The Owl Hand

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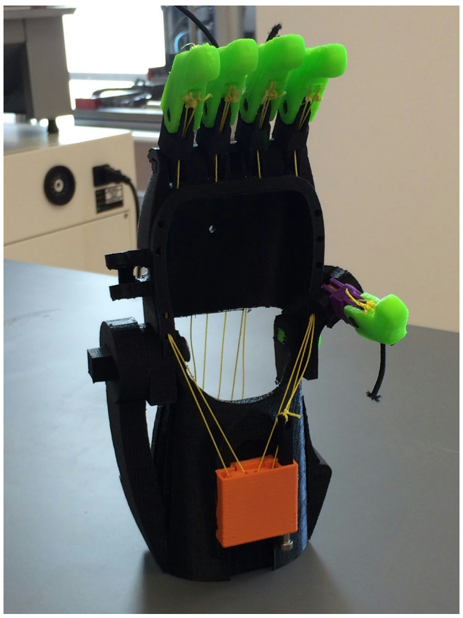
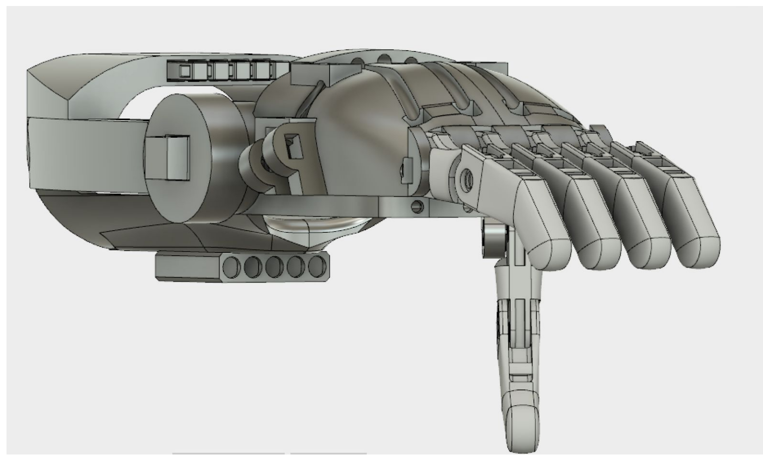
Abstract

We have created a new 3D printed prosthetic hand for patients who are born without fingers. This hand design, shown below, innovates on the popular Raptor Reloaded design by featuring dual rotation flexion, an opposable thumb, a grip locking mechanism, and adaptive grip.





Links to view the features of the Owl Hand

Dual Rotation Flexion:
https://github.com/as110/Owl-Hand/blob/master/Hand%20in%20Action/Dual%20Rotation%20Flexion.MOV

Opposable Thumb:
https://github.com/as110/Owl-Hand/blob/master/Hand%20in%20Action/Opposable%20Thumb%20Animation.mov

Grip Locking Mechanism
https://github.com/as110/Owl-Hand/blob/master/Hand%20in%20Action/Locking%20Mechanism.MOV

Adaptive Grip (Whippletree effect animation):
https://github.com/as110/Owl-Hand/blob/master/Hand%20in%20Action/Whippletree.MOV

Introduction

Dr. Gloria Gogola, orthopedic hand surgeon at Shriners Hospital, approached us with a list of design goals to improve the current state of 3D printed prosthetics.

First, she said that we should implement natural wrist tenodesis in the hand prosthetics. In our biological arms, the tendons that flex the fingers are located on the bottom of the forearm. So, our biological hands naturally tend to close when the wrist is rotated so that the palm extends upwards. Natural wrist tenodesis is important it leads to a power grasp. For example, when a user is holding a baseball, it is advantageous for the fingers to close at wrist extension because then the user can fling their wrist forward to release the ball forward. Additionally, natural wrist tenodesis is important for holding onto a bike because a comfortable grasp is achieved at wrist extension.

Second, Dr. Gogola expressed the need for an opposable thumb design. Currently, the Raptor Reloaded features a thumb that comes off the side wall at an angle that is not useful for grasping objects as seen in the picture below.

As seen below, the patient has to hold the tennis ball between the side of the thumb and the side of the index finger. This is an extremely awkward grasp that doesn't take advantage of any of the finger joints in the way that they are meant to be used. An opposable thumb will push the object into the other finger joints to stabilize grasp.

Third, Dr. Gogola stated that many of her patients have trouble holding onto objects for a long period of time. She wanted a prosthetic that would make it easier to hold onto objects. While all of the changes above help patients hold onto objects better, we interpreted this design challenge as a call to not only incorporate multiple grip patterns, but also reducing the force that patients have to continually exert to hold onto objects. Currently, e-NABLE hands have only two modes: extension of all the fingers, or complete flexion of all of the fingers. This means that they can only do one grip. However, we need different grips for picking up different objects. We need a cylindrical grip to pick up a water bottle, but a spherical grip for holding a ball.
Therefore, we divided this challenge into those two distinct objectives: multiple grips and force reduction.

Finally, Dr. Gogola asked that if we have the time, we should investigate the problem of partial fingers. Currently, e-NABLE hands are not customizable to accommodate patients with partial fingers. They don't have a slot on the between the fingers where the patients can slide their partial fingers into. The knuckle pins on the existing Raptor Reloaded design would protrude into the patient's partial finger. Furthermore, they don't have a device that will extend the patient's partial finger to the reach of the other fingers so that they can all close at the same time.

This list is organized in terms of Dr. Gogola's priorities. Since natural wrist tenodesis tops the list, we chose to address that problem first.

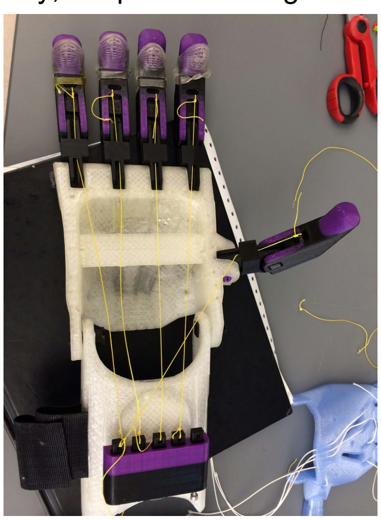
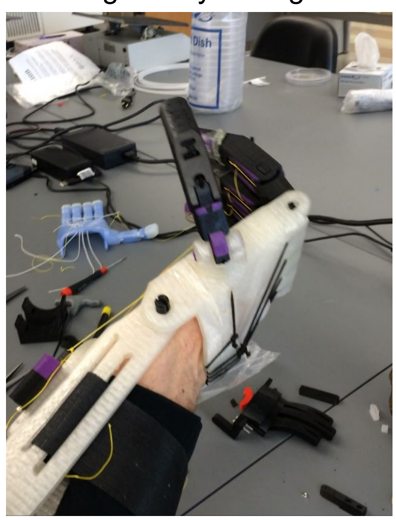
Natural Wrist Tenodesis

Problem Definition

Currently, e-NABLE hands close when fishing line pulls on the fingers. This fishing line is tied between the top of the forearm (the tensioning block) and the fingers. When the patient rotates the wrist to flex their hand downwards, the distance between the fingers and the forearm increases. This in turn tightens the fishing line, which pulls the fingers closed. In order to mimic natural wrist tenodesis, the goal is to increase the distance between the tensioning block and the fingertips when the hand is extended upwards.

Proof of Concept

The simplest solution to this problem is to flip the gauntlet onto the bottom of the forearm. This way, the patient can tighten the fishing line by flexing the wrist upwards.

