Low-Interference Wheelchair Footrest

Preliminary Report

Oct. 9th, 2024

BME 200/300 Lab 301 Design Project

Team Name: Footrest Fanatics

Clients: Mr. Dan Dorszynski

Advisor : Prof. Melissa Skala (UW-Madison - Department of Biomedical Engineering)

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Abstract

Out of all wheelchair users in the world, nearly one fourth have the capability to walk a quarter of a mile, and even more have some degree of ability to utilize their legs. Despite this, very few wheelchair footrests are able to retract and allow their user any deal of freedom with their legs to interact with the world around them. Many of those that do only have limited capability to vacate the vicinity of their operator's legs or otherwise require a degree of exertion from the legs of the operator that some wheelchair users may be unable to muster. The following report proposes a prototype footrest that has the capability to extend to act as a typical footrest and to retract in a short period of time to allow the user greater usage of their legs. In the future, the design and durability of the prototype will be put through testing in practical day to day life, and if judged to be successful in all criteria, may proceed to commercial production. The goal of the final prototype is to create a footrest that can fully extend and retract without the usage of a wheelchair operator's legs while also remaining compact and simple to remove from and attach to the wheelchair frame for easy transportation.

I. Introduction

Motivation

Wheelchairs are one of the most widely accessible mobility aids on the market. Worldwide, there are approximately 131.8 million people who use wheelchairs as their main way to get around in their everyday lives. Additionally, an estimated increase of 2 million people will be in need of assistive devices in the future [1], which creates a large demand for many kinds of assistive devices, such as wheelchairs. Wheelchairs come in all shapes and sizes, with adjustable accessories to fit the needs of the person using them. The benefit to having custom accessories is to avoid injury and increase function to maximize the user's quality of life [2]. Seat cushions, arm rests, and headrests come in varying sizes and heights to increase comfort and ergonomics, and footrests are also modifiable. Common wheelchair footrests are metal or plastic footplates that connect to the base of the wheelchair via metal bars, and most wheelchairs come with footrests already installed. The footplates that are already installed are often made to fit the average person, and do not account for varying leg lengths and foot sizes. Footrests also do not account for ambulation, or having minimal motor function still remaining in the arms and legs, and wheelchair footrests often hinder those movements. In addition, if the user wanted to change out the footplates, most wheelchairs do not allow for further modifications, or only have select models that configure to certain wheelchairs.

Existing Designs

While there are many wheelchair footrests and leg rests on the market, there is an issue with cross-model compatibility. in many cases, companies will make interchangeable footrests, but these accessories will either be made for the specific models made by that company, or not be compatible between manual and electric wheelchairs. The Hideaway Footrest by the company FOLD & GO [3] is an accessory that can be moved out of the user's way in order to stand is only compatible with two of the company's own models, and none made from other manufacturers. This is common among wheelchair manufacturers, with the Invacare Swing-Away Footrest [4] only being made for the select 9000 Series or Tracer Series wheelchairs, both of which are manual wheelchairs, and the footrests are not compatible with Invacare powered wheelchairs. The variability in attachments and different manufacturers for the base of powered wheelchairs adds to the complexity of cross-model compatibility.

There is also variability within the footrests themselves, with all different sizes and stirrups to hold the feet in place. The model from Drive Medical [5] has cloth stirrups to ensure the user's feet do not slide back if the wheelchair has the ability to tilt, a feature that the Invacare also includes, but the Hideaway model does not. Although the model from FOLD & GO does not have stirrups, it does have a single footplate configuration, allowing for it to be removed out of the way in one motion. All three models are mechanically operated, and also all can be removed from their original configuration in front of the wheelchair to allow for actions such as standing. Both the Invacare and Drive Medical models are able to be rotated laterally to the sides of the wheelchair, completely removing them from the front of the wheelchair, but simultaneously adding width to the wheelchair, which can hinder the mobility of the user all together. The Hideaway model folds underneath the wheelchair via hinges, which does not add any bulk around the sides, but does need to be operated near the end of the lower legs, requiring the user to bend at the waist. This causes issues if the wheelchair user does not have the mobility or flexibility to access the mechanics of the footplate.

In addition to the footrests and footplates on the market, there was a manual footrest designed to improve upon the client's existing footrests on the Sedeo Pro Quickie Q700m [6]. The previous Low-Interference Wheelchair Footrest [7] was electronically powered through the wheelchair's main electronics, and used linear actuators to move an aluminum footrest beneath the wheelchair, allowing for full range of motion in front of the wheelchair. However, from the client's feedback, the footrest was too noisy due to the linear actuators used, and the footrest did not meet weight criteria and deflection requirements.

Problem Statement

Currently on the market, there are no known wheelchairs that allow for users who have remaining function in their legs to maintain use of their feet in everyday life. Use of the feet may include opening doors, putting their feet on the ground for better mobility overall, and picking up objects from the ground. Current footrest models are static in their position and do not allow for modification in position, as well as heavy and are not easily removed for storage. While wheelchair footrests are essential in supporting the user's legs and feet when reclined or tilted, it is vital to design the footrests to be able to allow for greater mobility of the feet should the user need it. The revised footrest should be adaptable to the user's abilities and lifestyle, be easily removable, and have reduced weight while still remaining functional as a traditional footrest when in the original position.

II. Background

Relevant Biology and Physiology

There are many reasons that a person would need to use a wheelchair in their daily life, such as muscular dystrophy, paraplegia, or spinal cord injuries [8]. And with this wide variety of reasons also comes a wide variety in levels of mobility and dexterity. Many people who are in wheelchairs also maintain a certain level of mobility, defined as being ambulatory. Those who are ambulatory can, for some period of time, become independent of their wheelchair, but cannot for most parts of the day due to factors such as varying energy levels, chronic illnesses, or people who are recovering from surgery [9]. For this product, the aim is to create a footrest that accommodates as many people as possible.

