e-NABLE: Add lateral wrist movement to an e-NABLE standard hand design

Preliminary Report

BME 200/300

Client: Mr. Ken Bice - Wisconsin Chapter of e-NABLE: BadgerHands

Advisor: Dr. Edward T. Bersu - Biomedical Engineering Department

Team Members:

Haley Yagodinski, Team Leader

Courtney Florin, Communicator

Kelly Starykowicz, BSAC

Claire Mitchell BPAG

Jack Metzger, BWIG

Liam Granlund, BWIG

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Abstract

The e-NABLE community is working to help kids in need of upper limb prosthetics, knowing they will grow out of them within 1-2 years. The solution is to 3D print hands that can be altered in size to fit the individual in need. Multiple designs have been created, including *The Raptor Reloaded.* With this, the user bends the wrist forward to clench a fist, and backward to release the grip. But that is the only degree of freedom of the device. For those with sufficient lateral movement of their wrist, a means of turning the prosthetic's wrist laterally would provide benefit of this second degree of freedom. This second degree of freedom is currently not possibly due to hinges on the side of device. By adding this, everyday tasks like twisting off a cap or taking a drink of water can be done. The new design will replace the hinges with an accordion style material, which would allow for both degrees of freedom. After testing, it is hoped to allow for the individual to get the most use out of their 3D printed prosthetic. It can turn them into the kids with the "weird hand" to the kid with the cool hand.

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Introduction

Motivation

The e-NABLE Community is an amazing group of individuals from all over the world who are using their 3D printers to create free 3D printed hands and arms for those in need of an upper limb assistive device. They are people who have put aside their political, religious, cultural and personal differences to come together and collaborate on ways to help improve the open source 3D printable designs for hands and arms for those who were born missing fingers or who have lost them due to war, disease or natural disaster. Within that first year the e-NABLE community grew from 100 members to over 3000. They created over 750 hands for people around the world. Within another year they have more than doubled to nearly 7000 members and approximately 2000 devices created and gifted to individuals in over 45 countries. None of the designs are patented, but rather put out to communities to help those around them. Currently, the prosthetic only has one degree of freedom. By adding lateral wrist movement, a child will be able to do everyday task like taking a drink of water or twist off a cap.

Current Design- Raptor Reloaded

The current e-NABLE design is the Raptor Reloaded. This device is 3D printed with PLA, and assembled with an assembly kit that can be purchased online. This device is used for an individual with a palm, but no fingers. When the individual flexes their wrist, the fingers all close in the same motion. Ideally, the pointer finger and thumb will come together to allow the individual the ability to pinch or hold something like a piece of paper. The hinges on the side currently restrict any lateral movement. To allow for more capabilities of the hand, a second degree of freedom would be useful.

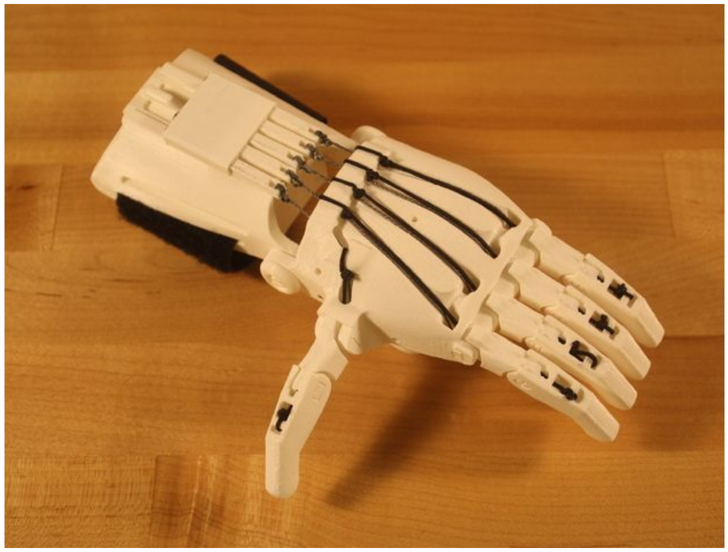

Figure 1. 3D printed and fully assembled Raptor Reloaded e-NABLE hand.