However, there are several flaws with this simple solution:

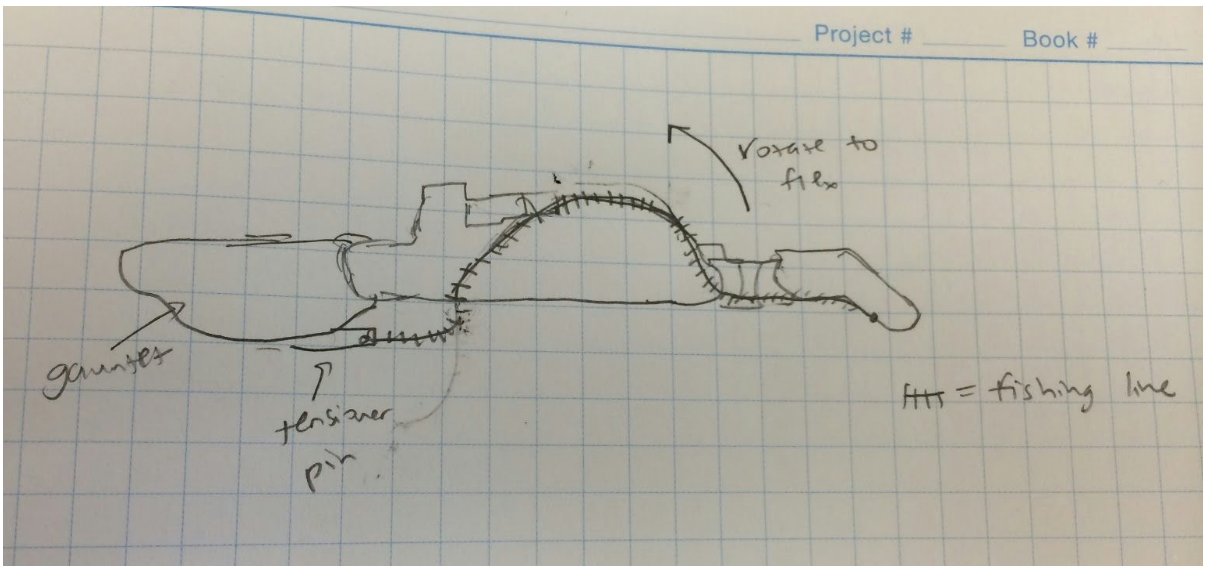
1) The fishing lines get in the way of the patient's palm. This means, that whenever the patient is holding something, that object can tug at the fishing line.

2) If we were to solve the above problem by building a case around the fishing lines, then when gripping an object, the patient would lose the tactile feedback of the object against their palm.

So, the challenge then became to route the cables so that they don't interfere with the palm. My initial thought that routing the cables in this new way would increase drag. I then did several experiments to determine the optimum cable routing configuration.

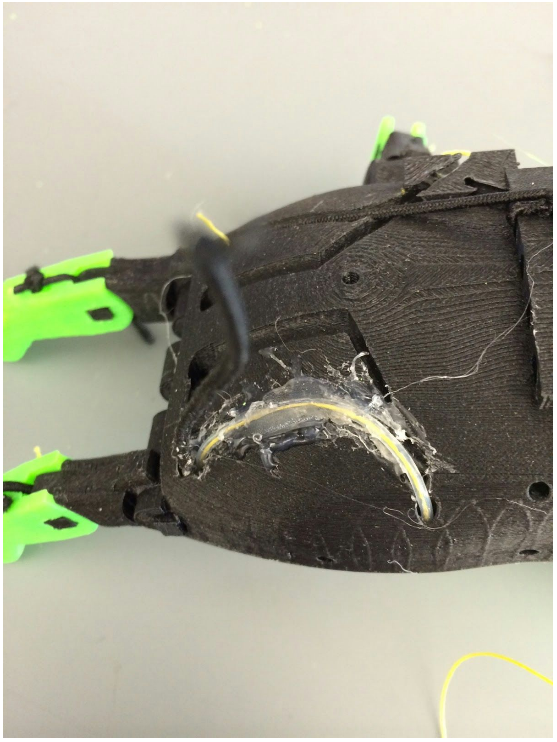
I took the proof of concept above and then added tubing along the line to make sure that the presence of tubing didn't affect the bending of the finger. As expected, it made no difference because the line had previously encountered no friction, and the tubing didn't interfere with the straight path. Once I proved that tubing still allows natural wrist tenodesis, I then proceeded with the rest of the tests.

I then started off by routing the cabling in the S shape pattern that I had modeled earlier. The routing of the fishing line is shown in the sketch below:



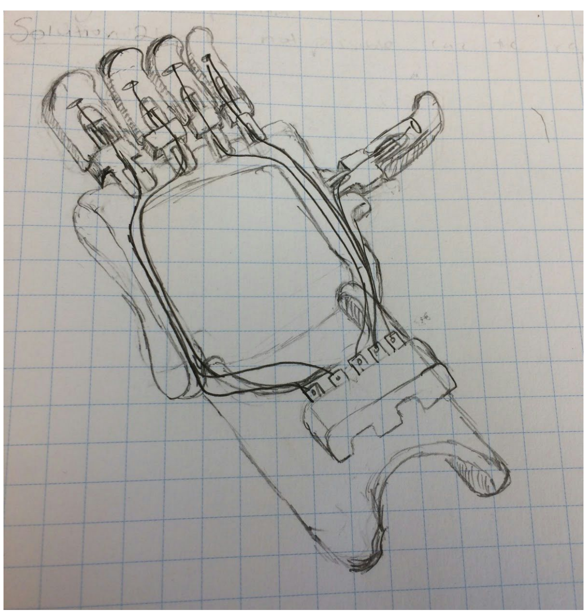
I noticed that while the finger still bends, it requires noticeably more force to do so. At some points, I bent the wrist backwards, but the fishing line had so much drag that the finger didn't correspondingly bend. Additionally, I noticed some fraying of the wire around the bends, especially the bend in the thumb block.

I then glued tubing into the S shaped channel to reduce the drag.

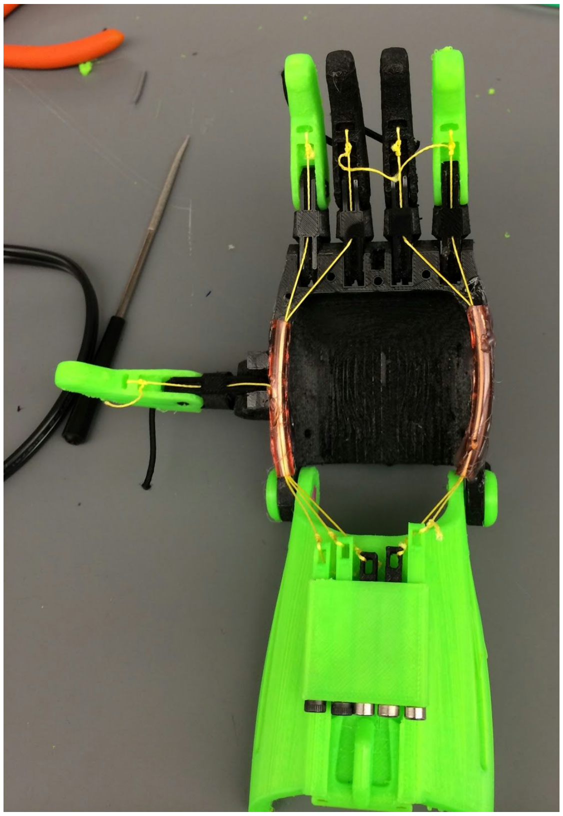


I noticed a smoother pull with the presence of tubing .There wasn't any time in which I was pulling without any flexion of the fingers. I still did notice that I needed more force than just the first configuration with a straight line routing.

So, the next idea was to route cables along the side walls of the hand as seen in the diagram below.



Finally, I glued tubing onto the side of the palm's base walls as seen below:

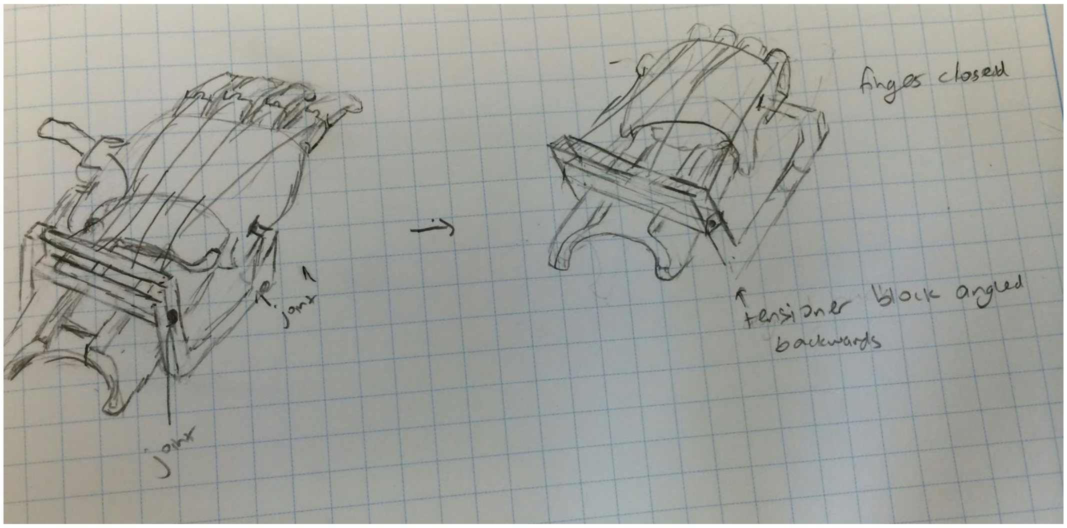


I noticed that it was much easier to flex the finger in this configuration than in the S-shaped configuration. Additionally, I noticed that when I flexed the fingers, the proximal phalange bends first and then the fingertip joins. In the unmodified Raptor Reloaded, the fingertip bends first, then followed by the proximal phalange. My configuration is better because if the fingertip bends first, then the fingertips get in the way of grasping objects by the time the proximal phalange bends in the traditional Raptor Reloaded hands.

