# Body Powered Finger Prosthetic Design

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Augmenting Human Dexterity – Spring 2022
Term Project: Report and Research Proposal

**Abstract**

This paper presents a novel approach to improving the quality of life for amputees through a passive prosthetic finger design. This body powered prosthetic finger design was made for someone who has lost middle and index fingers and a half of a thumb. The design consists of two main mechanisms, the first, uses a four-bar linkage mechanism to provide a grasping motion for the prosthetic thumb; the second mechanism utilizes strings loaded in tension and fed through TPU-printed middle and index fingers that flex in parallel with the ring finger. By mimicking the natural motion of fingers through the two mechanisms, this prosthetic design has the potential to greatly improve the quality of life for amputees. Further research is however needed to refine and improve these passive mechanisms, but this study provides a solid foundation for future prosthetic finger design. Ultimately, the incorporation of passive mechanisms in prosthetic devices can lead to increased dexterity and ease of use, allowing amputees to perform tasks more comfortably than before.

## I. Introduction

Finger amputation often results from accidents at work, home, or recreation. Thousands of people each year have finger related amputations, that result with partial or complete removal of fingers. It is estimated that as many as 45,000 finger amputations are performed in the US per year with an incidence rate of 7.5/100,000 people [1], [2]. Finger amputee's go through a rigorous recovery process often involving orthotic devices, pain medication, massage therapy, and ice or heat therapy[3]. Long term nerve damage often occurs with such hand injuries including cold sensitivity, pain, abnormal and phantom sensations, and in some cases neroma [4]. The physical recovery is difficult to overcome, but emotional recovery often couples with such an injury[5]. Loss of body parts, especially one as visible as a finger or hand is very traumatic, and its often very hard to accept [5]. Patients may need long term physiological therapy depending on the severity of their injury [5]. Patients can opt in to get a prosthesis if they want to and depending on their level of insurance, get funding, and not have to pay out of pocket. Traditionally patients will choose to see a prosthetist, who will work directly with them to get a personalized device made that serves the needs of their injury. Others choose to adapt to their injury and make best of what functionality still remains.

### *A. Background*

Many passive finger prosthetic devices exist today, with a variety of options available for amputees. A passive finger prosthetic, unlike active prosthetic devices, are designed with a non-electronic approach and do not have any active components such as sensors or motors. They are designed to be lightweight and comfortable to wear, while also providing functionality and resembling a natural appearance for its user. A major challenge for prosthetic design, is that no two users are the same, thus designing a device may require customization of components to fit specified users and to do specific tasks. For finger amputees, this is very prevalent specifically due to the nature of the the injury, and what portions of the hand still remain. The team will use existing passive technology and combine them to create a passive prosthetic that is useful for small mechanism manipulation and for large radius of curvature grasping.

One example of a state-of-the-art passive finger prosthetic device is the ThumbDriver by Naked Prosthetics as seen in Figure 1 below [6].This device uses a four bar linkage, where the two of linkages are crossed limiting the range of motion, but inducing a bending moment on the forth linkage that can be taken advantage of. This is a innovative solution that brings back the distal phalanx actuation and functionality to the amputee. Looking closer, the mechanism is coupled to the thumb, and many other devices of this nature rely on having some existing and functional proximal phalanx to drive the mechanism.

Fig. 1. Naked Prosthetics, ThumbDriver product that is used to help finger amputees regain function of the distal phalanx of the thumb with use of the thumbs proximal phalanx as the actuating input [6].

Naked Prosthetics has a fleet of useful products for finger amputees, another great product called the Griplock can be seen in Figure 2 below [7]. This device is an effective solution for amputees who are missing the entire finger, as it doesn't require body power input to actuate. However the trade off is the hands natural motion is loosed as the fingers are stuck in a static state unless external input is applied by users apposing hand. The functionality would be the main gain for a user to choose such a device, as it allows for gripping of objects, and the ability to apply adaptable and stable grips due to the ratcheting lock mechanism it uses in place of the MCP joints.

