Creating a Device for Easier Trail Surveying for Users With Quadriplegia

Benal Johnson and Nimit Baid

Augmenting Human Dexterity – Spring 2020 Term Project: Report and Research Proposal

Abstract

Quadriplegia is a form of paralysis that affects all four limbs of the body, impacting the ability of individuals with this condition to perform day-to-day tasks independently. There are many assistive devices available on the market that individuals with quadriplegia can use to maintain independence of daily tasks, but they are often generalized to provide pinch/grasp function in a variety of contexts and not tailored towards an individual task. In an interview with an individual with quadriplegia, it became evident that the lack of contextually appropriate, independently manipulated, and inexpensive made it challenging to perform certain tasks easily. The interview highlighted the importance of designing contextually appropriate assistive devices specifically for the trail surveying setting. Using the insights from this interview, we hypothesize that a device to assist in holding devices for surveying trails will improve the independence and reduce fatigue in individuals with quadriplegia. A functional prototype of this trail surveying device was built that held a smartphone vertically in place using a four-bar linkage. To determine if the device leads to increased feelings of independence and reduced fatigue, a study is proposed where individuals with quadriplegia will survey trails for a set period of time and self-report on their feelings of fatigue. If this hypothesis holds true, this device could lead to positive impacts in how individuals with quadriplegia interact with personal devices and maintain independence.

I. Introduction

Tetraplegia, otherwise known as quadriplegia, is a form of paralysis that affects all four limbs of the body [1] and is typically caused by external trauma to the body that results in spinal cord damage to the C1-C7 vertebrae [1]. Quadriplegia affects approximately 284,000 people within the United States [2] and has significant impacts on a person's ability to perform day-to-day tasks independently [3][4]. Enabling dexterous manipulation is a key priority in persons with quadriplegia [4] and there are many assistive devices that exist for enabling upper limb dexterity, such as body-powered grasping and pinching devices [5], bionic prostheses that provide grasp and pinch capabilities [6], and splints that prevent contractures in phalanges [7]. These assistive devices still have gaps with respect to their use in a variety of contexts; often times, a custom solution is needed [8]. To address a gap in assistive devices for custom solutions, this paper explores the effects of an assistive device geared towards increasing independence and managing documentation devices in the context of trail surveying.

A. Background

Quadriplegia is a form of paralysis that affects all four limbs of the body [1]. Quadriplegia is primarily caused by traumatic injury to the spine [1] [2], but can also be caused by a number of other conditions such as cerebral palsy, stroke, or amyotrophic lateral sclerosis [9]. Spinal cord injuries are typically classified by the location of the injury along the C1-C7 vertebrae of the spinal cord [10]. The extent of paralysis varies across persons with quadriplegia [11], as both the severity of the injury and the location of the injury along the spine determine the limbs affected [12]. Spinal cord injuries can be categorized as incomplete or complete [12]; incomplete injuries mean that some function and/or sensation remains in the limbs affected, while complete injuries mean there is complete paralysis and total loss of sensation [13]. Since this paper specifically looks at the effects of an assistive device for dexterous manipulation, we will focus specifically on quadriplegia's affects on the hands.

Hand Therapies in Quadriplegia: The hand is an important limb with regard to maintaining independence [3] and especially in completing day-to-day tasks in persons with quadriplegia [14] [15]. In research done by Ainsley et. al., it was described that “in a survey of male quadriplegic persons, 75 percent rated the restoration of normal function of hands and arms as more important than...the return of bladder and bowel function,...use of legs,...and sexual function” [15]. There are several types of hand therapies for patients with quadriplegia, which are highly dependant on patient preference, level of paralysis, and desired function(s) to rehabilitate [15] [14]. One type of therapy is surgical, which involves the transfer of tendons to aid in establishing lateral pinch and gross grasping function [15]. Another intervention that may be used in conjunction with or separate from surgery is hand splinting [14] [7], which helps in preventing contractures of the hands and phalanges. There also exist a number of assistive devices, such as prosthetics, that establish functions of pinch and grip [6] otherwise not present in people with quadriplegia.

Important design factors: In a systematic literature review by Orejuela et. al., it was noted that quadriplegic subjects’ primary goal after suffering a spinal cord injury was ”getting back into life, described as the possibility to perform any task by their own feeling independent with a sense of control of their lives” [5]. Independence is a key aspect of successful assistive devices [16]; designs that consider lower weight, simplicity of use, and adaptability tend to have less abandonment over time [16] [17] [18].

