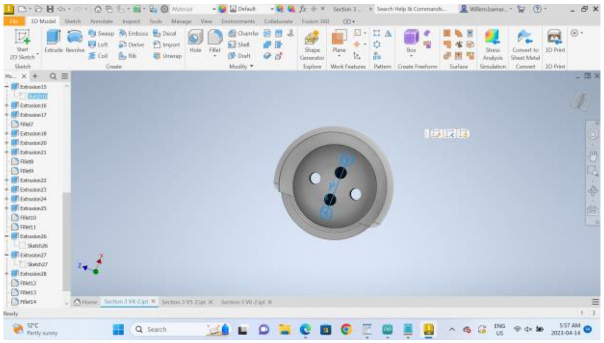
This version was made in tandem with the following to test these slightly different designs to see which was more effective. The front of the female end of the ball joint was cut out to give free movement in the forward direction to close the finger.

Section 3 V3.2-2



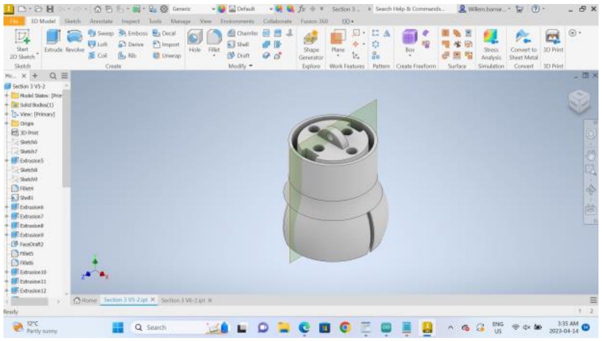
This version was made in tandem with the version above to test these slightly different designs to see which was more effective. The front of the female end of the ball joint was cut out and the edges of the cut were filleted to give free movement in the forward direction to close the finger. This version was more effective.

Section 3 V4-2



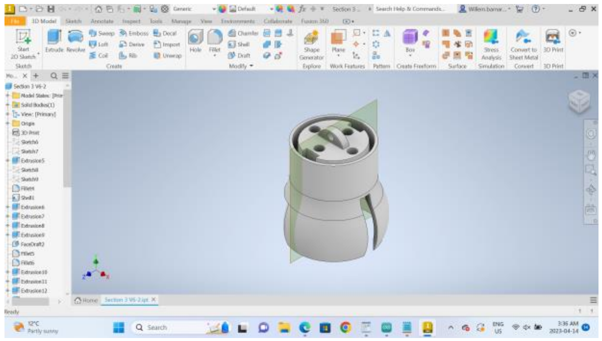
Cleaned up the cut out of the front by extruding out more. Add a second slot locking mechanism to strengthen and secure lock. The exit of two holes at the end of the anchor were shifted close to the center to give more range of motion to open and close finger.

Section 3 V5-2



The back part of the female end of the ball joint was cut out to give space between the ball joint and the tendon string. Moved the back hole at the end of the anchor back to original position since we do not need to extend the finger backwards.

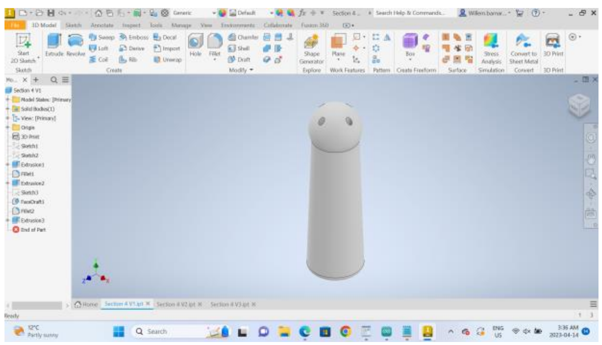
Section 3 V6-2



Expanded cut by 2mm width and 4mm height to give enough space for tendon string.

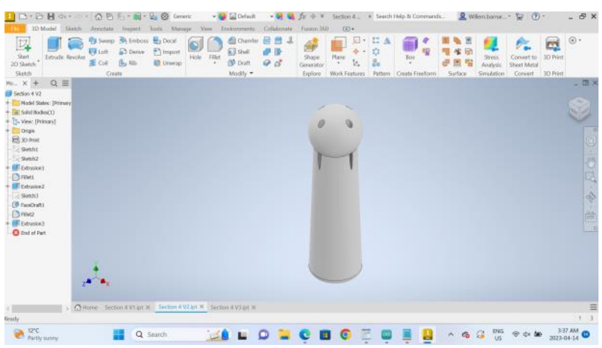
Section 4

Section 4 V1



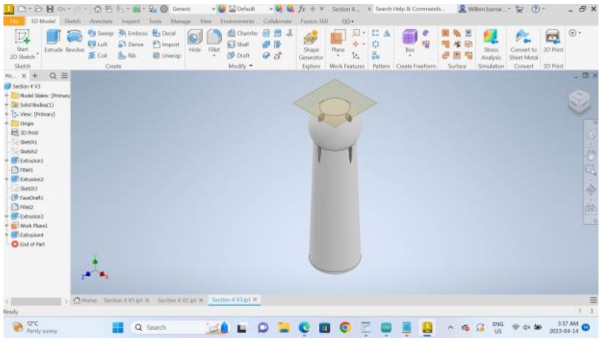
Male end of ball joint connected to a temporary palm bone and holes extruded through for tendon strings. This model was used to prove fitment of the ball joint.