Fig. 2. Naked Prosthetics, Griplock product that is used to help finger amputees gain function of the proximal to distal phalanx for multiple fingers by implementing a racketing lock mechanism that users can manipulate for different tasks. [7].

Other devices tend to rely on tension cable driven actuation of the prosthetic fingers. This concept resembles biology, specifically how tendons work to actuate fingers. When a muscle contracts, it pulls a tendon attach to it, causing the tendon to pull on the bone to which it is attached. Tendons act like cables, because they are only good mechanically in tension and not compression. Moreover, the tension cable driven designs tend to be under actuated, and use clever design to actuate more degrees of freedom. One example can be seen below in Figure 3, and it uses one cable and a motor to power flexion to all three DIP, PIP, and MCP joints [8]. This example uses a motor to power actuation, but if the cable is anchored down instead, it could be considered a passive mechanism instead. When the cable is anchored, it is at fixed length, and therefore it can be powered by some other portion of the hand that induces tension on the cable.

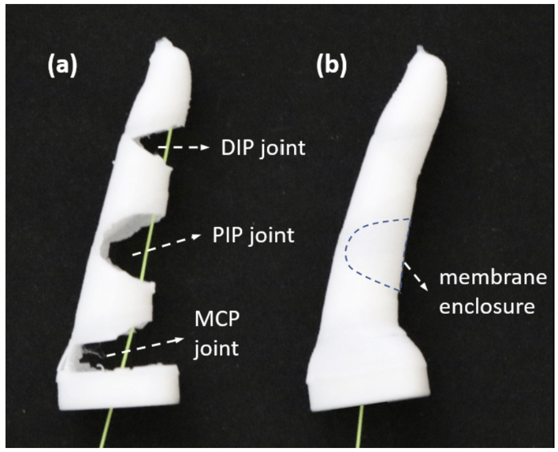


Fig. 3. Researchers at the University of Melbourne design a low cost 3D printable hand with tension cable driven fingers to power the actuation of the metacarpophalangeal (MCP) joint, the proximal interphalangeal (PIP) joint, and the distal interphalangeal (DIP) joint [8].

Each passive device is useful for particular tasks and made to fit certain injuries in terms of what users have lost function over. The team will use a combination of tension cables and linkages to drive the passive prosthetic fingers. It is hypothesized that it will help allow an amputee to do small mechanism manipulation and carrying larger objects that require high surface area grasping. With this configuration the user will be able to manipulate the prosthetic without external input, and supplement the specific small mechanism manipulation. The added surface contact area of the fingers and body power input will help with griping large raduis of curvature objects.

### *B. Overview*

In *Section II*, the interview case study will provide insights into the needs and preferences of a specific finger amputee interviewed. The information gathered during the interview and post interview process will then be used in *Section III*, to propose a tension driven device for the index and middle fingers and a four bar linkage for the distal phalanx of the thumb and the methodology for testing it. For the following *Section IV* and *Section V*, the potential significance of the findings will be emphasized for advancing the field of prosthesis's and improving quality of life finger amputees. Overall, the goal of this research is to contribute to the development of combing existing passive finger prosthetic technology to meet the needs of amputees and enhance their daily life.

## II. Interview case study

A need finding style interview was done on a single interviewee with a hand injury on the left hand for the purpose of developing a product to help with their daily life. The interviewee was a thirty-six year old male, that suffered a hand injury six years ago resulting in amputation of the the index and middle fingers down to the metacarpophangeal joints and the thumb down to the interphalangeal joint. Hand castings were done during the interview, shown in Figure 4, for the purpose of having a baseline to prototype with and to tolerance mechanical parts too. The interview consisted of questions to find pain points in the interviewees daily life, and deeply dive into them to understand the underlying needs of . The interviewee is a semi-truck driver, a father of a four year old and a one year old, works on house

Fig. 4. Hand castings of interviewee, on left it shows the left hand casting in an open configuration, and on the right the left hand casting is in a fist shape with thumb sticking out. The casting on the left will be used for testing fitment of the index and middle figures, while the casting on the left will be for fitment of the distal phalanx for the thumb.

related construction projects, and loves to ride bikes and motorcycles. This is just a general profile on the interviewee.

