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Low Interference Wheelchair Footrest

Preliminary Report

BME 301
3/02/2024

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Abstract

There exists a gap in the electric wheelchair footrest market due to many current footrest models being awkward, heavy, and often lacking user-friendly features for convenient removal and storage. These models specifically limit partially paralyzed individuals, to the point that another individual is needed when moving a footrest to a new position or off of the wheelchair completely. Fixing these issues and adding new features catered to the partially paralyzed would help enable them to perform beneficial movements with the comfort of a footrest. The proposed innovative footrest aims to reduce interference with daily tasks, provide adaptability with easy removal and storage, reduce weight, and streamline the design without compromising the essential support functions of traditional wheelchair footrests. The need for a universal footrest is challenging, as many electric wheelchairs are designed with differing frame and structure, wheels and suspension, seating, and user interface/controls. With an electronic design this project hopes to contribute to the development of an improved wheelchair accessory that better accommodates the diverse needs of many users.

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Introduction

Motivation/Global Impact

The design project's client, Mr. Dan Dorszinski, has requested a modification to his current wheelchair footrest to enable the ability for him to interact with the surrounding environment more effectively. Currently, Dan uses a power wheelchair with a stationary electric footrest that is able to move forward and backward, along with up and down with the wheelchair's seat. The main concern is that the current footrest design is unable to move out of the way for the client to transition off of the wheelchair, as the design doesn't enable the footrest to tuck under the wheelchair or be moved to the side. Because of these problems, the client currently doesn't use a footrest at all on his powered wheelchair, as the footrest mostly imposed challenges rather than being beneficial. A new design that would allow for more movement of the footrest would enable partial paralysis users to still have a footrest, but be able to have more leg freedom than a traditional wheelchair footrest often supplies. This modification not only addresses individual user needs but also holds the potential for a global impact by fostering increased mobility and movement independence. The development of a low-interference electric wheelchair footrest could set a precedent for more inclusive and adaptable designs, positively influencing the lives of countless individuals with mobility impairments on a large scale.

Existing Devices

There are many wheelchair footrest designs, but there is limited cross compatibility. Manual wheelchair footrests are not made to attach to and work with electric wheelchairs. Furthermore, most electric footrests are designed alongside a specific wheelchair body. The Matrix Ultra [1] has an electric footrest that cannot attach to the Go-Chair [2] who’s footrest won’t attach to the Sedeo Pro body for the Quickie Q700 M[3]. These limitations leave only two current designs that can attach to the client's wheelchair: the Sedeo Pro footrest and the previous Low-Interference Wheelchair Footrest[4]. However, at the moment the client doesn’t use a footrest at all.

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Figure 1: The Quickie Q700 M with Sedeo Pro body and footrest [3]

The Sedeo Pro, shown in Figure 1 above, is powered and controlled electronically through the wheelchair. There are buttons on the right hand side that allow the footrest to pivot around its connection to the wheelchair, but the motion is limited. No matter the orientation the foot pads, which are 33 centimeters, block the feet or legs from assisting in any movements. The foot pads are too far to be reached while seated, and require more force to fold up than the client could exert if they were reachable. The wheelchair allows for no orientation where the foot pads are not in the way of the rider if they try to lean forward with their feet on the ground or try to transfer off of the wheelchair.

Previously there was a manual footrest designed to fix the issues with the Sedeo Pro. This design can be seen in Figure 2 below and is lightweight, and easily removable. It consists of two 15.25 by 15.25 centimeter metal plates that are attached individually to two 3D printed PLA castor caps that slot into the bolt holes above the outermost wheels of the wheelchair. The metal plate is the foot pad and is connected to the castor cap by an automatic hinge. The castor cap doesn't require any bolts or screws to stay in place during use, meaning it can be easily removed. The automatic hinges were meant to allow the foot pads to easily fold up out of the way, however, they require a force in the hinge direction to start the movement process. This force is greater than the force required to fold the Sedeo Pro, and is therefore not usable by the client. The PLA also lacks strength and often snaps before the hinge is able to engage.

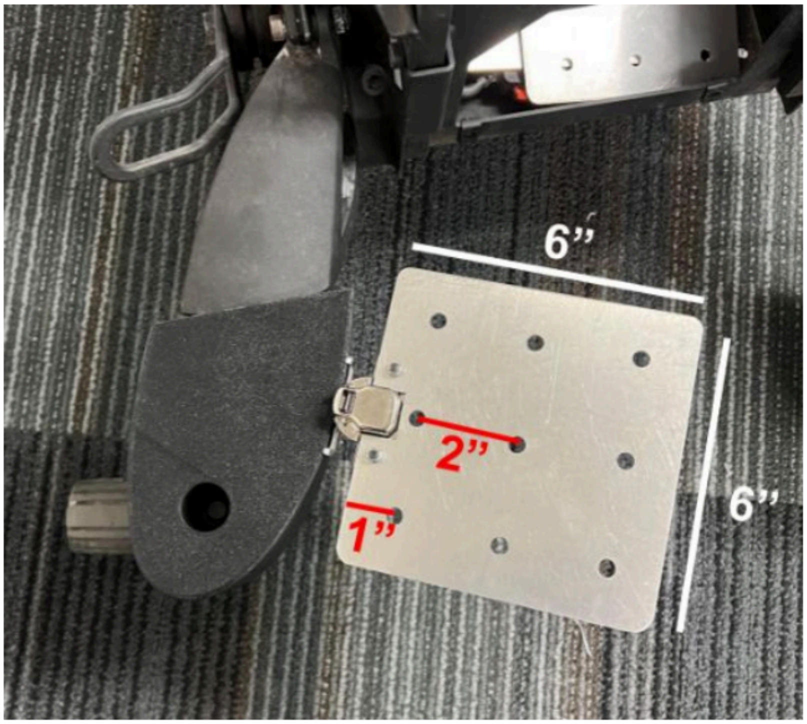

Figure 2: Previous Low-Interference Wheelchair Footrest design attached to wheelchair [4]