Section 4 V2



The temporary palm bone was shrunk by 2mm to give more range of motion for the ball joint.

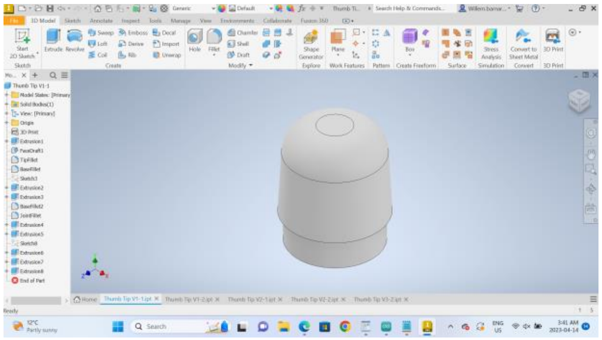
Section 4 V3



Top of the ball joint was flattened by taking off 2mm to give space for the tendon strings to move freely.

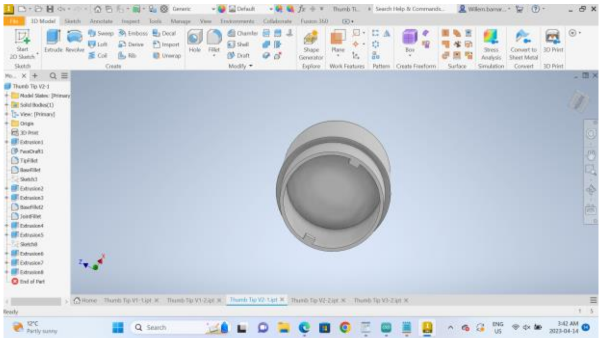
Thumb Tip

Thumb Tip V1-1



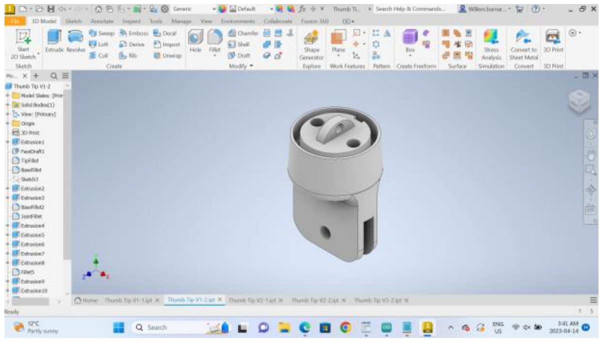
Widened version of Finger Tip V5-1 from 12.5mm to 15mm diameter. Height remained unchanged.

Thumb Tip V2-1



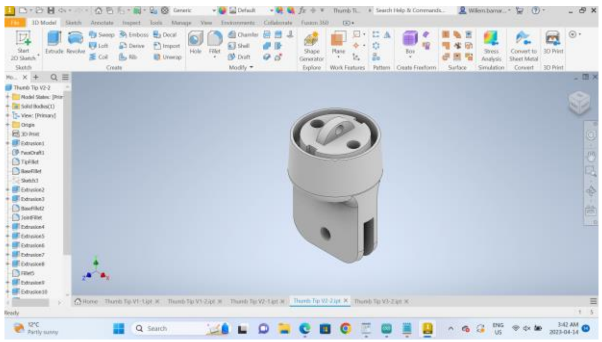
Added the second tab for the locking mechanism.

Thumb Tip V1-2



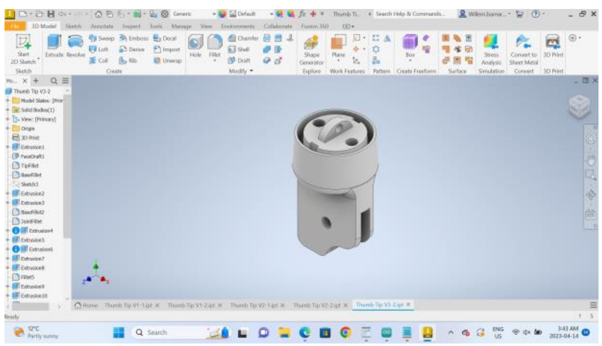
Widened version of V5-2 by same scale as Thumb Tip V1-1.

Thumb Tip V2-2



Added a second slot locking mechanism.

