LAFAYETTE COLLEGE

Department of Mechanical Engineering

[*Image: Wheelchair accessibility in tough terrain at Hawk Mountain, PA]*

Wheelchair Hill Assist Conceptual Design Report

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Abstract:

For our project, we decided to focus on the issue of how wheelchairs ascend and descend ramps of varying grades. We chose to address this issue because 2.7 million US adults are wheelchair users and we noticed an opportunity to help improve the quality of life for wheelchair users [13]. Our goal is to not create a fully powered wheelchair but to create a device that can be added to a manual wheelchair to help reduce the strain on the user while going up or down inclines. Although fully motorized wheelchairs can ascend and descend ramps, they have many other drawbacks that deter many users from using them including cost and portability. Through our research, we were able to find various types of wheelchairs and wheelchair attachments that tried to address these issues. Although they allowed the user to ascend or descend inclines, a vast majority of the users experienced challenges using these attachments, including portability, cost, and inefficient installation and removal. Another issue with these attachments is that they are often incredibly expensive or provide some sort of other hindrance to the user. With this in mind, we decided to focus on a couple of areas to help the user experience. These areas are cost, weight, accessibility, safety, efficiency of the installation and removal process, and portability while preventing the user from getting their hands dirty while operating the wheelchair.

The main point of our design was not to create an attachment that completely takes over the propulsion of the wheelchair, but to create something that would measure the effort/input of the user, and then amplify this effort to help the user on an incline, decline or flat surface, similar to how an E-bike works. Another important aspect of our design was we wanted the user to be able to change how much assistance they receive. Taking our research and the significant challenges wheelchair users face into account, we were able to come up with numerous designs, all of which are showcased in Appendix B. We were also able to come up with specifications and constraints that will inform our design process later during our prototyping and determine what our final design will be. Once we have determined what our final design will be, we will assign each member specific roles to ensure that we continue to progress smoothly throughout the year. In doing so, this will make sure that the entire group is progressing towards our final goal and make sure that all the work does not fall onto one person. We also created a basic schedule of when we should be completing each task to ensure that we complete our major deadlines of having a prototype by the end of the first semester, and having a working device by the end of the year.

I. Motivation For Project

Initially, we wanted to develop a project within either the medical field or 3D printing devices. We spent a few days brainstorming as many ideas as possible and realized that as a group, we mostly had an interest in medical technologies. While some of us thought 3D printing was interesting, most of us wanted to work on a project that would make a significant impact on people's daily lives. After beginning to focus on medical devices, we broke into smaller groups to come up with as many ideas as possible. Then as a group, we eliminated ideas by classifying them as too ambitious, too easy, or projects that didn't fit the scope of mechanical engineering well. We discussed and voted on each remaining idea to create a shortlist we wanted to research further. After doing this research and having further discussions, we narrowed ourselves down to prosthetics and wheelchair improvements. A few of us had personal connections to the idea of wheelchair improvements and its impact including family members and friends who use wheelchairs daily. Many of us also found prosthetic enhancements to be exciting. In deciding between the two topics we expected to have relatively split results, but after taking an anonymous poll we unanimously voted for wheelchair improvements.

As of 2015, there were 2.7 million wheelchair users in the US [13], and according to the CDC, 13.7% of US adults have some form of disability relating to their mobility [8]. Assistive mobility technology is a very large market, and many people stand to benefit from improvements in this field. We aim to make a quality of life change for people with mobility issues by allowing current wheelchair users to have more independence and perhaps even opening the door to the mobility-impaired to feel more comfortable with the idea of transitioning to a wheelchair.

We may have narrowed down from medical technology to wheelchair improvements, but this was still a broad category. That being said, we did still want to reach as wide of an audience as possible. This meant that we wanted to solve a problem with a device that could be implemented at relatively low cost, weight, and could be attached to an existing chair. We spent some time researching problems that wheelchair users experience. Table A.1 (Appendix A) is from a study conducted to measure the usability of assistive technology from a multi-contextual perspective. This table demonstrates some of the major identified challenges wheelchair users tend to face. Notably, users' experience issues are mainly within their community and outdoor environments, rather than at their homes or workplaces. Among challenges posed by outdoor environments include driving through streets, access to sidewalks, and climatic influences [6]. Ramps specifically have been identified as an issue for some wheelchair users within their communities [24]. Stairs were also a specific issue identified for wheelchair users [24]. These challenges and issues are intended to be mitigated by any wheelchair add-on design. Simultaneously, accessibility issues created by the add-on itself must be minimized and taken into consideration [25]. For example, Table A.1 (Appendix A) emphasizes the accessibility issues associated with restrooms or narrow aisles and ultimately the add-on we design should not worsen the accessibility of a manual wheelchair [6]. After discussing our research, we had two main interests, steep inclines and declines as well as stair climbing. We decided to put our focus on inclines and declines in part because of safety concerns for stair climbing as well as the difficulty involved with creating a stair climber that could also be an attachment for an existing chair. Now that we had a clear direction for this project, we needed to find out a little more about our particular audience and how we could hopefully impact them.

While wheelchairs do allow those who cannot walk or have limited mobility to travel on their own, manually operated wheelchairs can put a serious strain on a person's body especially their upper body. Injuries are not uncommon; between 42% and 66% of manual wheelchair users experience shoulder pain from frequent use of the chair [19]. These issues can be concerning for both wheelchair users and those considering using wheelchairs. There are powered wheelchairs, but they are bulky, very expensive, and can make the user feel as if they are giving up what mobility they still have. The goal of this project is to create a device that can be added to an existing wheelchair that is at a relatively low cost and low weight that will assist the user if they become tired or sore, but does not completely take away the feeling of autonomy that a user experiences from having a manual wheelchair. This will help lower the amount of fatigue experienced by manual wheelchair users and lower the barrier to entry for those considering a modestly priced wheelchair who fear being unable to independently push it. Overall the success of this project means we would safely implement an accessory allowing many current or new wheelchair users to experience more independence and ease of mobility even when trying to ascend and descend steep slopes.

Assuming we are successfully able to implement all of our ideas, we still need to make this project available to the public. It’s one thing to have a project that can bring about a quality of life improvement for people, but it’s another thing to actually get it to those people. We could attempt to file a patent and sell production rights, which if possible could be beneficial for us, but may limit the market of consumers. We could also make all of our work open source, and that would give opportunities to others to build off what we did or produce similar products cheaply. We have not yet discussed our plans for this last stage of the project, but it’s still an interesting concept. Ultimately, we would like to make a positive difference in the lives of the millions of wheelchair users out there.

II. Description of current state of the art

Currently, there are several different options on the market for wheelchair users to either have motorized wheelchairs or to add assistive technology to their wheelchairs to aid with mobility. Motorized wheelchairs constrain a wheelchair design in terms of cost and accessibility related to bulk and weight of the chair; therefore, wheelchair attachments try to mitigate the major cons associated with motorized wheelchairs. Wheelchair attachments, often referred to as mobility add-ons, are defined as “relatively small and lightweight accessories for manual wheelchairs that increase the chair’s mobility capabilities, which can be easily removed when not in use” [13]. There are significant gaps and opportunities for growth within this market to provide better opportunities and experiences for wheelchair users. Even with all the innovations occurring within wheelchair design, many users still experience difficulty associated with current wheelchair technology for daily usage [8]. Research was conducted to examine current wheelchair add-ons on the market and where improvements could be made. The assistive technology or add-ons available for wheelchair users fall into three main categories: push rim-activated power-assist wheels, wheelchair power drives, and mechanical advantage devices [13]. Diagrams for each of these main categories are shown in Figure A.3, Figure A.4, and Figure A.5 (Appendix A), respectively.

Pushrim-activated power-assist wheels (PAWAW) is a manual wheelchair to which motorized wheels are added to provide power and aid with mobility [16]. Essentially, a person uses their hands like normal to propel the wheelchair and the motors in the hubs of the wheels respond to the torque created by the user. This allows for the user to go further with one push than with a normal manual wheelchair. One of the issues associated with the use of PAWAWs is that the overall width of the wheelchair is increased due to the addition of the small motors in the hubs of the wheels. Added width contributes to accessibility issues for the user. Lastly, the transportability of the add-on is often challenging and requires the add-on to be lifted if removed, which is sometimes not possible for the user to do [16].

Next, there are wheelchair power drives which consist of three main components: a control unit, battery pack, and a drive unit. Wheelchair power drives include two main types of controls: user-controlled and attendant controlled. As indicated by their names, user-controlled means operated by the user and attendant controlled means operated by an attendant or helper to the user in the wheelchair. The biggest disadvantage of wheelchair power drives is the weight the add-on contributes to the overall weight of the wheelchair mainly due to the battery [12].

Finally, there are simple mechanical advantage devices. The main advantage of this type of device is it is lightweight due to the absence of a battery. This is a form of a propulsion device that makes use of levers to propel a user forward and backward. It reduces the overall effort of the user, but could potentially create muscular strain for the user from operation [12].

There has been a patent granted for a device that falls under the category of a user-controlled power drive that converts a manual wheelchair into an electric wheelchair [23]. The device includes the following components: a joystick, a communication unit, a motor, a retractable friction roller, and an engagement unit and power source. This device mitigates issues seen with electric wheelchairs including cost, portability, weight, and structural bulk [23]. Identified issues of the device include installation with the user needing to be in or out of the chair as the add-on is being installed or removed from the wheelchair.