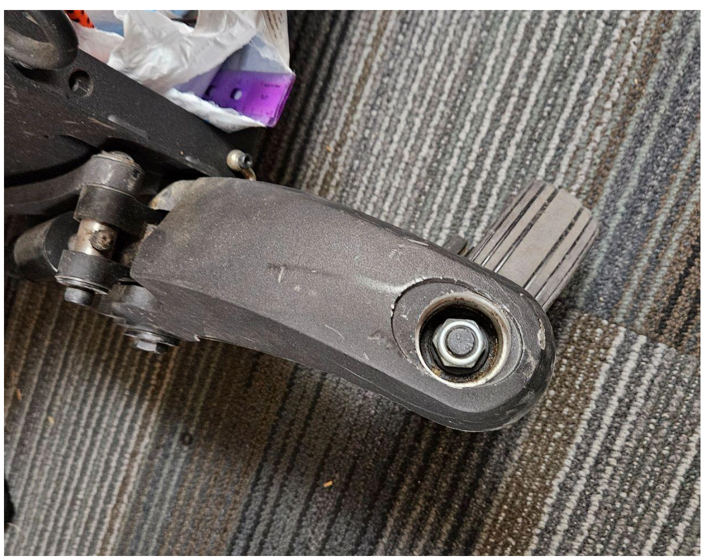

Figure 3: Bolt hole that the castor cap slots into

Problem Statement

This project aims to create an electric wheelchair footrest design to overcome the limitations of current models which are often cumbersome, heavy, and restrict leg movement and access to the ground. The goal is to create a footrest that is lightweight, easily detachable and foldable, user friendly, provides the user comfort, and also allows for interactions with the surrounding environment through the footrest itself.

Background

Physiology and Biology Research

Becker Muscular Dystrophy (BMD) is a genetic and progressive neuromuscular disease caused by mutations in the dystrophin gene [5]. BMD results in the production of abnormal dystrophin, a protein that protects muscle fibers from breaking down. BMD typically manifests between the ages of 5 and 15, leading to progressive muscle weakness and degeneration [6].

Besides patients with muscular dystrophy, other wheelchair users with a higher level of mobility could also benefit from a footrest design that is less interfering. For example, individuals with partial paraplegia may have some degree of leg function and could use their feet for certain tasks; patients with conditions like Multiple Sclerosis or Spina Bifida, where lower limb weakness is present but not complete may also benefit from the design. In other scenarios, individuals with heart conditions use wheelchairs to prevent overexertion but can still use their feet; and last but not least, some elderly individuals use wheelchairs for mobility assistance but can still use their lower body for tasks [7].

Design Research

In order to make the design more user friendly and versatile, the footrest should be retractable and electric powered. Upon research, linear actuators and stepper motors are some of the best options to achieve that. Linear actuators are a set of devices that create motion in a straight line, and are instrumental in adjusting the footrest position dynamically, thereby offering users the flexibility to use their feet for a range of daily tasks. A stepper motor, specifically, is a precise motion device that operates in discrete steps, also contributing to the dynamic adjustment of the footrest position. The design approach in this project not only aims to improve the user's independence and quality of life, but also seeks to push the boundaries of conventional wheelchair design.

Client Information

As stated, the client Dan Dorszynski suffers from Becker's Muscular dystrophy. Mr. Dorszynski has lost ambulation and requires the Quickie Q700 M [3], shown in figure 1, an electric wheelchair, for mobility. However, Mr. Dorszynski still has enough muscular strength in his lower body to use his legs for certain tasks, but finds the footrest on his wheelchair blocks this ability. To compensate for this, he allows his feet to remain free without the use of a footrest.

Design Specifications:

The improved wheelchair footrest must have the ability to be moved and not interfere with the user's ability to place their feet on the ground. This should not come at the cost of stability, as the footrest must be able to hold the weight of the client's lower body, being designed for a factor of safety of two, to account for any misuse. The footrest must also fit the client's feet, and should aim to fit as many inclusive foot sizes as possible, without being too large. This will be accomplished with a footplate around 25.4 centimeters, which is the clients foot size and around average for a man. The footrest will be most useful outside, so it must be durable and corrosion resistant. After those needs are met, the design's user friendliness would benefit from being as lightweight as possible, between 2-7 kg, to save on battery life, and be easily removable and storable. For the full product design specifications, refer to the Product Design Specifications located in **Appendix A**.

Preliminary Designs

Before any specific designs were drawn out the option between an electric or manual system for moving the footrest was considered. The manual system would be made of cables and pulleys to counterbalance the weight of the footrest, causing it to feel much lighter when being moved by the rider. In comparison, the electric system would use the wheelchairs built in buttons or a newly created joystick to control electric components that move the footrest. The wheelchair in use currently uses a variety of built in buttons to interact with the control system. In consideration of these principles, the electric system won due to being able to interface with how the wheelchair already functions while providing the ability for the client to not have to manually adjust the footrest's feet positions to transition. Further discussion between the two systems and the design matrix can be found in **Appendix C**.

