# E-Nable: Create a hold and release mechanism for hand designs


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## Abstract

E-Nable is a 3D printing open source volunteer community that provides low cost easily sourced prosthetics to individuals with an afflicted hand. The hand designs provided by E-Nable all have the same closing mechanism; the wrist is flexed causing wires to clench the fist. This flexion of the wrist leads to muscle fatigue especially while holding objects for an extended period of time. Currently there is no way to close the hand and keep the wrist extended. The goal of this project is to create a mechanism for locking the fingers in a closed position, while relieving muscle strain and wrist flexion during extended use of the device. To relieve this wrist fatigue we will develop a wire clamping mechanism to lock the the prosthetic hand grip size in place. This mechanism will be integrated into one of E-Nable's existing devices called the raptor reloaded. It will function by the user flexing the wrist the desired amount and then locking the flexor cables in place with a clamp on the back of the palm. The new design will be tested by attempting to hold different sized objects for predetermined amounts of time.

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## Introduction

### *Motivation*

In war-torn nations around the world, the most common form of limb loss results from land mines, which cause 26,000 amputations each year [1]. In addition to limb loss due to violence such as land mines or terrorist attacks, lack of access to health services further compounds the number of amputees in developing nations. With agriculture being a prevalent part of these countries' economies, the survivors of these accidents are typically farmers who thereby rely on physical labor to make a living. For these farmers and manual laborers, the loss of a limb threatens their very livelihoods.

Prosthetic devices are both monetarily and geographically out of reach to amputees in these developing nations, with the average cost of a prosthetic in the United States ranging from $5,000 to $15,000 [1]. Unfortunately, the issue of access to prosthetics does not end once an individual manages to obtain one, because the average adult needs a new prosthetic every 3 to 5 years, and children need a replacement every 6 to 12 months [1]. Since amputees in developing nations typically belong to the working class, low-cost, durable, and operational prosthetics are desperately needed.

### *Existing Devices and Current Methods*

Prosthetic hands primarily serve either functional or cosmetic purposes. Of the functional prosthetics, these can either be powered via electric motors/batteries or via body movements. Electric-powered prosthetics offer stronger grip force, since they aren't limited by the user's physical ability, and can be made to look more like an arm and hand. In contrast, body-powered prosthetics tend to be lighter and cheaper [2].

Myoelectric hands use electrical signals generated in the muscle and detected on the skin surface to control the prosthetic movements [3]. However, this type of prosthetic is expensive, ranging from $20,000 to $100,000 [4]. The bebionic myoelectric hand utilizes sensors and small motors to achieve fine hand movements with a weight comparable to a hand (Figure 1).

An example of a body-powered prosthetic is the split-hook design (Figure 2). This type of design utilizes cables attached to the user's shoulders. By contracting muscles in the shoulder, the user creates tension in the cable to either open or close hooklike pincers at the end of the prosthetic. While cheaper than a myoelectric hand, this design can cost up to $10,000 and its grip force is limited by the user's physical ability [4].


**Figure 1: bebionic Myoelectric Hand Prosthetic**
The bebionic hand prosthetic has a similar weight and appearance to a biological hand, and operates using small motors which detect electrical signals in the skin.