When designing a footrest that needs to be adjustable, there are measurements that need to be kept in mind, such as the length of the entire footrest. If the footrests are not in the optimal position for the user's needs, such as being too short, the feet and lower leg become unsupported, and will transfer most of the weight to the lower back and cause pain. Alternatively, if the footrests are too long, the weight transfers to the backs of the user's legs, which causes bedsores. Additionally, it is also important to keep the spine and pelvis in a neutral position, especially for those who use wheelchairs exclusively. The spine should keep an "S" curvature to ensure stability, and the shoulders should be square and level with the pelvis to maintain neutral position. The pelvis should remain level, with weight equally distributed on each side, to avoid tilting the spine and causing scoliosis [10]. The footrests must also be of equal height and length to prevent a tilt in the pelvis [11].

Client Information

The client, Mr. Dan Dorszynski, lives in Madison, Wisconsin and has lost mobility in his legs, and therefore requires the use of the Sedeo Pro Quickie Q700m wheelchair, seen above [6]. He is looking for a wheelchair footrest that can be removed completely from its original position in front of his wheelchair to be able to use his feet more. He would also like this footrest to be adaptable to his secondary wheelchair, and be easily removable for transfer or storage.

Design Specifications

This product was made specific to the client and his needs and specifications, but there is a possibility for mass manufacturing in the future for those who are having similar problems with footrests. The requirements for this product given to the team were that the footrest should perform normally as a wheelchair footrest when in the original position, then also be able to move out of the typical range of motion for the feet (0.762 m x 0.305 m around the wheelchair) with little to no restriction. The product should also work for as long as the average lifespan of a wheelchair (about 4 to 5 years [12]), weigh under 5 pounds, and should support the feet and lower leg on the backside to ensure support while the wheelchair is tilted. Finally, the client requires the product to be easily removable from the wheelchair and either stored or attached to his secondary wheelchair with little exertion.

III. Preliminary Designs

Design 1: Lattice Ball Jointed Footrest

The first design blossomed from the idea of having the footrest itself change in size. This would ideally allow a greater degree of freedom of movement for the footrest, as it would be more compact and subsequently could fit in areas that a full sized footrest could not. The footrest was proposed to be made of a rigid rubber diamond lattice mesh. Two actuators underneath the mesh would support the brunt of the weight placed on the footrest, as well as doing the work of compressing the mesh. Once activated, the actuators would retract, collapsing the mesh down to a fraction of its original dimensions as seen in Figure [1]. The mesh would be connected to two supports that projected downwards from under the operator’s seat, each attaching to a corner of the mesh closest to the wheelchair by a ball joint mechanism. The collapsed mesh would be able to swing downwards on these ball joints, having enough clearance to clear the ground once collapsed. The inverse of this process could occur once the footrest was desired by the operator once again. This design had a few main flaws. The most pertinent of which was the question of what specific materials the lattice itself would be made from, as most materials with the desired degree of movement would have too high a degree of rigidity. However, the team decided that it would be possible to integrate several cables attached to the framework of the wheelchair to add additional support if the materials of the lattice were found to bear a brunt of the weight that they were not rated for.

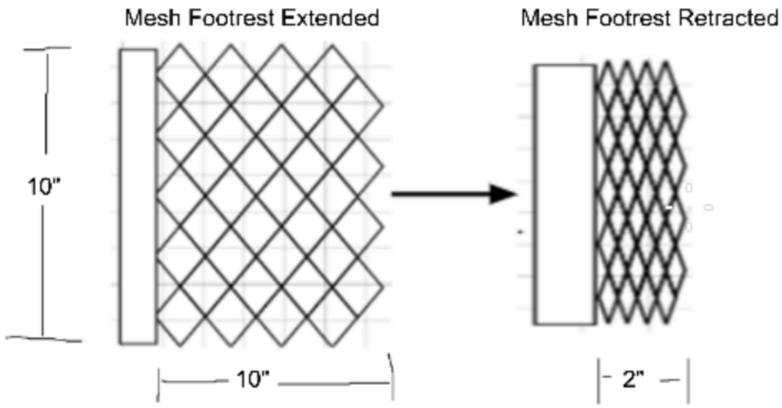

Figure [1]: Top View of the Lattice Footrest in its Extended and Retracted States

Design 2: Telescoping Sunglasses Footrest

The second design envisioned by our team is the Telescoping Sunglasses Footrest design. This design was originally devised after considering a pair of crutches that could adjust to several different heights. The design itself utilizes two rail systems, one on each side of the operator's seat which are already part of the existing design of the wheelchair model the prototype is designed for. In this design, the footrest would consist of two individual footrests connected by a single bar underneath them, thus begetting the moniker "sunglasses". The two corners of the footrest closest to the wheelchair would be attached to the rail systems by two telescoping rods, one on each side, with the bottom connected to the footrest and the top connected to an apparatus on the rail system. This would allow the user to simply utilize their hand to move the entire footrest back and forth by grabbing and moving the apparati on the rail systems. In addition to this, the team intended to move the footrest itself up by collapsing the telescoping beams so that the footrest could lie flush under the seat of the wheelchair as seen in Figure [2]. It was quickly discovered that if a cable were to be wired through the telescoping beam and anchored to both the footrest and the front of the seat, the tension in the cable would cause the telescoping beams to collapse upwards when the footrest was moved backwards along the rails, away from the anchoring point at the front of the seat. This would allow the user to move the footrest on the vertical and horizontal axes with a singular hand actuated movement. To change the speed at which the telescoping beams collapse upwards, the team formulated the idea of using moving pulleys to change the ratio of the distance the footrest would move in the horizontal direction to that it would move in the vertical direction, allowing proper clearance of any structural pieces required under the wheelchair.