I: Autonomous Footrest

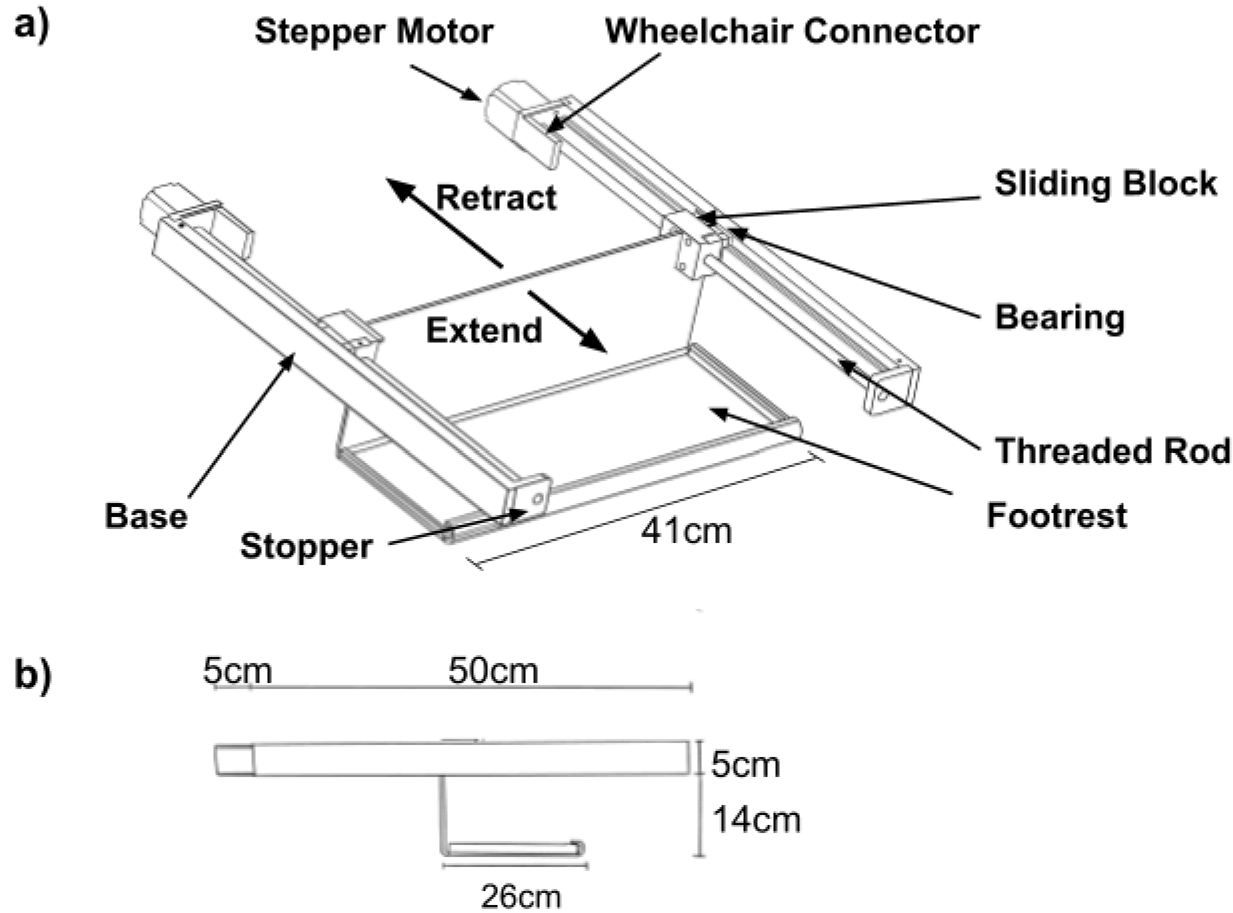

Figure 4: Autonomous Footrest. a) 3D Footrest Design with labels. b) Side view with dimensions

The autonomous wheelchair footrest design, as shown in figure 4, uses a completely hands free system that is meant to be integrated with the control interface of the wheelchair. Even though the design consists of multiple assembly parts, the overall mechanism can be broken up into two main parts, the footrest and the linear motion slider. The footrest itself consists of welded steel that makes the L shaped traditional pattern seen in most wheelchairs. Around the edges at the bottom of the footrest there are edge and flange bends creating the slight curved over pattern instead of a flat sharp edge. The footrest is connected to the linear motion slider via threaded nails into the sliding block. The sliding block itself is the bridger of the footrest and the linear motion slider. The block is connected to a linear bearing on its backside to aid with friction and force assistance, while in the middle, the threaded rod is fit to aid in motion, both forward and backward. The threaded rod is often referred to as a lead screw and is driven by a motor to move the block along its path. The stepper motor provides precise and controlled motion by converting electrical pulses into incremental steps, creating the linear motion needed to move the sliding block and footrest, with additional power as needed from the wheelchair battery. Once the stepper motor has reached its maximum forward distance, a stopper is used to cap off the threaded rod. The stopper is also used for support as the footrest cannot go forward anymore. Furthermore, upon switching to the reverse direction, the sliding block and footrest are able to go all the way back under the wheelchair until the stepper motor has fully decreased in steps and the block has reached the wheelchair connector, the limiter of the reverse direction. The wheelchair connector, as the name states, is the final piece of the design, connecting the entire mechanism to the wheelchair. This is done through either a fixed welded connection or a multiple pin connection, of course on both sides of the wheelchair for maximum support.

The current design in solidworks is listed in **Appendix D,** and is being evaluated and changed to reflect the most stable dimensions, supports, and future materials.

