Assisting Partial Hand Amputees with Grasping Soft Objects

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Abstract

Amputees are individuals who have suffered from limb loss. This condition can significantly impact this population's ability to complete certain tasks involving dexterous manipulation. A common solution for this disability are prosthesis, but they can be very expensive and uncomfortable for the user. In an interview conducted with a quadrilateral amputee including partial-hand loss, we learned that she struggled grasping soft objects such as a sponge to wash the dishes.Using this information, we hypothesize that partial-hand amputees will be able to complete more daily tasks on their own by using a toolbox of devices that attach to their hands. Our goal is to design an affordable and functional wearable sleeve around the palmar side of the hand that can be tightened using a motor and switch and can be attached to different items for varying daily tasks. A functional prototype of this motorized wearable sleeve was assembled. If the hypothesis holds true, these findings can have a broader impact on amputees in which wearable sleeves can be more cost-efficient and accessible compared to the current market's prostheses.

I. Introduction

Amputees are individuals who have lost or removed a limb due to an injury or disease, and millions of people suffer from this condition [1]. This condition has a paramount impact on how these individuals are perceived by society as well as affects the way in which they complete their daily tasks [2]. As a result, this may be mentally stressful for those with this condition [2]. One common modern solution for this condition involves EMG technology, which utilizes electrical signals created by muscle contractions to perform a specific task by the device [1]. However, this methodology lacks full control by the user since there may be times when a muscle contracts unintentionally, which may be dangerous in certain situations. For quadrilateral amputees that have lost limbs in their legs and arms, completing daily tasks such as bathing and washing the dishes become very challenging. This paper focuses on an easily accessible motorized sleeve that can attach cleaning items, and it is primarily for individuals who have had their fingers amputated.

A. Background

As there are many different kinds of amputees in the human population, upper body amputations are one of the most common including partial hand loss and the upper limbs [3]. To support this demographic, the current recommended technology for amputees is prostheses, which are wearable devices that replace a missing limb to enhance the body's overall functionality. One issue with prosthetic devices is that they can be extremely expensive with prices ranging from $7,000 to$75,000 depending on the level of functionality of the device [4]. In addition, prostheses can also be very uncomfortable for the user because the fit between the socket and limb may be too tight or loose.One application of this device was demonstrated in Rokib Raihan's research that involved the integration of EMG sensors onto a wearable and wireless mouse for those with amputations above the hands [1]. Since the EMG sensors are able to detect the electric signals created by muscle contractions, this device provides implicit feedback and may feel more natural to the user. However, the use of EMG sensors is not always stable such that the user's muscle can unintentionally contract and result in undesirable motion. On the contrary, in a study by Leonardo Franco, et al., it was shown that a manually actuated supernumerary finger can be used to assist amputees without fingers with grabbing large objects [5]. This device does not require any electrical components and is very easy and cheap to manufacture. However, the user must be able to use one hand to mount this device onto their other hand, and this may be difficult for amputees with partial hand loss on both hands. We hypothesize that partial-hand amputees will be able to complete more daily tasks on their own by using a toolbox of devices that attach to their hands. Our goal is to design an affordable and functional wearable sleeve around the palmar side of the hand that can be tightened using a motor and switch and can be attached to different items for varying daily tasks.

B. Overview

We hypothesize that a motorized wearable sleeve can be used for partial-hand amputees in which it will be able to self-tighten using a spooling mechanism, and also attach a variety of cleaning tools such as a sponge or washcloth. In Section II, a quadrilateral amputee was interviewed to learn more about their daily needs and challenges as an amputee. Using the information we learned from the interview, Section III elaborates on our proposed design of the motorized wearable sleeve where its intended use will allow the user to clean and bathe much easier. If our hypothesis is correct, our study can encourage more research into self-tightening sleeves for tasks involving grasping soft objects, which is mentioned in Section IV. Lastly in Section V, these findings can have a broader impact on amputees in which wearable sleeves can be more cost-efficient and accessible compared to the current market's prostheses.

Customer Statement	**Need Identified**
"…a lot of times what I'll do is I'll put like beeswax or coconut wax on my hands to make them a little tacky, because I've got so much scar tissue on my hands…"	Device is sticky or grippy to assist in lack of tackiness
"I can't slip my hand into something like [a device with a tacky substance on the inside] because it's grippy."	Device is easy to slide a hand into
"I use a lot of jeweler's tweezers because they got the dipped tips on them, and you can pick things up."	Device has a handle that's easy to grasp
"It has to be the right pressure the scissors won't cut."	Device needs enough pressure to cut things
"Usually you have to have fingers to be able to reach both sides and pull the spring loaded [plier] together."	Device closes and opens pliers more easily

Fig. 1. Interview samples paired with needs interpreted by interviewers.