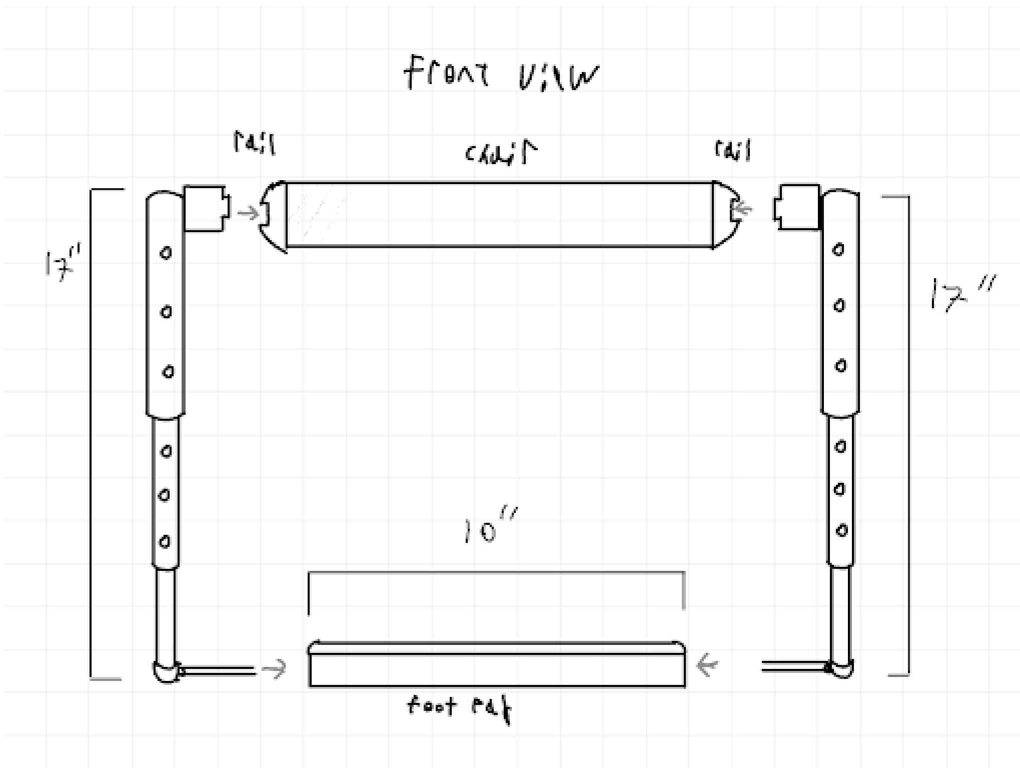

Figure [2]: Front view of the Telescoping Mechanism and Rail System

Design 3: Hand Crank Panel Footrest

The final design proposed by our team is the Hand Crank Panel Footrest. This design consisted of using a series of hinges and cables to collapse the footrest to an almost entirely flat sheet under the seat of the wheelchair. The footrest consisted of two completely separate pieces, one for each foot, with the back of each footplate being connected to the main backplate of the footrest by a hinge. Supports would be added under the footplates, but they would only connect to the footplate itself and would simply exert pressure on the backplate when in use, removing much of the strain on the footplates. The outside corners farthest from the wheelchair of the footplates would be attached to an electrical or a manual winch system which in turn would be attached to the main frame of the wheelchair. Once activated, the footrest and their supports could fold upwards and lie flush with the backplate of the footrest as seen in Figure [3]. The supports themselves would be connected to the footplates by hinges, allowing them to also lie flush against the footrests if pushed aside by the user. The entire back plate of the footrest would be connected to the front of the seat of the wheelchair by yet another set of hinges. As the cables continued to be pulled backwards towards the winch system, the entire flattened footrest apparatus would be pulled up and under the seat, allowing for complete clearance of the operator's legs until desired in its extended form once again. This footrest design also held the possibility of the operator only having a singular footplate in usage at any given time, allowing for them to rest one leg while utilizing the other to interact with the world as they see fit.