Many of the conceptual drawings and designs were inspired by prior art from other technologies. The hub motor, Figure A.1 and A.2 (Appendix A) used in E-Bikes inspired a few designs, which can be found in Appendix B. This allows E-bikes to be pedaled while the motor is running. The intent in the conceptual designs is that the hub motor would allow the wheel to spin while also being pushed by the user. Other designs have and will be influenced by technologies outside of current motorized wheelchair prior art.

Ultimately, manual wheelchairs are a very inefficient form of transportation. Just to transverse inclines or declines requires a significant amount of upper body strength and endurance. Especially over a longer period of time, using a wheelchair can contribute to upper-body injuries such as chronic shoulder pain [12]. The identified needs of wheelchair users coupled with analysis of current technology highlight the need for assistive technology that help wheelchair users navigate slopes. The major areas identified for potential improvements in the current technologies are cost, weight, accessibility, safety, and transportability while preventing the user from getting their hands dirty while operating the wheelchair. Wheelchair add-ons tend to be heavy, restrict accessibility, and costly, so the goal of our wheelchair add-on design is to combat these factors while creating an affordable and transportable product.

III. Planned Approach

The main goal of the design is to assist wheelchair users on inclines and declines. To achieve this goal, we have come up with specific design objectives. To generate conceptual designs, our approach was to first identify the most important functions that our design should be able to achieve. We were able to identify that our design should be able to measure the effort/input of the wheelchair user, apply both positive torque and negative torque, control the direction of the wheelchair, and allow folding/interfacing with common wheelchairs. Table B.1 (Appendix B) is a morphology chart we completed as a team that lists various options of how we could achieve these design objectives.

The device should be able to apply both positive and negative torque to have control of both speeding up and slowing down the wheelchair. Measuring the effort of the user is one of the main goals of the design process. As stated above, many users struggle with inclines and declines and using their wheelchair for prolonged periods. By taking into account the effort of the user, we would be able to greatly reduce the strain wheelchair users face daily. While measuring the effort of the user is important, so is measuring the input from the user. As seen in Table B.2 (Appendix B), we want the user to have control over the speed, which could include having a manual throttle or having a knob to control the amount of assistance. We also want the user to have control over the direction of the wheelchair. This could include having a joystick or buttons.

This is also taken into consideration when we want to measure the input of the user. Another important design goal is to provide a comfortable ride for the user by eliminating the jerk of the device. Having transitions between the different modes of the device and progressive stops will provide a more comfortable experience for the user and eliminate any safety concerns. Our last objective is to allow the device to interface with common/standard wheelchairs and continue to allow the wheelchair to fold easily. By allowing the wheelchair to still fold, the user would not have to take off the device every time they want to store their wheelchair. This reduces any extra work the user would have to do to use our device. The ability to interface with common/standard wheelchairs will allow for our device to be used by as many wheelchair users as possible.

Taking into consideration these design objectives, we have created some conceptual designs found in Appendix B. These conceptual designs were all generated by an individual member of the design team. Some of the designs are full designs, while others focus on the placement of various sensors and components of the system. Many of these designs came from each individual team member taking into consideration the design objectives listed above; however, not all objectives were satisfied with each design. For example, a couple of designs did not allow for the wheelchair to fold with all components on the wheelchair. The importance of this feature will have to be determined through the surveys and interviews we will be conducting in the near future. Some designs also came from looking at the prior art. While we have many different designs, this large compilation of ideas will help us narrow down to what will be the most effective motor assistive device while also taking into consideration cost, weight, and other considerations. After looking at the initial conceptual designs created by our team, we have identified that our project will be composed of decoupled systems: motors, and the overall control strategy. From identifying this, we will now design the systems separately. We can design them separately because there is a weak coupling between the different systems. We have identified the major subsystem to be the drive train, so we have further considered how we could achieve this subsystem. These considerations can be found in Table B.2 (Appendix B).

Another important part of our planned approach was developing constraints and specifications for our design. The specifications identified complement our design objectives. These have been informed by research of the largest areas of improvement for wheelchair users. They will be further refined as our project continues to develop and there is community outreach and surveys to identify more specifications that best suit the scope of the project. There are various engineering metrics that will inform the specifications. Some measurable quantities we have identified are the velocity, acceleration, weight, and incline grade. Metrics that stem from these are maximum and minimum velocity on level ground, and specified incline/decline. Another metric includes maximum and minimum acceleration on specified incline/decline and level ground. Also, the weight of the attachment is another metric that is important to keep in mind throughout the design process. Additionally, negative and positive torques must decrease the user effort on inclines and declines. These complement the design objectives stated above and shown in the conceptual drawings. Some of the specifications need to be refined to further specify more quantifiable metrics once more research and project development has occurred.

Our specifications are as follows:

- Carrying a person of a specified weight at a specified speed on level ground
- Carrying a person of a specified weight at a specified speed on a specified grade incline
- Carrying a person of a specified wright at a specified speed on a specified grade decline
- Wheelchair is able to be operated by user while the motorized attachment is functioning
- The wheelchair is able to be folded to some extent when not in use
- The wheelchair is able to accelerate and decelerate at a certain rate
- The effort of the wheelchair user is measured
- The system adjusts appropriately to the measured effort of user
- The sensors that measure the speed of wheelchair, acceleration/deceleration, and/or incline/decline grade influence the motor and damper control subsystems
- The transition in speed are smooth and eliminate jerk
- The user interface and other subsystems controls direction of the wheelchair

The design also has constraints and that have been developed through research, discussion and will continue to be informed by further research and community outreach as is described below in stakeholder and external partnership. The constraints of this design also stem from ADA regulations and ISO standards [21,24]. These are international and American standards for wheelchair design and are seen as appropriate standards to follow. The ISO in particular is highly regarded as having appropriate constraints and standards across various fields [21].

Our constraints are as follow:

- The wheelchair design does not violate ISO 7176-1 establishing static stability of the chair [21]
- The wheelchair design does not violate ISO 7176-2 establishing the dynamic stability of electrically powered wheelchairs [21]
- The wheelchair design does not violate ISO 7176-3 establishing the effectiveness of brakes [21]
- The wheelchair design does not violate the ISO 7176-6 which established the maximum speed of an electric wheelchair at 15 km/h [21]
- The wheelchair design does not violate the ISO 7176-10 determining the obstacle-climbing ability of electrically powered wheelchairs [21]

- The wheelchair design does not violate the ISO 7176-14 requirements for power and control systems [21]
- The wheelchair design does not violate the ISO 7176-25 requirements for batteries and chargers [21]
- The wheelchair design does not violate the ISO 7176-25 requirements for wheelchair dimensions [21]
- The design does not exceed a specified weight
- The wheelchair does not tip over when a person is using it

The specifications and constraints of the project will develop over time, with further design development, design objectives, research, and talking with stakeholders. Currently, the specifications and constraints need to be more quantifiable by identifying specific weights, speeds, accelerations, and incline grades. For example, the maximum speed should be quantified upon further project development. Interactions between subsystems will also be further specified as designs develop. The constraints may change in time as well for similar reasons. Overall the current specifications and constraints are a good current measure of what the project needs to accomplish and how it needs to accomplish it.

The current design of the project is still in development. It will continue to develop throughout the year as we do more research, talk with stakeholders, and continue designing. The aim of this project is to develop a device to aid wheelchair users in going up and down inclines. To develop a design and actual device we have and will continue to take various steps to accomplish this. This includes brainstorming design objectives, and conceptual designs as well as setting up constraints and specifications for our design. In the future we will continue researching, talking with stakeholders, and developing different designs to fulfill the design objectives, specifications, and constraints. This will leave us with a successful design and product that will enable many wheelchair users to have more autonomy.

IV. Roles and Responsibilities

We have organized our team structure into various categories. Our charter, which can be found in Appendix C, states that we will have a team leader who will lead the team in weekly meetings, create and follow the agenda for the upcoming meeting, and make sure that the team is on schedule. The assistant leader will run the meeting if the team leader cannot or if the group is getting off task. The subteam leaders will be in charge of their respective group since there will be a subteam leader for each category during the project. They will be responsible for making sure their teams reach their deadlines on time. The budget leader will interact with Colt Hauser who is in charge of purchasing and will maintain a spreadsheet that tracks purchases. They will also make sure that we have a budget and we will follow the budget we created. The scribe will be in charge of recording minutes for each meeting. The sprint/schedule manager will be in charge of creating the biweekly plans for what each member is responsible for and the progress they have made on their designated tasks. The sprint, which measures short term goals for the project, will be color coordinated to show the progress of the task and make sure that it is being properly filled out; green will indicate that the task is complete, and blue will indicate that the task is in progress. The technical shop liaison is in charge of revising the engineering drawings and bringing materials to and from the shop. The copy editor will compile/assemble reports and finalize them. Once they are finalized, the copy editor will then submit the reports.

Currently, we have the team leader as Charlotte Sullivan. She took over this role after Professor Utter led the team for about two weeks. The scribe team is composed of Katie Rice, Charlotte Sullivan, and Nicole Stanec. There were multiple people interested in this position, so we created a team to prevent feeling overworked. The budget team has Carolyn Pye, Katie Rice, and Emily Eng. The sprint/schedule leader is Drew Freeland. We have roles that are currently filled and some that are vacant. The vacancies will be filled as the project progresses and these tasks are necessary. The positions are also fluid so people may rotate between the different positions and be in more than one position at a time. We do not have a set schedule for when rotations will occur, but we plan on creating a schedule as the project picks up. Check-ins will also occur frequently to ensure that people have a balanced workload and no one feels overworked or like they are not contributing enough to the team. Once we have a set conceptual design that we plan on building, the roles will be better divided and the people on campus will have roles that focus more on building than the students not on campus. This will help balance the work and make sure everyone is contributing fairly.