Problem Statement

e-NABLE international community 3D prints ultra low cost upper limb prosthetics and delivers them free to those in need. Almost all the hand designs (used for those missing fingers but still have a palm) strap a gauntlet on the forearm, and the functional part of the prosthetic hand to the remaining palm. The user then bends the wrist forward to clench a fist, and backward to release the grip. But that is the only degree of freedom of the device. For those with sufficient lateral movement of their wrist, a means of turning the prosthetic wrist laterally would provide benefit of this second degree of freedom. The project is to design and test a modified e-NABLE design that adds lateral wrist movement.

Background

Biology and Physiology

The current application of the *Raptor Reloaded* prosthetic is flexion and extension of the wrist. Flexion is bending the palm downward to the wrist, where extension is the motion of raising the back of the hand.[2] Another function of the wrist is lateral movement, which has two degrees of motion, abduction and adduction. A typical wrist has the ability of adducting 40 degrees and abducting 17 degrees.[1] An additional motion is rotation. While the wrist is able to rotate, this rotation occurs at the elbow. Two terms describing this motion are supination and pronation. Supination is rotating the forearm to a palm up position and pronation is rotating the wrist 180 degrees to a palm down position.[2] The purpose of our design is to allow for abduction and adduction of the individual, since wrist flexion and extension are already possible.

Client Information

e-Nable is an international community that 3D prints inexpensive upper-limb prosthetics for children and adults in need. Our client is Mr. Ken Bice, who runs his own e-Nable chapter called Badger Hands in the Madison area.

Design Specifications

The prosthesis, Raptor Reloaded, should maintain its current capabilities with the addition of a lateral movement to give the user another degree of freedom.The design must be usable by an individual with a palm, but no fingers. It must be 3D printed, ideally with materials that are well obtainable around the world. The design will be able to be repeated onto several prosthesis of different lengths and widths. The device must still maintain its original forceful grasp with the fingers and thumb. Because the prosthetic is typically used for children, it needs to last 1-2 years until they grow out of it. While wearing the prosthesis, the customer must be able to move their hand two degrees of freedom with ease. The weight or size of the device must be appropriate to the size of the user so it does not hinder them. The prosthesis must be easy to put on and off and should be easy to clean in between uses.

Preliminary Designs

Design 1- The Accordion

The first design is nicknamed “The Accordion” (Figure 2) due to the folded flexible TPU material that connects the hand and wrist. This design removes the pins which held the original model together at the wrist. The pins restricted the ability to adduct and abduct the wrist. TPU is used for the connection due to its ability to be 3D printed as well as its adjustable flexibility. This would allow the durability of the hand to be maintained while allowing for optimal rotation. The design is compact and doesn’t interfere with pre existing mechanical elements. Additionally it would require little maintenance and would be more comfortable for the user. This design would require testing to observe if it can reach the desired range of motion. A drawback of this design is the requirement of more than one material for 3D printing.