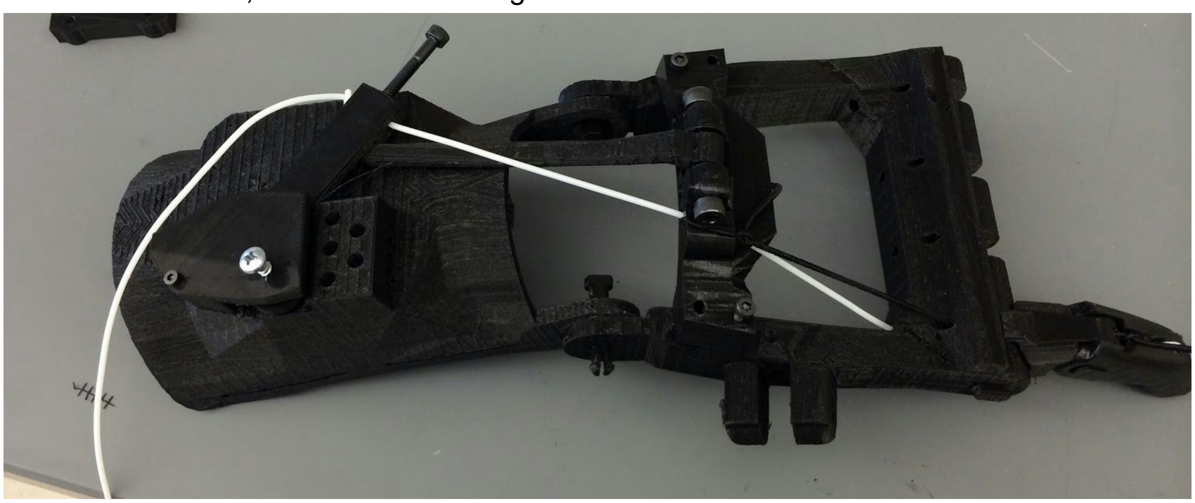
After these experiments, I concluded that routing the cables through the side of the bottom walls is the best routing configuration that I tested. Less force is required to flex the fingers. Additionally, it allows the phalange to bend before the fingertip, which is better for gripping.

Other approaches investigated but deemed less successful

In addition to these experiments, I also investigated whether it is possible to still keep the tensioning block on the top of the forearm as long as the tensioning block itself moves when the wrist is extended upwards. The diagram below gives the details of my first proposed design that does just that. The tensioning block is set on a rotating hinge. When the wrist is extended upwards, the bottom of the tensioning block is pulled, causing the block to rotate backwards and increase the tension on the fishing line.



The disadvantage to this design is that there are a lot of moving parts, which increases the risk of something going wrong.
Instead of the proposed design, I decided to create a simple proof of concept by incorporating a rotating tensioning block. This hand is actually the Flextensor designed by Peter Binkley. I simply changed the wiring to achieve natural wrist tenodesis. A push pull cable was tied from the top of the fingertip to the rotating tensioner block in the back. When the wrist extends, the cable rotates the tensioner backwards. This increases the distance between the fingertip and the tensioner block, which flexes the finger.

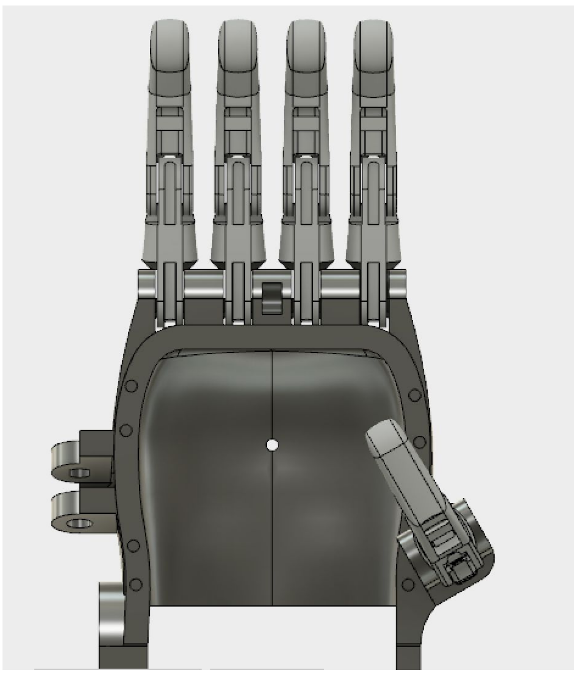


The link to see this design in action is:
https://github.com/as110/Owl-Hand/blob/master/Supplementary%20Videos/%20Rotating%20Tension%20Block.MOV
However, it had several drawbacks that ultimately made me drop the design.
1) The bar that goes from the wrist to the gauntlet that pushes back the tensioner block frequently breaks.

2) The hand cannot extend downwards because that would pull the tensioner block to rotate forwards. However, in the resting position, the block was in the furthest forward position that it could rotate. Therefore, the wrist cannot flex downward.

Conclusion

In order to achieve natural wrist tenodesis, the method of routing the cables along the sidewalls on the base of the palm worked the best. I modeled channels in CAD to replace the PTFE channels.

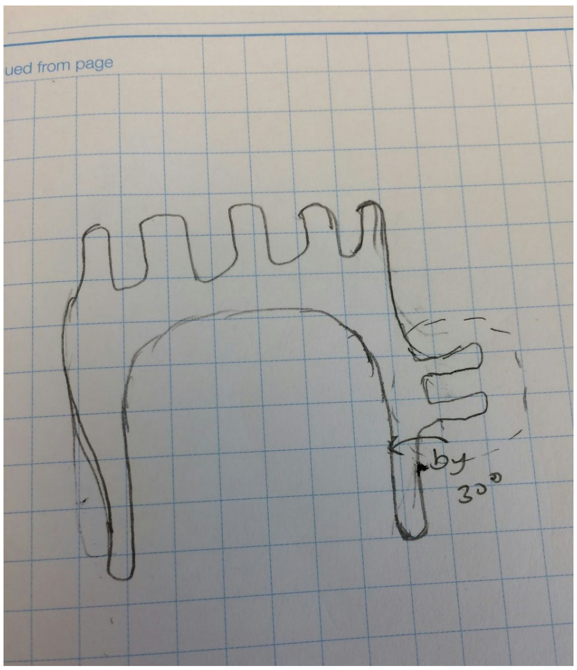


However, after soliciting feedback from the e-NABLE community, I learned that there are still some grasping motions that are better for wrist flexion as opposed to wrist extension. For example, for picking up small objects with tip to tip grasp, wrist flexion is better because it brings the hand closer to the object to be picked up. So, I modeled a dual rotation flexion hand design. The fingers are extended when the wrist is in a neutral relaxed position. Extending or flexing the wrist will close the fingers. This design offers more functionality than a hand with just natural wrist tenodesis. The final design can be seen in the picture below.

Proper Thumb position

Problem statement

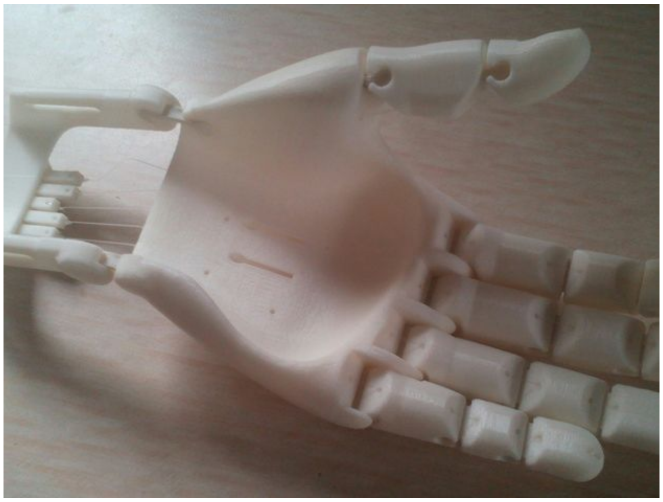
The hinge joint on the palm for the thumb needs to be rotated 30 degrees about the z axis in order to achieve anatomical accuracy. An opposable thumb points towards the middle finger when the fingers are flexed. In order to measure the angle of rotation, I examined the Raptor Reloaded and a design that has the correct thumb angle, called the Flexyhand. I then flexed the thumb of the Raptor Reloaded until it was in line with the natural thumb angle on the Flexyhand. I measured this angle to be 30 degrees.