B. Overview

We hypothesize that the creation of an assistive device to hold camera equipment for surveying and documenting trails will improve the independence, wellness, and quality of life of persons with quadriplegia. The ability for individuals to independently manipulate the device will allow for increased feelings of independence and enablement amongst persons with quadriplegia. In addition, the creation of an assistive device that is able to hold documentation equipment for trail surveying will allow for individuals’ greater enjoyment of the trails without worrying about managing and holding their camera equipment. Section II outlines the challenges and needs of those with quadriplegia with respect to independent manipulation of assistive equipment. To test our hypothesis, we propose an assistive device for holding a smartphone in a level plane which will allow us to qualitatively measure the effects of this assistive device on sentiments around independence, enjoyment, and wellness in the context of hiking. If our hypothesis holds true, this study has the potential to have much broader impacts for assistive devices as outlined in Section V.

II. Preliminary results

To understand the needs around designing an assistive device for persons with quadriplegia, we interviewed a mature adult with quadriplegia. Our interview was conducted in-person at the interviewee’s residence to ensure their comfort and understand what types of assistive devices they use in their daily life. The interview was recorded for the purpose of transcription and reference. In this 90 minute interview, we asked the interviewee about their day-to-day routines, their hobbies, and their desires and wants from assistive devices in general.From this interview, we were able to gather a variety of insights that helped inform our understanding of our interviewee’s general desires, as well as specific areas of needs.

This interview specifically made apparent the shortcomings of existing assistive devices to flex across a variety of contexts and uses. Because assistive devices for upper mobility are typically designed for more general use and to provide basic pinch/grasp capabilities, they fall short in other tasks. They pointed out that actions such as manipulating knives to chop vegetables while cooking and holding camera equipment to document surroundings were challenges where there was no existing assistive solution. To circumvent these shortcomings, our interviewee would either hire a cook to prepare meals or purchase pre-chopped goods. The body-powered assistive device that the interviewee used was not effective for the context of cooking due to its limited pinch capability, lack of heavy object manipulation, and angle of attachment on their body.

In addition to the lack of appropriate assistive devices, the interviewee mentioned that specific tasks were acutely challenging due to the limited use of their phalanges. Partial or complete paralysis of different parts of the upper body are common in quadriplegia, which commonly affects the ability for persons to complete day-to-day tasks. This can lead to feelings of a lack of independence in individuals with quadriplegia. Having a multitude of contextually appropriate assistive devices or an assistive device that can flex across multiple use cases is important in ensuring independence of users with this condition. Due to the expense of buying new assistive devices and the gaps in existing assistive devices, the interviewee ended up designing their own low-cost device. Their device consisted of a 1.5” diameter dowel rod with a metal hook attached to the end, enabling them to reach high places, open doors, and have a low-cost and portable solution across a variety of uses. The ease of building this device made it so that the interviewee could also customize it the way they desired by having a shorter handle or a longer hook depending on what they needed. This DIY assistive device designed by the interviewee highlighted the need for low-cost, independently usable, and contextually appropriate assistive devices.

The interviewee also spoke about their trail surveying work in detail. They document trails and hiking paths via a camcorder video feed and a smartphone for photographs. Managing and accessing both devices is difficult when there is no assistive device to hold both pieces of equipment. Based on the needs that the interviewee mentioned, we gathered a list of needs to guide our design of an assistive device for a trail surveying setting; an abbreviated list of needs can be seen in Figure 1, while the full list of needs is available in Appendix B in Figure 5. These needs led us to believe that an assistive device for the trail surveying context could address some of the needs for this setting.

Question/Prompt	**Customer Statement**	**Interpreted Need**
What do you need to survey different trails?	I need to be able to take pictures and videos of the trail	Product provides easy access to surveying tools
	I need to be able to manipulate my surveying equipment easily	Product enables easy manipulation of survey tools
	I need to be able to lift my wheelchair’s arm to get in and out of my chair	Product does not attach to left wheelchair arm Product can be removed/moved out of the way of the wheelchair arm Product can be independently removed from the wheelchair
	I need to be able to document several aspects of the trails I survey	Product can securely hold multiple survey items easily

Fig. 1: Key user needs from the interview process.