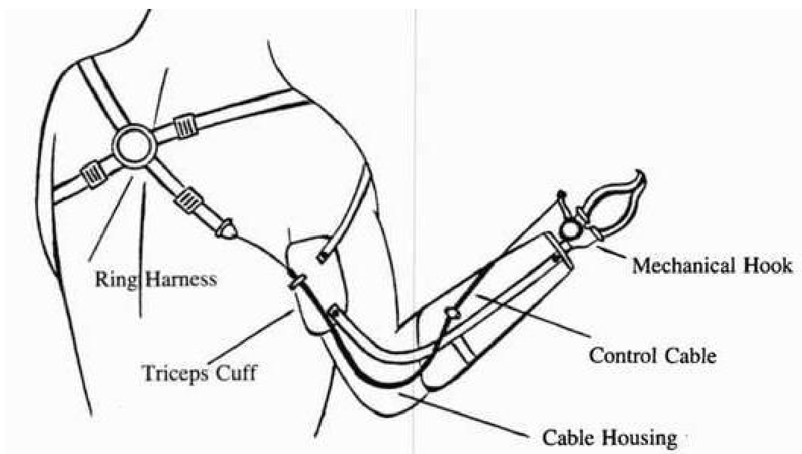


**Figure 2: Split-hook Hand Prosthetic**
The Split-hook hand prosthetic attaches at the shoulder. Using their muscles, the user applies tension to the cable to either open or close the hook at the terminal end of the prosthetic.

***Problem Statement***

E-Nable is a large community of volunteers serving people in need of low-cost prosthetics. To date, over 10,000 volunteers have made and delivered 2,500 to 3,000 prosthetics to people in over 90 countries [5]. Currently, all E-Nable hand designs have the same closing mechanism: the wrist is flexed, causing wires to clench the fist. If the user wants to continuously hold an object they must keep their flexed bent at an awkward angle (see Figure 3 for hand closure mechanism). This fatigues the forearm and wrist, making it difficult to hold things for a prolonged time. The purpose of this project is to create a locking mechanism on the prosthetic so that objects can be held more long term. To do this, the team must design a way to pull the contraction cables and lock them in place until the user wishes to release the item.

## Background

### *Client Information*

Mr. Ken Bice is the leader of BadgerHands, the Wisconsin chapter of E-Nable. E-Nable is an organization which provides open source 3D print files of prosthetic upper limbs. Using these files, E-Nable's volunteer community of 10,000 volunteers assembles and delivers 3D printed prosthetics to over 90 countries around the world [5].

### *Product Design Specifications*

The prosthetic hand closing mechanism of the fingers needs have a way to maintain finger flexion without requiring the user to continuously flex the wrist. The optimal mechanism for this design would be a one handed locking mechanism that could also be unlocked using only the afflicted limb. The team will first try to design a mechanism that is two handed, or one hand with assist. We are using the assumption the user of this new design has one fully functional hand. The materials used in the new locking mechanism must be easily sourceable. The current hand can be built with 3D printed parts and components you can buy from a craft store. The locking mechanism must be either printable, or found in the same kind of store. The prosthetics are often used in developing countries; machined parts or expensive off-the-shelf items are prohibited in our design. The assembly of the new device must be simple, like the current hand. A Youtube tutorial video is currently used for assembly of each of the hands, and the new lock mechanism will have to be conveyed to new users in the same way. Certain materials, such as rubber bands and excessive metal in the hinges, cannot be in the final design. Rubber bands tend to have a very short life expectancy on these hand prosthetics due to the hot, dry climate they are used in. Metal parts in the hinges are considered a safety hazard to the patient and must not be used. 3D printed parts will be used wherever possible in the final design. The final device cost must stay between the current $12-$20 because each prosthetic is delivered for free by volunteers in the E-Nable community to each recipient. Maintaining a low device cost is essential for the E-Nable community to thrive.

## Preliminary Designs

Before brainstorming ideas for a clamp design, a base prosthetic was chosen to modify. The team decided to alter the Raptor Reloaded (RR) hand design (Figure 3). Based on the more simplistic design of a modified hand versus an arm, and the availability of an already printed hand from the client. This design is meant for users who have no fingers but a partial palm. The fingers are closed by flexing the wrist, which increases tension in the flexor cables, closing the hand. By releasing the flex of the wrist, the elastic string behind the fingers help to open the hand back up.