During the interview the team video recorded specific tasks the interviewee struggles with, specifically buttoning buttons, tie shoes for himself and his kids, putting his daughters bracelet on, and other tasks. Questions were asked in order to draw out needs or pain points, and based on the nature of his responses, the team would ask to more about them or ask him to show us to understand.

Following the interview, using a recording of the interview, needs were extracted and placed into groups. A hierarchical list of primary needs and secondary needs was made, shown in Table II, where the primary needs represent a group of similar secondary needs found during the interview. The interviewees responses show that the product should incorporate not being noticeable to others, enable griping of large objects, and help with precision movements.

TABLE I

SUMMARY TABLE OF INTERVIEWEE'S PRIMARY NEEDS CAPTURED DURING INTERVIEW DECOMPOSITION.

| Level of Importance | Primary Need |
|---|---|
| 1 | Product should not be noticeable to others |
| 2 | Struggles when griping large curvature surfaces |
| 3 | Struggles with small mechanism manipulation |

## III. Proposed Device & Test Methods

### A. Proposed Device

The proposed prosthetic device consists of two main passive mechanisms, one for the missing index and middle fingers and the other for the missing half of the thumb. The passive mechanism for the index and middle fingers allows the flexion and extension and is directly powered by movement of the existing ring finger as further described in detail below. The passive mechanism for the thumb also allows the flexion and extension through the four bar linkage design and is illustrated in detail later in this Proposed Device section.

The passive mechanism for the index and middle fingers was motivated from the simplification of the prosthetic device because the team believed that the flexion and extension of the fingers could still be achieved with a simple design with a small number of degrees of freedom. The team considered that the size of the prosthetic device must be small enough to fit inside construction gloves because the interviewee desired to wear the gloves over the prosthetic device to hide it. That is, the team had to minimize the number of components to prevent bulkiness of the prosthetic device. The approach to this design consideration directed our attention to utilizing the existing fingers to achieve flexion and extension of the prosthetic middle and index fingers. The team thought of a parallel mechanism that would allow prosthetic middle and index fingers to flex and extend in parallel with the existing ring finger.

As shown in Figure 5, the team generated a prototype of the parallel mechanism consisting of two main components: a coupler and a string. The coupler would provide a structural connection between a ring and printed middle and index fingers. In this way, when the ring finger flexed or extended with the ring, the proximal phalanx of the printed middle and index fingers would flex or extend in parallel with his ring finger by a pin joint at the lug. To achieve the flexion of the middle and distal phalanx of the middle and index fingers, a strong string loaded in tension was used. Each phalanx of the middle and index fingers had a hole for the string to be fed through. One end of the string was anchored at the finger tip of middle and index fingers and the other end of the string was anchored at a U-shaped coupler placed on a leather mold. In this way, When the string was loaded in tension by a tension adjuster and proximal phalanx of the middle and index fingers were flexed by the ring finger, the trapezoidal middle and distal phalanx would get pulled in by the string, achieving the flexion. Because the fingers were printed out of TPU, the fingers had the elastic characteristics to flex and extend without the needs of pin joints and return springs between each phalanx.