III. Methods

Device concept: The objective behind this device was to allow the user to operate their devices more independently while freeing up active human engagement. We developed a trail surveyor that can clamp onto a wheel chair arm and carry various devices to enable hands free operation of a phone and camcorder. The device features a quick release mount to easily mount and remove the phone. Users can interact with this device and control precise positioning using a joystick. The arms of the structure are spring balanced and the phone mount features a spherical ball joint to allow for fine manual adjustments to the user’s liking. This trail surveyor will be able to hold recording devices for the user to allow for longer duration trail surveys and reduce fatigue while enhancing precise adjustment capabilities.

Subsystem description: The device consists of three main sub assemblies - the motor mount(figure 2), stabilizing arm (figure 4) and the phone holder (figure 3). The motor base is a 3D printed part that provides the interface for the wheel chair arm and holds the motor assembly. The motor is connected to the arm with a d-shaft and can control precise angular positions. The stabilizing arm is a four bar linkage that keep the phone mount horizontal at all positions of the actuated arm. The assembly is also spring balanced to alleviate the moment load on the motor when moving the devices. All linkages are made from laser cut plywood pieces with a 3D printed stiffener to reduce torsional strain under loading. The assembly has a range of motion of approximately 100 deg covering a variety of camera angles. Finally the phone mount is a modified product that allows easy connect and release features while making the it accessible using wrists only. The spherical joint at the phone mount allows for final adjustments and hold the phone secure in that orientation. This preliminary prototype shows the possible degrees of freedoms possible for a simple device. Future iterations may include a suspension stabilizer for the recording device to make the footage smoother. While this is a good proof of concept, the final arm dimensions and required adjustments can be understood by observing user interactions.

Fig. 2: 3D printed motor mount base.

Fig. 3: 3D printed phone mount.

Fig. 4: Stabilizing arms functioning in the full assembly.

A proposed study: To test our hypothesis and establish the need for such a device we will conduct a study with 10 participants affected by quadriplegia who use a wheelchair on a daily basis. The procedure would include two 10 minute trail surveys one with manual device handling and one with the trail surveying tool installed. Each participant will be asked to record details of the trail surface and other features along the trail. At the end of the sessions a survey would collect information on the ease of use for the recording devices, self reported fatigue levels, and freedom of use for the recording devices during the run. In addition to this the footage from all runs will be analyzed for quality, stability and the amount of useful information gathered about the trails.

Based on the responses and the analysis if the recordings we will determine the response of the users and compile any feedback from post study interviews.

IV. Intellectual Merit

The eventual goal of the device is to make it easy for the users to hold and operate daily electronics such as phones and cameras. The proposed study collects user feedback in the form of both qualitative interviews that provide information about the user experience and quantitatively in the form of video analysis for stability. Video analysis algorithms can be used to determine how the users are interacting with the device. IMU data can also be collected to understand the dynamics of the device such as shock loads and natural frequencies to contribute to better design practices for the future. There is a risk of the device not acting reliably or over complicating the simple processes that we need to be aware of. User feedback would play an important role here. This will help us understand where actuation is truly needed and helps the cause benefiting over the convenience of manually adjustable devices. Future studies may incorporate a manual spring balanced arm eliminating the added weight of the motor and other electronics for more independence for the user.

V. Broader Impact

Our work is going to provide a baseline understanding of user interaction experience with an automated device for daily use. The intention would be to not only use this tool for surveying trails but for general navigation and holding personal devices throughout the day. We believe that such a device has a huge potential to not only survey trails but to gather user data on how people with quadriplegia interact with their personal devices. It can enable users to stay better connected with family and friends and unlock the true potential of modern electronic devices by making it more accessible for them. By removing the barrier to the continuous use of these devices we can really help people stay connected with their communities.

References

[1] SpinalCord.com, "Quadriplegia & Tetraplegia: Definition, Causes, Symptoms, and Treatment." [Online]. Available: https://www.spinalcord.com/quadriplegia-tetraplegia

[2] "Facts and Figures - National Spinal Cord Injury Statistical Center," 2020. [Online]. Available: https://www.nscisc.uab.edu/

[3] C. L. Lysack, C. A. Zafonte, S. W. Neufeld, and M. P. Dijkers, "Self-care independence after spinal cord injury: patient and therapist expectations and real life performance," *The Journal of Spinal Cord Medicine*, vol. 24, no. 4, pp. 257–265, 2001.