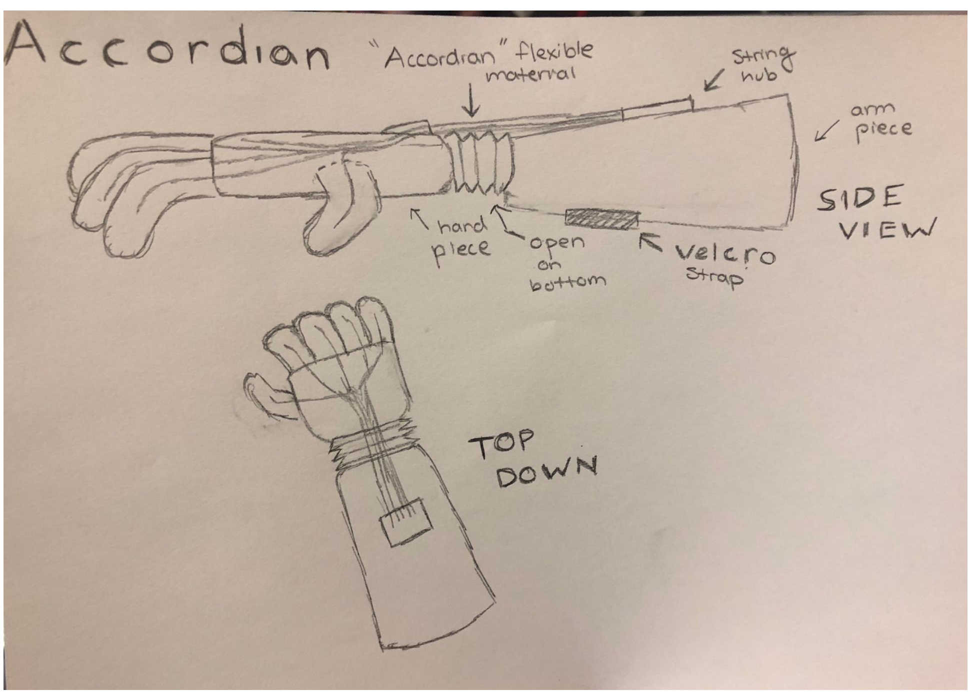

Figure 2. Drawing of The Accordion design with a side view and top down view.

Design 2- The FrizB

The second design is titled the "FrizB" (Figure 3), on account of the frisbee like disc that exists on the back of the hand piece. There is a circle shaped case that is hinged onto the arm piece. This hinge allows for movement forward and back of the wrist, essentially taking the place of the old pins holding the pieces together. The palm piece would be designed to have a disc shaped protrusion on the back that fits into the circle case and sits in a track. As it sits in this track it should be allowed to spin and account for adduction and abduction of the wrist. This design does however require a movement of the strings in order to account for the addition of the casing and protrusion. This would require testing and refiguring in order to not interfere with the current capability of the hand which is to close the fingers when the user brings their wrist forward.

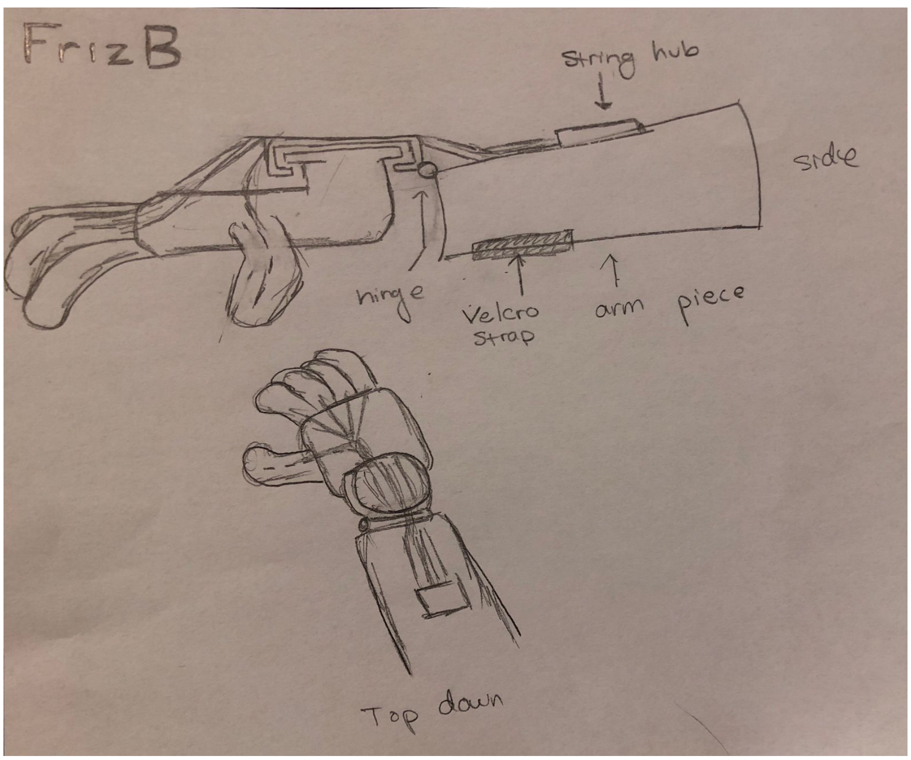

Figure 3. Drawing of the FrizB design with a side view and top down view.

