Department of Mechanical Engineering

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

Wheelchair Hill Assist Design Report

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Abstract:

After a few days of brainstorming and research, the group decided to focus on the issue of how wheelchairs ascend and descend ramps of varying grades. This project is important because 2.7 million US adults are wheelchair users and there is a surprising lack of resources/designs created to address this issue [13]. The 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 them including cost and portability. Although there are some products which allow the user to ascend or descend inclines, a vast majority of them 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, the product should 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 aspect of the final product is not to create an attachment that completely takes over the propulsion of the wheelchair, but to create a device 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 the final product is that the user should be able to change how much support they receive. After conducting research and determining any significant challenges the user could face, various designs were created by the group, all of which are showcased in Appendix B. The research also allowed for the creation specifications and constraints that will inform the design process later during our prototyping and determine what the final design will be. In order to make sure things progress smoothly, the group has split the responsibilities into three main sub-teams and has assigned each member roles to ensure that all the work does not fall onto one person. A basic schedule of when certain milestones should be completing each task to ensure that the major deadlines of completing conceptual designs for each sub-team by the end of the first semester, and having a working device by the end of the year.

I. Team Mission Statement

Through the application of our mechanical engineering knowledge, our mission is to make areas that are difficult to navigate more accessible for people with limited mobility. The focus of this project is to assist people who use wheelchairs or are considering using a wheelchair. Additionally, we believe that people should not be limited in their accessibility based on their ability, or socio-economic status.

II. Motivation For Project

Initially, developing a project within either the medical field or 3D printing devices was of interest. A few days were spent brainstorming as many ideas as possible and it was realized that most interest was within the bubble of medical technologies. While some thought 3D printing was interesting, most of us wanted to work on a project that would make a significant impact on peoples' daily lives. After beginning to focus on medical devices, smaller groups were created to come up with as many ideas as possible. Then as a group, ideas were eliminated by classifying them as too ambitious, too easy, or projects that didn't fit the scope of mechanical engineering well. Each remaining idea was discussed and voted on to create a shortlist of ideas which prompted further research. After doing this research and having further discussions, the project scope was narrowed 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. This made wheelchair technologies generally the top choice, but prosthetic enhancement was believed to still be in the running. An anonymous poll was used to decide between these two topics, and while somewhat split results were expected, the poll unanimously favored wheelchair improvements.

As of 2015, there were 2.7 million wheelchair users in the US [11], 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. The aim of this project is 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.

The project scope was narrowed down from medical technology to wheelchair improvements, but this was still a broad category. That being said, reaching a wide audience was a priority. This meant that the project would benefit from being designed to solve a problem with a device that could be implemented at relatively low cost, weight, and could be attached to an existing chair. To try and determine which issue to attack, time was spent 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. Stairs were also a specific issue identified for wheelchair users [24]. These challenges and issues are intended to be mitigated by the design of the 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 [6] and ultimately any add-ons for this project should not worsen the accessibility of a manual wheelchair. After discussing our research, there were two main interests, steep inclines and declines as well as stair climbing. The project focus was centered 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 there was a clear direction for this project, more research needed to be done about the particular audience and how this project could 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 [17]. These issues can be concerning for both wheelchair users and those considering using wheelchairs. There are powered wheelchairs, but they are bulky, 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 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 the ability to 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 the project is successfully able to implement all of our ideas, this new system still needs to be made 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. An attempt could be made to file a patent and sell production rights, which if possible could be beneficial for us, but may limit the market of consumers. All of the work could also be made open source, and that would give opportunities to others to build off what was done in this project or produce similar products cheaply. Plans for this last stage of the project have not yet been discussed, but it’s an interesting concept. Ultimately, the motivation of this project is to use engineering knowledge to make a positive difference in the lives of millions of people by improving the wheelchair user experience.

III. <u>Description of current state of the art</u>

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 [7]. Research was conducted to examine current wheelchair add-ons on the market and where improvements could be made. This research fueled motivation for the team to provide a light weight, low cost, accessible, safe, and transportable add-on device for a wheelchair to assist a person who uses wheelchairs to ascend inclines and descend declines and helping to improve their quality of life. The assistive technology or add-ons available for wheelchair users traversing slopes fall into three main categories: push rim-activated power-assist wheels, wheelchair power drives, and mechanical advantage devices [12]. Diagrams for each of these main categories are shown in Figure 1, Figure 2, and Figure 3, respectively.

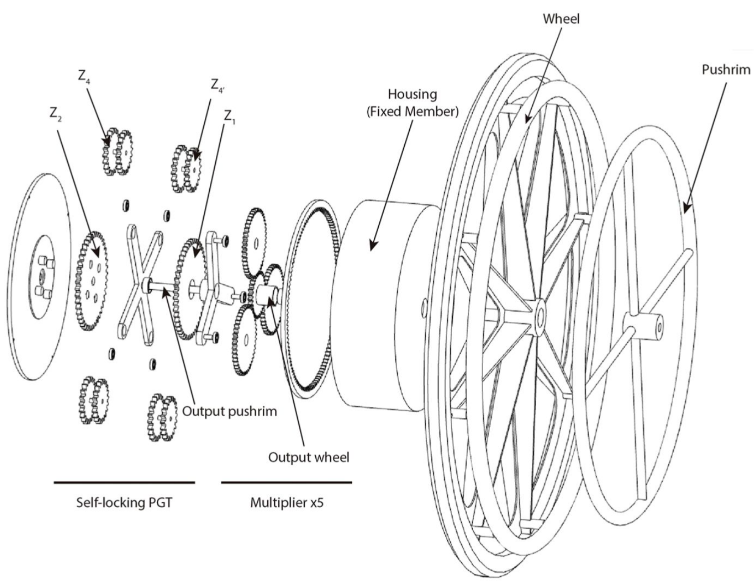

Figure 1 Pushrim-activated Power Assist Wheels (PAWAW) [33]