II. Preliminary results

To understand more about partial hand amputation, we interviewed a need-knower in this space. They were forced to receive a gangrene-induced double partial hand (and leg) amputation over 30 years ago.

Since this procedure occurred while they were already an adult, learning to reuse their limbs was even more difficult than when this type of procedure is used on children and infants [6]. Over the course of a 1.5-hour virtual interview, the team was able to determine a multitude of needs specific to this individual. During this interaction, we were able to record the conversation for a transcript, and so our need-knower could demonstrate motions and devices they have already designed for themselves. The team learned that they struggle with any fine manipulation, because their grip is so limited in dexterity. Our need-knower is an avid beadworker outside of her day job as a hairdresser, and struggles with certain precise manipulations involved with beading, such as holding small beads in place to insert a thread, or tying knots. Additionally, their lack of finger strength makes heavy objects difficult to maneuver. They often need help carrying boxes or other objects around the house. Not only are heavy or small objects an obstacle, but the high quantity of scar tissue on her hands results in a lack of skin tackiness. Figure 1 outlines some of the primary pain points this potential user is facing.

These general needs were represented in a specific case: holding soft, wet objects such as wash cloths or sponges. The need-knower's attempts to use such products resulted in an unfortunate paradox. If the product was grippy enough to grab on to their non-tacky skin, it was too grippy to slide their hand in. If it was loose enough for their hand to slide in, then it wasn't tight enough to stay on their hand during use. This issue has made bathing and washing dishes very frustrating, due to the lack of devices to assist in this space. This lack of equipment underscored another theme in the interview: independence. Our need-knower has been making devices for themself for over 30 years, and has achieved an incredible level of autonomy. With that being said, they still struggle with some chores around the house such as bathing and cleaning. They are highly invested in not needing to rely on someone else for as many tasks as possible.

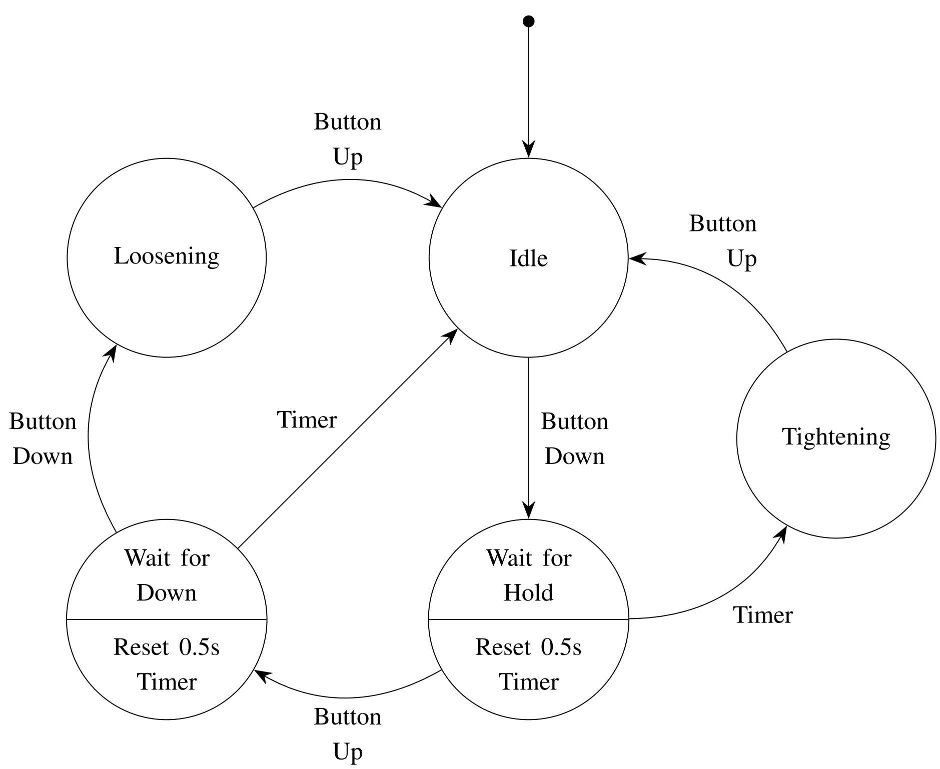

Fig. 2. State diagram of the button used to tighten and loosen device.