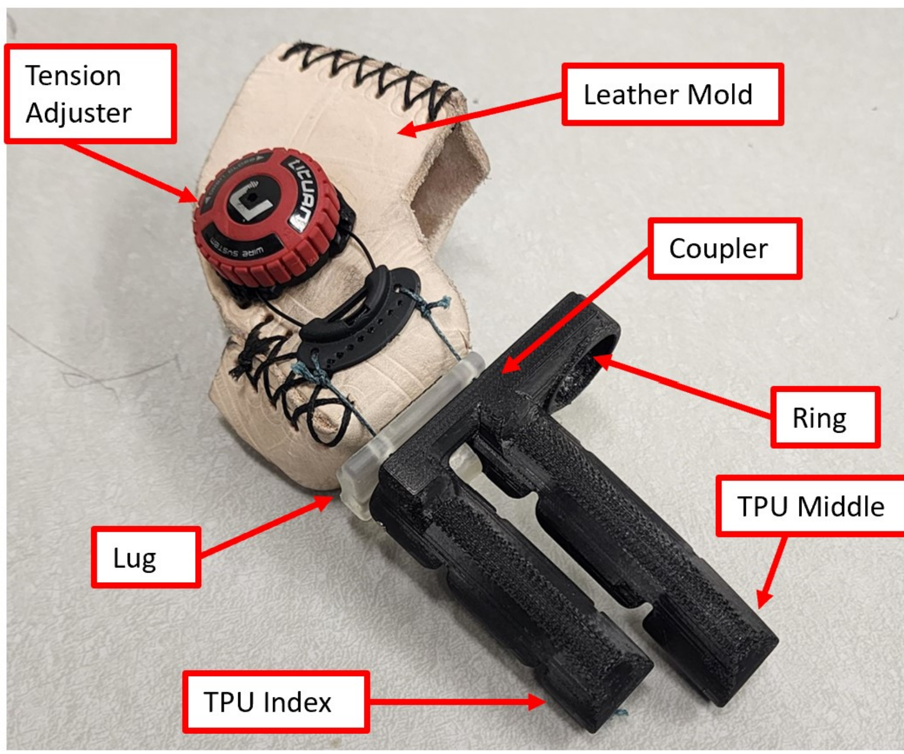


Fig. 5. The passive mechanism prototype for the index and middle fingers printed out of TPU, leather mold, and tension adjuster for actuation.

Furthermore, shown in Figure 5, the leather mold serves as the interface between the user and the fingers themself. A socket or mold is used in this case to distribute the load induced on the fingers over a large area of the soft tissue of the user and for comfort and ease of use. Leather is a strong and durable material but also has enough compliance to be comfortable for the user to flex, so the team decided use this for the socket design. For manufacturing, the leather is cut in the desired pattern with consideration of where it needs to be stitched together later, and then it is wet formed to hand casting via vacuum bag and left to dry.

For the distal thumb, the team used the ThumbDriver by Naked Prosthetics [6] to heavily influence the design to help the interviewee with large radius of curvature grip strength. The final iteration is shown below in Figure 6, and fits well for our user, but still does not fit inside a construction glove. The device relies on the function of the proximal phalanx in order to actuate, and it does so via the driver link that is directly coupled to the the thumb. As the user induces flexion, the combination of the driver link and the coupling link causes the flexible rubber grip to rotate inward as the distal thumb normally would. From here when the user grips an object the load is transferred through the links back the radial border of the thumb. The device gets strapped to the wrist via the wrist strap attach, and to help ensure there is enough compliance, a revolve one degree of freedom joint is added to the strap to ensure the wrist flexion and extension has no impedance on the mechanism.