There are four ways of creating a new thumb and I have ordered them below by increasing complexity.

Solution #1 is modify the existing Raptor Reloaded .stl's to change the thumb angle. However, after combing through the .stl's, I could not find any parameter that allowed me to change the thumb angle. This solution is not feasible.

Solution #2 is to design a new thumb with a fixed angle that is anatomically correct. This has already been done by Gyrobot, a mechanical design company in the UK, in their flexy hand design.



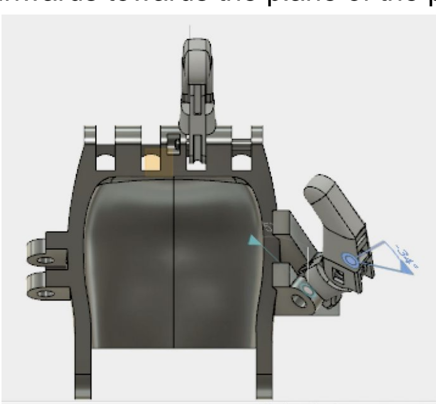
Solution 3 is to design a palm in which the user can physically rotate the thumb to change the angle. This would add a layer of complexity but can be done by designing a hinge around which the thumb hinge can rotate.

Solution 4 is to design a palm in which the user can parametrically change the thumb angle. After investigating Fusion 360, I've discovered that while the angle of an object can be changed, it leaves a huge void where the object used to be before the angle change. So, this solution is not feasible.

For feasibility purposes, I went forward with Solution 2.

Proof of Concept

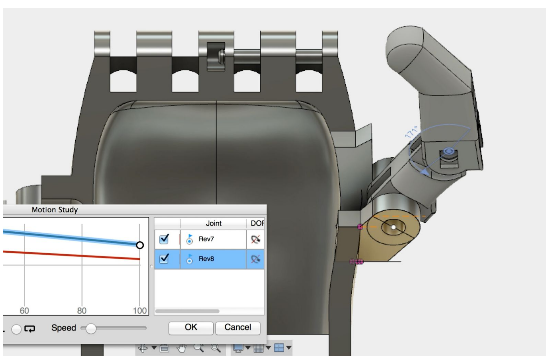
I made a quick proof of concept change to the thumb position by just rotating the thumb joint inwards towards the plane of the palm by 30 degrees.



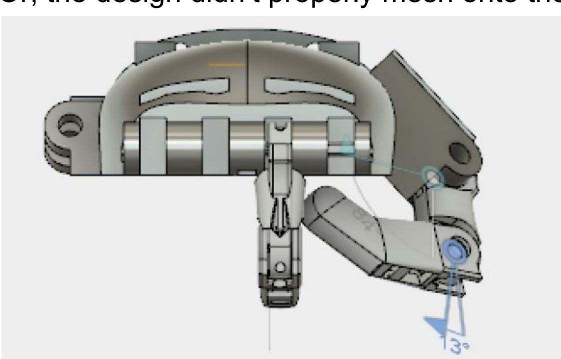
The link to see the rotation of the thumb is:
https://github.com/as110/Owl-Hand/blob/master/Supplementary%20Videos/Proof%20of%20Concept%20Thumb%20Animation.mov

Dr. Gogola pointed out that the thumb angle was not perfect yet. She said that the thumb joint has to be rotated more inwards towards the plane of the palm. The joint has to also be rotated in the xy plane so that the thumb faces the middle finger when it rotates. To measure the first angle, I held a cylindrical object and measured the angle of my thumb relative to the palm using calipers. To measure the second angle, I made the following configuration:

With these angles in mind, I made several failed attempts to mesh the thumb onto the existing palm design. It was purely a software problem that I couldn't add the thumb onto the plane of a curved surface in fusion 360. The design would either be at the wrong angle:

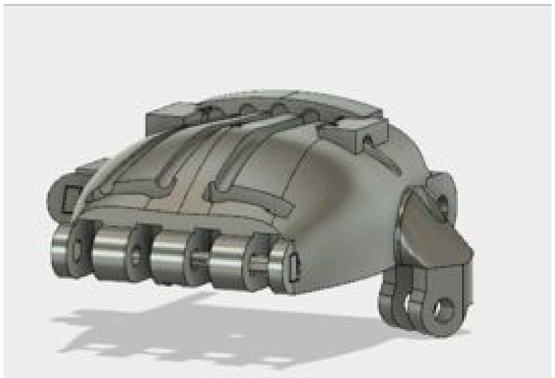


The link to see an animation of this thumb position is:
https://github.com/as110/Owl-Hand/blob/master/Supplementary%20Videos/Cosmetic%20thumb%20animation%20.mov
Or, the design didn't properly mesh onto the palm as seen in the failed design below:



Conclusion

Eventually, we realized that the previous problem arose because we tried to model the thumb joint on the side of the palm. By modeling the joint on the side walls on the bottom of the palm, we can create a thumb joint that is at the correct angle and cleanly meshes with the side of the palm as seen in the final joint design below.

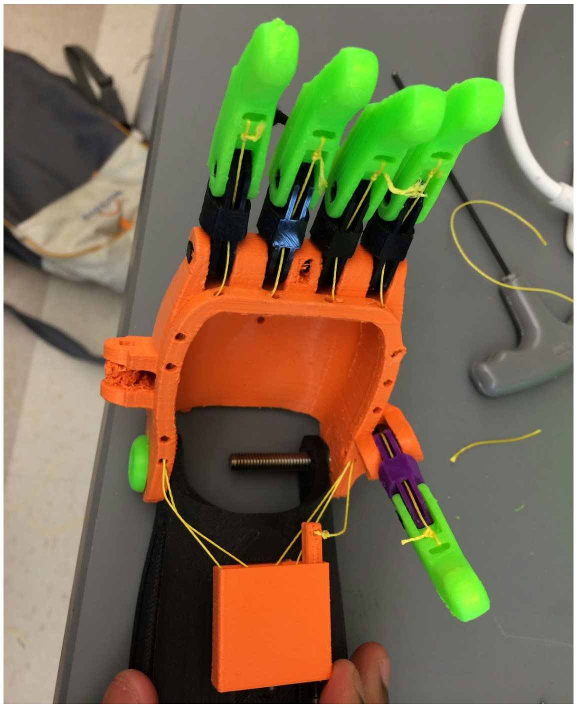


Please click the following link to see the animation of this thumb design: https://github.com/as110/Owl-Hand/blob/master/Hand%20in%20Action/Opposable%20Thumb%20Animation.mov

The only ramification with this design is that I would have to print the palm in a vertical arrangement instead of facedown. This would mean more support material. However, in this phase of testing, I was focused on creating feasible designs. Optimizing for printability would come later.

I then made a proof of concept of the opposed thumb position:

I then integrated the natural wrist tenodesis and opposable thumb position.



Helping Patients Grasp Objects

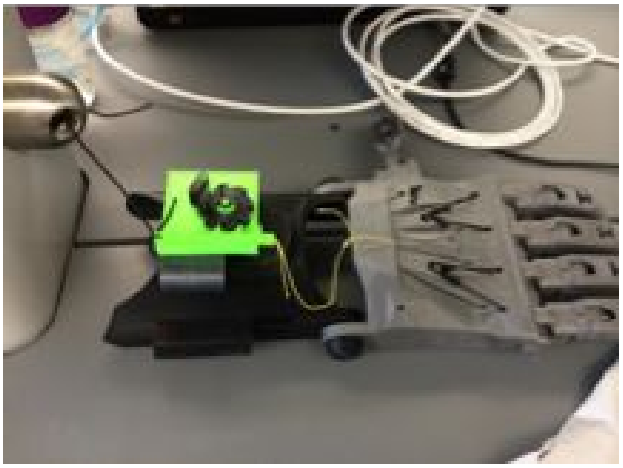
Problem Definition

To help patients hold onto objects, we need to reduce the force that the patients are exerting to close the fingers. This problem has two parts. First, when holding objects for an extended period of time, we need to completely eliminate the need for the patient to exert force. Second, a smaller force to extend the wrist has to cause a greater flexion in the fingers than in previous designs.