Members of the team are expected to maintain a level of professionalism and respect. We will give our peers the benefit of the doubt and set each other up for success rather than failure. Each person will be held accountable and will hold each other accountable. Communication is the key to success, so open communication will be set. In order to have open communication, all members are expected to be at meetings and let everyone know if they will not be attending. We will be conscious of the way we interact with one another and remember to be open and respectful. We are a small group, so we need to work well together. This team cannot perform its best work without everyone in the team working their hardest. As long as everyone is giving their all, the team will succeed.

V. <u>Team Schedule</u>

In the first week, Drew Freeland introduced the team to a time organization system she had used in a prior internship called the Scrum Agile Mindset [32]. All information is recorded in a spreadsheet. The system involves a record of hours each team member can work outside of class in a given week estimated by each student at the beginning of that week. Each team goal is listed on the spreadsheet and separated into short term and long term goals with estimated times needed to achieve each goal. Team members record the amount of time they actually work on each goal and every increment of work is tallied up into the amount of time each team member worked that week and into how much time has been dedicated to working towards each goal.

The team has decided to impose an internal deadline to complete a rough draft one week prior to the actual deadline for any report or presentation the group must deliver. This extra week allows for plenty of time for team members to revise any parts of the report as well as for Professor Utter to offer any advice. Additionally, this extra week gives the copy editors plenty of time to look through reports and for any team members to fill in gaps in the report in the event that another team member does not complete their portion of the report.

The team has completed the brainstorming process in determining the topic of the project. Currently, we are brainstorming potential concepts for what our end goal could look like. Upon completion, the team will begin the development of the website. In addition to concept generation, the team is currently working on a survey, which can be found in Appendix D, which will be sent out to wheelchair users and related healthcare professionals, the responses to which will help the team further refine the final design.

Leading up to October 18th, the team plans to refine the current conceptual designs and begin working on prototype and subsystem development. Following October 18th, the team will continue to revise and refine the website, concept drawings, and prototype, as well as begin working on the midyear progress report. The team is using Gantt charts for team scheduling as seen in Appendix E. As seen in Table E.1 (Appendix E) the team schedule uses a color coding system to show the type of event and duration of a specific task. The Gantt chart also shows the duration of each task and deliverable due dates in respective tabs of the excel sheet (Table E.2 and E.3 (Appendix E)). The current Gantt chart is a rough draft of the semester schedule and will develop and change as the semester progresses. The team goal for the end of the semester is to have a completed design and an initial prototype of the device and this is reflected in the current schedule. Overall, this will put us in a good position to complete a fully functional wheelchair add-on to assist going up and down inclines by the end of the school year.

VI. Required Resources

Though the designs are still in the conceptual phase, some components that are consistent between designs include motors, batteries, a control system such as an Arduino, various sensors, and parts for a user-controlled interface. The team will require a wheelchair to test prototypes, as well as time and space to machine, 3-D print, and assemble the device. Based on the common components, the budget may be estimated by the following table:

Table 1: Conservative Budget Estimate

Component	Description	Estimated Quantity	Estimated Unit Price	Estimated Total
Wheelchair [4]	use as base model	1	$80-200	$200
Motor [1]	changes wheel motion, requires high torque (based on 12V electric bicycle motors)	1-2	$20-100	$200
Battery [2, 3]	power motor, control system, rechargable (may be SLA or lithium ion)	1-2	$60-120	$240
Arduino [5]	control system inputs and outputs	1-2	$20-40	$80
Accelerometer/ Altimeter [14]	determines position, orientation, and altitude	1-2	$20-40	$80
IR sensors [15]	detects obstacles	1-2	$10	$20
Switches [20]	turn device on and off	1-2	$0.50-5	$10
Buttons [19]	for emergency shutoff, different modes	4	$1-5	$20
Joystick/Throttle [9, 18]	for user-controlled maneuvering	1	$15-360	$360
Other	raw materials, wires, fasteners, extra sensors, test dummy, battery charger, etc.	n/a	n/a	$300
			Total:	$1,510

This is a conservative budget estimate based on rough approximations since costs of components such as the motor and batteries are going to vary depending on the specificity of the design constraints. The budget is anticipated to change as the project continues.

VII. Stakeholders or external partnerships

Throughout the design process, our team will consult a combination of individuals with technical backgrounds and individuals who have experience working with or using wheelchairs. At this point, our team has been in contact with Professor Venture, the head of the IRB committee, and we are in the process of completing an IRB application that will allow us to gather information from a variety of healthcare professionals and wheelchair users. Once the IRB application has been approved, we plan on conducting interviews and sending out surveys that focus on the current difficulties faced when tackling inclines and declines in a wheelchair as well as user interface preferences. For the surveys, we hope to achieve a larger input group with the help of the connections of the individuals who were interviewed using the survey questions similar to those in Appendix D. At the end of the interview and survey process, we hope to have a better idea of what design would best assist the target audience. Since none of the team members use a wheelchair, it is difficult to design a product without additional feedback. Many of the people we hope to interview are friends or relatives who have agreed to help once proper approval is received.

Throughout the design process, we will also seek feedback from our faculty advisor, Professor Utter, on aspects of the design that extends past our current schooling. This feedback will be mostly informal coming from discussions during class time. More formal feedback will also be requested throughout the year corresponding with the relative progress of the deliverables. In addition to Professor Utter, we intend to consult our assigned lab tech, Rob Layng, on improvements to designs that would allow parts to be cheaper and easier to manufacture without sacrificing the quality of the part. Additionally, we have elicited the help of Professor Nees from the psychology department to share his expertise on human factors in engineering especially his experience in how technology impacts those with disabilities. As needed, we may also consult current and past professors on questions related to the subject matter of their course. For example, controls professors may be consulted regarding aspects of the design which require more complex controls than those discussed in class. Although these are all the people we hope to elicit feedback from at this point, we are continuing to look for additional relationships that may help our design project to be both functional and effective.

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Appendix A: Background Research and Prior Art

Table A.1 Usability Issues Applicable to the Usability Scale for Assistive Technology (from a usability study conducted to measure the usability of assistive technology from a multi-contextual perspective) [6].

Table 3. Usability Issues Applicable to the Usability Scale for Assistive Technology–Wheelchair Mobility Intervention Framework

Subscale	Usability Issues	Reported Problems	Possible Intervention	Stakeholders
Home Usability	• Indoor mobility • Home arrangement • Space • Wheelchair suitability • Exit and entry	• Clutter • Organization • Narrow space in kitchen and bathroom • Narrow entrance • Wheelchair damages the house	• Home modification • Reduce clutter • Widen doorways • Pad wheelchairs to reduce impact	• User • Clinician • Technician • Home owner/family
Workplace/School Usability	• Access to classrooms and workstation	• Wheelchair does not fit with the table • Narrow aisles in classroom • Problems reaching the table	• Provision of adjustable workstations • Ensure ADA compliance • Intervene through Individualized Education Program	• User • Clinician • Employer or school admin
Community Usability	• Shopping	• Narrow aisles • Obstacles • Problems with reach • Restrooms inaccessible • Streets inaccessible	• Ensure ADA compliance • Encourage use of reachers	• Community • Store manager • End users • Architects • Policy advocates
	• Going to restaurants	• Narrow aisles • Restrooms inaccessible • Seating problems	• Ensure ADA compliance	
Outdoor Usability	• Driving through streets • Access to sidewalks	• Sidewalks uneven, cracked, and unsafe	• Inform civic authorities • Improve PWC stability and capability to drive on rough terrain	• Community • Policy advocates
	• Climatic influence	• Wheelchair frame corrosion • Electronic components fail • Terrain slippery • Falls and accidents • Surface barriers	• Improve material resistance • Improve concealment of wheelchair parts • User training	• Manufacturers • Technology developers • Researchers
Usability: Ease of Use	• Limited reach	• Difficulty performing tasks such as picking up objects and accessing work surface	• Postural interventions • Consider use of a reacher	• User • Clinician • Technician
Usability: Seating	• High incidence of pain in lower back, hips, and shoulders • Problems with postural alignment	• Pain when sitting for a long time	• Periodical seating evaluation and intervention	• User • Clinician • Technician
Usability: Safety	• High incidence of falls and accidents	• Environmental hazards • Device safety • User awareness	• User training • Clinician/technician training • Identify and reduce environmental hazards	• User • Clinician • Technician • Researchers

Note. ADA = Americans With Disabilities Act; PWC = power wheelchair.