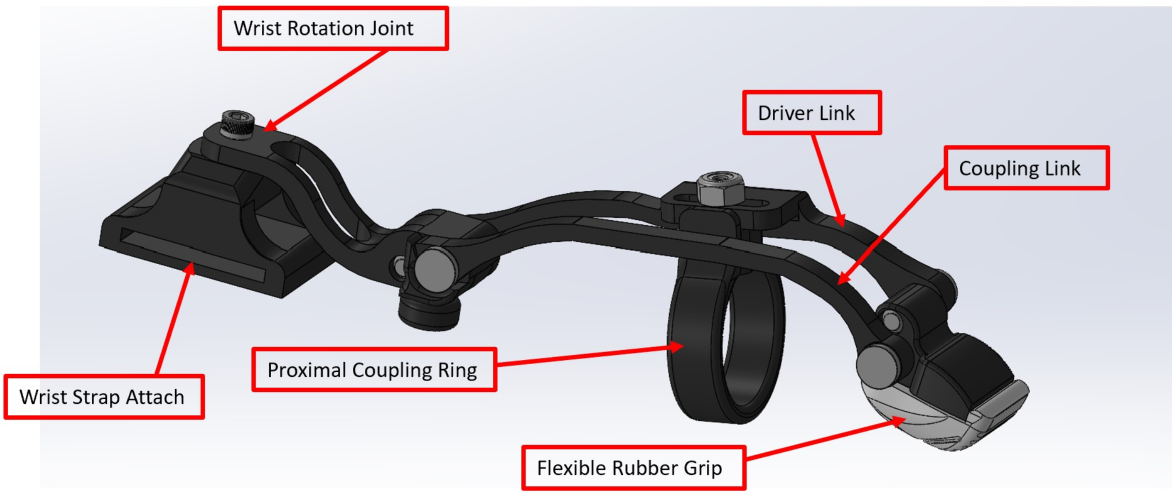


Fig. 6. The isometric views of the passive mechanism prototype for the index and middle fingers printed out of TPU.

To prototype this device the team used resin (SLA) 3D printing to iterate and learn what new features need to be included to ensure comfort and functionality. Also when designing such a mechanism, the geometry of users hands will vary, but the goal is to bring the mechanism as close as possible to the user without impeding the fingers proximal phalanx movement. Additional detail can be found for both proposed devices (like design files for replication) in Appendix B.

### *B. Test Methods*

It is hypothesized that users will use this device more frequently if it is inside a glove and not noticeable to others versus being open to viewing by others. In order to test this, the team would employ user assessments evaluating five different users, instructing them to use the prosthetic fingers with and without wearing gloves. By wearing the gloves on both hands, to other people it seems that the user has no impairment and they don't take notice, and allow for the user to feel more comfortable to wear the device and use it more. At least two of the five should be instructed to use the prosthetic fingers without any visual impairment over a period of time and log each time they used it, what they used it for, and the setting. The other users should use the device with a glove to hide the components and be instructed to do the same, and by gathering both sets of data the team could determine the affect of the gloves presence along with the device. Other proposed tests would be limitation of functionality related, specifically precision testing of the prosthetic device to check whether the thumb, middle, and index fingers could provide sufficient normal forces to grip a small/large objects. Additional testing would be flexibility of the leather mold to check whether the user would feel comfortable with wearing the leather mold, versus using traditional composite mold techniques.

## IV. Intellectual Merit

Researchers and designers who are interested in designing prosthetic fingers that involve cables in tension to actuate the flexion and extension of the fingers would benefit from learning's found. When designing prosthetic fingers, a variety of techniques can be used for body powered actuation as stated before in section I-A, so determining which one that is most useful is the challenge when designing for specific use case. For this design, the team specifically converged on using TPU for the index and middle fingers, and by using this material it allows for the fingers to be printed as a single part to reduce their overall volume. Also using a leather mold for the finger design would help other designers make material decisions for their designs. If the test methods presented are confirmed, then it would show that shrinking finger prosthetic designs down and blending them in would increase use of them among users. Further work on this device should include adding a layer of foam like material to inside of the leather mold for better fitment and comfort. Testing should be done to ensure the friction with the tension cables are not to much, and optimization of the path the tension wire follows will be coupled. For the Thumb device, more stops need to be added to limit the range of motion for flexible thumb tip and more optimization of the position of the holes is required.

## V. Broader Impact

If this prototype is proven viable through the test methods presented, it will help enable small mechanism manipulation for finger amputees, and users will use this device more due to its ability to be hidden by wearing gloves. The team decided this is an open source invention for other designers and engineers to help design better finger prosthesis's. For our teams interviewee, the devices presented will potentially impact him and inspire him to reach out to more doctors or insurance to get his own prosthetic professionally designed.