To solve the first problem, we tried to make a ratchet system that would allow extension of the wrist, but not flexion. Basically, once the fingers were closed, they would remain that way.

Proof of Concept

We devised a ratchet and pawl system with a quick release mechanism and a linear drive.



In the picture above, the string from the hand pulls a pinion. The pinion then rotates the ratchet. The ratchet spins in one direction, dictated by the clicking of the pawl, but it cannot spin in the other direction. The ratchet knocks the pawl back with each click, but the pawl returns back to the ratchet by a rubber band.To release the ratchet, one simply has to release the pawl from engaging back with the ratchet.

I eventually parted with this design for two reasons. First, the design had too many pieces under high tension and so the parts would break or the rubber bands would come undone. Second, it didn't really work to lock the wrist because the wrist would just extend in the other direction and the wire would become slack. So, the ratchet never really engaged at all.

Next, I moved on to an integrated ratchet and pawl system in which they are meshed onto a gear as seen below:

The arms on the pawl in in the middle flexed as it moved around the surrounding ratchet gear However, I ran into trouble for now to stop the ratchet gear from rotating. Obviously the patient can't screw a bolt everytime he or she wants to stop the ratchet gear. Once I reduce the size of the whole contraption, any plastic piece that I put there will snap off.

I envisioned that this contraption would be at the wrist joint.
To mesh it onto the hand, the palm could mesh onto the pawl and the gauntlet could mesh with the ratchet gear.

However, for the purposes of engaging and disengaging the ratchet and pawl system, I actually had to make a pin design that would be slid in and out of the wrist joint as seen in the picture below:

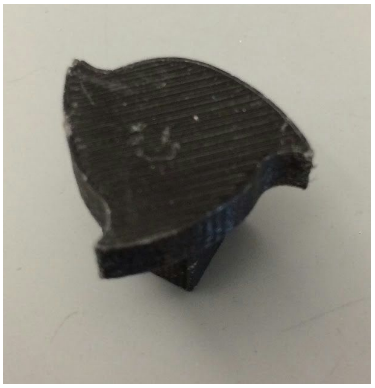
The pin engages with the ratchet gear attached onto the palm. When it is slid in, the piece cannot rotate because the square pin cannot rotate in the square hole in the gauntlet. To disengage, the user simply has to pull the pin out.
If the palm and gauntlet formed the pawl and ratchet, then I couldn't disengage the system without physically separating the palm and gauntlet at the wrist joint.

Below is my attempt at making the pawl as part of a pin.

When printing at that small of a scale, the pawl broke. The arms of the pawl necessarily had to flex in order to allow one directional movement, but the tradeoff was that the piece was structurally weak.

Conclusion

We proceeded to make another pin that was more rounded and didn't have any weak corners.



The tradeoff with this design was that while it didn't break, it didn't allow movement in any direction. So, this served as a true lock.

The second solution to helping patients hold onto objects was removing the elastics so that the patient didn't have to continually overcome that force.

No Elastic Tenodesis:

In current e-NABLE hands, the user has to overcome the strength of elastics extending the fingers. This means that the patient needs to exert more force to close the fingers. In order to change that, we created tensioning blocks on both sides of the gauntlet. A fishing line going from the top of the finger ties off to the tensioning block on the top. So, flexing the wrist opens the fingers and extending the wrist closes the fingers.

However, this design didn’t work because if I make the bottom forearm cables taut so that when the hand is extended upwards, the proximal phalanges don't have any give, then the wrist cannot flex downwards to the point where the proximals extend upwards. Basically, at a certain point, both the flexor and extensor fishing lines are taut. At that point, the hand cannot move from that position.

Removing the elastics in my design is an area that I would like to pursue more deeply.

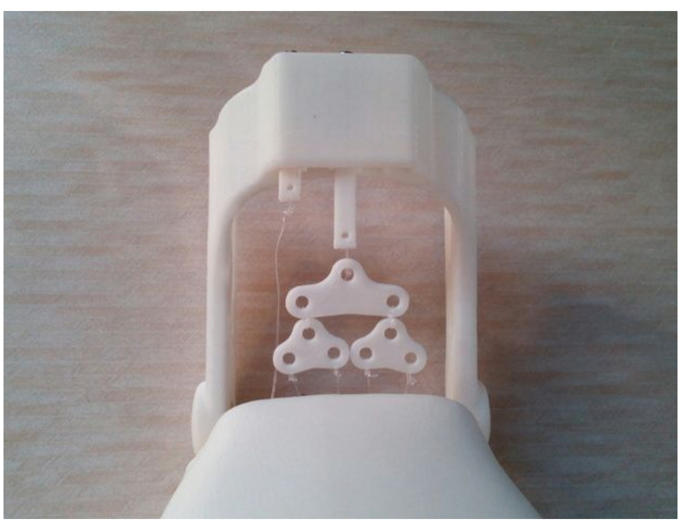
Multiple Grips

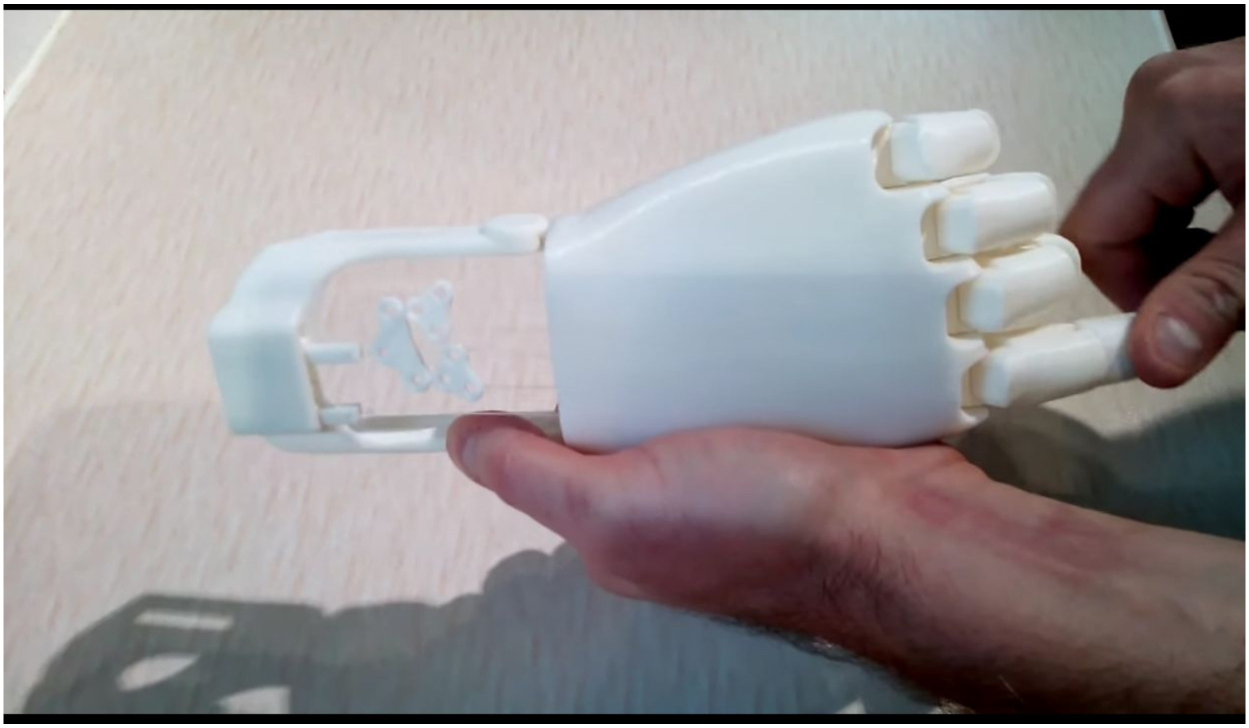
Problem statement: In order to toggle between grips, we need to differentially change the tension on the fingers. If, for example, the index finger has more tension than the thumb finger, then it will close faster than the thumb. So, instead of the tip of the thumb meeting the tip of the index finger, the tip of the thumb will touch the middle of the proximal phalange. This forms the physical basis to differentiate between tip to tip grasp and key pinch grasp.

This problem can be broken down into two parts. The first part is switching between cylindrical and spherical grip. The second part is switching between key pinch and tip to tip grip.