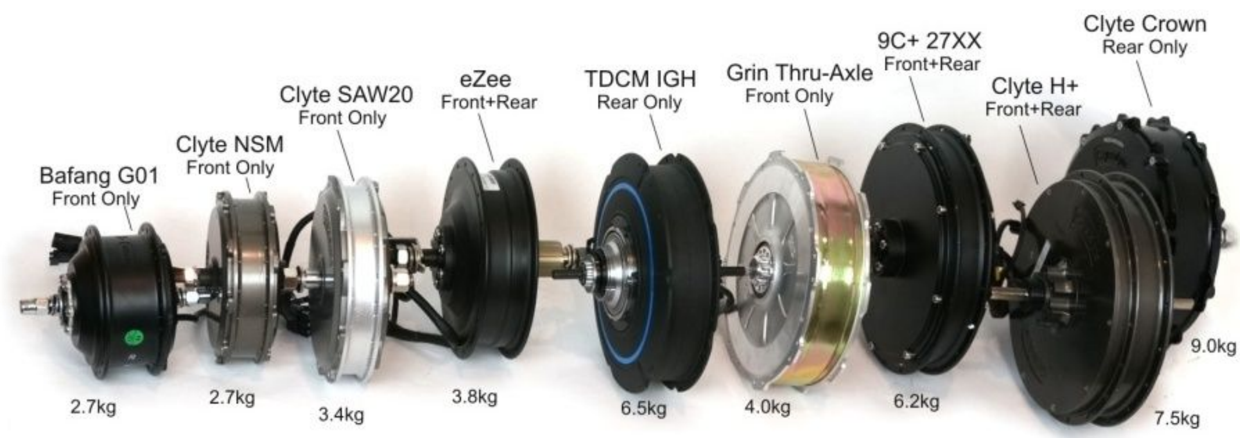


Figure A.1 Hub Motors used in E-Bikes [10]

Figure A.2 Hub Motor in E-Bike Wheel [10]

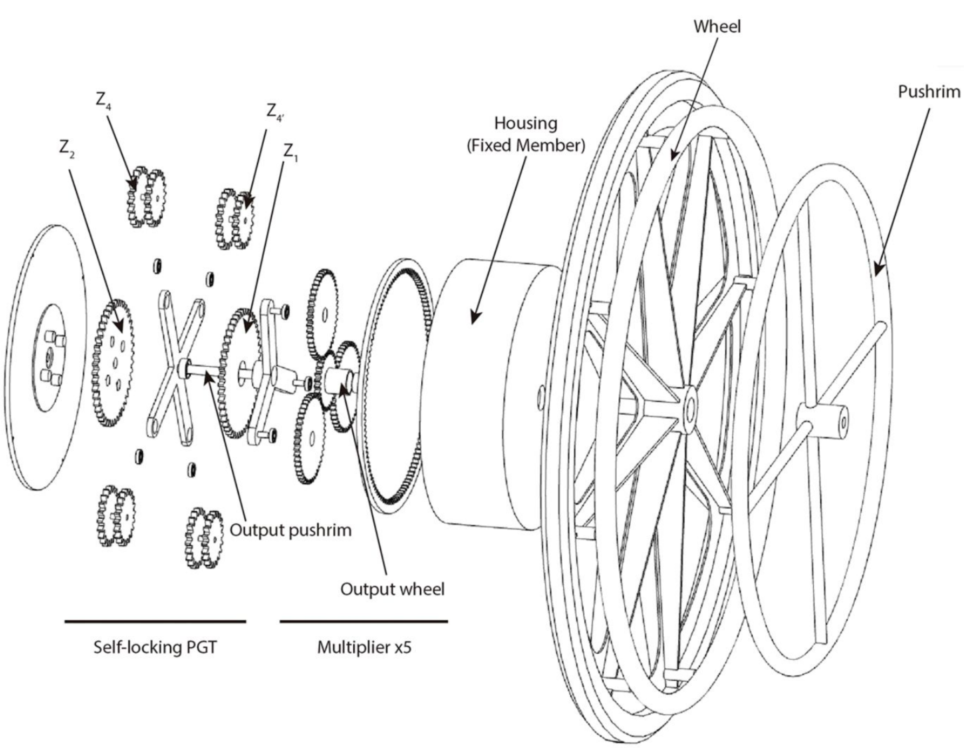


Figure A.3 Pushrim-activated Power Assist Wheels (PAWAW) [33]

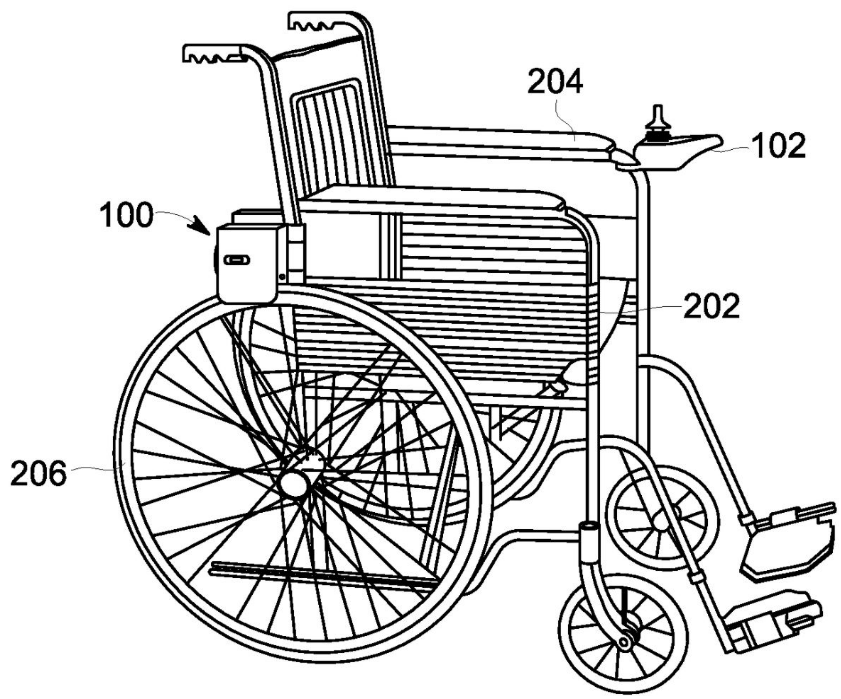


Figure A.4 Wheelchair Power Drives [24]

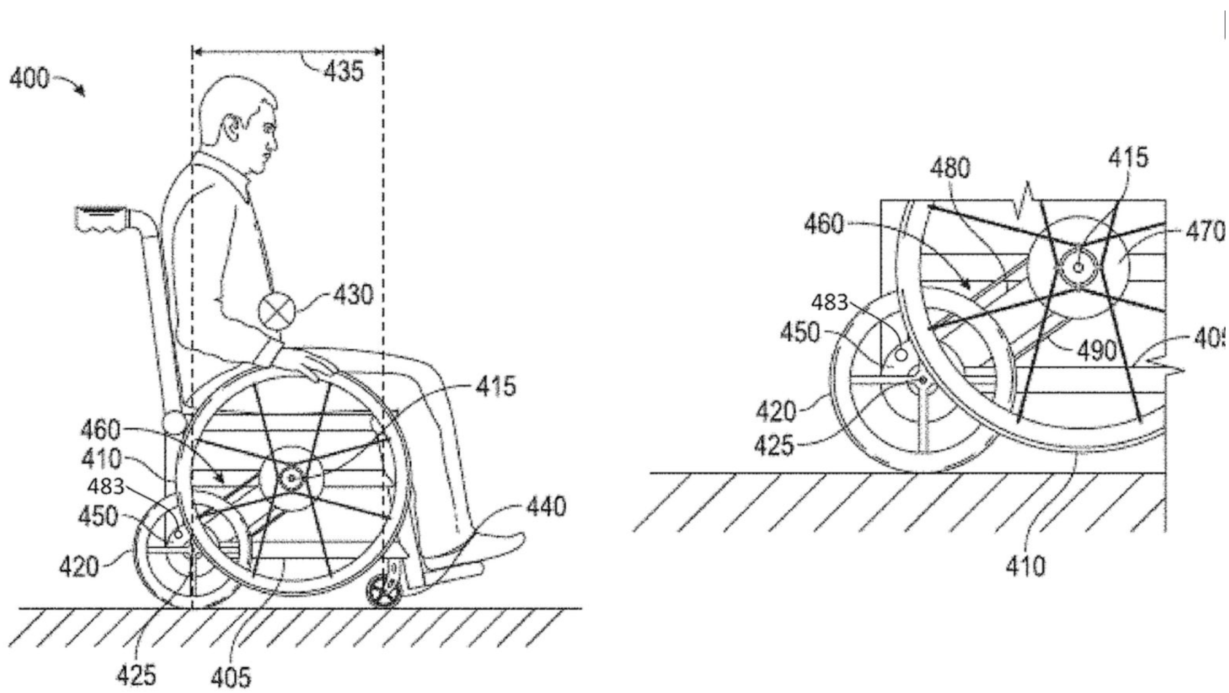


Figure A.5 Mechanical Advantage Add-on [32]

Appendix B: Conceptual Designs and Morphology Chart

Table B.1 Morphology Chart

Eliminate Jerk	**Measure Effort/Input**	**Apply Positive Torque**	**Apply Negative Torque**	**Control Direction**	**Allow folding/ interface with common wheelchairs**
● Having a transition between different commands (stopping, accelerating, decelerating) ● Interface to allow the operator to transition at their desired speed ● Anti-tip device ● Progressive stop	● Speedometer ● Cruise Control ● Manual throttle ● Knob to control the amount of assistance ● Variety of sensors ○ Grade ○ Velocity ○ Terrain ○ Heart rate ○ Weight of user/center of gravity	● Additional wheel in the back ● Attachable handle with its own wheels and motor ● Booster attachment to wheel ● Consider mechanism of an e-bike	● Use the same motors as we are using to drive the wheels ● Active rotary damper ● Emergency stop	● Joystick ● Steering wheel ● Two buttons (left and right) ● IR sensor to allow wheelchair to maneuver around obstacles	● Completely separate component (like a handle of a scooter) ● Removable ● One on each side of the wheelchair that attaches to the solid bar. The width would be small enough so it could still fold

Table B.2 Drivetrain function/means and other considerations (Transmit positive/negative torque)

Motor Types	**Transmission**	**Apply Negative Torque**
● Brushed DC ● Brushless DC Motors	● Hub Motor ● Belt Drive ● Direct Wheel to Motor Interfaces ● Differential ● Pinching the wheels with driven wheels (Friction Drive)	● Resistive loading ● Running motor backwards ● Variable Rotary damper (passive?) ●