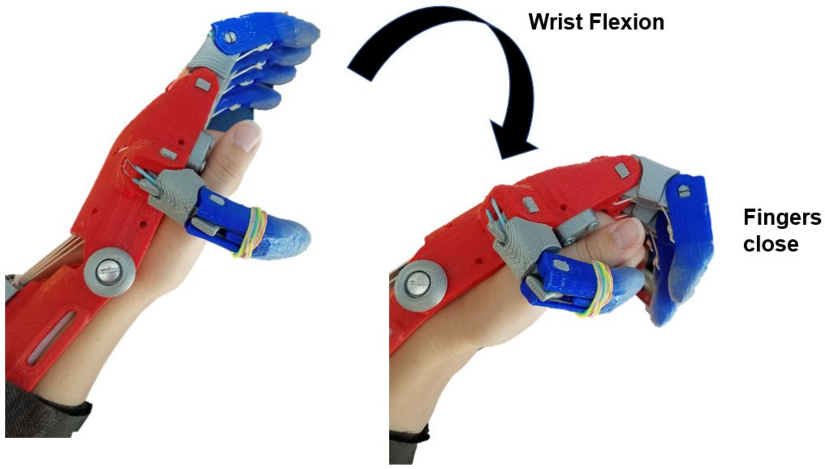


**Figure 3: E-Nable Raptor Reloaded Hand Closure Mechanism**

The Raptor Reloaded is closed via flexion in the wrist. Wrist flexion tenses the flexor cables thus curling the fingers.

***Pawl Ratchet Mechanism***

The locking mechanism for this design is located on the wrist joint (Figure 4). The 3D printed palm piece currently has two holes on the end that are connected by a pin to the forearm gauntlet. This joint will be redesigned to have a tooth-edge circle on the palm part, and a pawl ratchet on the gauntlet. The lock mechanism is a one hand with assist design. This means that closing the hand requires on hand (the injured one in this case), but to open the fingers of the prosthetic, a second hand is required to release the ratchet. This design is easy to operate, but lacks a few features that would make is more user-friendly. It requires the user to always keep the wrist flexed during continuous use while holding an object. Even though the muscle doesn't apply force this whole time, it is still bent at an uncomfortable angle. This design also does not allow for use of the prosthetic normally without activating the locking mechanism.

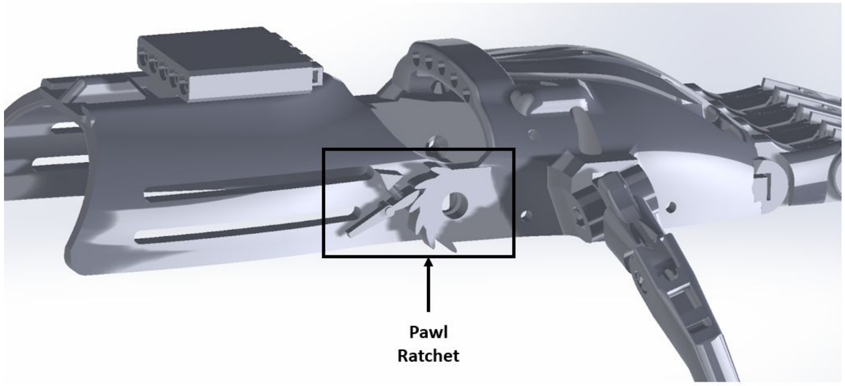


**Figure 4:** The pawl ratchet design looks the same as the current design, with the addition of a locking ratchet at the palm piece-gauntlet joint. This pawl ratchet (boxed above) allows tension to be taken off the wrist and moved to the joint during extended use of the prosthetic.

***Gear Shift***

The gear shift design allows for normal use of the device when prolonged wrist flexion is not required. When the locking mechanism needs to be activated, the user then must use the other hand to move the flexor cable box back on a track and lock it in place (Figure 5). This motion is the same as shifting gears in a car. The figure below demonstrates how multiple slots can be created to flex the cables and fingers closed to different clench sizes of the hand.

This design does not require any extra parts to be bought, only an adjustment to the 3D printing of the forearm gauntlet. It would have to be lengthened and adapted to have slots rather than a single track as it currently does. The slots are a limitation to the design, because the device can only be as precise as the number of slots available to use. The more slots, the better finger precision available. However, due to 3D printing capabilities, the slots cannot be so thin that they would break when stresses are applied during continuous holding of an object. The other concern with this design is there would be stress applied via wrist extension to the users palm because the cables would pull back on the hand while pulling back the tensor box. There would have to be a design mechanism to stop it from extending too far back from what is comfortable.