[4] L. A. Simpson, J. J. Eng, J. T. Hsieh, and D. L. Wolfe, "The health and life priorities of individuals with spinal cord injury: A systematic review," *Journal of neurotrauma*, vol. 29, no. 8, pp. 1548–1555, May 2012. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3501530/

[5] J. F. Orejuela-Zapata, S. Rodriguez, and G. L. Ramirez, "Self-help devices for quadriplegic population: A systematic literature review," *IEEE transactions on neural systems and rehabilitation engineering*, vol. 27, no. 4, pp. 692–701, 2019.

[6] A. Prochazka, M. Gauthier, M. Wieler, and Z. Kenwell, "The bionic glove: an electrical stimulator garment that provides controlled grasp and hand opening in quadriplegia," *Archives of physical medicine and rehabilitation*, vol. 78, no. 6, pp. 608–614, 1997.

[7] S. Krajnik and M. Bridle, "Hand splinting in quadriplegia: current practice," *The American journal of occupational therapy*, vol. 46, no. 2, pp. 149–156, 1992.

[8] S. L. Garber and T. L. Gregorio, "Upper extremity assistive devices: assessment of use by spinal cord-injured patients with quadriplegia," *The American Journal of Occupational Therapy: Official Publication of the American Occupational Therapy Association*, vol. 44, no. 2, pp. 126–131, Feb. 1990.

[9] M. Clinic, "Amyotrophic lateral sclerosis (ALS) - Symptoms and causes." [Online]. Available: https://www.mayoclinic.org/diseases-conditions/amyotrophic-lateral-sclerosis/symptoms-causes/syc-20354022

[10] I. Bromley, *Tetraplegia and Paraplegia: A Guide for Physiotherapists*. Elsevier Health Sciences, Jul. 2006, google-Books-ID: PdpfDwAAQBAJ.

[11] Brain and S. Cord.org, "Quadriplegia | Types of Paralysis | Brain and Spinal Cord Injury Information." [Online]. Available: https://www.brainandspinalcord.org/quadriplegia/

[12] C. R. Foundation, "What is a complete vs incomplete injury?" [Online]. Available: https://www.christopherreeve.org/living-with-paralysis/newly-paralyzed/how-is-an-sci-defined-and-what-is-a-complete-vs-incomplete-injury

[13] R. L. Waters, R. H. Adkins, and J. S. Yakura, "Definition of complete spinal cord injury," *Spinal Cord*, vol. 29, no. 9, pp. 573–581, Nov. 1991, number: 9 Publisher: Nature Publishing Group. [Online]. Available: https://www.nature.com/articles/sc199185

[14] D. W. Lamb and R. M. Landry, "The hand in quadriplegia," *Paraplegia*, vol. 9, no. 4, pp. 204–212, 1972.

[15] Ainsley J, Voorhees C, and Drake E, "Reconstructive hand surgery for quadriplegic persons... occupational therapy program," *American Journal of Occupational Therapy*, vol. 39, no. 11, pp. 715–721, Nov. 1985, place: North Bethesda, Maryland Publisher: American Occupational Therapy Association. [Online]. Available: https://search.ebscohost.com/login.aspx?direct=truedb=ccmAN=107567051site=ehost-live

[16] P. Rigby, S. Ryan, S. Joos, B. Cooper, J. W. Jutai, and I. Steggles, "Impact of electronic aids to daily living on the lives of persons with cervical spinal cord injuries," *Assistive technology: the official journal of RESNA*, vol. 17, no. 2, pp. 89–97, 2005.

[17] P. Bell and J. Hinojosa, "Perception of the impact of assistive devices on daily life of three individuals with quadriplegia," *Assistive technology: the official journal of RESNA*, vol. 7, no. 2, pp. 87–94, 1995.

[18] E. Biddiss, D. Beaton, and T. Chau, "Consumer design priorities for upper limb prosthetics," *Disability and Rehabilitation: Assistive Technology*, vol. 2, no. 6, pp. 346–357, Jan. 2007, publisher: Taylor & Francis _eprint: https://doi.org/10.1080/17483100701714733. [Online]. Available: https://doi.org/10.1080/17483100701714733

[19] Z. Jiryaei, A. A. Alvar, M. A. Bani, M. Vahedi, A. S. Jafarpisheh, and N. Razfar, "Development and feasibility of a soft pneumatic-robotic glove to assist impaired hand function in quadriplegia patients: A pilot study," *Journal of bodywork and movement therapies*, vol. 27, pp. 731–736, 2021.