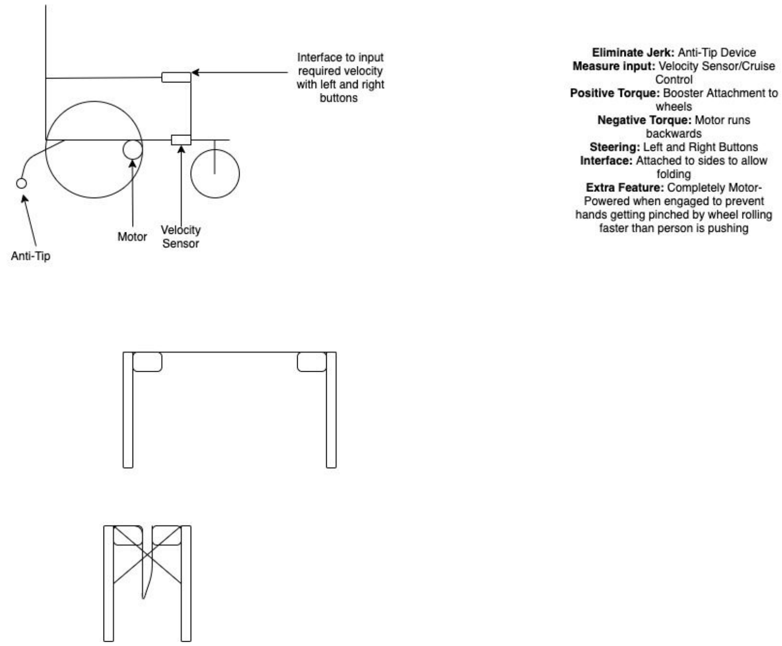


Figure B.1 Wheelchair design with motor-driven wheels

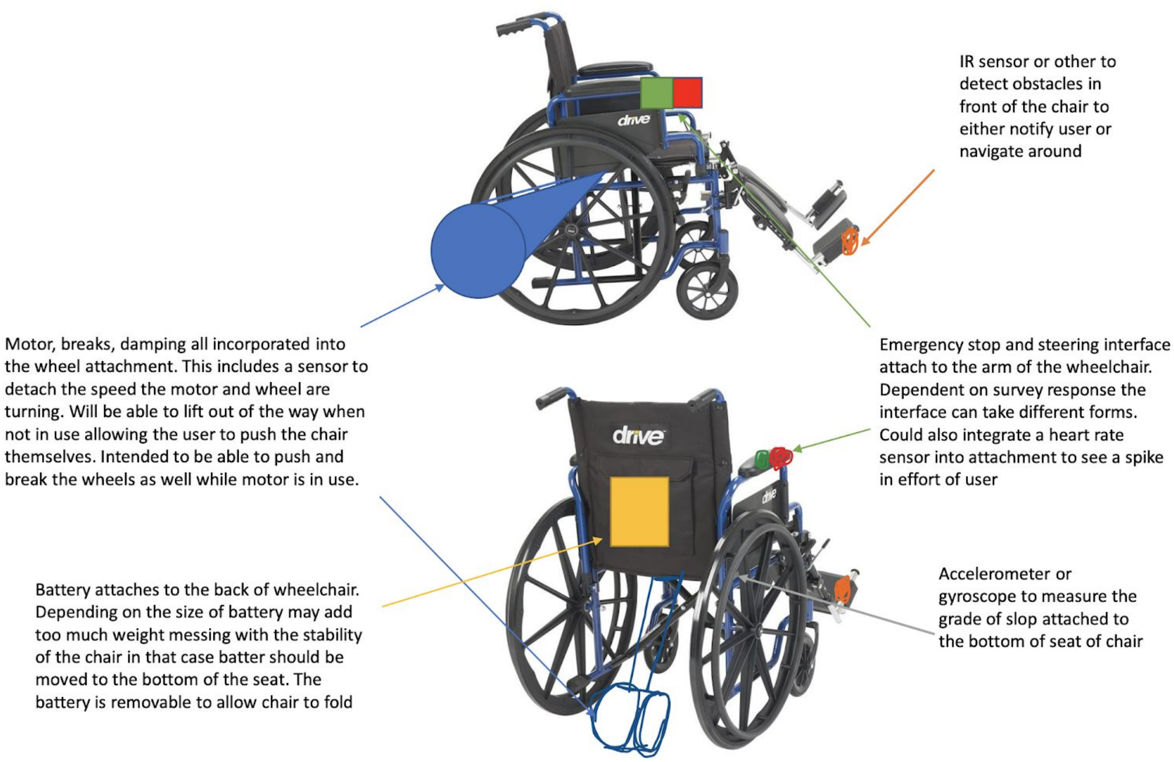


Figure B.2 Attachable wheel to the back of the wheelchair[4, modified]

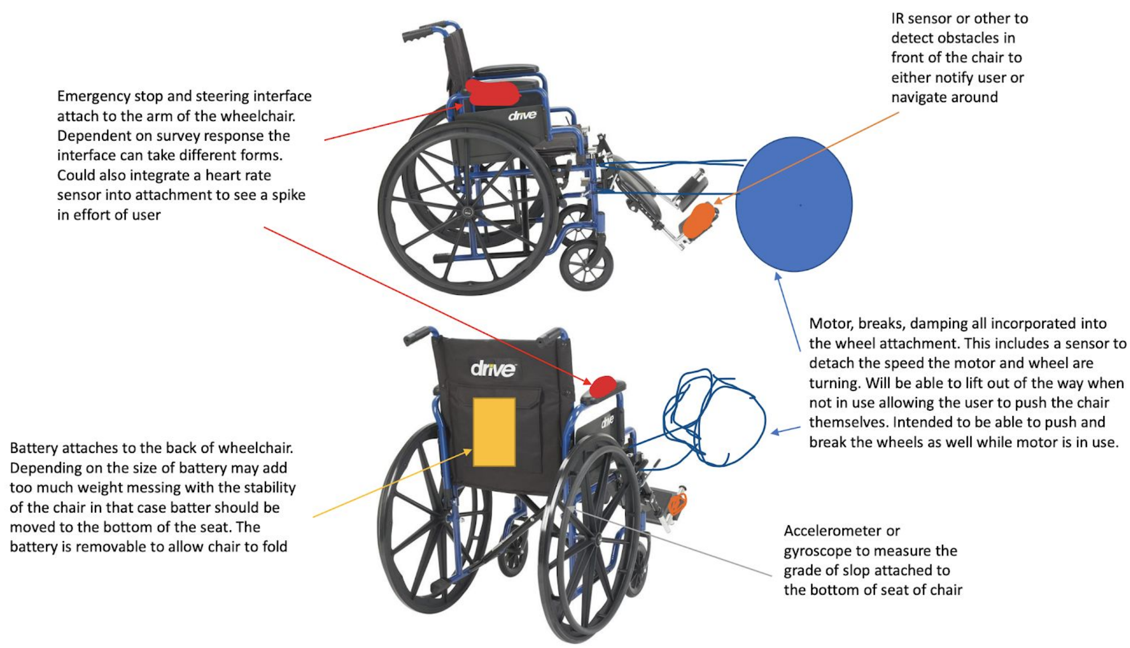


Figure B.3 Attachable wheel to the front of the wheelchair [4, modified]

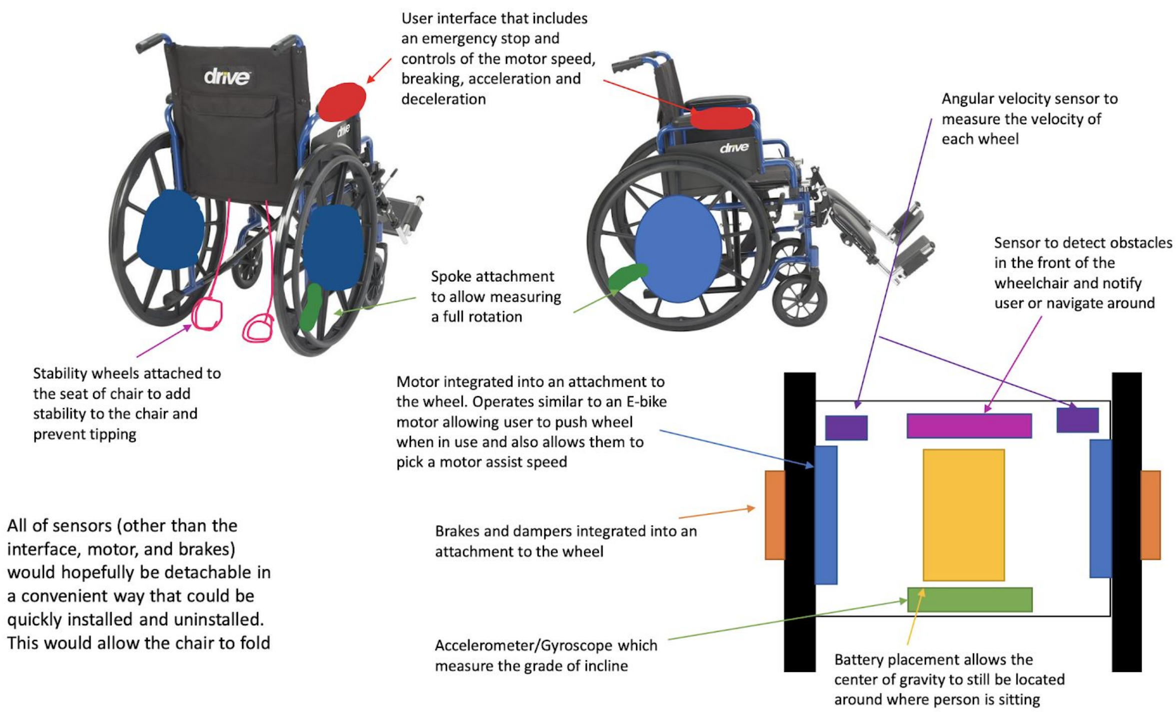


Figure B.4 E-bike mechanism design with layout of various components under the seat [4, modified]