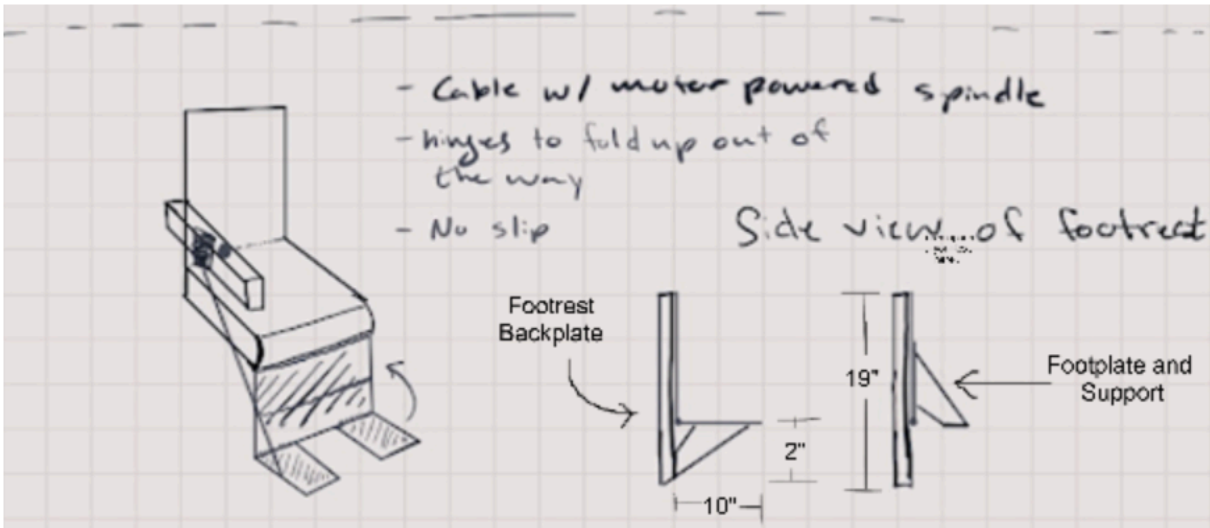

Figure [3]: Hand Crank Panel Footrest Initial Design and Collapsing Mechanism

IV. Preliminary Design Evaluation

	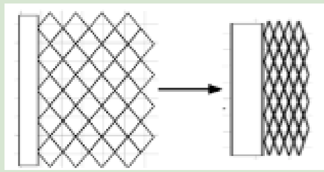		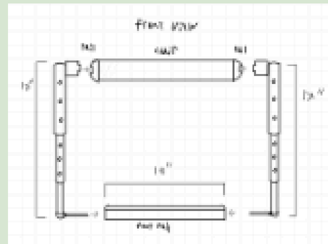		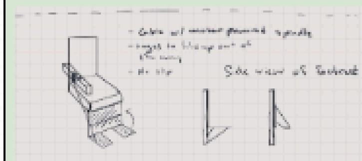	
Design Criteria	**Design 1: Lattice Ball Joint Footrest**		**Design 2: Telescoping Sunglasses**		**Design 3: Hand Crank Panel**	
Ease of Use (25)	3/5	15	4/5	20	4/5	20
Client Comfort (20)	4/5	16	5/5	20	3/5	12
Safety (20)	4/5	16	4/5	16	5/5	20
Compactability (15)	3/5	9	4/5	12	3/5	9
Cost (10)	3/5	6	3/5	6	4/5	8
Ease of Fabrication (10)	1/5	2	3/5	6	2/5	4
Total (100)	64		80		73	

Figure [4]: Low Interference Wheelchair Design Matrix

Figure [4] depicts the design matrix the team used to judge three designs against six different criteria. The criteria are weighted more by the value at which the team and the client categorize as the most crucial (25 points) to the least crucial(10 points). The most important criteria was ease of use. This is defined as the client's ability to operate the footrest and retract or detract the mechanism when the footrest is in or out of operation. Client comfort and safety both are weighted at 20 points. Client comfort is defined as the client's ability to operate the device using the least amount of mobility as possible to prevent injury or discomfort. In addition to this, client comfort is also general comfort of the client and how the legs feel when the footrest is in use. Safety is defined as the client's ability to use the footrest with no threat of pinching from joints that aren't completely hidden away or injury due to electronics and wiring. Compactability is defined as the ability of the footrest to fully fold up and not be an obstacle or hindrance to the client in any way while not in operation. Cost and ease of fabrication are weighted the lowest with 10 points. Cost is defined as the cost of materials that will be used or implemented during the manufacturing of the footrest. This is not weighted highly because the $200 that is funding this project will be sufficient enough funds to see the project through. Ease of fabrication is defined as the team's ability to design, manufacture, and test the product in the timeframe of one semester during BME 200/300. This criteria was weighted amongst the lowest because the given time frame should be adequate for the production of each of the three designs.

Design 1 did not score highest in any of the criteria. it received a ⅗ in ease of use because the lattice mechanism is more complicated than design 2 and 3 and the design itself is very unstable with no clear way to extract and retract the footrest. It scored a ⅘ in client comfort because all designs didn't vary much and the lattice design made an angle from the knee to the ankle more accessible that could help reduce swelling in the client's feet. This design scored a ⅘ in safety because overall it didn't have any excess parts that could pinch and if electrics were implemented the wires could easily be stowed underneath the chair. Design 1 scored ⅗ in compatibility because the legs condense against the side of the chair where designs 2 and 3 are primarily under the chair. It scored ⅗ in cost because the design is primarily made up of steel bars and the lattice mechanism would be an added cost to manufacture. This design scored lowest in ease of fabrication because the lattice design would be an added difficulty in the limited time span of one semester.

Design 2 scored highest in ease of use, client comfort, compatibility, and ease of fabrication. This design tied with Design 3 in the ease of use criteria because both designs are easily capable of retracting and extracting based on the client's needs when the client requires. This is because both designs have features where the client will not need excessive range of motion to operate the footrest mechanisms. Design two scored highest in client comfort because of its ability to create an angle to help elevate the legs and reduce swelling in the feet. This design also scored highest in Compatibility because of its ability to completely fold up and out of the way underneath the chair in order to get rid of an added obstacle for the client. It also scored highest in ease of fabrication because this design has the least amount of moving parts and should be relatively easy to manufacture in the specified time.

Design 3 scored highest in ease of use, safety, and cost. This design tied with the highest score for ease of use as stated earlier in the text because of the reduced mobility needed to operate the footrest. Design 3 scored highest in safety because like design 2 it is capable of folding under the chair and therefore will not create added obstacles for the client, in addition to this, design 3 does not require any electrics that might injure the client making this the safest design. This design also scored highest in cost because it would have primarily been manufactured with a metal sheet behind the legs and wooden footplates to make the design cheaper but this also sacrifices the sturdiness of the structural integrity.