Design 3- The Pulley

The third design was called "The Pulley" (Figure 4) because it consists of a pulley system to help move the wrist laterally. Like the other two designs, it does not have the pins covering the wrist joint, since these restrict the wrist laterally. The pulley is attached to the wrist, near where a watch face would sit. The string of the system is attached to the thumb and the pinky finger. The idea behind this design is that as the user adducts his/her wrist, the pulley pulls the pinky finger in the proper direction to assist the adduction and vice versa. However, it was unclear how the user would activate the pulley. If not created properly, the pulley string could end up restricting the lateral movement, which would be counterproductive. Though the design should maintain the capabilities of the current prosthetic, the strings of the pulley could potentially interfere with the strings of the hand. Also, this design would be easy to break and difficult to reproduce.

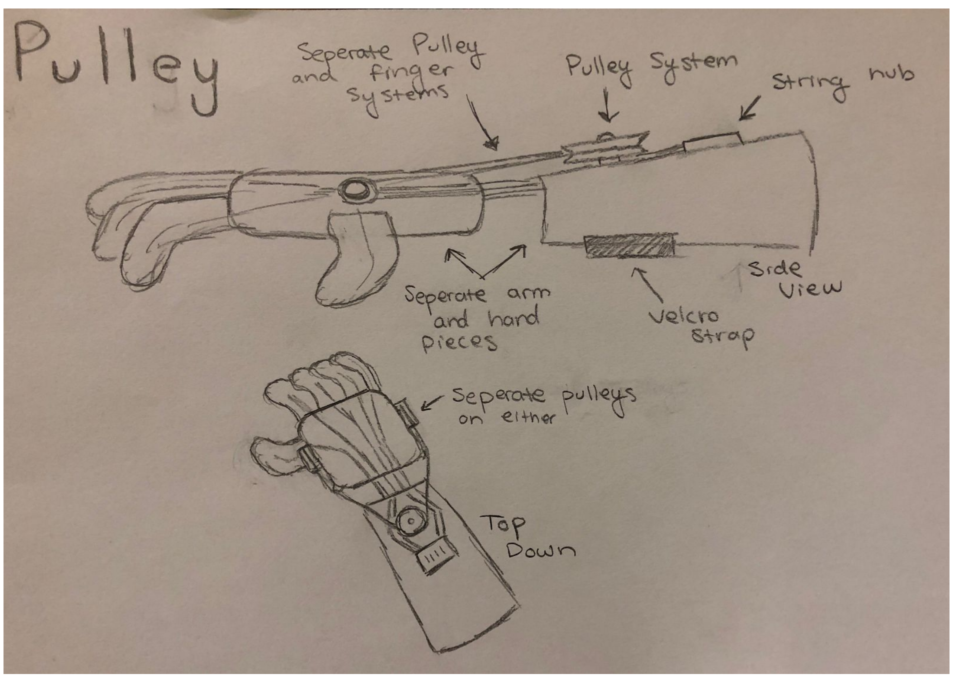

Figure 4. Drawing of the Pulley design with a side view and top down view.

Preliminary Design Evaluation

Design Matrix

Criteria	Weight	The Accordion		The FrizB		The Pulley	
Maintain Current Capabilities	25	(4/5)	20	(4/5)	20	**(5/5)**	**25**
Range of Motion	20	(3/5)	12	(3/5)	12	**(4/5)**	**16**
Patient Comfort	15	**(5/5)**	**15**	(2/5)	6	(3/5)	9
Functionality/Ease of Use	15	(3/5)	9	**(4/5)**	**12**	(2/5)	6
Durability	10	**(4/5)**	**8**	(3/5)	6	(2/5)	4
Reproducibility	10	**(3/5)**	**6**	(2/5)	4	(2/5)	4
Cost	5	**(5/5)**	**5**	**(5/5)**	**5**	**(5/5)**	**5**
Total	100		**75**		65		69

Table 1. The design matrix includes criteria used to evaluate the designs. The Accordion design won.