Part 1

Solution 1: Depending on the object, the patient should be able to switch between cylindrical and circular grip. This problem has already been solved in the e-NABLE community. A mechanical design company called Gyrobot published an open source hand design using a reverse whipple-tree mechanism to achieve adaptive grip.



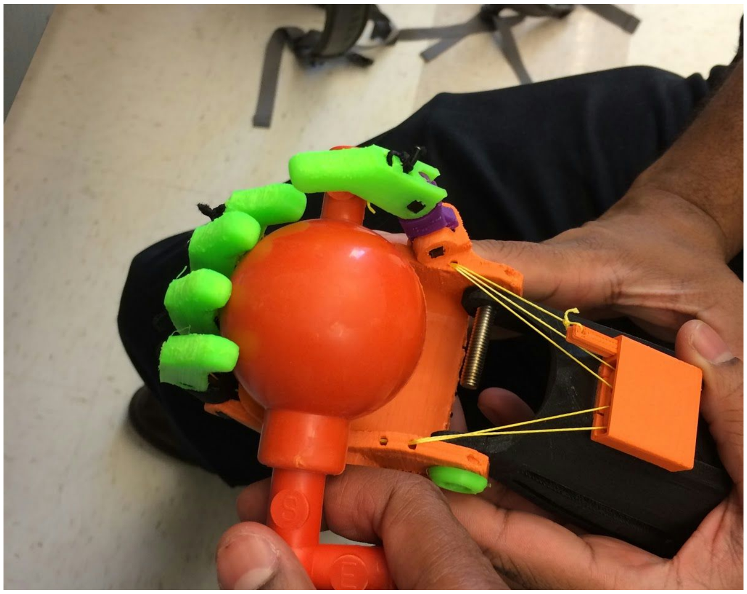


A whippletree mechanism is used to distribute force from uneven pull across multiple linkages into a uniform single force at the load. Here, we are using a reverse whippletree to cause uneven pull across the fingers (causing differential tension in the segments) by a uniform single force by flexing the wrist. A reverse whipple tree allows the fingers to flex until they encounter an object. So, if the user was trying to hold a cylindrical object, the fingers would flex differently than if the user was trying to hold a spherical object.

Conclusion

I explored this solution by simply replacing by tensioner block with Jason Bryant’s Gripper box that features a swiveling pin with four holes. String from the ring finger goes into the middle right hole and out the far right hole to then tie off onto the pinky finger. String from the middle finger goes into the middle left hole around the pin and out the far left hole to then tie off onto the index finger.

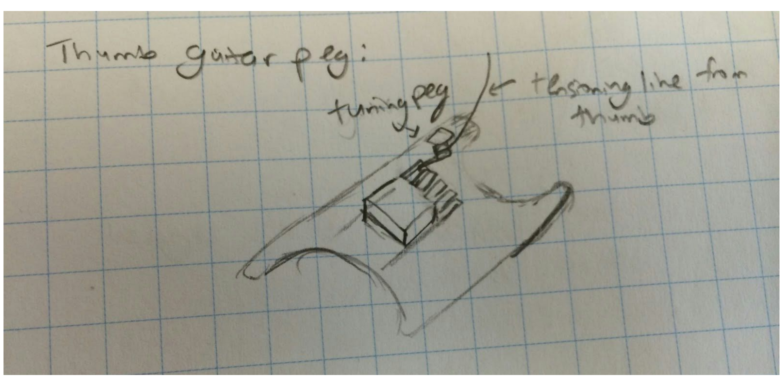
So, if the pinky finger needs to flex more to create a true circular grip, the pin will simply swivel.



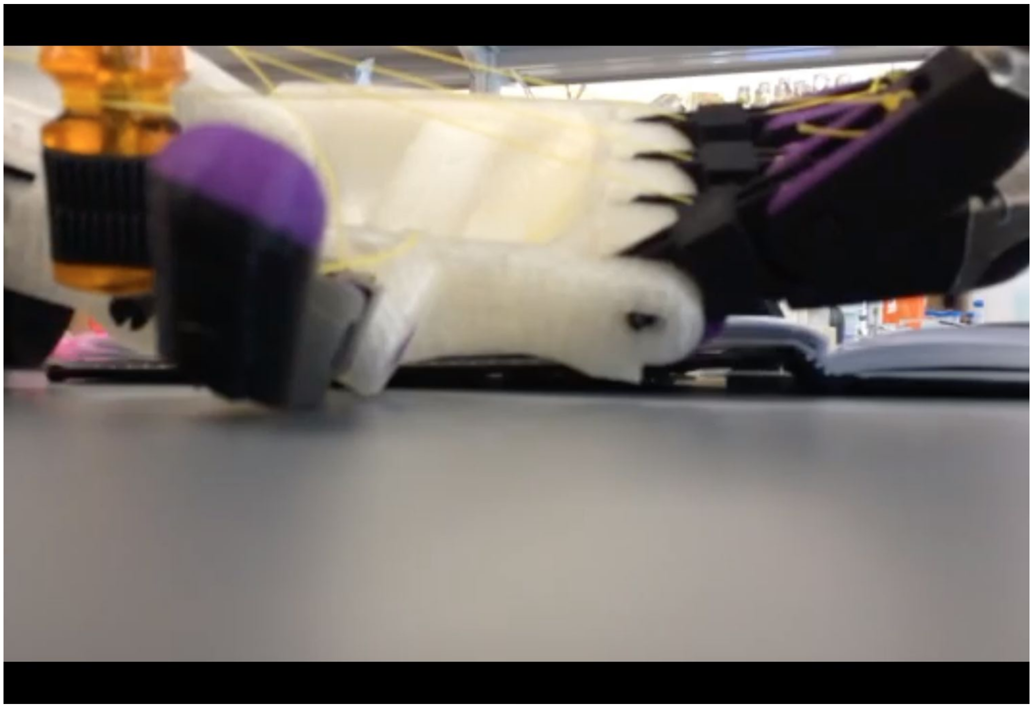
As seen in this picture below, the patient can achieve true circular grasp by swiveling the whippletree pin.

Part 2:

Solution 1: In order to switch between key pinch grip and tip to tip grasp, we must adjust the tension on the thumb. If the thumb has more tension than the index finger, then the hand will close into key pinch grip If the thumb has the same tension as the index finger, then the hand will close into tip to tip grip. To adjust the tension, we can use a guitar peg mechanism on the thumb.