The results of the design matrix concluded that Design two, having the highest score in four of the criteria and also receiving the highest score at 80 points will be the final design that will be utilized for the rest of the semester. This design includes two foot plates, a mechanism that will be easy for the client to operate, and added features such as the angle to prevent swelling in the feet for comfortability, making this the obvious design to move forward with.

V. Fabrication/Development Process

Materials

The footrest will have two main portions, each with its own needs and therefore potentially different materials, consisting of the telescoping mechanism and the footrest itself. The telescoping rods that extend from the chair and support the footrest will be made of Aluminum, or a type of Aluminum alloy. Aluminum is relatively light for a solid metal but also strong. Light materials are favored in our design because of our client's request for the footrest to not be bulky. Many telescoping rod mechanisms on the market are made of aluminum due to these qualities. Aluminum is also easy to modify due to not being exceptionally hard, so it can be tapped to place the holes we need for attachment and for locking the telescoping mechanism with a spring button. The footrest itself will likely also be made of aluminum. This choice is due to the same qualities listed for the telescoping part but also due to our attachment method which will be welding. Welding the footrest to the telescoping aluminum rods will work better since they are of the same material that is compatible with welding.

Methods

The methods for the fabrication of the footrest are also split into the supporting mechanism and the footrest itself, or the footplate. Machining and hole tapping will be the main processes used for the telescoping mechanism, where the rods might have to be adjusted for length and will need holes tapped for the insertion of the spring buttons. The aluminum rods might also need to be modified with welding to ensure the telescoping mechanism does not detach. Welding will mainly be used for the attachment of the footplate to the telescoping rods. Welding is a much stronger and more permanent method of attachment than using screws or clips of some sort, and is therefore favored for our design, since our footrest must be as sturdy as possible given our low weight requirements and material choices. Finally wheels will be screwed in at the base of the footrest into holes that will be drilled.

Final Prototype

Our team has not constructed any prototypes at this point of the design process. We have created basic 3D animations in Blender of the functions of the footrest to illustrate how it works, which can be found in **Appendix B,** but have yet to create any physical parts. We are planning to use CAD to model our design properly and follow by manufacturing the parts once we obtain our materials. While prototyping, we plan to test the durability and effectiveness of our design thoroughly to ensure we meet our client's requirements.

VI. Testing & Results

Testing will be dedicated to ensuring the structural integrity of the footrest. This is important to the client because of past projects that could not meet these specifications. The footrest must also be able to extract and retract efficiently and quickly in order to be useful to the client. Testing for these concerns will be done using the client's spare wheelchair that is in storage at Engineering centers building as well as mechanically testing the materials used in the footrest, mainly consisting of steel bars. Mechanical testing should also be done on the telescoping component of the mechanism to ensure stability. In addition to this testing on the telescoping component concerning the ability to condense and decondense without error is necessary. The client will also be advised to come in for a testing day where the team will take notes on discomfort, need for more stability, safety concerns etc.

VII. Discussion

We have yet to construct a prototype and conduct any testing. After we are able to start prototyping and testing changes can be implemented and we can ensure that our design is strong enough. In our testing and research for our design we must consider that our client's information is used properly and privately, since we will be making the footrest for his measurements and abilities. We are aware of the possibility that our design could be manufactured and used publicly, which could help many people with similar conditions to our client using our features designed specifically for him.

VIII. Conclusions

The team had been commissioned to create a prototype footrest that could be attached to a wheelchair and would hold the capability to extend and retract with little effort by the user so that they would be able to utilize their legs when desired. Paramount to this project was ease of use for the client along with their safety, so that they would never have to fear the possibility of injury to their legs or feet while using this project on a frequent basis. Secondary was the capability of the footrest to detach easily and to be as lightweight and compact as possible to facilitate storage and transport.

The team found that the best design to these criteria was the Telescoping Footrest design. This design showed great promise by its simplicity of use and few mechanical segments that could act as weak points to the system. This fact also has the benefit of greatly reducing the cost of the prototype. The lightweight materials combined with the incredible collapsibility of this design should be capable of meeting the client's requirements for the transportability of the device.

Moving forwards with the project, the next step will be constructing the full prototype for the footrest. Most critically in this process will be the focus on procuring telescoping pieces that will not break or slip out of alignment under duress. The system that attaches the telescoping poles to the rail system is also a critical point of potential failure in the design, so measures will be taken to test the stress on this specific mechanism.

The final goal of this project is to create a functioning prototype of the design that is sturdy enough to act as a fully functioning footrest for our client. It is possible that the footrest may be analyzed and utilized as the basis for other similar collapsible wheelchair footrests in the future, but at this time the team has no express plans to create a market viable design based on this footrest.

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X. Appendix

A. Product Design Specifications

Low-Interference Wheelchair Footrest

Product Design Specification

Sept. 19, 2024

BME 200/300 Lab 301 Design Project

Team Name: Footrest Fanatics

Clients/Advisors : Mr. Dan Dorszynski, Prof. Melissa Skala

Team Members: Elaina Rizzo, Elleana Thom, Yair Ben Shaul, Timothy Mendler

Project Function

Currently on the market, there are no known wheelchairs that allow for users who have remaining function in their legs to maintain use of their feet in everyday life. Use of the feet may include opening doors, putting their feet on the ground for better mobility overall, and picking up objects from the ground. Current footrest models are static in their position and do not allow for modification in position, as well as heavy and are not easily removed for storage. While wheelchair footrests are essential in supporting the user's legs and feet when reclined or tilted, it is vital to design the footrests to be able to allow for greater mobility of the feet should the user need it. The revised footrest should be adaptable to the user's abilities and lifestyle, be easily removable, and have reduced weight while still remaining functional as a traditional footrest when in the original position.