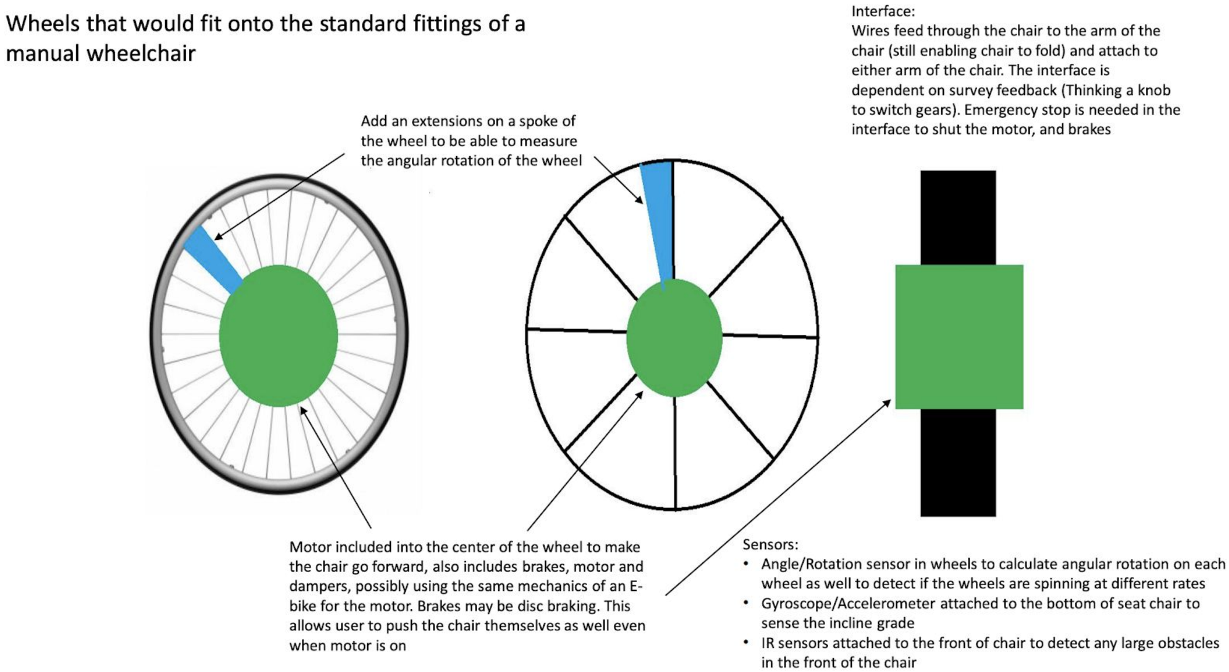


Figure B.5 Detachable wheels powered by motors at the hub

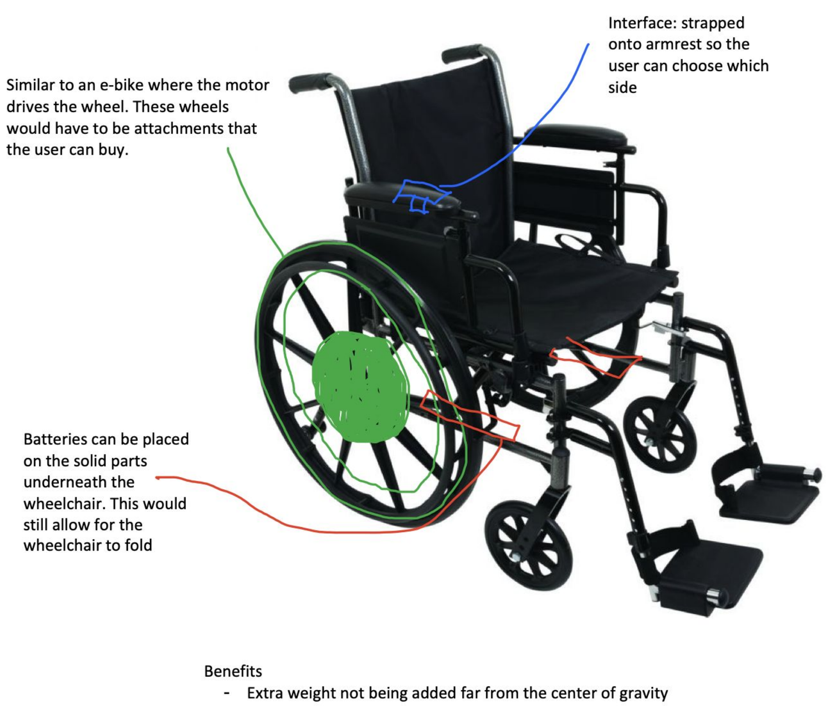
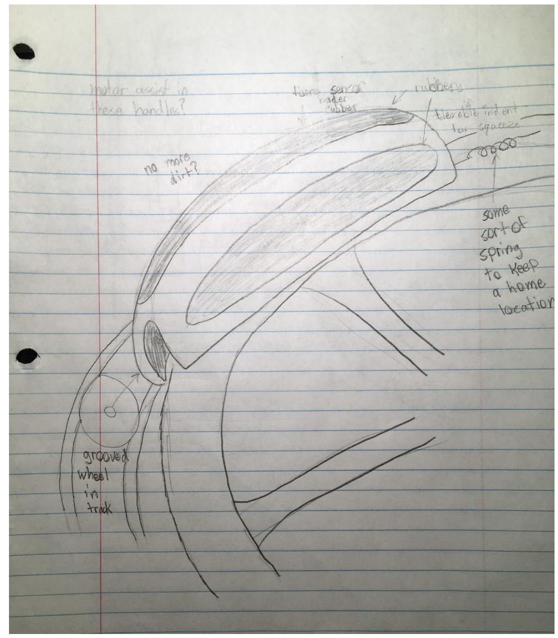


Figure B.6 Wheelchair design with new wheel attachments [30, modified]

(a)

(b)



(c)

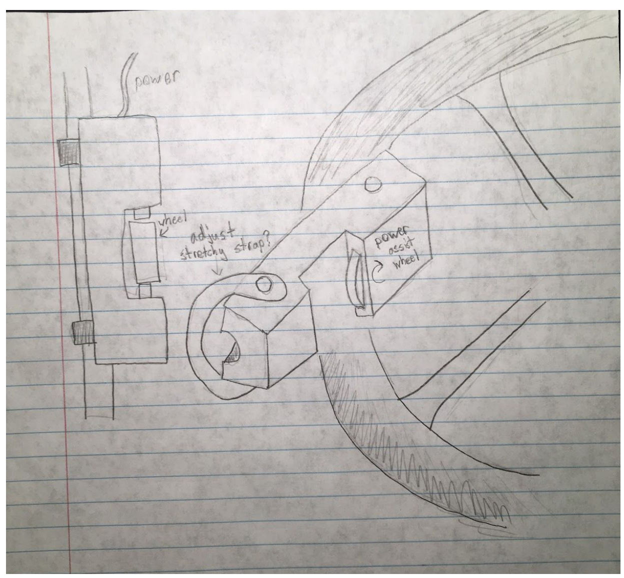


Figure B.7 (a) Overall wheelchair design (b) Force sensor design (c) Motor Attachment

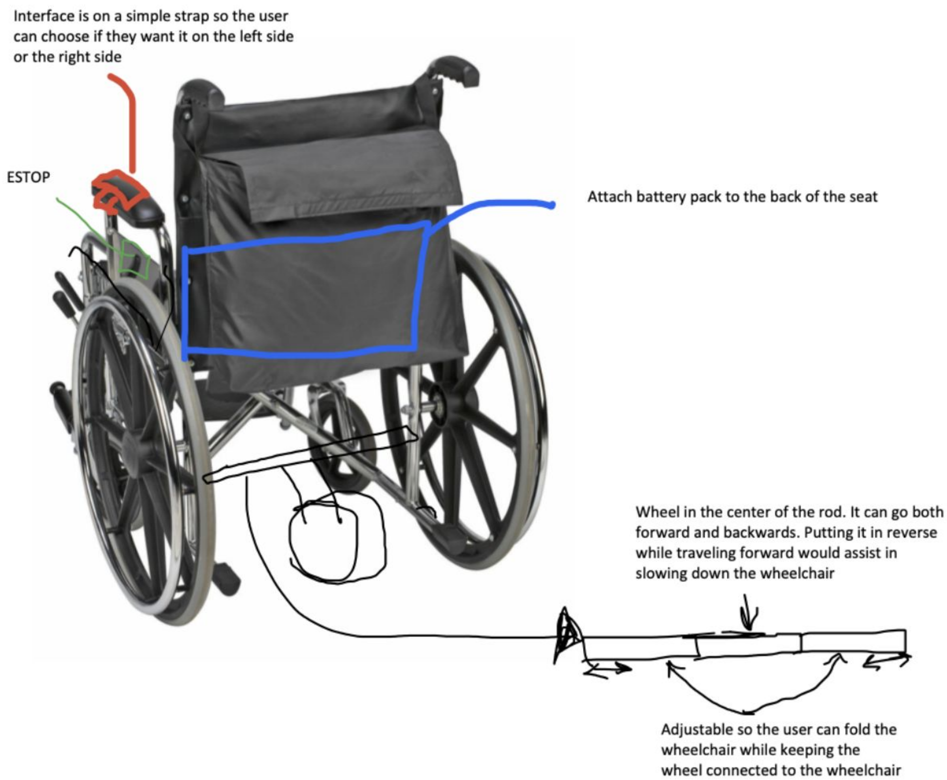


Figure B.8 Rear wheel addition with expandable bar[29, modified]