II. Lock and Pulley

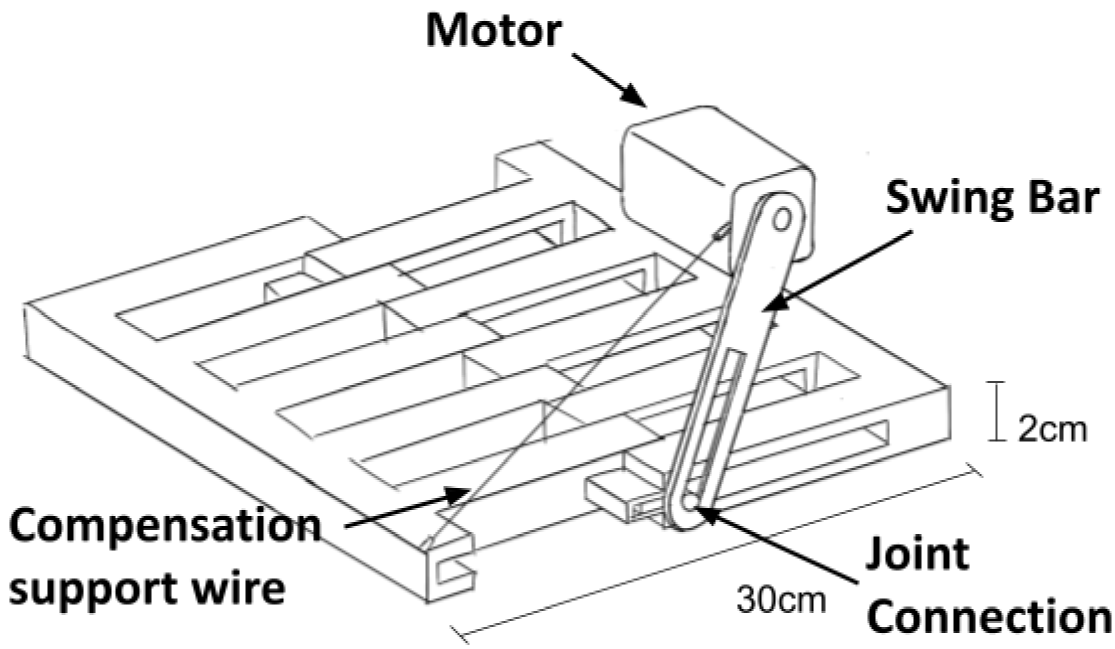

Figure 5: Lock and pulley footrest

The lock and pulley design is aimed to solve the problem that the space underneath the seat of the wheelchair is not long enough to fit a footrest of all standard shoe sizes. The footrest itself consists of two parts, an outer plate and an inner plate, connected in a fork orientation. When being stored, the two plates can be retracted, minimizing space used. When extended, the motor is powered and through the swing bar, pushes the footrest outward. With force applied at the joint of the two pieces of footrest, the outer plate will slide out first, eventually pulling the inner plate along when the ends make contact as shown in figure 5. When being retracted, opposing force will pull the outer plate backward, eventually pushing the inner plate backward as well. The swing bar has a carved out track that connects to the joint of the two plates and engages in circular motion with respect to the motor. Notably, there is also a compensation wire that holds the outer plate since the outer plate will be floating and static equilibrium is not reached. The compensation wire connects to the motor to provide tensile strength to overcome the force applied by the user.

III. Sliding Footrest

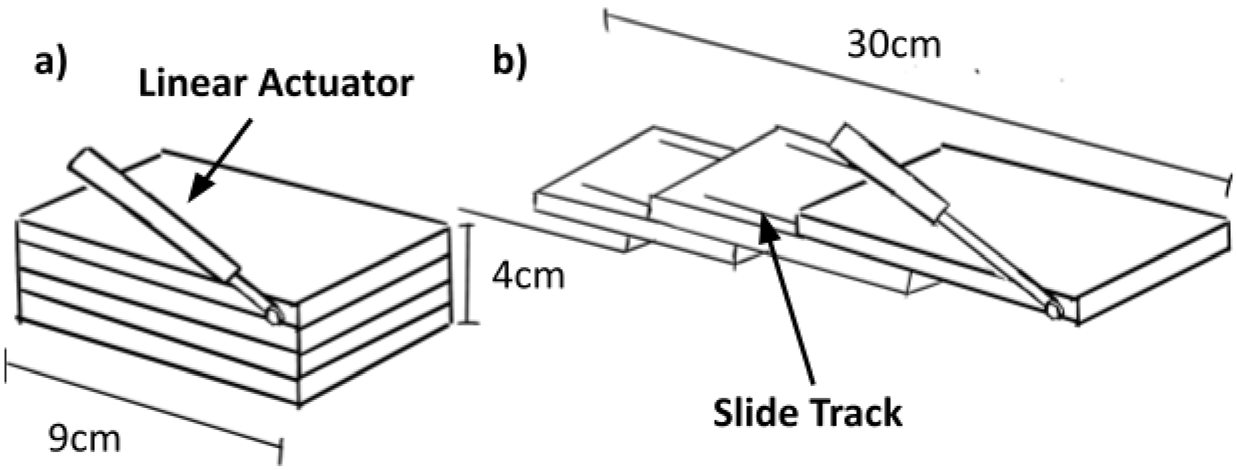

Figure 6: Sliding Footrest. a) Retracted state b) extended state

The sliding footrest design uses a very similar sliding mechanism compared to design II. The sliding footrest design uses overlapping plates that extend out, at a certain angle to create overall flatness of the footrest, as shown in figure 6a, that will extend on top of each other to create more space for the user, which is achieved by the linear actuator. The linear actuator is connected to the top most plate thus when extended, pulls the top most plate outwards and brings the rest of the plate one by one through the slide track, eventually making an extended footrest as shown in figure 6b. The result is a weaker joint at each intersection of the plate but with a better distribution of load on each plate. While this design shows weaker joints, the team suggest using acrylic for the footrest material for its ease of cleanness and aluminum alloy for the supporting structure because of its strength.

Preliminary Design Evaluation

Design Matrix

Table 1: Design Matrix I.

Criteria (Weight %)	Autonomous Footrest	Lock and Pulley	Sliding Footrest
Size (35)	3/5	4/5	5/5
Durability (25)	5/5	3/5	4/5
Weight (20)	4/5	5/5	2/5
Cost (10)	5/5	4/5	3/5
Fabrication (10)	4/5	2/5	2/5
Total	80	75	73

Size: This criterion is given the highest weighting because a larger footrest will limit maneuverability under the wheelchair as the increase in area could cause problems upon retraction and room when traveling. The sliding footrest won this category as it is both short and thin when contracted, without compromising usability.