Client requirements

- Has the ability to be removed for translation to another wheelchair or be stored
- Provide the function of a traditional wheelchair footrest
- Total weight of less than 5 pounds
- Has the ability to move with the rest of the wheelchair during reclining

Design requirements

1. **Physical and Operational Characteristics**
   a. **Performance requirements**

      The wheelchair footrest will have a lifespan of 3 to 5 years, equal to the lifespan of the average wheelchair base [1]. The client must be able to retract and extend the footrest a minimum of 3 to 4 times per day, for everyday that the wheelchair is in use. The product must not have a total weight exceeding 5 pounds. The footrest should be able to retract to the extent where the client may reach an area of 0.762 m x 0.305 m around the wheelchair with no restricted movement.

   b. **Safety**

      The footrest extension should not take up much room in order to prevent the inability of the user to exit through doorways of an area safely and efficiently. The footrest should easily swing to the right of the wheelchair for the user's ease of movement from wheelchair to car, bed, chair, etc. All wiring of the extension should be safely stowed to prevent injury to the user as well as damage to the product from climate effects. If the footrest requires a battery proper labeling must be applied to make it known the mechanism is battery powered.[2] Material used in the footpads should be anti-slip to mitigate risk of a fall, in addition to this the material needs to be sturdy enough to withstand the load applied by the user's legs while avoiding materials that can be sharp or cause pinching.[3]

   c. **Accuracy and Reliability**

      The footrest needs to be able to attach to the user's wheelchair for as long as the wheelchair itself lasts. Speed of the footrest from "in use" to "stowed" must be accurate and efficiently timed. If battery powered - battery must be able to last the entirety of the day before needing a charge. The footrest must be able to withstand the weight of the user's legs without breaking or degradation to the mechanism.

d. **Life in Service**

The footrest will be used both indoors and outdoors, therefore the mechanism will need to be weatherproof with an emphasis on water resistance due to wiring in the motor. Throughout the product's life span it will need to be unharmed in the removal process from the wheelchair. The footrest is also required to be easily condensable for most efficient transportation and last the entirety of the wheelchair's lifespan (3-5 years)[1]

e. **Shelf Life**

Storage climate conditions are not harmful to the product. The footrest should be able to be stowed or folded for long periods of time without wear or degradation to the materials of the footrest or the mechanism and electrical system. Batteries will need to be stored in a safe, dry, and neutral temperature environment. All attachments, brackets, braces, or hinges must be able to withstand constant motion throughout the day without losing stability over time.

f. **Operating Environment**

The footrest will be exposed to both indoor and outdoor environments. The footrest must be able to withstand all weather conditions and range of temperatures in the Midwest including, water, ice, snow, rock, mud, uneven ground, cold and hot conditions and wide humidity ranges. The footrest must have proper clearance in order to account for these things and consideration of all safety and environmental concerns while deciding the materials that will be used in the project. While the footrest is being stored it must also be able to withstand less frequent use in areas where problems may arise, such as; hinges, braces, or brackets.

g. **Ergonomics**

The ergonomics of wheelchair footrests are incredibly important to consider, as most people bound to wheelchairs will spend a great deal of time utilizing them every day. There are four main components to the overall ergonomics of the footrest. Firstly, it must be safe for all users, meaning that it should not be able to pinch, cut, or hurt the user in any other way. Secondly, it needs to be the proper height both above the ground and below the seat level of the wheelchair. There is no universal height for footrests, so it is best to make them to customer specifications. The only requirement is that they maintain proper ground clearance, or about 0.05 meters [4]. The third is that it can withstand the full weight of the human legs for extended periods of time, or about 33% of your body weight. This means that they should be able to withstand (on average) 250 N of force. The fourth is that the footrest is comfortable, meaning that it should be longer than the average human foot (0.269 meters) and should have a good deal of traction [5].

h. **Size**

The footrest should be large enough to fully support the average human foot length (0.269 meters) and should be at least as wide as the average human's hip width (98.70 cm) so that their feet may sit comfortably straight out in front of their body [6]. The footrest should also be able to easily fit through door frames, the standard width of which is about 91.44 cm in the U.S. [7]. In order to decrease the size of the wheelchair footrest during storage, it would be beneficial to make the individual parts hinged or be able to collapse in on themselves. Preferably, the overall dimensions of the collapsed attachment should be no more than 35.56 cm x 45.72 cm [8], which is the average size of a drawstring bag. If the device was needed to be larger, it could be made to be smaller than 48.26 cm x 33.02 cm x 17.78 cm [9], which is a standard size for a backpack. By these standards being met, the footrest would be quite easy to store and transport.

i. **Weight**

The client will need to be able to lift, store, and reattach the footrest with minimal exertion, thus the design must be lightweight while also maintaining structural integrity. Standard wheelchair footrests with various compositions range in weight from 3-10 pounds. The aim for this product is to reduce the amount of work required for removal and installation of the footrest, thus the team aims to have the design weigh in on the lower end of this range, with 3-5 pounds being the target.