III. Methods

To reduce struggle in this area for our need-knower, our group developed a self-tightening sleeve with interchangeable attachments. The sleeve attaches around the user's hand and stays on without the user needing to use fingers. A neoprene sleeve opens up and allows for a user to insert their hand. An additional layer of neoprene on the inside of the device shields the user's hand from any movement of threads. Then, by pressing a button, a motor will spool a cable that is woven through the device. This spooling action will tighten the sleeve around the user's hand, until a desired level of tightness is reached. To loosen the device, the user double-clicks on the button to wind the spool in the opposite direction. The complete state diagram is shown in Figure 2. For specific cleaning tasks, the user will be able to interchange the specific type of cleaning pad or washcloth on the palm via a quick-connect mechanism with magnets.

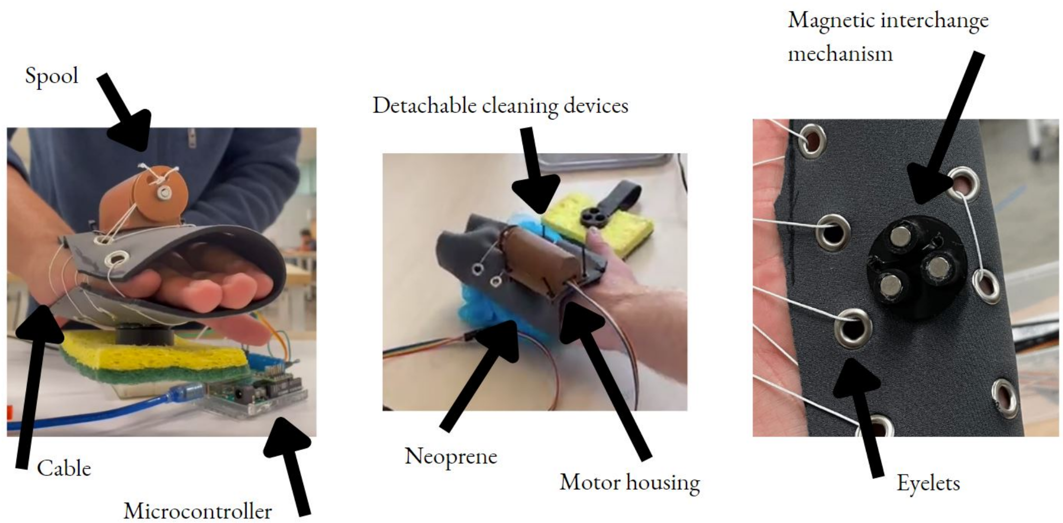

Fig. 3. Annotated device components

The design components are outlined above in Figure 3. More detail on their implementation is provided in Appendix A.

The current state of the device is a table-top demonstration of its capabilities. The button, microcontroller, and power supply all remain on a table or nearby surface, while the device itself is actuated by the motor on the back of the device. Ideally, the system will be miniaturized to fit wholly on top of the device, and be on the back of the user's hand. Using a smaller microcontroller, a micromotor, and a battery would successfully miniaturize the system to fit on top of the device itself.

A study to test our hypotheses would focus on partial hand amputees. Ideally, we would be able to conduct this study with 15-30 adult individuals who have had part of their hand amputated. Subjects would have to have hands between 50-80 mm in width, be older than 18, and struggle with holding soft fabric objects. These criteria ensure that subjects fit within the demographic of adults, that their hand fits in the device, and that this solution could actually help them. The study itself would focus on the efficacy of the device in allowing partial hand amputees to complete more of their daily tasks by themselves.

The study would first measure the subjects' comfort with using sponges and washcloths. Each subject would be asked to hold each of these objects for as long as they could while performing regular washing tasks, such as cleaning dishes or scrubbing a counter. At the end of the control trial period (5-15 minutes depending on subject capability), subjects will be asked to rate their difficulty with each task on a scale of 1-5, and any quantitative data about their performance will be recorded (use time for each object and their respective weights). After a 20-minute break, the subjects would be prevented with our device, and asked to use it without any clarifying instructions from the design team. If use can't be achieved without outside instructions, it will be provided. The same cleaning tasks are completed and the same cleaning tools are used, over the course of another 15 minute interval. Subjects then rate both the difficulty of completing the tasks and the difficulty of using the device itself. The same quantitative data from the control section of the study will be recorded as well. After all data has been collected, subjects complete a final form on their opinions of the device, its efficacy, and any other subjective feedback they may have. After the completion of this, they are free to leave and study is complete.