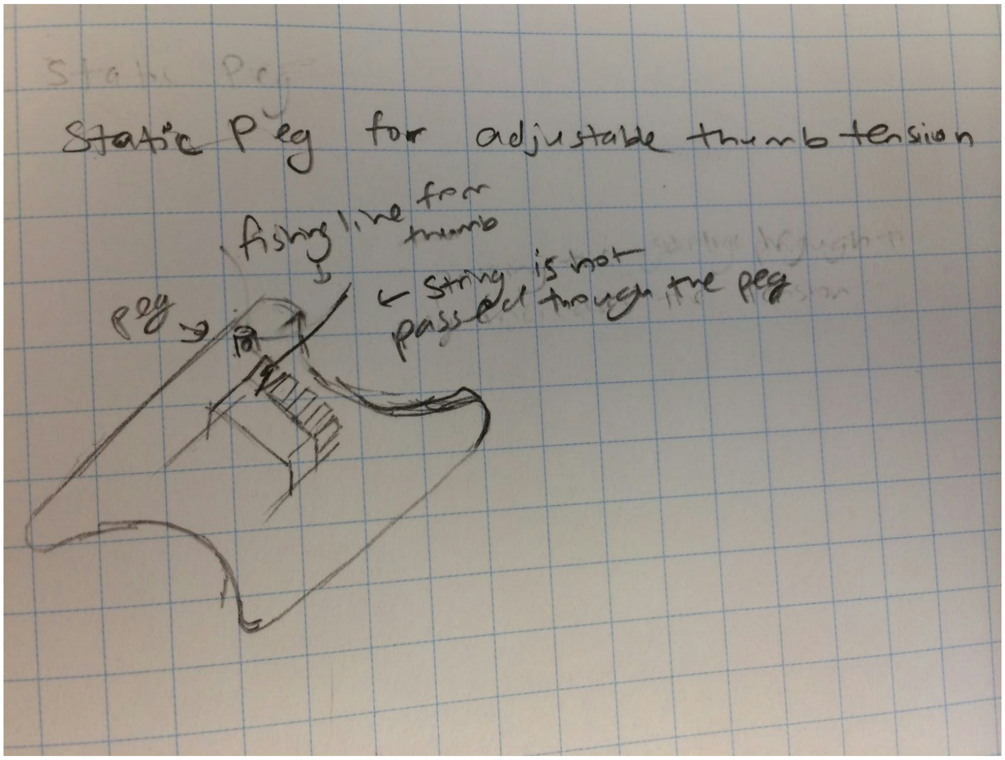


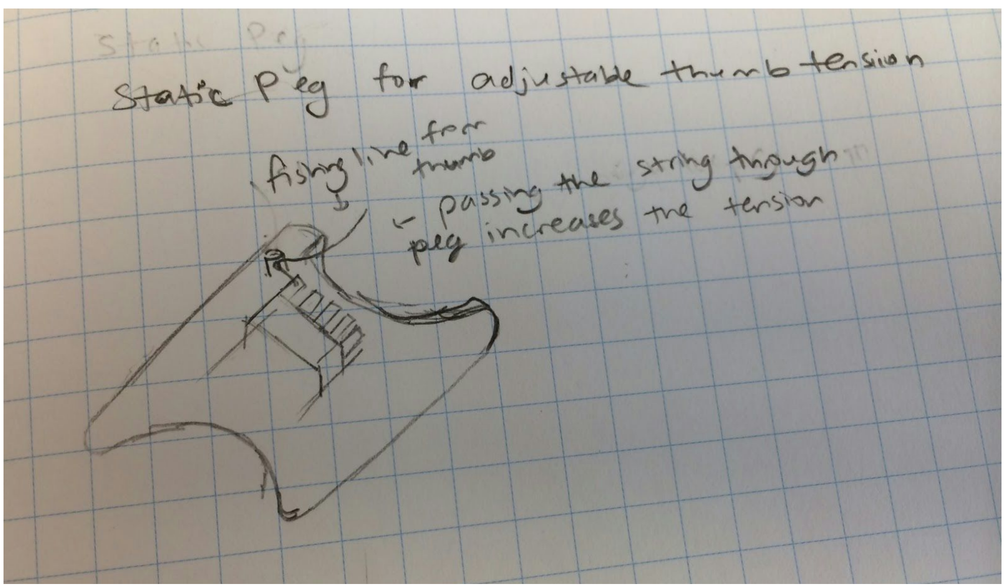
I have demonstrated proof of concept of this design by wrapping tensioning cord from the index finger around a screwdriver. The screwdriver acts as my tensioning peg in this case. By rotating the screwdriver, I can increase the tension in the finger.



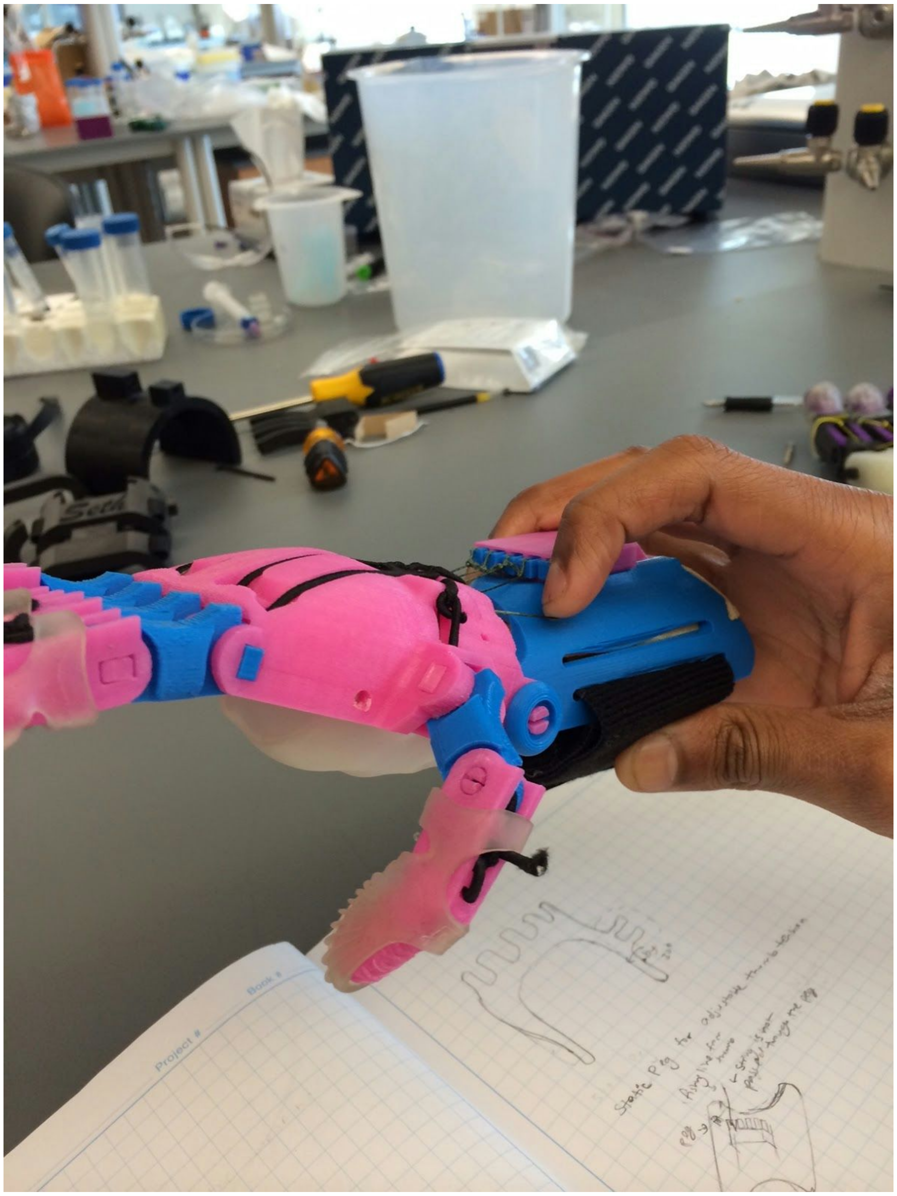
A disadvantage in this design is that adding a tuning peg would increase complexity because there are more moving parts. Additionally, it's more time consuming to change tension because the user has to wind the tuning peg just the right amount.

Solution 2: Instead of having a tuning peg that the user can rotate to increase tension, a simpler solution would be to place a stationary peg to the side of the tensioning block. When the fishing line routes through the stationary peg, the tension on the thumb is increased because routing through the peg adds distance from the thumb to the tensioning block. This solution is easier to use for the patient as well because he or she just has to slip the string around the the peg to switch between key and tip to tip grips.





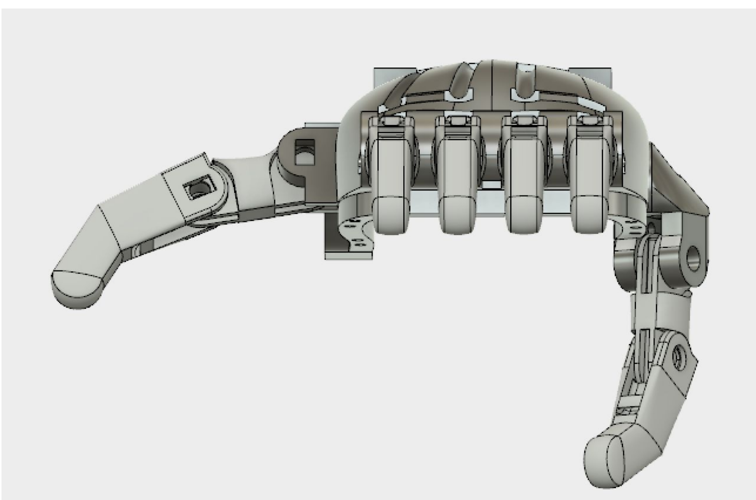
A proof of concept for this design is shown below.



The position of my index finger acts as a stationary peg and increases the distance that the cord has to travel.

We were unable to fully address this last feature in my hand design. The opposable thumb that I designed prevents key pinch grip because my thumb angle cannot be physically rotated from the opposable thumb angle. Therefore, the thumb never touches the side of the index finger.

To solve this problem, we can either model a rotatable thumb joint so that the user can move it for key pinch. Or, we can create a hand with two thumbs: one thumb in key pinch position and another in opposable thumb position. The design below illustrates the concept of a two thumb hand.



In order to evaluate the two designs, I would like to solicit patient feedback. The solution of having a physically rotatable thumb angle would mean more work for the patient's other hand. But, the second solution of having two thumbs is not an anthropomorphic design and might not be favorable to the patient.