## References


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# Appendix A
# Interview Decomposition

## A. Full Table of Interviewee's Needs

TABLE II
Table of primary and secondary needs found during the interview of left handed finger amputee.

| Primary Needs | Secondary Needs |
|---|---|
| Not being noticeable to others | - Wears gloves so new people don't notice missing fingers, and for work tasks outside of the truck<br>- Being noticeable is the major problem of any prosthetic devices for him<br>- He wants passive systems<br>- He doesn't want people to notice his missing fingers<br>- Wants to wear a pair of nice tight flexible gloves with rubber at fingertips |
| Gripping heavy objects for carrying/moving them | - Not enough grip strength to carry heavier objects with 3 fingers on left hand<br>- Wine barrel, carrying plywood, lifting things that includes grip friction<br>- Home projects, lifting things and moving them |
| Precision movements and small object manipulation | - Typing with all fingers is difficult, his fingers are somewhat numb, thus doesn't get haptic feedback<br>- Shoe tying took a long time to learn<br>- Tying shoes takes a while and often wears boots because it's more convenient<br>- Using the thumb to ring finger becomes very challenging for small<br>- He wants a good grip from his left hand to hold nails and hammer using his right hand<br>- Wants to be a good caretaker and finds it frustrating<br>- Using left hand for twisting the key is challenging<br>- Keeping the tip of the thumb available is very important for phone use<br>- Doctor wanted to ensure his palm doesn't get stuck curled, thus for a year he needed to wear a mold, but in turn he has really good palm maneuverability and palm grip strength<br>- He wants to work on things in the way that right-handed people would do<br>- Allowing the wrist maneuverability/dynamics is really important |

# APPENDIX B
# INVESTIGATIONAL DEVICE DETAILS

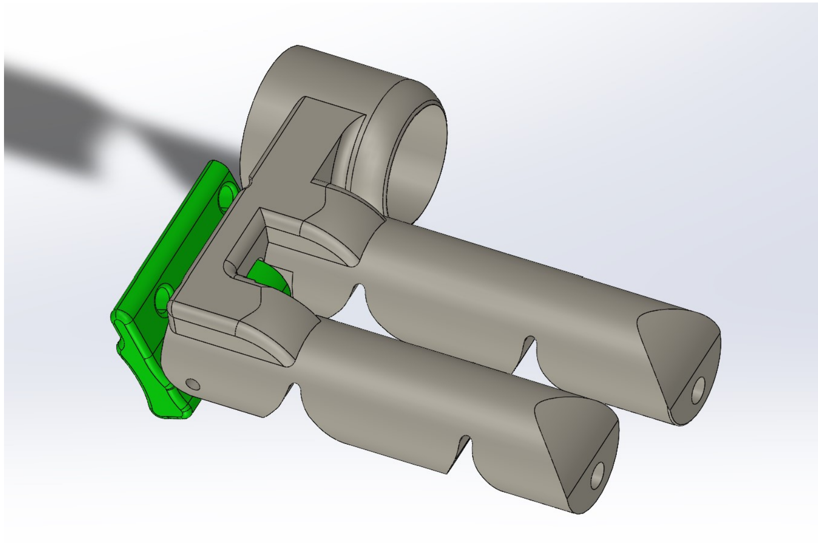

Fig. 7. The isometric view of the passive mechanism prototype for the index and middle fingers printed out of TPU with green male lug for single degree of freedom MCP joints.