Though we all have completed CITI training, we would still need to receive IRB approval to complete this study. The purpose and background of the study reported to the IRB would include the content from the beginning of the introduction, and the research team's hypothesis. The criteria for subject selection would be as mentioned above, and possible complications all surround over-tightening of the device on users' hands. Additionally, all subject identities will be protected throughout the study and the release of data from the study.

IV. Intellectual Merit

The device our group has developed should allow for a deeper study of how modular sleeves can aid tasks that involve grasping soft objects. Rather than studying or iterating upon solutions such as prosthesis or a supernumerary finger, we instead aimed at creating an original solution of a self-tightening sleeve. Our investigation on how to create a self-tightening sleeve should prompt more study of devices that can be worn like sleeves and be easily worn by those with impacted dexterity. The electromechanics that allow the sleeve to tighten with a linear motion could either be improved in terms of size and durability, or replaced with a complex passive mechanism.

If our hypothesis is correct and it makes tasks like scrubbing dishes easier, more applications for a self-tightening sleeve could be found. Given more time and resources, we could better test our hypothesis with a trial with a group who have partial hand loss. On the other hand, if it does not simplify these tasks, the gripping factor of the material, tightening mechanism, and attachment mechanism need to be diagnosed for both functionality and comfort.

V. Broader Impact

Our assistive device can hopefully serve as an alternative to a prosthetic for performing scrubbing tasks. These devices are not only expensive, but also might not assist in cleaning tasks very well. Because the device is easy to build and non invasive, our group would like to make it open source and welcome iteration upon it. A website or other repository could make it a readily available blueprint for those with partial hand loss. Eventually, it could be sold commercially in retail stores or online at an inexpensive price because of its low cost components. This should make assistive devices for those not only much more widely available, but also more normative.

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Appendix A
Investigational Device Details

The design components are outlined in Figure 2. The motor housing and spool are 3D-printed from PLA. The thread that tightens the mechanism is a standard thread provided by the teaching team. The material of the sleeve is 2 mm thick neoprene, and features metal eyelets to reduce friction for the thread. Hole placement was determined in an attempt to optimize the tightening mechanism and make it more homogeneous. Optimizing where holes are and how much tension is applied to each part of the system is an area for future improvements to this design. The motor used to actuate the system is a 12V DC gearmotor, and is controlled by an Arduino Uno with a Dual MAX 14870 motor controller board.

The majority of the iteration for the prototype occurred around the profile of the neoperene sleeve and the position of the cable routing holes. The prototype initially suffered from severe bunching and binding, and didn't tighten evenly. By making the seam of the device a curve that follows the shape of a hand, and by tightening the device from the middle, a significantly more even tension was applied and bunching was reduced.