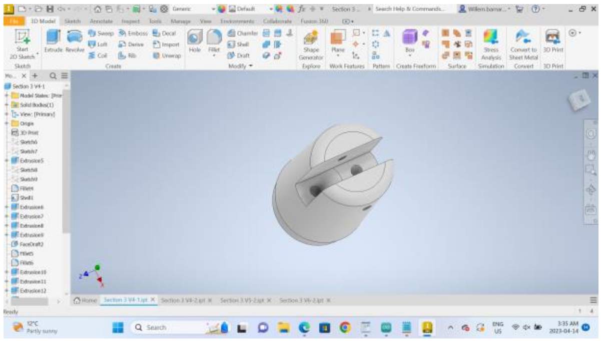
Thumb Tip V3-2



Extended the back half of joint by 5mm to create a physical constraint.

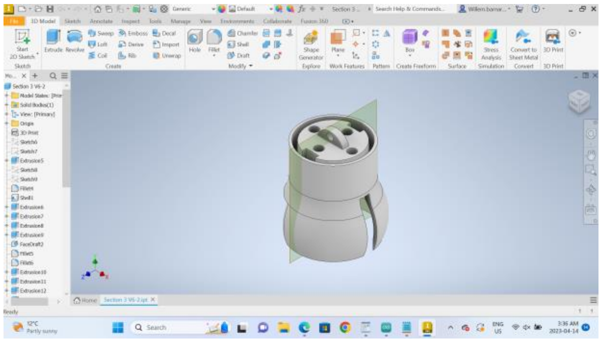
Thumb Section 2

Thumb Section 2 V1-1



Same as Section 3 V4-1.

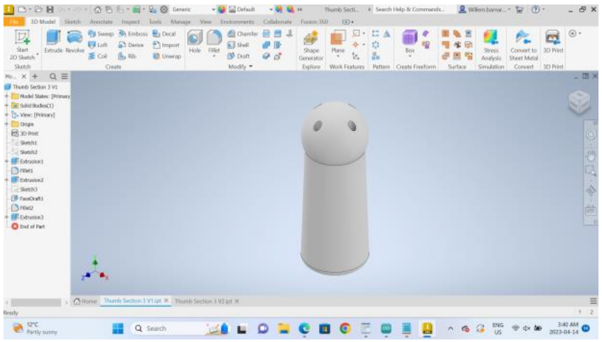
Thumb Section 2 V1-2



Same as Section 3 V6-2.

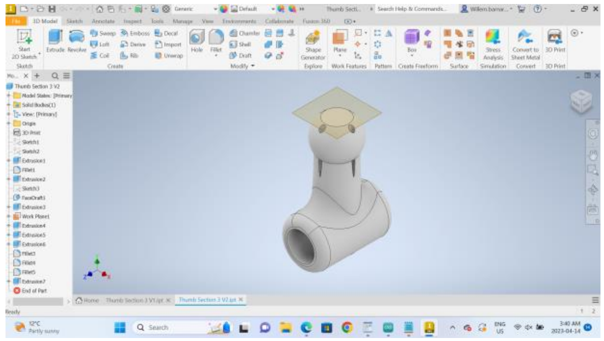
Thumb Section 3

Thumb Section 3 V1



Shortened Section 4 V1 by 20mm.

Thumb Section 3 V2



Added a cylinder across the bottom of the previous section which would be used in a hinge like motion to simulate an opposable thumb. Inspired by InMoov thumb movement.

Scale

Middle Scale V1

Final version of each section of the pointer finger and scaled it up by 10% in Cura.

Ring Scale V1

Same parts as final version of pointer finger

Pinky Scale V1

Final version of each section of the pointer finger and scaled it down by 15% in Cura.

Testing and Final Product

Not many tests were run with metal gear servos to prove the movement driven by motors, but the finger works as intended when the tendon strings are pulled. When the front string is pulled the fingers collapse to a closed position and when the back string is pulled, the fingers open with some resistance. The metal gear servos were found to be 180-degree servos which also do not offer a wide enough range of motion to fully close or open the finger. When the left and right strings are pulled the finger moves slightly to the left and right due to the physical constraints of the ball joint which works as intended. The servo, in this case, does have the adequate range of motion to move the finger from side to side.




Conclusion

The project concluded amid Stage 4 where I was unable to fully refine the palm due to time constraints and I was only able to get limited testing with the metal gear servos. The first goal of designing the fingers so they can be taken apart and the tendon strings can be replaced was completed. The fingertips and middle sections are removeable to access the tendon string and the separate anchors to replace either of the strings. Even further, no piece of the finger is permanently in place and can be taken apart and put back together with the right tools. This makes repairs to any part of the system much more efficient in terms of time, cost and materials. The second goal was not completed to as high of a standard as the first since testing with the motors was limited. The ball joint was created, and the concept of movement was proven when the finger is driven by human force and the left and right movement was proven to be effective with the metal gear servos. But the open and closing movement offered a challenge for the metal gear servos and the full proof of concept is not yet there. Moving forward the palm of the hand should be much more refined in the future. Finding a way to link the fingers together to truly make a hand and connecting the servos in a physical dock will help with testing. After the palm is complete linking it to a wrist and then an updated version of the original InMoov forearm is the next step. Finally, there is a lot of potential for realistic movement through the combination of the two servos movements to create more advanced and realistic movement in robotic hands.