[20] L. A. HARVEY, J. BATTY, R. JONES, and J. CROSBIE, "Hand function of c6 and c7 tetraplegics 1-16 years following injury," *Spinal cord*, vol. 39, no. 1, pp. 37–43, 2001.

Appendix A
Discovery Decomposition

Topic of the interview: everyday activities and hobbies with quadriplegia

1) The bionic glove: An electrical stimulator garment that provides controlled grasp and hand opening in quadriplegia: [6].

- Background/Hypothesis: This article looks into the design of a bionic brace that helps improve the functioning of hands after a spinal cord injury. It takes inspiration from foot drop stimulators and applies similar technologies to assist in grasping and opening of hands.
- Methods: The device uses adhesive electrodes over motor points. Conductive panels inside the glove connect the electrodes to the controller. When the wrist flexes it triggers hand opening and when the wrist extends in initiates pinching action with fingers. Nine subjects were tested in this study.
- Results: Of the nine only one of the subjects relied on an aid. The glove was able to detect signals and apply forces that were measured to analyze performance. Data was collected and graphed for presentation.
- Conclusion: The bionic glove has been shown to boost hand function in multiple patients. The glove proved to be non-invasive and accsible from a financial standpoint. It has promising results and could be used for long term.
- Test Hypothesis: The bionic glove performed as expected with some challenges. The adoption was easy and smooth. With a few iterations it can be made accessible and more functional.
- Citation: Reference [1] A. Prochazka, M. Gauthier, M. Wieler, and Z. Kenwell, "The bionic glove: an electrical stimulator garment that provides controlled grasp and hand opening in quadriplegia," Archives of physical medicine and rehabilitation, vol. 78, no. 6, pp. 608–614, 1997.

2) Hand splinting in quadriplegia: current practice: [7].

- Background/Hypothesis: Persons with C-5, C-6, C-7, and C-8 quadriplegia are at risk for loss of range of motion and hand architecture due to muscle weakening and paralysis. Hand splints are recommended to mitigate the risk of losses in hand architecture, yet the intervention timing of splint use and the type of splint used varies. This paper seeks to review the varied timings and uses of these splints.
- Methods: 200 descriptive surveys were sent to occupational therapy department heads in hospitals and rehabilitation centers. Of the 101 surveys returned, 89 surveys came from occupational therapists working in rehabilitation and 12 from occupational therapists working in acute care settings.
- Results: Data collected from the surveys were split by the use of static or dynamic splints, listing the reasons as to why certain occupational therapists chose one type of splint over another. Data was also divided by frequency of use of one type of splint over another as well as the reasoning as to the frequency of use.
- Conclusion: The survey results suggest that the use of static splints with quadriplegia patients is common practice, but they are not used as frequently as literature on the subject recommends. Different types of quadriplegia also require different frequencies and types of splint use.
- Test Hypothesis: The use of types of splints and frequency of their use varies by patient need and type of quadriplegia.

3) The hand in quadraplegia: [14].

- Background/Hypothesis: There exist a great many interventions into improving the hand dexterity and upper limb function for persons with quadriplegia, but they are dependent on many factors, including time of intervention, relative mobility, and patient's opinion on the intervention(s). This paper reviews interventions and recommendations of them in relation to mobility and muscle function of certain cases involving a variety of quadriplegic patients.

- Methods: Quadriplegic patients were grouped based on available muscle power involving the arms and hands.
- Results: Each grouping of quadriplegic patients based on muscle power were analyzed in context of available muscle function to suggest ideal interventions (surgical, splints, electronic aids) that would improve the patients' independence in doing daily tasks.
- Conclusion: Different interventions are more effective for some patients than others based on patients' available muscle function in the upper body, arms, and hands. Interventions should be aimed at improving dexterous muscle function based on available muscle function, not based on anatomical cord damage.
- Test Hypothesis: Effectiveness of interventions for improving hand dexterity should take into account available muscle function and outcomes for patient independence.

4) Development and feasibility of a soft pneumatic-robotic glove to assist impaired hand function in quadriplegia patients: A pilot study: [19].