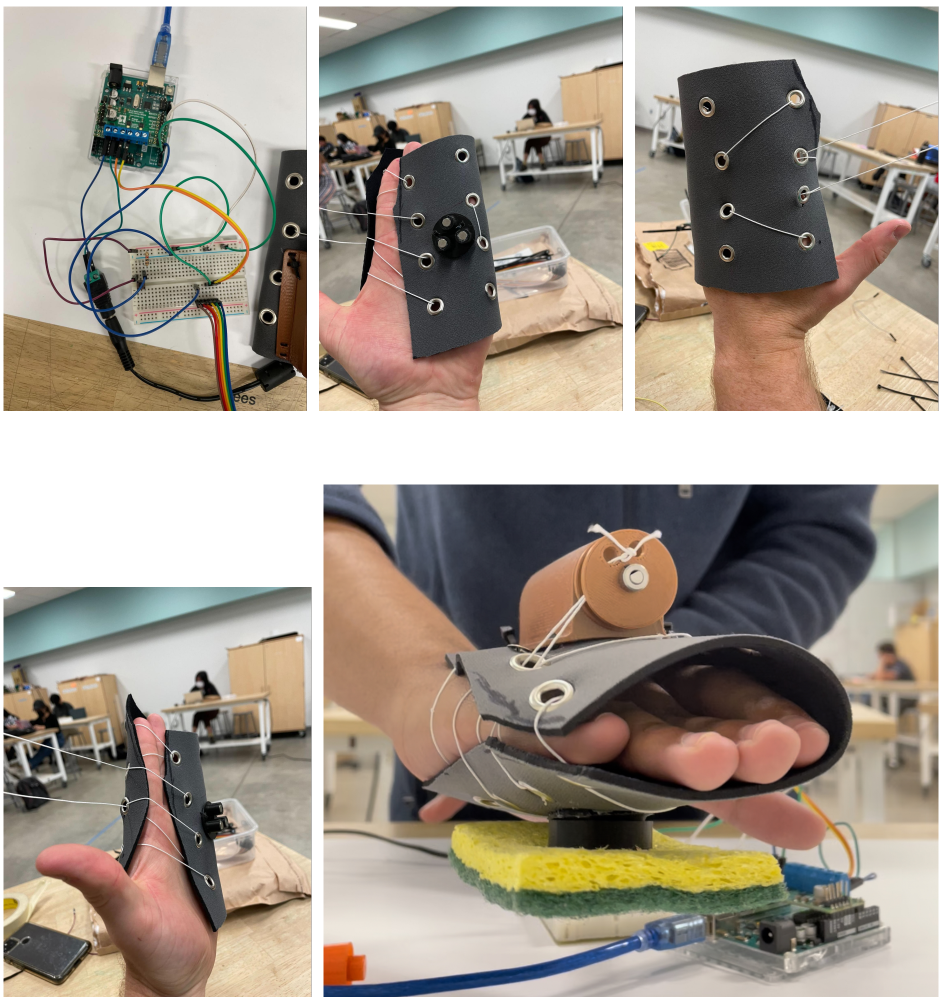

Fig. 4. Pictures of device in current state.

Appendix B
Collecting and Analyzing Interview Data

A. *Hierarchy of Needs*

- Device is ergonomic
  - Device is easy to slide a hand into
  - Devices grips dishes so they can be washed
  - Device allows user to grip washcloth and switch between hands interchangeability
  - Device has a handle that's easy to grasp
  - Device is sticky or grippy to assist in lack of tackiness
- Device enables opening/closing without fingers
  - Device cuts paper in straight lines
  - Device closes and opens pliers more easily
  - Device cuts hair
  - Device needs enough pressure in order to cut things
  - Device holds on to objects
- Device can hold onto large objects
  - Device holds comb for cutting hair
  - Device assists picking objects without hands
  - Device has to be firmly pulled onto hand
  - Device relies on a mechanism to attach on user's hand as opposed to grip
  - strength
- Device supports fine articulation
  - Device grasps and manipulates tiny objects
  - Device holds onto two small objects at once
  - Device accounts for limited wrist and finger articulation
  - Device ties shoelaces
  - Device makes using zippers easier
- Device that assists in touching
  - Device accurate to type one key
  - Device has easy to use buttons
  - Device operates normally with touchscreen information
  - Device supports elevated arms during writing motions
- Device aids in making daily life more comfortable
  - Device facilitates wheelchair use
  - Device wears rings

B. Weighted Matrix

Criteria:	User comfort	Ease of use	Cutting ability	Throwing ability	Gripping ability	Typing ability	User affordability	Novelty/group interest	
Weight:	4	4	2	1	3	2	1	1	
1	3	2	2	0	4	0	5	2	43
2	5	4	0	0	5	0	4	3	58
3	3	2	0	0	5	0	3	4	42
4	4	4	1	0	5	0	2	2	53
5	3	5	0	0	5	0	4	2	53
6	4	3	1	0	5	0	4	3	52
7	5	5	0	0	3	0	0	3	52
8	3	3	1	0	5	0	3	3	47
9	2	3	5	0	0	0	3	2	35
10	2	4	5	0	0	0	1	3	38
11	2	1	3	0	0	0	1	1	20
12	3	2	4	0	1	0	2	2	35
13	3	3	4	0	0	0	2	2	36
14	3	2	0	0	5	0	4	2	41
15	2	4	0	0	5	0	1	3	43
16	3	5	0	0	4	0	5	2	51
17	2	4	0	0	3	0	1	1	35
18	2	3	0	0	5	0	3	2	40
19	3	5	0	0	4	0	3	1	48
20	2	5	0	0	5	0	3	3	49
21	3	2	0	0	4	0	3	2	37
22	3	4	0	0	5	0	2	2	47
23	2	4	0	2	3	0	1	2	38
24	2	3	0	3	3	0	5	3	40
25	3	2	0	0	4	0	2	2	36
26	3	5	0	0	3	0	2	2	45
27	3	5	0	3	0	0	2	4	41
28	5	4	0	5	0	0	2	3	46
29	4	5	0	5	0	0	2	3	46
30	4	2	0	0	0	3	3	1	34
31	3	3	0	0	0	4	1	3	36
32	5	4	0	0	0	4	2	3	49
33	5	4	0	0	0	0	2	3	41
34	2	3	0	0	0	0	4	1	25
35	5	5	0	0	4	0	3	2	57
36	4	4	0	0	3	0	4	2	47