j. **Materials**

The client has specified that they have no particular allergies to materials that may be used in the footrest. As the footrest will be subjected to all sorts of weather conditions and terrain, it would be best to use a material that is not capable of rusting and is easy to clean. All mechanization (motors, winch systems, hinges, locks, cables, rail systems, etc.) should be able to withstand these conditions. As there is a weight requirement given by the client of 5 pounds, the structure would preferably be made out of a lightweight material that is also sturdy enough to withstand the 250 N or force required. Aluminum is an appealing material choice due to its low price and low weight, paired with decent strength and durability. Steel is a more sturdy, albeit more expensive and heavy choice of material for the structure. A combination of the two in the overall design depending on parts should be researched. The other main material will be utilized on the footrests, which will likely be a rubber or resin material for its higher degree of friction and comfort for the operator's feet.

k. **Aesthetics, Appearance, and Finish**

Due to our product's design being specialized for our client, any cosmetic/aesthetic choices are made to his preferences. When asked about cosmetics during our meeting, the client stated that he has no preferences as long as the design is reasonable and that he encourages us to be creative with the aesthetics of the products. This leaves a high degree of freedom for our design in regard to aesthetics. Since there are no preferences from the client, the aesthetics of the footrest will probably be simple and emphasize durability over eye-catching designs. Due to the wheelchair being subjected to outdoor conditions and contact with different materials, the finish of any metal parts should offer rust resistance, and parts that may make contact with the client or surroundings should have textures and finishes that are relatively resistant to abrasion, yet not uncomfortable to make contact with.

2. **Production Characteristics**
    a. **Quantity**

The client has not expressed a desire to create multiple units of the footrest but has mentioned that he has several backup wheelchairs. If he is satisfied with the completed design it is reasonable to assume that a few more units could be made for his backup wheelchairs. The client is open to the possibility of mass production but stressed that the product is mainly meant for his own personal needs and use.

    b. **Target Product Cost**

While there are few other detachable footrests for wheelchairs that are sold separately, the ones that are usually range from $35 to $60 dollars. Most of those are not automatic and require work on the part of the operator to move them. In the event that an automatic footrest is designed, it is likely to cost a deal more than the manual ones, likely in the range of $80 - $120. As the prototype will likely cost more than any units of the final product that might be mass produced, it is expected to cost not more than $200 dollars to produce.

3. **Miscellaneous**
    a. **Standards and Specifications**

ISO 7176: This standard outlines the specifications in which wheelchairs are tested and the requirements they must meet. Parts 1 [10] and 2 [11] outline the requirements for static and dynamic movement of the wheelchair as a whole. The product must not obstruct the movement of the wheelchair in any way in order to meet this. Part 14 [12] outlines the testing standards to all electrical systems that are a part of the wheelchair. If battery powered or rechargeable, the product must be tested in accordance with this section.

CFR890.3920: The FDA classification of a wheelchair is a class I medical device. This regulation is in reference to wheelchair accessories that have the intention to meet the specific needs of the user. Because the product is not intended for use as a protective restraint, it is exempt from the premarket notification procedures [13], as well as the good manufacturing practice requirements, subject to limitations.

If the product has the intention for mass manufacturing, it will be important to keep billing and insurance standards in mind, such as Medicare Insurance [14]. The footrest needs to be up to date on electric wheelchair regulations in the state of Wisconsin.

b. **Customer**

During our initial meeting, the client mentioned several preferences for the design of his footrest. Notably, he stated that he prefers designs that feature two separate footrests, one for each leg, as opposed to a single piece. However, he is still open to any design as long as it meets his needs. The client has expressed interest in designs that are less bulky, referring to previous designs. He also said that in the case we design a single-piece design, he would prefer it to swing to the right when stored. The client has mentioned that he disliked how loud the previous design was, so any motorized designs should be evaluated for noise. Additionally, the client informed the group that he likes unique designs that “think outside the box” and innovate, since many footrests on the market are similar.

c. **Patient-related concerns**

This device is designed specifically for the needs and abilities of our client, but it is possible that others can benefit from it as well. If we intend to mass produce this device, our design should take into account a patient’s degree of mobility in their lower extremities and how well they can use their arms to operate the functions of the device. The device should offer some adjustability to fit the patient’s feet under different circumstances. The device should also be removable and storable while being able to fit wheelchairs of different sizes and models than our client’s for it to be available to patients.

d. **Competition**

Most commercial wheelchairs have footrests custom to the brand and model of wheelchair, however there are models of removable and modular footrests. The model from Fold-&-Go [15] highlights a foldable design, but only works with certain models of wheelchair, and is priced at $129.99. The standard footrests that are not retractable have an average price of around $50 [16]. Comprehensive research into foldable wheelchairs can be found [17], which highlights the folding of the entire wheelchair, making the device unusable while folded. The team’s product intends to fold independently from the rest of the wheelchair to maintain usability.