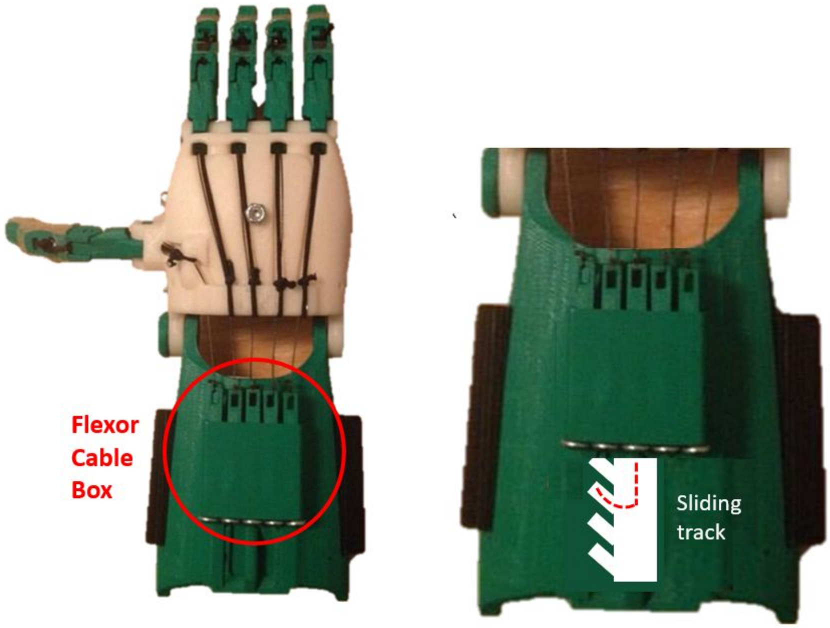


**Figure 5:** The gear shift design uses a sliding track with slots to adjust the cable tension. Adjusting tension will cause the fingers to close and the slot allows for continuous finger flexion without flexing the palm the entire time.

***Hand Clamp***

The hand clamp, like the gear shift, allows normal use of the prosthetic without needing to engage the clamping mechanism. The locking mechanism in this design consists of a clamp that presses down on the tensor cables (Figure 6). This works by flexing the wrist; adding tension to the cables and closing the fingers. The clamp is then lowered over each of the cables resting on the back of the palm. The location of the clamp is on the palm and not the forearm. This design allows for the user to extend their palm after locking the cables in place because the tension in the cables will be maintained. The hand clamp design is one-handed with assist, because it doesn't require two hands except to lock and unlock the continuous use mechanism.

With regards to design; a new palm piece, new clamp mechanism, and high friction materials would need to be made and sourced to complete the device. The high friction material will be the difficult part of this design, while keeping sourcing in mind. The negative of this mechanism will be the chance the cables slide loose of the clamp.