Durability: Durability is paramount in the design of a wheelchair footrest, as the rest must withstand the rigors of daily outdoor use and remain supportive and safe. The autonomous footrest has the most supporting material and therefore scored the highest.

Weight: Lighter footrest designs allow for easier use and less strain on the wheelchair and its power supply. The lock and pulley has the least components and is therefore the lightest.

Cost: A low cost is important to allow as many people to purchase the footrest as possible. Each design uses similar amounts of structural material, however most of the cost comes from the electronic components. The linear motor slider is the least expensive so the autonomous footrest is scored the highest.

Ease of Fabrication: A design with a straightforward production process can be completed sooner, smooth replicability, and allow for more testing and changes. Also, an intricate design can lead to more mistakes, wasting time, and raising costs. The simplest design is the autonomous footrest.

Proposed Final Design

After discussing the possible outcomes of each design and evaluating the design matrices, the team has decided to proceed with the electronic version of design I. While this choice aligns with our primary direction, the team recognizes the intrinsic value in the alternative designs. For example, the sliding mechanism featured in designs II and III are components that can be used to integrate into design I. The team believes that this feature provides the footrest with two degrees of freedom, allowing for both forward/backward and up/down movements. By selectively incorporating beneficial elements from other designs, the team intends to enhance the overall functionality and performance of our chosen electronic design.

Fabrication/Development Process

Materials

The proposed prototype includes a strategic selection of materials to ensure both functionality and durability. The primary supporting structure will be using lightweight aluminum alloy. Aluminum performs well resisting strain, with a modulus of elasticity of 68.9GPa, a bearing yield strength of 386MPa, as well as a relative light density of 2.7g/cc.[8] This material is chosen for its exceptional strength-to-weight ratio, providing structural integrity while minimizing overall weight. From force analysis, the material beam will need to withstand 300N of tension and 280N of compression to give an overall safety factor of 2. The footrest itself will likely be constructed from acrylic. Acrylic is even lighter, with a density of only 1.2g/cc, and still has a tensile yield strength over 60 MPa, making it ideal for the application.[9] Both aluminum and acrylic are chosen not only for their individual properties but also for their compatibility, ensuring function in the final prototype. The selection of materials aligns with industry standards for safety, resilience, and ease of use, contributing to the overall quality and performance of the design.

Methods

The focus will primarily center on the integration of materials, specifically an aluminum supporting structure and an acrylic footrest since aluminum alloy gives essential mechanical strength to the supporting structure, and acrylic footrest provides a light-weighted, easy to clean interface. The fabrication process will follow precise measurements and design considerations, ensuring the ability to fit a diverse range of wheelchair models. The aluminum supporting structure will be crafted using CNC milling or lathe techniques in the TeamLab to ensure accuracy and structural integrity [8]. The design will allow for adjustable features, accommodating user preferences. The acrylic footrest will be shaped through precision laser cutting or CNC routing, ensuring a smooth and ergonomic surface [9]. The assembly process will involve joining of the aluminum structure and acrylic footrest to the given linear actuator portion. Quality control measures will be implemented throughout the fabrication process to align industry standards for safety and durability. See **Appendix B** for support mechanism.

Final Prototype

There are no working prototypes at this time. CAD drawings and other 3D models can serve as a rough estimate of the final prototype, however, design alterations and modifications will be implemented when necessary. Moving forward, the focus will be on translating the conceptual design into a tangible and functional prototype. Prototyping will provide a basis for testing, ensuring overall validity of design. As the project transitions into the prototyping stage, attention will be given to refining the design, addressing potential challenges, and ensuring that the envisioned footrest aligns seamlessly with its intended purpose. The design timeline will be strictly followed to ensure the delivery of the final prototype.

Testing

There is no testing conducted at this time. The following plans roughly outline some of the potential testing methods the team will conduct. Functional testing will focus on the footrest's adjustability and compatibility with diverse wheelchair models, while durability and stability testing will simulate real-world usage scenarios including client specific outdoor areas. User experience testing, primarily composed of several surveys that focus on key aspects of the wheelchair, aims to gather feedback on comfort to ensure positive user experiences. Material and component testing will scrutinize the durability of construction materials. Safety testing will identify and rectify any hazards associated with the footrest, including stability under load and potential weak joints. This comprehensive testing plan aims to validate the wheelchair footrest's design, fostering reliability, safety, and user satisfaction in the pursuit of enhanced mobility and inclusiveness.

Results

There was no testing conducted at this stage of the process; therefore, no results were obtained. However, the team made decisions regarding certain material options and implemented adjustments to current designs, yielding valuable results. These outcomes are anticipated to align with specifications, client requirements, and expectations.

Discussion

No final prototype has been developed, and there are no results from tests conducted at this time. As the team continues to construct our initial prototypes and refine our designs, conclusions will then be drawn to determine the most appropriate decisions. Currently, the team is contemplating future aspects of the device and its potential applications in various scenarios outside the current scope. The adjustability features of the footrest design could create supportive structures in rehabilitation equipment, providing adaptable support during various stages of recovery. The customizable ergonomic features could be adapted for use in workstations, allowing for the creation of adjustable arms or supports for desks. This design-focused approach highlights the multifunctionality of the footrest concept, transcending its initial purpose for wheelchair users.

Conclusions

Everyone deserves comfort in their day to day life, and a footrest that allows a person to not drag their feet across the ground everywhere they travel is necessary for any wheelchair bound person. Anyone who requires an electric wheelchair, but not an attendant, has to choose between this comfort, and their mobility outside the chair. Because currently manufactured footrests are designed with the foot pads blocking the feet from touching the ground without a way for the rider to position them out of the way, it is clear that the current footrest designs do not account for partially paralyzed people and expect all users to have an attendant. The autonomous footrest design will aim to solve this problem by allowing the rider to push buttons that slide the footrest underneath the wheelchair when it isn't needed. This will allow the design to act as a footrest when needed, but also get completely out of the user's way when unwanted.