- Background/Hypothesis: One of the most common disorders in people with quadriplegia is having a weak grip strength that can affect activities of daily living. The study presents the design of a comfortable bionic glove with pneumatic actuators and used range of motion as an indicator of feasibility.
- Methods: The glove consists of two parts, a wearable neoprene glove and the robotic pneumatic actuator. Silicone tubes are used to transmit the flow of air. When the air pressure is turned on, the silicon tubes move in the direction of flexion of fingers. The data was collected from two healthy participants and five spinal chord injury patients.
- Results: The tests indicated that the subjects reached a range of motion of 70-75º. The spinal chord injury patients were satisfied with the performance of the bionic glove. The glove was successful in griping simple objects.
- Conclusion: The study demonstrated that the bionic glove design can deliver significant increases on range of motion along with high user satisfaction. Some aspects need to be improved to make the device more applicable.
- Test Hypothesis: The glove performed as expected with a higher satisfaction rate than anticipated. The range of motion did increase with the use of this bionic glove.
- Citation: Jiryaei, Zahra, et al. "Development and feasibility of a soft pneumatic-robotic glove to assist impaired hand function in quadriplegia patients: A pilot study." Journal of Bodywork and Movement Therapies 27 (2021): 731-736.

5) Self-Help Devices for Quadriplegic Population: A Systematic Literature Review: [5].

- Background/Hypothesis: This article explore and discusses the main needs, expectations and barriers for people with quadriplegia. It also discusses major advantages, disadvantages and challenges facing the current assistive technologies. We look at functional and no-functional requirements related to these technologies and how people interact with them on a daily basis.
- Methods: A thorough search was performed using the SLR methodology looking at current evidence and analysis of current technology. Human cases of quadriplegia from varying age groups were included.
- Results: Up to 80 percent of respondents stated that they would adopt any technology if it could restore some grasp functions, and almost 60 percent of this population will accept to undergo to a surgical procedure if the system implanted could help to improve these functions. Results showed that the primary interest was to recover the natural upper limbs functions. The major hurdles for adoption are associated with poor performance of the devices, low reliability, not meeting needs or expectations, lack of training, complex maintenance or cleaning.

- Conclusion: Assistive technologies allow SCI patients to reintegrate with society and daily economic, recreational and social activities. There is a huge coordinated effort of engineers and scientists to create assistive technologies. Research in this context should tend to the development of new personalized devices adapted to specific circumstances.
- Test Hypothesis: Assistive technologies have a number of pros and cons and a user centered design approach needs to be implemented for success of upcoming assistive technologies.

6) Hand function of C6 and C7 tetraplegics 1 - 16 years following injury: [20].

- Background/Hypothesis: C6 and C7 tetraplegics have paralysis of finger and thumb flexor muscles but retain voluntary control of wrist extensor. This study focuses on quantifying the hand function in such patients 1-16 years after the injury.
- Methods: Sixty-five patients were identified for this study. A few parameters were chosen: Range of motion (ROM), lateral and palmer grasp and Extensibility of the extrinsic finger flexor muscles. Data was then collected and analysed for results. The effectiveness of lateral and palmar grasps was measured with GRT.
- Results: Only 16 hands had ‘moderate’ or ‘severe’ loss of passive range of motion. Most participants stated that they themselves moved or stretched their hands regularly for therapeutic purposes.
- Conclusion: Subjects used novel and creative ways to perform tasks in the tests. Currently there are no quantitative tests for measuring functions. Currently there is little consensus about optimal management of the C6 and C7 tetraplegic hand and no splinting or manual therapy protocol has been rigorously evaluated.
- Test Hypothesis: Hand functionality can be quantified for tetraplegic patients and data can be analyzed to gain insights on performance and recovery.

APPENDIX B
INVESTIGATIONAL DEVICE DETAILS

A. Future Device Improvements

The prototype demonstrates the capabilities of an assistive device that can aid to hands-free use of mobile devices,however, there are shortcomings that can be improved in the future iterations. When in use, the device struggles to maintain lateral stability and exhibits a lack of sufficient stiffness. This is a combination of compliance in the materials chosen due the additive manufacturing process and the structural support in the lateral direction. Using materials like sheet metal for construction can help in this area by enabling tighter tolerance manufacturing and assembly of the device components. Considering that the device is supposed to be mounted on a wheelchair arm, there is a requirement for a suspension system for the arm to stabilize the device. This can either be done at the base of the arm to stabilize the whole section or at the phone mount to locally stabilize the phone. The clamping mechanism can be simplified and turned into a clip on version for ease of use and to establish a rigid base connection. The current prototype is power through a wall mount adapter but this can be changed so that the device can draw power from the wheelchair battery eliminating the need for extra power electronics specifically for the assistive device. in addition to this a phone charging feature can be added to the phone mount that can keep the phone charged at all times. Form a controls standpoint, adding speed control could allow the users to make fine adjustments to position the device to their liking. Adding a button press command to stow away the device when not in use will be a great addition towards making the trail surveyor a friendly and useful tool.