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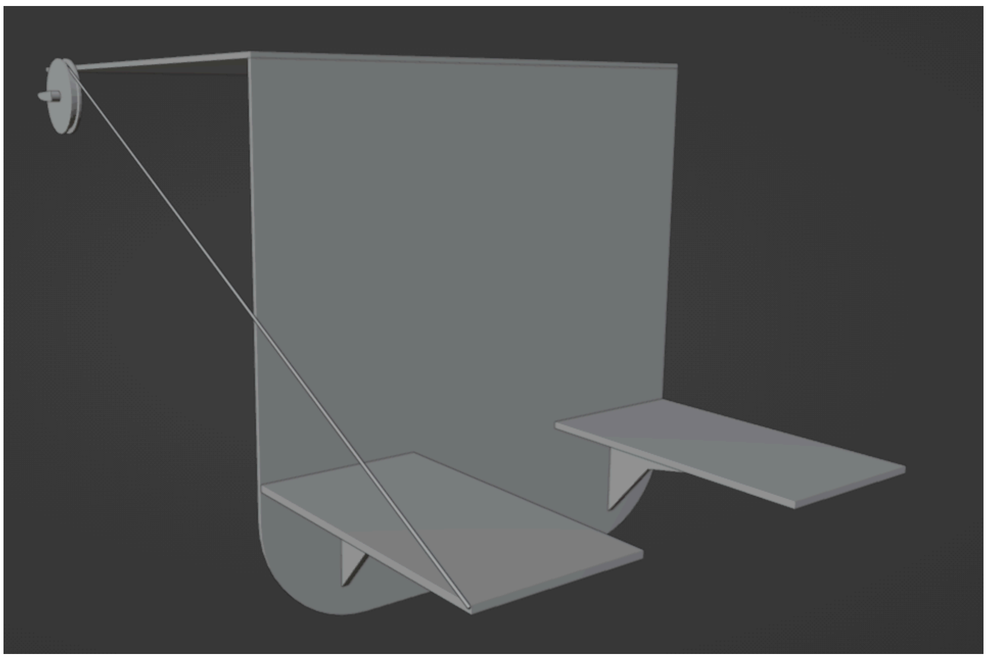
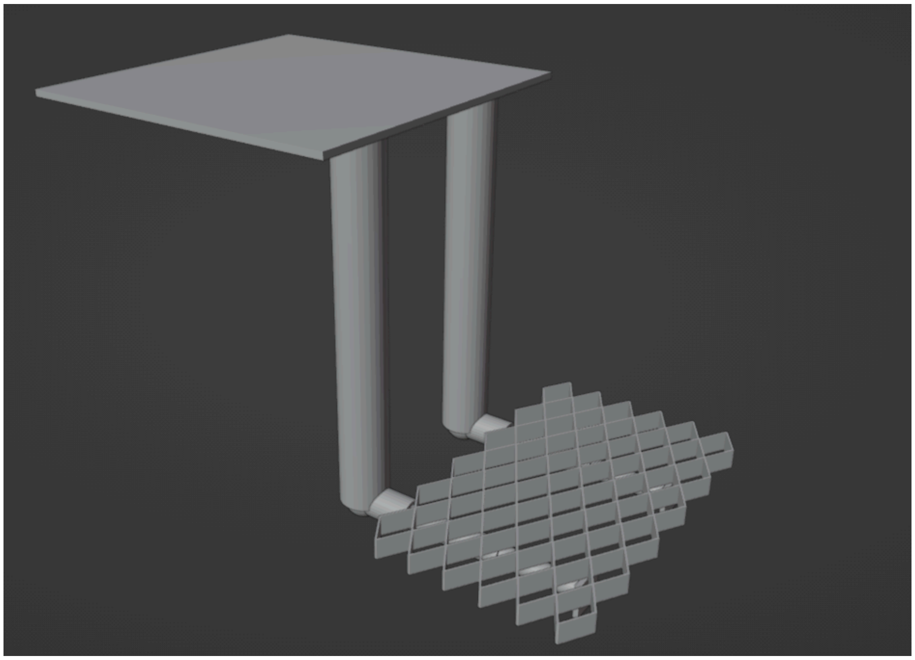
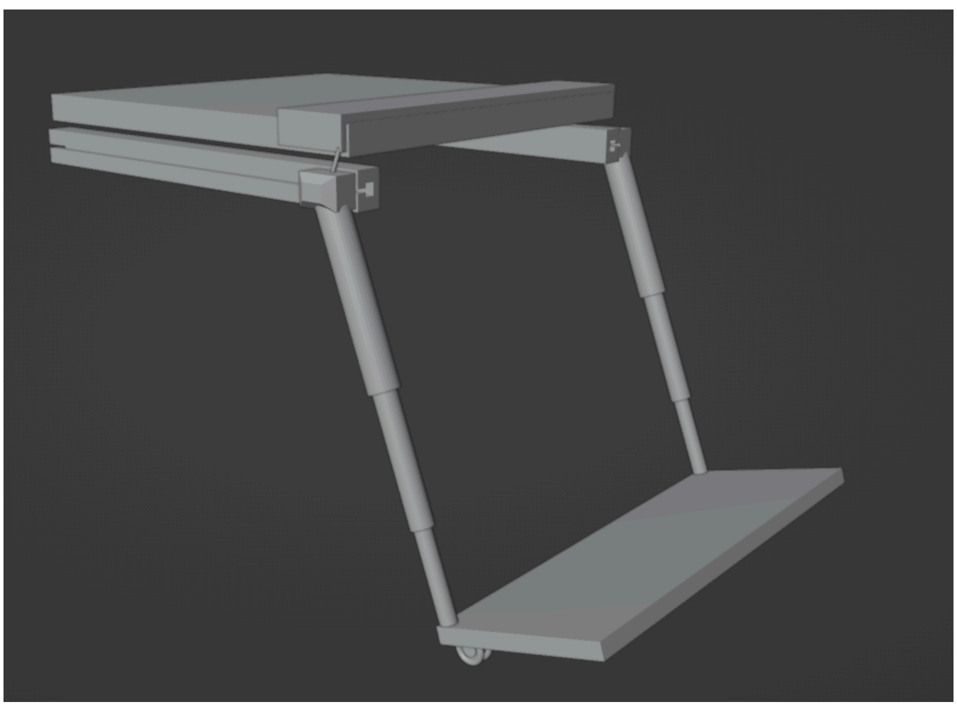
B. Blender Footrest Model Screenshots



Concept Model of the Hand Crank Panel Footrest



Concept Model of the Lattice Ball Joint Footrest Design



Concept Model of the Telescoping Sunglasses Footrest Design