Design Matrix Summary

The most important criteria, given a weight of 25, is that the design must maintain the current capabilities of the Raptor Reloaded. This means that it cannot interfere with the strings of the wrist flexion motion. The next most important criteria is the range of motion of the arm, with a weight of 20. Ideally, the prosthetic will have full range of motion in the wrist. Patient comfort is the next most important criteria. The individual will be wearing the prosthetic on a daily basis, so a high score is given to the design that will be the most comfortable. Functionality and ease of use is also a criteria that needs to be considered. It needs to be able to be put on the individual daily and function the same every time. A high score is given to the most reliable design. Durability and reproducibility are both given a weight of 10. The prosthetic needs to be durable enough to survive in all operating conditions without too much wear. It also must be able to be reproduced by people all over the world, so the material must be able to be 3D printed. Finally, cost is the last criteria. The design must fit within the $200 budget.

Proposed Final Design

Overall, The Accordion design had the highest score. We will continue with this design moving forward. After meeting with the client, we hope to make some refinements to better improve the design. The Accordion didn't win in the two most highly weighted categories, so we hope to better these aspects of the design.

Fabrication/Development

Materials

To manufacture the prosthetic, Polylactic Acid (PLA) will be used to 3D print the parts at the Makerspace. Thermoplastic Polyurethane (TPU) will also be used to print the accordion part of the prosthetic because it can be adjusted for different flexibility. We were also supplied an assembly kit by the client that includes: elastic string, normal string, velcro, foam pads, etc.

Methods

A mockup of the design will be created using AutoCAD and 3D print it by taking advantage of the Makerspace at UW-Madison. In order to produce the product with the desired components, assembly will be completed with the client after all of the parts are printed. If time allows, the preliminary design will be evaluated and modified to create a device of higher quality for final presentation.

Testing/Future Results

In order to test the prototype, we will 3D print it sizeable to one of us. With that, we will be able to place the hand on and test the degrees of abduction and adduction that can be done. Without a real test subject, it can be hard to determine the strength of the wrist that the patient will have. This will need to be taken into consideration.

Another test will be done to see how well everyday task can be done with the prosthetic. We will place the prosthetic on a team member and have them twist off a cap and take a drink of water. The results of this test will allow us to know if we successfully created a device for real-life application.

Lastly, we will need to verify that the design did not interfere the current applications of the prosthetic. After full assembly of the prototype, it will be evident if the current strings still have their full range of motion as they do now. If complete wrist flexion is interfered with, new thoughts on assembly will need to be considered.

Discussion

Once results from testing are obtained, there will be a meeting with the client to discuss the application of the results to the future direction of the project and improvements to the design that can be made.

References

[1] J. Ryu, A. K. Palmer, and W. P. Cooney, "Wrist Joint Motion," *Biomechanics of the Wrist Joint*, pp. 37–60, 1991

[2] Stride, B. (2018). *Wrist Movements*. [online] Ergovancouver.net. Available at: http://www.ergovancouver.net/wrist_movements.htm [Accessed 9 Oct. 2018].

Appendix

Appendix A: PDS

Function: e-NABLE international community 3D prints ultra low cost upper limb prosthetics and delivers them free to those in need. Almost all the hand designs (used for those missing fingers but still have a palm) strap a gauntlet on the forearm, and the functional part of the prosthetic hand to the remaining palm. The user then bends the wrist forward to clench a fist, and backward to release the grip. But that is the only degree of freedom of the device. For those with sufficient lateral movement of their wrist, a means of turning the prosthetic's wrist laterally would provide the benefit of a second degree of freedom. The project is to design and test a modified e-NABLE design that incorporates abduction and adduction to the wrist movement.