Appendix C
Collecting and Analyzing Interview Data

A. *Interpreting and Analyzing Interview Data*

	It is easy to transport	The product is portable
	It helps me reach things off the ground or above me	The product is versatile in its reach
	I have multiple different sizes for different context	The product has adjustable sizing for versatility
	Its sturdy to use and doesn't break	The product is durable and can withstand reasonable forces on it
What do you like/dislike about your quad bike?	I like that I can control the throttle using my head instead of unclipping my hands	The product allows for throttle adjustments without the user disengaging the hand pedals
	I can't shift my bike at all while in the hand grips	The product allows user to shift easily without removing hands from the hand pedals
	I wish I could get into the seat on my own and lift the whole crank assembly out of the way	The bike can fold the crank assembly out of the way to allow the user to get in the bike seat from the wheelchair
	I wish I could transport my bike easier	The bike can fold up small to be transported
What are the shortcomings/positives of your body-powered grabber?	The angle doesn't always work well for picking things up	The product has adjustable angles for manipulating grip angle
	The grabber can't pick up heavy objects	The product is able to pick up heavier objects
	The grabber isn't able to pick up certain objects	The product can be manipulated to pick up objects of different geometries
	Sometimes the arm drops things	The product grips things until the user disengages it
	It can pick up heavier items	The product should be able to pick up heavy things
	Buying longer versions is expensive	The product should have length adjustments without the need to buy a new product
	I feel that it is very sturdy and doesn't break when i drop it	The product withstands drops and handling
	I feel that it is easy to use	The product is intuitive and easy to use
What would help you with your love of crafting?	I wish i could cut things easier - right now I use my mouth	The product makes it easy for the user to cut different shapes
	I wish that I could have a device that cuts and grabs	The product should account for a series of actions instead of single use

Question/Prompt	Customer Statement	Interpreted Need
What do you need to survey different trails?	I need to be able to take pictures and videos of the trail	Product provides easy access to surveying tools
	I need to be able to manipulate my surveying equipment easily	Product enables easy manipulation of survey tools
	I need to be able to lift my wheelchair's arm to get in and out of my chair	Product does not attach to left wheelchair arm Product can be removed/moved out of the way of the wheelchair arm Product can be independently removed from the wheelchair
	I need to be able to document several aspects of the trails I survey	Product can securely hold multiple survey items easily
Challenges around cooking + the kitchen	Getting things from the back of the fridge is difficult	Product can have long or adjustable reach
	I find it hard to peel vegetables and fruit	Product has a sharp edge peeling function
	It is hard to chop and dice things, so I buy pre-cut stuff from Trader Joe's	Product needs to be easy to use when chopping vegetables and shouldn't require complex motions.
	Handling/lifting a hot tea kettle is dangerous so I use the microwave to heat up water	Need to have a simple way to pour water instead of lifting.
What do you find most challenging about gardening?	It is really hard to manage the hose and it gets wrapped around my wheelchair wheels	Product needs to have an anti tangle feature or some sort of guard to prevent this Product allows for easy manipulation of hose without tangling in chair
	Plucking weeds is challenging	Product needs to grasp firmly and allow adjustable angle
What challenges do you face while bird watching and what devices help you do that?	Adjusting the monocular and holding it in place is tough	Fixturing with minimal effort is useful to reduce fatigue
	Monoculars are good because they're easy to adjust focus on with one hand	Easy single handed adjustment is a plus
	It is portable and easy to transport	Portability and compact size, easy assembly is needed
What do you like about your existing assistive hook + dowel tool?	It is cheap to make	The product is affordable to make
	It helps me when I travel and in my day-to-day	The product is helpful around a wide range of contexts and uses

Fig. 5: Full needs chart

Weighted Design Needs
Adjustable - 3
Portable - 2
Versatile - 3
Ability to be used independently - 1
Durable - 1

Rating System
1 (little) - 5 (great)