Figure B.9 Option for where we can place batteries, Estop, user interface and speedometer [25, modified]

(a) **(b)**

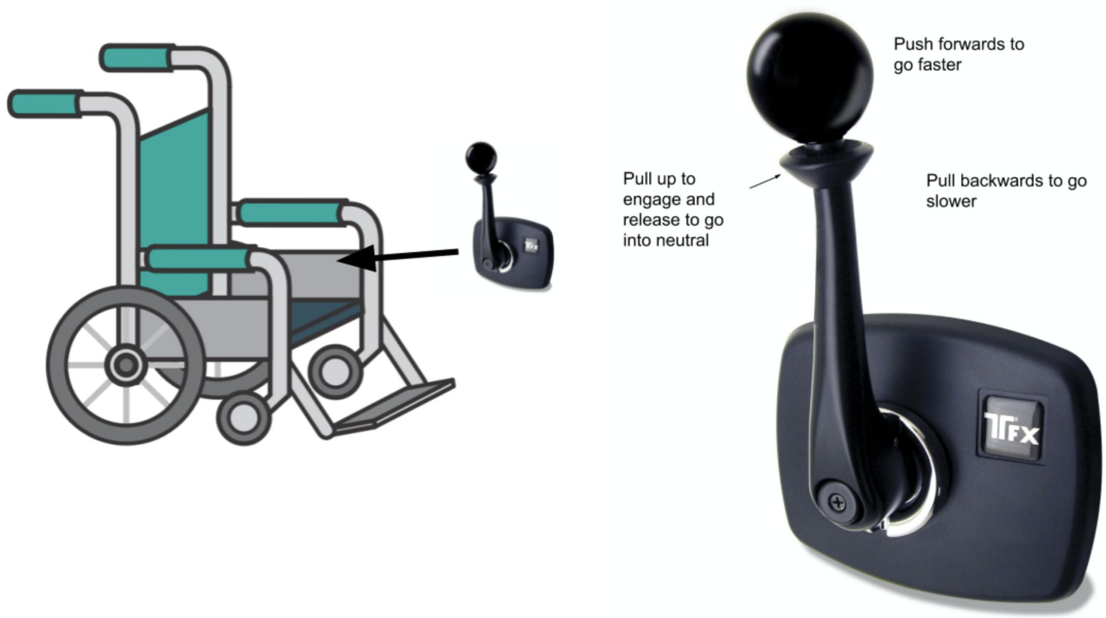


Figure B.10 (a) Placement of throttle (b) Throttle with description of mechanism [26,27, modified]

Figure B.11 Placement of batteries and sensors [28, modified]

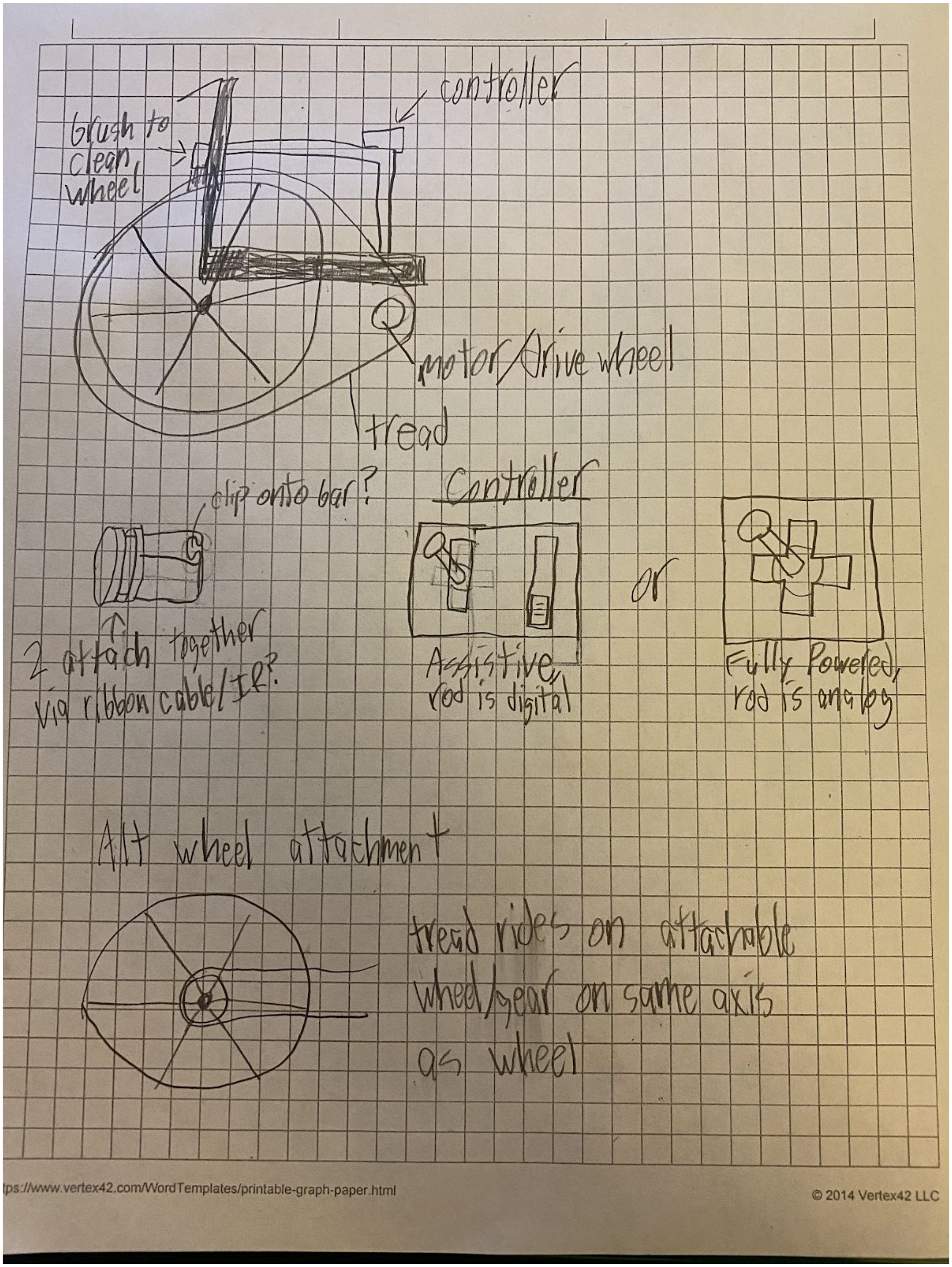


Figure B.12 Motor/drive wheel with a description of a controller

Ideas for Device/Attachment

- ~~One piece attaches to the back axel of the wheel chair – the motor that drives the chair~~
- The "controller" can be attached in multiple places
    - wheelchair user can use or someone assisting someone in a wheelchair
- Something that drives a boat type of thing, can maneuver and turn the wheels
- Some type of hanging attachment on the back of the wheelchair so the device can be stored and used if necessary
    - Easy snap button to be attached or detached
    - Easily folds with the fabric of the rest of the wheelchair
    - Some type of mesh with zippers/pocket system to hold the rest of the device (battery etc.)
        - Also holds a charger cord
    - Charging cable (?) how do we power?

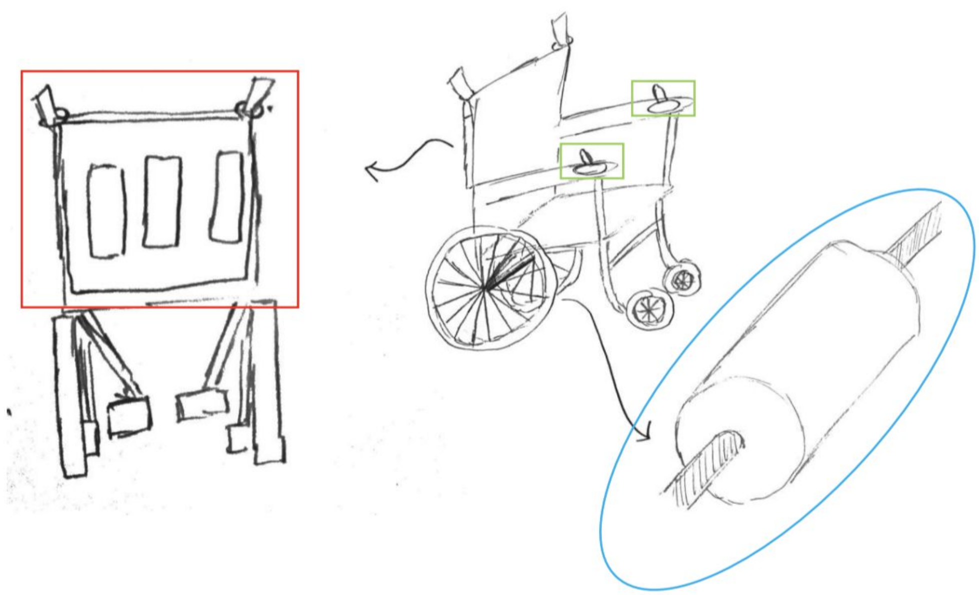


Figure B.13 Wheelchair design with hanging attachment for storage

APPENDIX C: Team Charter

Roles and Responsibilities:

- Leader of team
  - Runs the meeting
- Assistant Leader
  - Runs the meeting if the leader cannot
- Subteam Leaders (upcoming)
- Budget person(s)
  - Interact with Colt Hauser (Purchasing)
  - Maintain a spreadsheet that tracks purchases
- Scribe (one person or rotating, or or or)
- Copy Editor(s) of sort
  - Compile/Assemble Reports
  - Finalizes/Submits
- Sprint/Schedule Manager
- Technical shop liaison
  - Engineering drawing revision
  - Bring materials to/from shop

Internal Team Deadlines:

- Scrum Agile Mindset Upcoming

Expectations for Discussions during Meeting + What we'll strive for:

- Make and follow meeting agendas (Team Leader)
- Maintain a level of professionalism and respect
  - We need to give our peers the benefit of the doubt
    - Don't assume another person isn't doing their part (trust each other)
  - Set each other up for success
    - Personal accountability and holding each other accountable
  - Communicate with the group!