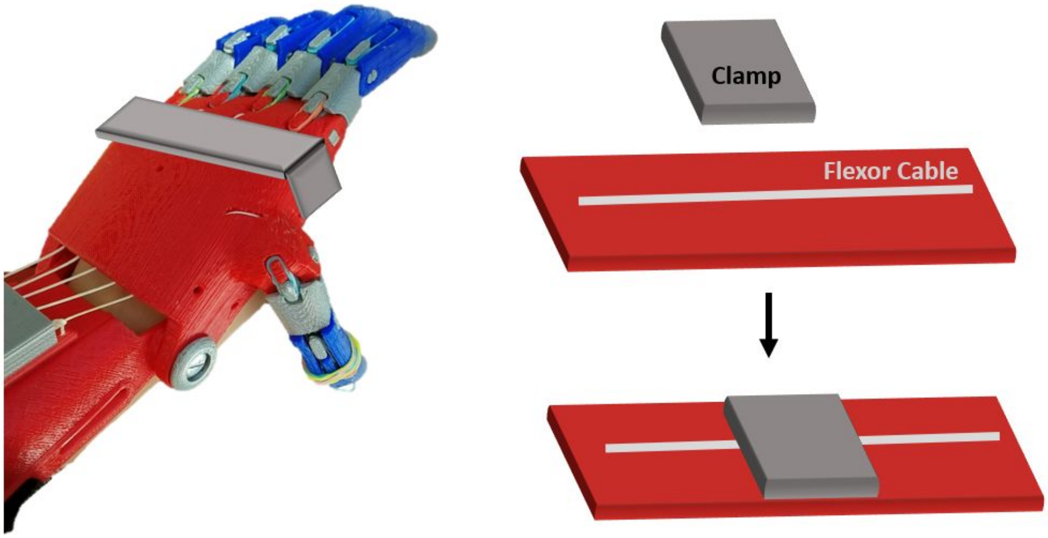


**Figure 6:** The hand clamp mechanism  preventing the movement of the flexor cables in order to lock the grip size in place.

***Hand Ratchet***

The hand ratchet mechanism works with the same mechanics as the pawl ratchet. The difference being there is no longer a gauntlet that attaches to the arm of the user. The entire closing mechanism is on the back of the hand, with a knob that turns to wind up the tension cables (Figure 7). The mobility of this design is a bonus because the user now has full range of wrist motion. The downside is the only way to use the hand mechanism is to twist the knob on the hand with the users free hand, there is no way to have one-handed use. The release mechanism is the same as the pawl ratchet, with a push button that allows the knob to spin and release the tension.

**Figure 7:** Hand Ratchet mechanism operating similar to that of the pawl ratchet mechanism however winding the flexor cable around a spool on the back of the hand to allow wrist freedom.

## Preliminary Design Evaluation

### *Design Matrix*

| | Pawl ratchet Mechanism | | Gear Shift Mechanism | | Hand clamp - (put on the breaks) | | Knob - Hand Ratchet Mechanism | |
|---|---|---|---|---|---|---|---|---|
| **Ease of use (30)** | 18 | 3/5 | 12 | 2/5 | 24 | **4/5** | 6 | 1/5 |
| **Hand precision (25)** | 15 | 3/5 | 10 | 2/5 | 25 | **5/5** | 20 | 4/5 |
| **Sourcing/ Cost (20)** | 16 | 4/5 | 20 | **5/5** | 8 | 2/5 | 16 | 4/5 |
| **Ease of assembly (15)** | 12 | 3/5 | 15 | **5/5** | 12 | 4/5 | 9 | 3/5 |
| **Safety (10)** | 8 | **4/5** | 8 | **4/5** | 4 | 2/5 | 8 | **4/5** |
| **Total (100)** | 69 | | 65 | | **73** | | 59 | |

**Table 1.** Design matrix evaluating each design on the criteria of: ease of use, hand precision, sourcing and cost, ease of assembly, and safety.

### *Summary of Design Matrix*

From our product design specifications, the user requirements were weighted higher than the assembler requirements. Ease of use and hand precision were given the highest weight. Ease of use was determined by considerations given to the operation ability using only the afflicted limb, amount of assistance from the functional hand, and the ergonomic use. Hand precision was rated by how many different sizes the hand could make while keeping a closed grip on what it was holding. Sourcing/cost were determined by how easily the materials can be acquired for the final design in a local craft store or by 3D printing capability. Ease of assembly is rated the same as stated in the design specifications. The safety section was rated from an engineering perspective on how difficult it will be to design the prosthetic to lock a flexed fist and maintain the finger flexion over time.