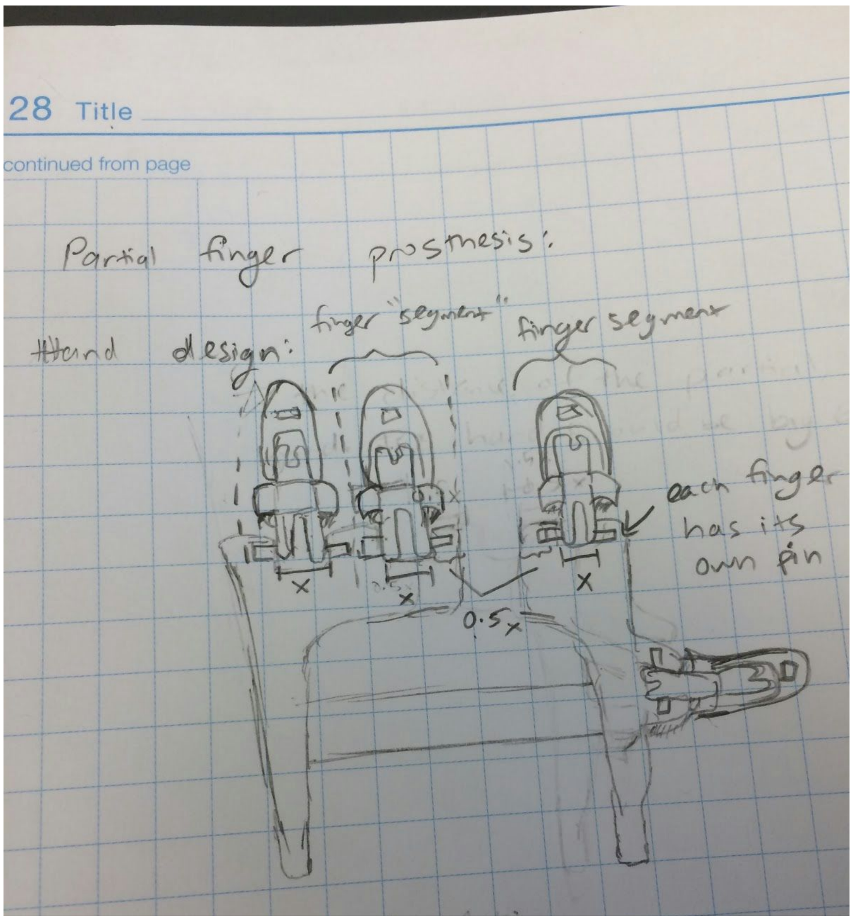
Partial Fingers

Problem statement: This design challenge can be split into two parts.

Part 1: Create a hand in which the user can parametrically create a slot for the patient's partial finger. The current Raptor Reloaded model doesn't have a parameter that defines the width between two fingers, so I would have to make a new palm design

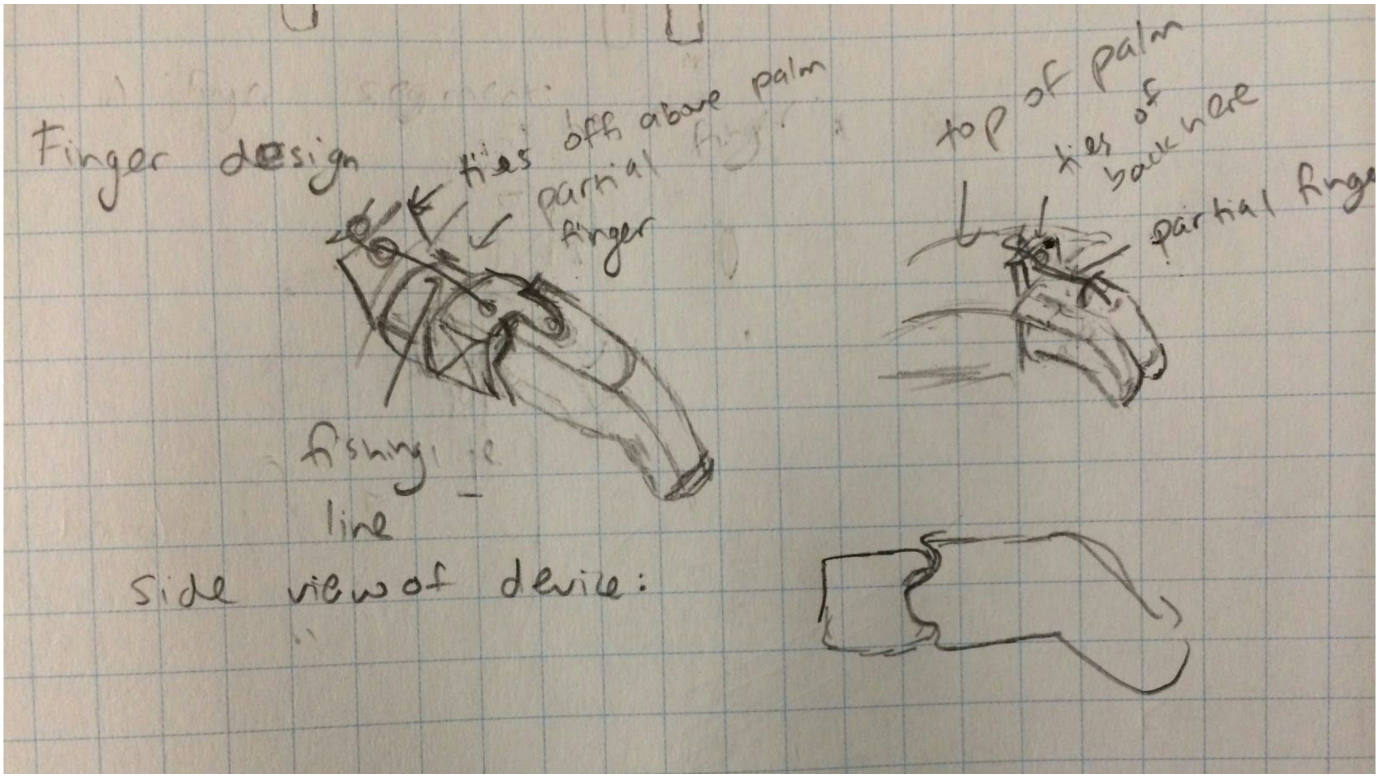
Part 2: Create a parametric extension for the partial finger so that the partial finger can become the same length as the other fingers. This extension should be powered with the partial finger

Solutions:
For part 1:
Solution #1: Create a palm on Fusion in which you can make gaps for the partial finger. This can be done in fusion 360 by joining finger “segments”, which are defined as the distance across a finger plus half of the gap between the finger on both sides.



The size of the partial finger helps define the size of the hand. The hand should be big enough so that the gap for the partial finger is big enough, even if it means the hand is a little bigger than the recommended palm size.
For part 2:
Solution #1: If the patient has enough strength to move his or her partial digit, then flexion of the extender digit can be powered by rotation of the partial finger. If we tie a fishing line between the extender digit to a slot right above the palm, as seen below, then the patient simply has to move his or her partial digit downwards to increase the tension in the fishing line, causing the extender

digit to rotate.



A proof of concept test has been done to show that the partial finger does have enough power to flex the extender digit. The result is shown in the figure below.

Solution #2: We can use the same partial finger design as in Solution #1, but instead, we can tie the fishing line to the same tensioning block on the gauntlet that the fishing line from the other fingers tie off to. This solution would be used in case the patient does not have enough mobility in their partial finger to flex the finger about the interphalangeal joint.

While I thought of these solutions in the initial feasibility report, I never got the chance to implement my ideas because we chose to focus on the four higher priorities on Dr. Gogola's list.

Conclusion and Further Directions

Over the course of this summer fellowship, we designed a hand that has several improvements to the Raptor Reloaded. Our design features an opposable thumb, dual rotation flexion, adaptive grip, multiple grips, and a locking mechanism. By the end, we have developed a fully functional feasibility prototype.

We would like to further investigate removing the elastics, being able to obtain key pinch, and solutions to the partial fingers problem.

The next step would be to optimize the hand design to better suit the added features. First, we aim to optimize for printability. This means reducing support material or creating custom support material when necessary. Next, we would like to optimize for natural wrist tenodesis by figuring out a way to further reduce the drag on the fishing line. Additionally, we would like to optimize the hand for grasp by designing a metacarpal arch and designing fingertips with a more surface area.

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