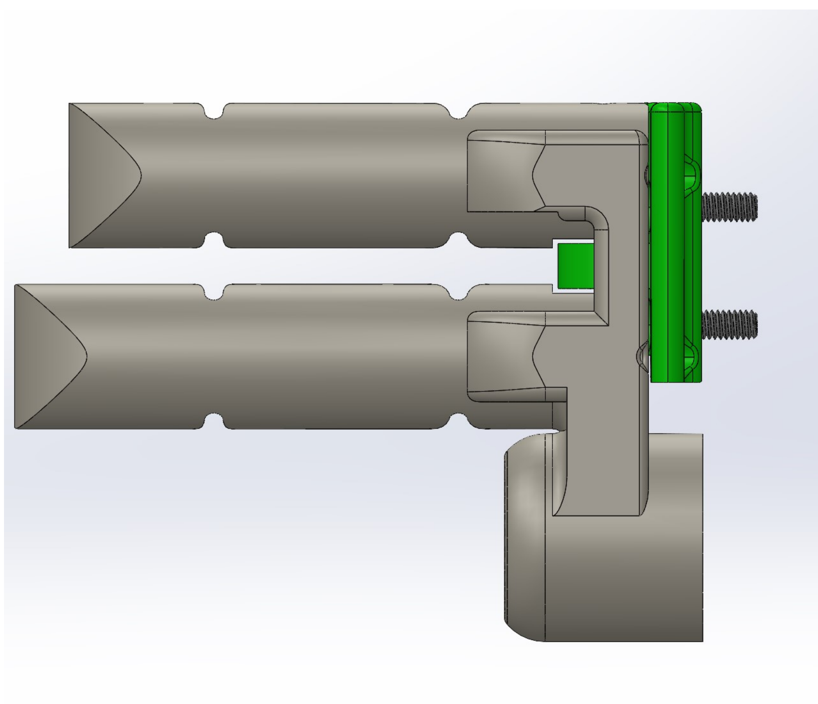

Fig. 8. The top view of the passive mechanism prototype for the index and middle fingers displaying the offset of the ring finger relative to the index and middle fingers .

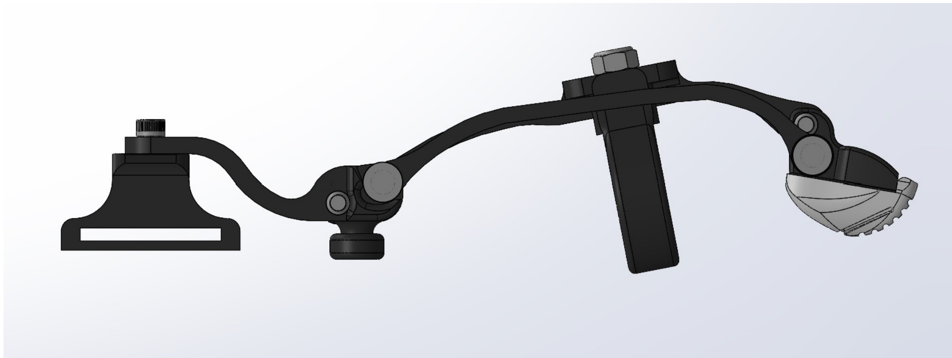

Fig. 9. The side view of the passive thumb mechanism prototype when it is at the highest rotational state, or when the links are hitting the stops.