Based on the design criteria the hand clamp design was determined to be the best design by a narrow margin over the pawl ratchet mechanism (Table 1). The hand clamp design would be the easiest to use and more ergonomic than the other designs as it allows for normal one handed use of the device but then additionally allows for the option to lock the grip and once the hand is closed and locked, the user still has wrist movement. It also would have the highest hand precision out of the designs considered because it does not rely on the hand grip to match up with a gear teeth. The Hand Clamp will need a couple of new materials including some sort of rubber for the break and a specific type of cable- rather than fishing line which is sometimes used- to ensure the clamping mechanism does not break it. Other designs rated higher because there would be minimal, if any, extra materials required. Once the new parts are printed there will not be a significant increase in assembly difficulty because there are no springs or complex pieces in this design. Lastly, the Hand Clamp rated low in safety because of the anticipated potential for slippage failure more than other devices.

### *Proposed Final Design*

The design going forward is the hand clamp design. It scored highest on the design matrix, and we think it will be the most precise at closing the fingers and keeping them closed. The final design of the clamp still needs further brainstorming of materials and methods. The exact mechanism to maintain pressure on the tensor strings has yet to be determined.

## Fabrication and Development Process

### *Materials*

Hand pieces including the fingers, joint pins, palm, gauntlet and string actuator are all 3D printed using an ultimaker 3 with PLA filament. The elastic cables can be obtained from a craft store and are non-brand-specific to our design. The flexor finger cables and breaking material that will be used in the clamping mechanism are not yet determined. The bolts connecting to the string actuator are dependent upon the scale of the print but are also non-specific as the plastic is not threaded.

### *Testing*

Testing will be conducted by attaching a demo bar to the device. This will allow members of our team to wear and use the device as the prospective users would, see Figure 8. Then, a series of holding tests will be performed using the classic Raptor Reloaded or the Raptor Reloaded with hand clamp modification. The classic and modified will be compared in both their regular, non-clamp use and clamped (or continuous wrist flection in the case of the class RR). The tests will measure object size and weight and the duration of time holding the object. Qualitative tests will be taken to decide whether the new mechanism is more comfortable to the user than the old one. Moreover, different combinations of flexor cables and clamp materials will be tested to produce maximum clamping force and prevent slippage.

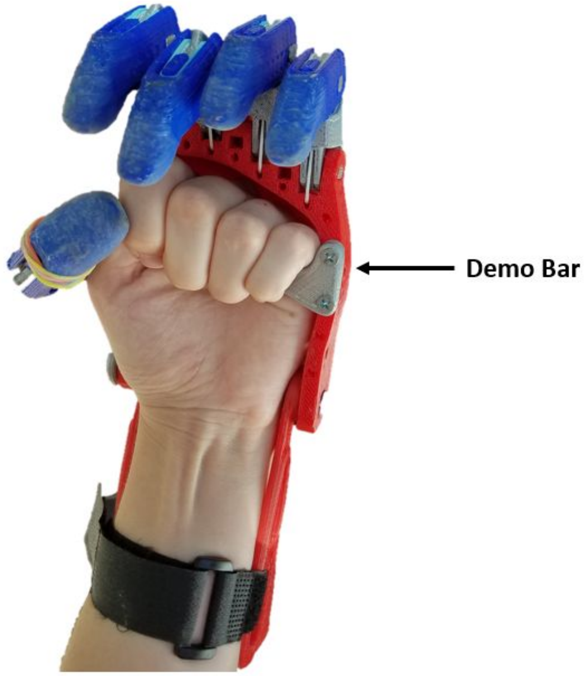


**Figure 8: E-Nable Raptor Reloaded with Demo Bar**

Here the Raptor Reloaded is being worn by an able-bodied person via use of a demo bar.

## Conclusion

In conclusion, there is high demand for low-cost, easily sourced hand prosthetics. E-Nable is a community of volunteers dedicated to creating 3D prosthetics to fill this demand. Current E-Nable devices are limited because constant wrist flexion is required to continuously hold objects. Therefore, after thorough brainstorming, we propose the addition of a clamp to the existing E-Nable Raptor Reloaded device. The clamp will function by holding down the flexor cables and preventing the fingers from uncurling. As usage of the clamp is option, the device can be operated as normal or in the clamped position if desired. Testing of this device will be conducted against the existing RR via a demo bar. Moving forward, more brainstorming must be done on the exact mechanism of the clamp and materials that will be used.