In the coming future the team must order materials for and then fabricate the autonomous footrest. Once a prototype is created testing can begin. Tests will start with measuring durability. Then basic usability will be judged by the group before asking the client to test it themselves. This will minimize the chance that the device breaks while the client is testing it, therefore limiting their chance of injury, as well as the chance of wasting their time. Once testing is done and feedback is received changes can be made to the device. The group already considers an additional degree of freedom in the vertical plane to be a possible next step once this design fixes the client's main problem.

References

[1]“Worlds Lightest Electric Wheelchair,” DiscoverMyMobility, https://www.discovermymobility.com/store/powerwheelchairs/green-transporter/matrix/worlds-lighest-electric-wheelchair.html?gad_source=1&gclid=CjwKCAiA6KWvBhAREiwAFPZM7m8QM__mfBzAogxxk-xo7k1txdhoQ15cRM46kpmUBXBG2sJh-I9DrxoCLSEQAvD_BwE (accessed Mar. 2, 2024).

[2] “Worlds Lightest Electric Wheelchair,” DiscoverMyMobility, https://www.discovermymobility.com/store/powerwheelchairs/green-transporter/matrix/worlds-lighest-electric-wheelchair.html?gad_source=1&gclid=CjwKCAiA6KWvBhAREiwAFPZM7m8QM__mfBzAogxxk-xo7k1txdhoQ15cRM46kpmUBXBG2sJh-I9DrxoCLSEQAvD_BwE (accessed Mar. 2, 2024).

[3] “Q700 M Sedeo Pro,” Wheelchair Sales Indesign, https://www.wheelchairsales.com.au/q700-m-sedeo-pro/ (accessed Mar. 8, 2024).

[4] L. Baumann et al., Low-Interface Wheelchair Footrest Poster Presentation. 2023., https://bmedesign.engr.wisc.edu/projects/f23/super_footrest (accessed Feb. 24, 2024).

[5] M. Li et al., “Becker Muscular Dystrophy: Case report, review of the literature, and analysis of differentially expressed hub genes - neurological sciences,” SpringerLink, https://link.springer.com/article/10.1007/s10072-021-05499-2 (accessed Mar. 8, 2024).

[6] C. C. medical professional, “Becker muscular dystrophy (BMD): Symptoms & Treatment,” Cleveland Clinic, https://my.clevelandclinic.org/health/diseases/23541-becker-muscular-dystrophy-bmd (accessed Mar. 8, 2024).

[7] “Wheelchair users,” Physiopedia, https://www.physio-pedia.com/Wheelchair_Users (accessed Mar. 8, 2024).

[8] ASM material data sheet, https://asm.matweb.com/search/SpecificMaterial.asp?bassnum=ma6061t6 (accessed Mar. 7, 2024).

[9] “The Online Materials Information Resource,” MatWeb, https://www.matweb.com/search/datasheet.aspx?bassnum=O1303&ckck=1 (accessed Mar. 7, 2024).

Appendices

Appendix A: Product Design Specifications

Low Interface Wheelchair Footrest

PRELIMINARY PRODUCT DESIGN SPECIFICATIONS

BME 301

Lab Section #: 302

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February 8th, 2024

Function :

Currently, there is a noticeable absence in the market of wheelchair footrests that facilitate individuals who are not fully paralyzed to execute beneficial movements, such as using their feet to open doors or retrieve objects from the floor. Moreover, existing footrest models exhibit drawbacks, as they tend to be cumbersome, weighty, and lack user-friendly features for convenient removal and storage during periods of non-utilization. While footrests play a pivotal role in providing support when the wheelchair tilts or reclines, it is imperative to devise an innovative wheelchair footrest that accommodates enhanced foot mobility for users as needed, while offering seamless storage options. The refined footrest should possess adaptability to suit an individual's necessities, have effortless removal and storage capabilities, reduced weight, and a more streamlined design, all while retaining the essential benefits of a traditional wheelchair footrest.

Client requirements:

- Total weight of less than 5 pounds
- Must have the ability to fold and be easily storable
- Must be able to withstand 200 lbs
- Has the ability to move with the wheelchair during reclining or uprising position
- Still be able to provide the benefit of a traditional wheelchair footrest

Design requirements:

1. Physical and Operational Characteristics

    a. *Performance requirements*:

The wheelchair footrest must have a lifespan of at least five years, corresponding to the average time duration that a wheelchair base lasts [1]. To preserve reproducibility, currently, the production cost should remain under $200. The footrest should be lightweight and durable, weighing under 5 pounds total while being strong enough to hold the user's weight on a continuous basis. The rest should promote user comfort and accessibility, with adjustable features to adapt to individual needs. Lastly, the footrest needs to be easily storable, preferably on the side of the wheelchair.

b. *Safety*:

The materials used when creating the footrest must not be sharp or be able to cause injury to the user. The storage mechanism should be user-friendly and secure, preventing any accidental deployment or collapse during storage, and minimizing the risk of pinching hazards. While also being durable, the material used for the footrest should be as anti-slip as possible, mitigating the risk for falling. If electronics are used in the footrest design, the wires should not be visible or have the ability to be tangled in the footrest. The footrest design must comply with relevant wheelchair safety standards and regulations to guarantee a high level of safety and reliability for users.

c. *Accuracy and Reliability*:

The footrest should be able to securely connect to the wheelchair for its entire lifespan. All joints and plates should stay unbent and at desired angles under normal conditions.

d. *Life in Service*:

The footrest will mostly be used outdoors, and will be repeatedly packed and unpacked during transport when it isn't needed on the wheel chair. This processes is expected to happen hundreds to thousands of times over the life of the footrest, as it should last at least as long as the wheel chair it is designed for, so 5-10 years [2]

e. *Shelf Life*:

The footrest will fold into itself to allow for easy storage, and transportation. It will need to withstand being transported in suitcases or bags. All parts should hold together when folded so as to not have bending or tearing of joints connected to pieces that hang off the main body. The components of the footrest will be durable metals with centuries of shelf life, and motors or linear actuators that have at least 5 year life spans as long as the sensitive insides are kept sealed.

f. *Operating Environment*:

The footrest will be used inside and outside at all times of the year. This means it must function in any weather, and will encounter water, dust, mud, bumps and should be able to support the clients throughout.

g. *Ergonomics*:

The footrest should be able to support the clients legs and feet, which is estimated to be 12.2% of their body weight [3], while the footrest itself remains lightweight to allow it to be removed and transported easily. The footrest must require little force to be moved out of the way to limit its interference with everyday activities such as leaning forward, transitioning out of the wheelchair, or opening doors. All edges should be sanded down or covered to stop injury opportunities.

h. *Size*:

The design should take a client specific approach when considering the size. The footrest should account for the coverage of the entire feet according to client specific shoe size, excluding margin of error from the shoes. According to Nike's shoe size chart, the corresponding length should be at least 31.3 cm in length [4]. Due to personal habits, the actual feet size is smaller than given on the chart. The aim is to provide a necessary amount of support while resting, while keeping as minimum for portability.

i. *Weight*:

The design should take into account the client's specific condition: muscular dystrophy, and the client's request to disassemble and reassemble for packaging. Common wheelchair footrest, made from various types of a combination of plastic and metals, ranges from 3-10 lbs. The footrest will aim to minimize burden during transportation and the process of disassembling to ensure proper alignment with portability. Thus 3-5 lbs is a reasonable range for the design.

j. *Materials*:

Since, by client request, the footrest is mainly used outdoors, the footrest should be constructed using high quality and corrosion resistant materials. This provides services to various weather conditions. Frame can be designed from aluminum alloy for its exceptional strength-to-weight ratio [5], allowing movability along with durability. Since the footplate is meant to be de-attachable, the footplate should use non-slip, easy to clean material to provide a clean surface to the user, using acrylic to PVC. For better ease of fabrication, tough PLA can be considered using 3D printing to provide dynamic shapes [6].

k. *Aesthetics, Appearance, and Finish*:
The aesthetic and appearance of the stamp will be uncomplicated, it will be a silicone item with no finish to minimize contamination during use. It will be a ductile design that is meant for multiple uses.

2. Production Characteristics

a. *Quantity:*
The client aims to create an initial prototype as an attachment to their current wheelchair. Upon the successful development of this prototype, there is potential for scaling production to serve a larger user population.

b. *Target Product Cost:*
The final market product cost aims to be less than 10% of the development cost, including materials fees during the design process.

3. Miscellaneous

a. *Standards and Specifications*:
ISO 7176: This is the international standard that outlines the testing protocols for different mechanical elements of a wheelchair. Sections 1[7] and 2[8] pertain to the wheelchair's static and dynamic stability during motion. Additional sections address specifications related to the wheelchair's size, required space for maneuvering, durability, among other characteristics. It is crucial to acknowledge these factors, as the testing equipment could influence the wheelchair's inherent physical attributes.

CFR890.3920: This is the FDA regulations regarding wheelchair components. A wheelchair component is defined as a medical device that's an integral part of a wheelchair, including those sold separately, which applies to our design. These devices are not required to undergo the premarket notification process,[9] subject to limitations.

b. *Customer*:
The footrest is specifically designed to fit the needs of our client, Dan Dorszynsk, who has expressed dissatisfaction with existing footrest options, which limit his capacity to perform small daily tasks, like opening doors. With that said, the design principles and solutions the teams develop could be applicable to a broader

audience, as other wheelchair users with varying degrees of mobility may experience similar challenges and could benefit from the final design.

c. *Patient-related concerns*:
This footrest is designed for patients like our client, whose legs still have some strength and can perform lighter duty tasks and support the body without the footrest when sitting. These patients do not need the footrest for the majority of the time, and will only need them when traveling. Hence it should be easily removable, for packing when traveling. The height of the footrest should also be adjustable, as study has shown improper height of the wheelchair footrest may lead to increased average pressure, potentially leading to ulcers and other problems for patients with less mobility of the lower bodies[10].

d. *Competition*:
Most wheelchairs footrests come with the wheelchairs themselves, [9] although there are still a wide variety of footrests available on the market. Prices range from 30 dollars[11] to 120 dollars[12]. Most of the footrests share a similar design. With metal frames for support and connection, and plastic or metal footrest itself attached to the frame that can fold up sideways. Some premier ones come with cushions or paddings for legs.

References:
[1] P. Ngamwongsa-Nguan, P. Arayawichanon, and N. Manimmanakorn, “Manual Wheelchair Longevity and Related Factors among Spinal Cord Lesion Patients,” Asia-Pacific Journal of Science and Technology, vol. 22, no. 03, Jul. 2017. Accessed: Feb. 6, 2024. [Online]. Available: https://www.researchgate.net/publication/320506147_Manual_Wheelchair_Longevity_and_Related_Factors_among_Spinal_Cord_Lesion_Patients
[2] M. Nazari, “How long does a power wheelchair last,” Gilani Engineering, https://www.gilaniengineering.com.au/how-long-does-a-power-wheelchair-last/#:~:text=The%20lifespan%20of%20Power%20Wheelchair,-Typically%20the%20lifespan&text=A%20top%2Dquality%20wheelchair%20with,between%203%20to%207%20years (accessed Feb. 8, 2024).
[3] Table 4.1 anthropometric data - kinovea, https://www.kinovea.org/tools/references/2009%20-%20Winter%20-%20Table%204.1%20-%20Anthropometric%20data.pdf (accessed Feb. 8, 2024).
[4] “How to measure your foot to find the right shoe size,” Nike.com, https://www.nike.com/a/how-to-measure-foot-size (accessed Feb. 8, 2024).
[5] “Aluminum 7075: Alloy data sheet and properties |,” United Aluminum, https://unitedaluminum.com/aluminum-7075-alloy/ (accessed Feb. 8, 2024).
[6] “3D Print Guide,” UW Makerspace, https://making.engr.wisc.edu/3d-printing-the-makerspace/ (accessed Feb. 8, 2024).