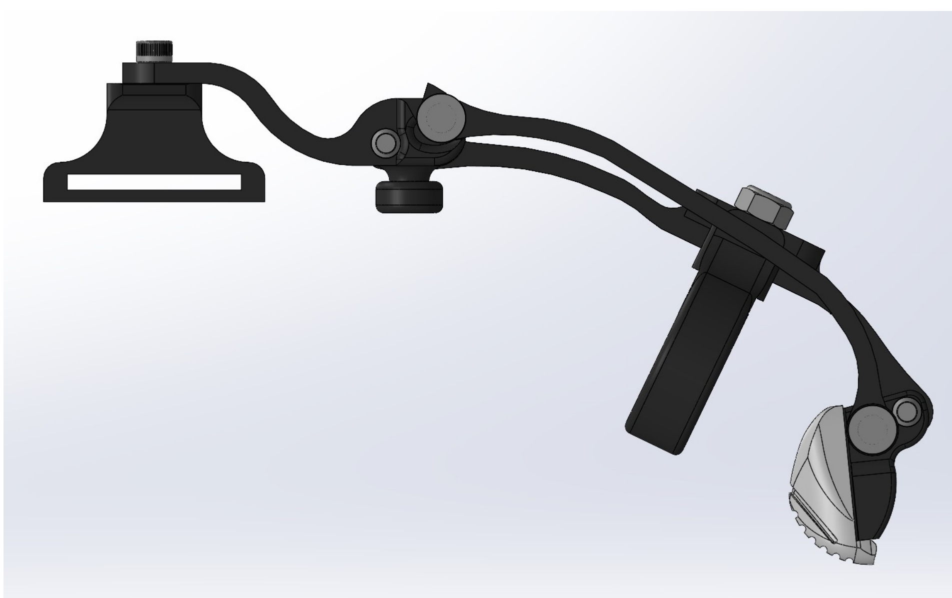

Fig. 10. The side view of the passive mechanism prototype for the distal thumb 4 bar linkage shown fully flexed.

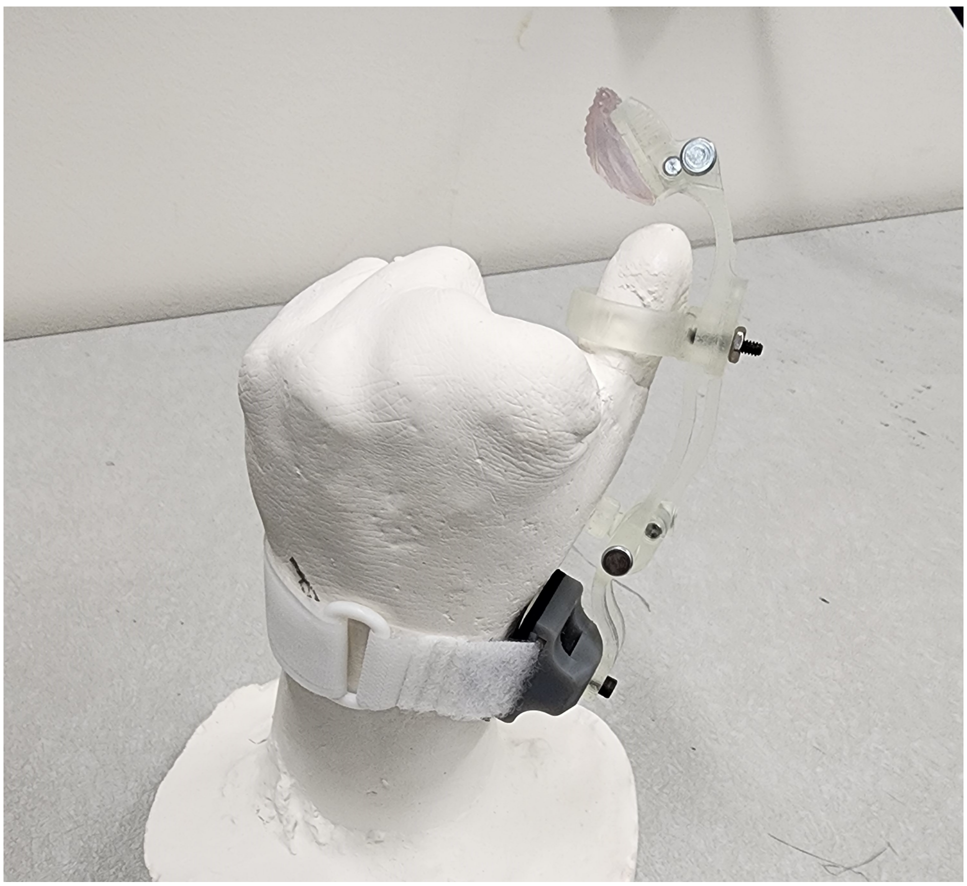

Fig. 11. Showing how the passive thumb mechanism will attach to users hand, and how the wrist strap attaches to the device.