## References

[1] E. Strait, Prosthetics in Developing Countries. 2006.

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[4] "How Much Does a Prosthetic Arm Cost? - CostHelper.com," CostHelper. [Online]. Available: https://health.costhelper.com/prosthetic-arms.html. [Accessed: 02-Oct-2018].

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## Appendix

### *I. Product Design Specifications*

**<u>Client Requirements:</u>**

- The device fingers should be able to close and stay closed without continuous wrist flexion.
- Materials should easily be sourced in developing countries.
- The new design should be relatively simple to assemble.
- The final product should cost $12-$20.

**<u>Design Requirements:</u>**

1. **Physical and Operational Characteristics**

- *Performance requirements:*
  - User should be able to hold simple objects such as a water bottle without fatiguing the wrist.
  - Comparable gripping abilities compared to current designs available.
- *Safety:*
  - The device should have rounded corners and dull edges where possible to avoid injuring the user.
  - Metal hinge components should be avoided to allow for a shearing break of the prosthetic joints in the case of a fall, avoiding potential harm to the user being caught in the device being bent at an awkward angle.
- *Accuracy and Reliability:*
  - The device's grip mechanism should allow for comparable or improved hold maneuverability to the existing Raptor Reloaded prosthetic.
- *Life in Service:*
  - The plastic parts should outlast the strings, rubber bands, Velcro straps, etc. On a Raptor Reloaded, in a high heat region, such as Africa or southeast Asia.
  - The Velcro straps and flexor cord should last one year and the extensor stretchy cord should last 3 months.
  - If the part is destined for use in the USA, the extensor cord should last closer to a year.
- *Shelf Life:*
  - The device should be able to be printed and sit in a box put together without degrading or falling apart.

- In terms of durability, the limiting factor will be rubber bands or elastic strings shelf lives.

- *Operating Environment:*
    - These devices are often sent to war-torn developing countries, where the climate is hot and humid.
- *Ergonomics:*
    - The device must comfortably fit on the user.
- *Size:*
    - The gauntlet of the device will fit snugly around the wrist and/or forearm of the user, being large enough to provide mechanical stability to the user.
    - The device can be scaled to match the size of the user.
    - The size will be more constrained by the final weight of the device.
- *Weight:*
    - The device should be as light as possible while maintaining mechanical strength.
    - It has the potential to be used my small children so keeping the materials light and keeping a weight/material reducing design should be considered.
    - The typical weight of existing E-Nable devices is ~1lb, so our design should be as close to that as possible.
- *Materials:*
    - Materials must be able to withstand the specified environmental conditions and be resistant to degradation due to chemical and temperature exposure.
- *Aesthetics, Appearance, Finish:*
    - The final product shall be aesthetically pleasing to look at as it will be in plain view on the user.
    - The product shall have no burs or sharp edges that can possibly harm the user or snag on clothing.
    - There is no finish needed as 3D printed plastic is ready to use once cured.

**2. Production Characteristics**

- *Quantity:*
    - Device part files will be available online for volunteers to 3D print and assemble.
- *Target Product Cost:*
    - Current E-Nable designs typically cost between $12-$20. Therefore, to maintain affordability, this device should not exceed $20.

**3. Miscellaneous**

- *Standards and Specifications:*
    - N/A
- *Target Population*

- The target group for this device is a user who has one working hand and one hand that is missing all digits (palm intact).
- Users of the device range in age from children to adults, so the design must be scalable in size.

- *Patient Related concerns:*
  - Materials must be easily found and replaced.
- *Competition:*
  - The Bebionic prosthetic hand utilizes motors and sensors to achieve precise hand movements.
  - Prosthetic hands which are solely cosmetic range from $3,000 to $5,000 [2].
  - Prosthetic hands which operate using elastic cables, typically cost about $10,000.
  - Cosmetically realistic myoelectric hands may cost $20,000 to $30,000 or more. These contain processors that can tell how much pressure the user is putting on a held object and whether it is hot or cold.