[7] ISO. (2014). Wheelchairs — Part 1: Determination of static stability. https://cdn.standards.iteh.ai/samples/56817/abc81b2284d1465f91679e4588c269be/ISO-7176-1-2014.pdf
[8] ISO (2014). Wheelchairs — Part 2: Determination of dynamic stability of electrically powered wheelchairs. https://cdn.standards.iteh.ai/samples/57753/61ac15402fd74aee98b3aa1803400f2b/ISO-7176-2-2017.pdf
[9] Wheelchair component, 21CFR890.3920(1983)
[10] "Red Steel Swing-away footrest assembly for wheelchairs, 1/CS," BettyMills.com, https://www.bettymills.com/medline-red-steel-swing-away-footrest-assembly-for-wheelchairs-1-cs-wca808965re-medwca808965re?gad_source=1&gclid=CjwKCAiAlJKuBhAdEiwAnZb7lX068ne0R7_gvrR-HvohwxkysGcxemzIpdo6apr8KxxLn1JhSSovxRoC0GIQAvD_BwE (accessed Feb. 8, 2024).
[11] "Elevating leg rest, black calf pad, 1, elevating leg rest, Black Calf Pad," Grainger, https://www.grainger.com/product/59PP70?gucid=N%3AN%3APS%3APaid%3AGGL%3ACSM-2295%3A4P7A1P%3A20501231&gad_source=1&gclid=CjwKCAiAlJKuBhAdEiwAnZb7ldBPpFdeupFDsgQhNMiNOFSJhuu8zA9fFGG_ZKO0fA-K3MuF5leaQxoCjGYQAvD_BwE&gclsrc=aw.ds (accessed Feb. 8, 2024).
[12] P. Tederko et al., "Influence of wheelchair footrest height on ischial tuberosity pressure in individuals with paraplegia," Nature News, https://www.nature.com/articles/sc2014242 (accessed Feb. 2, 2024).

Appendix B: Supporting Structure

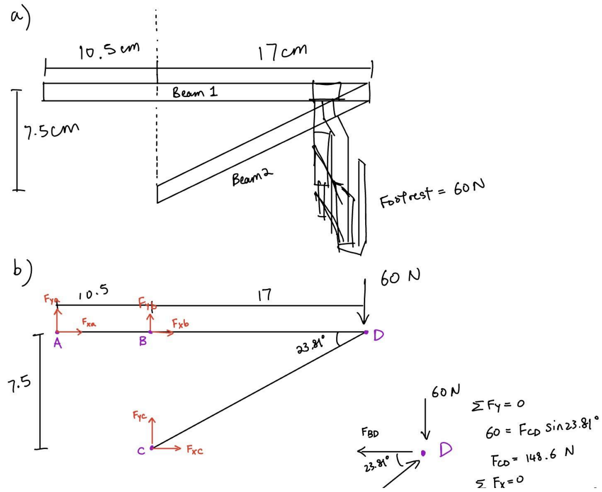

Figure 1a- support mechanism. B- force analysis

The mechanical structure uses triangular support beams, with the horizontal beam withstand 300N of tension and the tilted beam withstanding 280N of compression. that will be able to withstand 2x bodyweight for potential misuse of the device such that the patient accidently put whole body weight on the footrest

Appendix C: Electronic versus manual design matrix

Table 1: Design Matrix II

Criteria (Weight %)	Design 1: Electric Footrest		Design 2: Manual Footrest	
Ergonomics (35)	5/5	35	4/5	28
Weight (25)	4/5	20	2/5	10
Adjustability (20)	3/5	12	2/5	8
Cost (10)	2/5	4	4/5	8
Ease of Fabrication (10)	3/5	6	3/5	6
Total = 100	77		58	

Ergonomics: The number one goal of this design is to make the footrest feel light to the user and easy to move. Though the counter balance could be constructed for this purpose, the electric system would use buttons or a joystick similar to the system used by the rest of the wheelchair, and therefore intuitive to any rider. The electric system would also require less force to use.

Weight: The actual weight of the design is ranked as the second most important factor, as this will affect how easy it is to handle when detached from the wheelchair, as well as how much extra power will be drained when accelerating. This is the main deciding factor as the manual system must use weight to counterbalance the footrest, where the electric system can be designed much lighter and closer to the center of gravity of the rest of the wheelchair.

Adjustability: This is the ability for the design to be used on other wheelchairs besides the clients Quickie Q700 M. Research hasn't shown a lot of promise for either system to be very adjustable, but the more compact electric system would have an easier time.

Cost: The cost of certain electric components such as a linear actuator, or motor is significantly higher than the cost of materials such as cables and pulleys.

Ease of Fabrication: The Quickie Q700 M has built in circuits and logic that can be adapted into the electric system design, unlike the manual design which would have to be crafted around the limitations of the wheelchair.

Appendix D: Solid Model of the Autonomous Footrest Design

The design is currently being updated and modified as dimensions and overall structure are being tested and measured to reflect the best weight distribution and combined loading abilities.