Client Requirements:

- Need to add a second degree of freedom to existing prosthesis.
- Current prosthesis design is for individuals with a palm but no fingers.
- Advancing Raptor Reloaded design
- Cannot lose any of the functions already implemented with the first degree of freedom.
- Must be 3D printed

Design Requirements:

1. **Physical and Operational Characteristics:**

   a. *Performance requirements:* The prosthesis should maintain its current capabilities with the addition of a lateral movement to give the user another degree of freedom. It needs to be able to withstand everyday use.

   b. *Safety:* The prosthesis needs to add a lateral motion without overusing the user's wrist or palm. The motion needs to be a simple motion that will not put strain on the user's residual limb. It needs to fit and be fully controlled by each individual user.

   c. *Accuracy and Reliability:* The precision and accuracy of this design depend on each individual user. Overall, it should have two degrees of freedom. The radial flexion should approach 17 degrees and the ulnar flexion should approach 40 degrees.

   d. *Life in Service:* The prosthetic will typically need to last 1-2 years, or until the child grows out of it. The material and strings should not be damaged with daily use.

e. *Shelf Life:* The device will be given to the recipient within a couple weeks of being printed and assembled.

f. *Operating Environment:* The device will most likely be used in room temperatures(68-77 degrees Fahrenheit). Noise level will not affect the prosthesis. The device needs to be able to withstand subtle debris, such as dust, but the materials previously used for the prosthesis will be sufficient. Because children will most likely be operating this device, all the pieces must be well secured to ensure nothing is lost or damaged.

g. *Ergonomics:* The patient for this prosthesis must have a palm to be able to wear the *Raptor Reloaded* design. The device must be accurately measured to fit the patient comfortably. However, the design will be able to be repeated onto several prosthesis of different lengths and widths. The device must still maintain its original forceful grasp with the fingers and thumb.

h. *Size:* The device will be designed and printed specifically for each patient. The e-NABLE prostheses range from fitting kids to adults. The *Raptor Reloaded* prosthesis is just the wrist and hand so the length and size of the forearm will not be needed. A kid's(5-8yr) hand is between 5 and 7 inches and an adult's hand ranges from 7 to 10 inches.

i. *Weight:* The weight of the finished product should be anywhere from around 100-280g depending on the age and size of the user. (values from the similar 3D prosthesis *Cyborg Beast*) This means that the hand is generally lightweight so the user is relatively unhindered, even in the case of small children.

j. *Materials*: Current common materials are ABS, PLA, and Nylon. Nylon is not recommended because Nylon filament must be kept desiccated when not in use. ABS and PLA materials result in durable parts that rarely change with respect to mechanical characteristics over time.

k. *Aesthetics, Appearance, and Finish:* The prosthetic will be 3D printed. Aesthetics are not as important as function. New additions will fit the aesthetics of the current model.

2. **Production Characteristics:**

a. *Quantity:* There is a need for one altered prosthesis that can then be replicated.

b. *Target Product Cost:* The budget for this project is $200.

3. **Miscellaneous:**

a. *Standards and Specifications:* In order to maintain quality prints across many different types of printers, e-NABLE asks for volunteer fabricators to target the following quality specifications:

- No large gaps in between shells. The print must be "water-tight".
- Layer height between 0.1mm and 0.25mm.
- No experimental, scented, or chemically-treated filament.
- Printer must be properly calibrated to achieve the dimensional tolerances necessary for functioning hands.

b. *Customer:* While wearing the prosthesis, the customer must be able to move their hand two degrees of freedom with ease. The weight or size of the device must be appropriate to the size of the user so it does not hinder them. The prosthesis must be easy to put on and off and should be easy to clean in between uses.

c. *Patient-related concerns:* Each prosthetic is made unique to each patient, therefore sterilization is not necessary and since the design is general, sizing will be adjusted for each specific person, and there will be no patient data to store.