Telescoping/Folding + adjustable grabber	15	15	10	5	5	50
Adjustable snake neck tool for storing survey equipment	12	9	10	5	5	41
Swivel tray for storing survey equipment	12	6	10	5	3	36
Self-feeding scissors	9	12	6	5	5	37
Body powered grabber	15	15	10	3	3	46
Holdable cutter for paper/crafts	9	12	8	5	3	37
	Adjustable (3)	Versatile (3)	Portable (2)	Independence (1)	Durable (1)	Final Scores

Fig. 6: Weighted matrix of user needs from interview results

B. Solution finding from user needs

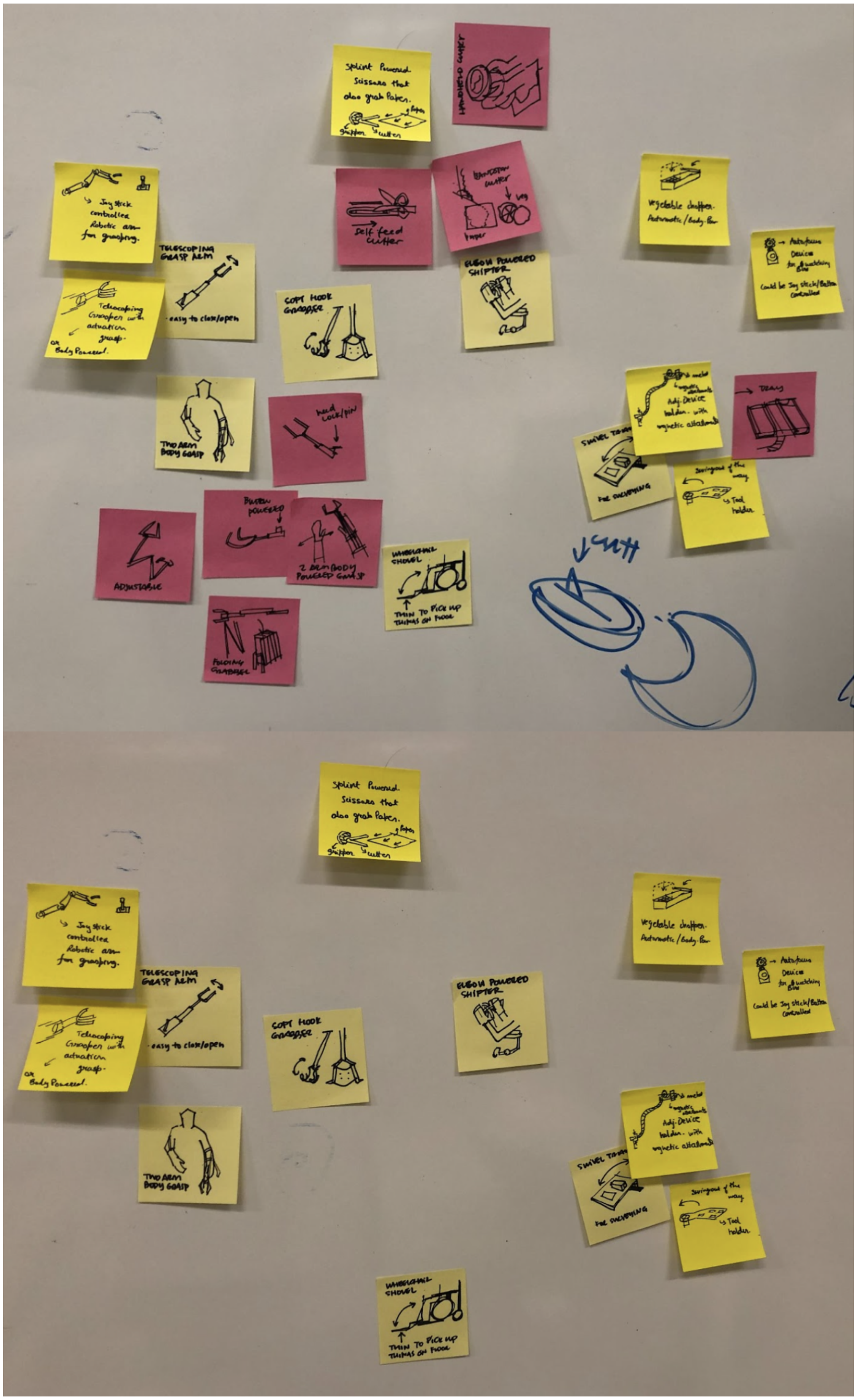

Fig. 7: Needfinding exercise and sketches to distill solutions from interview insights.