Attendance:

- All members expected to be at meetings, so please let us know if you're not going to be there.

Communication + Conflict Resolution:

- Open and respectful

APPENDIX D: Survey Questions

Wheelchair User Survey

Do you use a wheelchair currently? Yes or No

Age Range (please circle one):
10-20 20-30 31-41 42-52 53-63 64-74 75 and up

Instructions: Please fill out the survey to the best of your ability. If you do not feel comfortable answering a question, feel free to not answer it. This survey is optional and we appreciate your willingness to participate in this survey. It should take about 15 minutes of your time.

1. What describes your current wheelchair?
    a. Collapsible self-propulsive wheelchair (primarily user-operated)

https://www.amazon.com/Pride-Mobility-JAZZYSPORT2-Electric-Wheelchair/dp/B00N3NKLAK

    b. Non-Collapsible self-propulsive wheelchair (primarily user-operated)
    c. Collapsible push-only wheelchair (primarily assistant-operated)

https://www.amazon.com/Medline-Lightweight-Transport-Wheelchair-Handbrakes/dp/B007WA1ZG4

    d. Non-Collapsible push-only wheelchair (primarily assistant-operated)
    e. Electric/powered wheelchair

https://www.amazon.com/Pride-Mobility-JAZZYSPORT2-Electric-Wheelchair/dp/B00N3NKLAK

2. To what extent do you people you know struggle going uphill in a wheelchair?

1	2	3	4	5
No Difficulty				A lot of difficulty

3. To what extent do you people you know struggle going downhill in a wheelchair?

1	2	3	4	5
No Difficulty				A lot of difficulty

4. What kind of assistance would you prefer for going uphills?
    a. A device that prevents backward motion, but you still need to push yourself up the incline (manual power)
    b. Assistive power as an addition to but not replacement of manual power
    c. A motor that continually replaces manual power (similar to an electric wheelchair)
    d. Other:
    e. No preference

5. What kind of assistance would you prefer for going downhills?
    a. An unpowered device that reduces the speed of the wheelchair
    b. A motor that reducing downward speed
    c. Other:
    d. No preference

6. Are you independent when using a wheelchair?
    a. Yes
    b. Sometimes need assistance
    c. Need assistance

7. What is your preference in having an interface on your wheelchair? An interface would be used for control or to display useful information

1	2	3	4	5
No Interface		Indifferent		Prefer Interface

8. How much do you agree with this statement? You would use a wheelchair that weighs more if it means the battery-life would be greater.

1	2	3	4	5
Strongly Disagree				Strongly Agree

9. Is an increase in weight a large concern? (please circle one)

1	2	3	4	5
No Concern				VERY concerned

10. How much do you agree with this statement? You willing to pay more for a higher performance device

1	2	3	4	5
Strongly Disagree				Strongly Agree

11. Which would you prefer for a motorized assistive device?
    a. Limited motorized assistance (user still pushes the chair with some motor help)
    b. Full motorization

12. Are you interested in adding functionality to your wheelchair by installing addons?

1	2	3	4	5
No Interest				VERY Interested

If so, what functionalities or products are you considering?:

13. How helpful motor assist would be?

1	2	3	4	5
Not helpful				VERY helpful

14. In what situations would you see yourself using a power assist device?

15. If you have used a power assist device before, what did you like about the device, and what did you not like about the device? If you have not used a power assist device before, what stopped you from using one?

16. Are there safety concerns that you have with being on steep inclines and declines? If yes, please explain.

<u>**Health Care Providers Survey**</u>

Are you currently a working health care provider? (please circle one)   Yes   or   No

What is your occupation? ______________________________

What is your interaction with wheelchair users?

Instructions: Please fill out the survey to the best of your ability. If you do not feel comfortable answering a question, feel free to not answer it. This survey is optional and we appreciate your willingness to participate in this survey. It should take about 15 minutes of your time.

1. To what extent do you people you know struggle going uphill in a wheelchair?

1	2	3	4	5
No Difficulty				A lot of difficulty

2. To what extent do you people you know struggle going downhill in a wheelchair?

1	2	3	4	5
No Difficulty				A lot of difficulty

3. What kind of assistance would you prefer for going uphills?
    a. A device that prevents backward motion, but you still need to push yourself up the incline (manual power)
    b. Assistive power as an addition to but not replacement of manual power
    c. A motor that continually replaces manual power (similar to an electric wheelchair)
    d. Other:
    e. No preference

4. What kind of assistance would you prefer for going downhills?
    a. An unpowered device that reduces the speed of the wheelchair
    b. A motor that reducing downward speed
    c. Other:
    d. No preference

5. What is your preference in having an interface on your wheelchair? An interface would be used for control or to display useful information

1	2	3	4	5
No Interface		Indifferent		Prefer Interface

6. How helpful motor assist would be?

1	2	3	4	5
Not Helpful				VERY Helpful

7. Is an increase in weight a large concern? (please circle one)

1	2	3	4	5
No Concern				VERY concerned

8. Are you interested in adding functionality to your wheelchair by installing addons?

1	2	3	4	5
No Interest				VERY Interested

9. How much do you agree with this statement? You willing to pay more for a higher performance device

1	2	3	4	5
Strongly Disagree				Strongly Agree

10. What other obstacles may a motor assist device enable wheelchair users to overcome outside of going up and down hills?

11. What types of power assist devices have you encountered? What are improvements or drawbacks to these devices?

12. What are the safety concerns that you have seen with wheelchairs on steep inclines?

APPENDIX E: Gantt Chart

Table E.1: Semester Gantt Chart Tasks and timeline through Sept. 13th

**For the entire timeline* https://drive.google.com/file/d/1blwdfm0jCRODBc5OberlfQLKv9zi5fbT/view?usp=sharing

Table E.2 Semester Gantt Chart Tasks and Duration

Task	Duration (days)	Start Date	End Date
Select General Issue	1	2-Sep-20	4-Sep-20
Select a Specific Design	5	5-Sep-20	9-Sep-20
Create Individual Drawing Files	5	10-Sep-20	14-Sep-20
Complete Rough Draft of Preliminary Design Report	6	10-Sep-20	15-Sep-20
Time for Utter to Review	3	16-Sep-20	18-Sep-20
Complete Final Copy of Preliminary Design Report	3	19-Sep-20	21-Sep-20
Plan 5-Min Presentation	6	15-Sep-20	20-Sep-20
Begin Website Development	6	22-Sep-20	28-Sep-20
Conceptual Drawing Refinement	5	16-Sep-20	16-Sep-20
Prototype Development	17	18-Sep-20	4-Oct-20
Subsystem Development	14	21-Sep-20	4-Oct-20
Complete Design Proprosal Rough Draft	7	5-Oct-20	11-Oct-20
Time for Utter to Review	4	12-Oct-20	15-Oct-20
Complete Final Copy of Design Proprosal	4	15-Oct-20	18-Oct-20
Complete Statement of Individual Goals	3	16-Oct-20	18-Oct-20
Plan 5-Min Presentation	3	16-Oct-20	18-Oct-20
Website Update	4	22-Oct-20	25-Oct-20
Prototype Refinement	30	19-Oct-20	17-Nov-20
Plan 5-Min Presentation	3	14-Nov-20	16-Nov-20
Complete Midyear Progress Report Rough Draft	10	14-Nov-20	23-Nov-20
Time for Utter to Review	4	21-Nov-20	27-Nov-20
Complete Final Copy of Midyear Progress Report	5	28-Nov-20	2-Dec-20
Website Update	4	3-Dec-20	6-Dec-20
More Prototype Refinement	17	20-Nov-20	6-Dec-20
Complete Poster and Design Presentation Rough Draft	8	6-Nov-20	13-Nov-20
Time for Utter to Review	6	14-Nov-20	19-Nov-20
Complete Final Copy of Poster and Design Presentation	14	21-Nov-20	3-Dec-20

Table E.3 Semester Gantt Chart Deliverables and Due Dates

Assignment	Due Date
Conceptual and Prelinary Design Study	21-Sep-20
Presentation #1	21-Sep-20
Website Update #1	28-Sep-20
Design Proposal	19-Oct-20
Prensentation #2	19-Oct-20
Statement of Individual Goals	19-Oct-20
Website Update #2	26-Oct-20
Presentation #3	16-Nov-20
Midyear Progress Report	3-Dec-20
Website Update #3	7-Dec-20
Midyear Poster and Complete Design Presentation	(TBD)