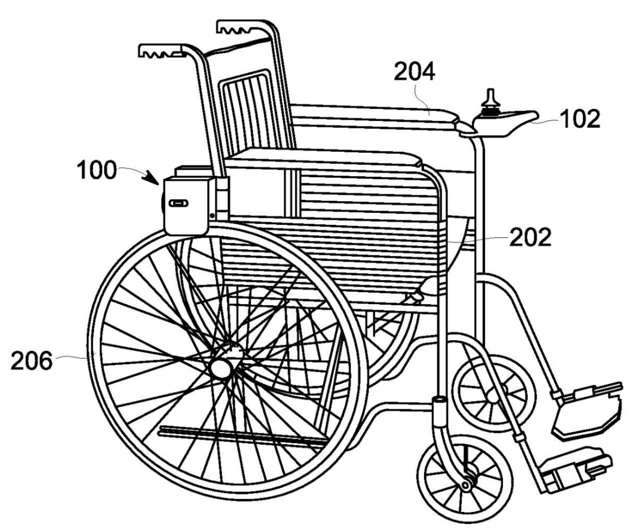

Figure 2 Wheelchair Power Drives [23]

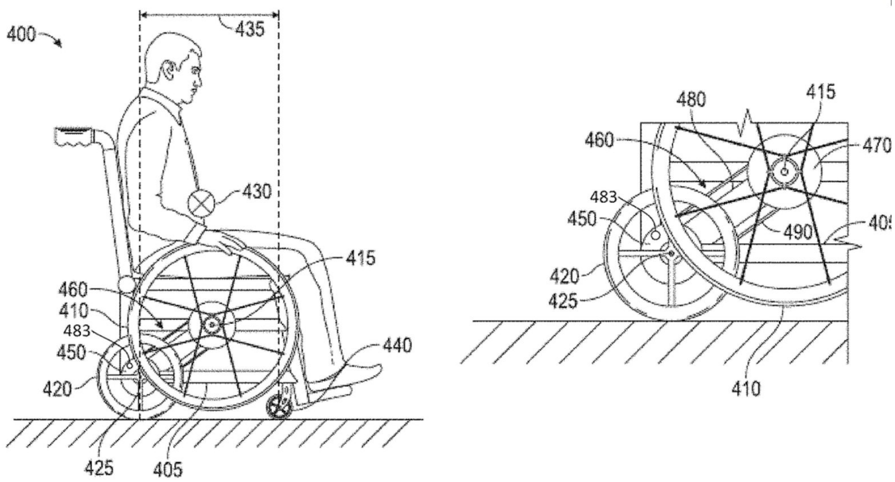

Figure 3 Mechanical Advantage Add-on [32]

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 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 have the ability to propel themselves further forwards or backwards 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 [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 (See Figures B.4, B.5, & B.6). This allows E-bikes to be pedaled while the motor is running [10]. 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 been influenced by technologies outside of current motorized wheelchair prior art in addition to the prior art as seen in Appendix B (See Figures B.1-B.3, B.7-B.11, B.13).

Ultimately, manual wheelchairs are a very inefficient form of transportation [12]. Just to traverse inclines or declines requires a significant amount of upper body strength and endurance [12]. 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 the wheelchair add-on design is to combat these factors while creating an affordable and transportable product.

IV. Planned Approach - Overall Goal and Design Objectives

The main goal of the design is to assist wheelchair users on inclines and declines. As stated above in the motivation section of the report, the attachment we would like to create will allow wheelchair users to gain independence and experience less struggle when ascending and descending steep slopes. In order to achieve this goal, specific design objectives have been generated by the team that will assist us in achieving this overall goal. 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 for folding/interfacing with common wheelchairs. Table 1 is a morphology chart we completed as a team that lists various options of how we could achieve these design objectives.

Table 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 brake	• 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

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 using the effort of the user as an input, this creates the ability to reduce the strain wheelchair users face. The torque and effort inputs from the user are both significant measurements for the device. As seen in Table 2, the add-on will include manual throttle or a knob to enable the user to control the speed or assistance outputted from the device. Also, there's the potential to include a joystick or buttons to enable the user to control the direction of the wheelchair.

Table 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?)

User control of the wheelchair is taken into consideration when measuring the input of the user. This includes the user choosing a desired speed and effort level based on their own needs. Another key goal is to eliminate the jerk of the device to meet ergonomic requirements for the user by ensuring a comfortable ride. Including transitions between different modes of the device and progressive stops will provide a more comfortable experience for the user and mitigate safety concerns. The last objective is to allow the device to interface with standard wheelchairs and to allow the wheelchair to fold easily. By allowing the wheelchair to fold, the user would not have to deal with reinstallation and removal of the device each time they are finished using the chair. This allows the user to have an efficient usage of the device. The ability to interface with standard wheelchairs allows for the device to be used by a larger consumer base.

Conceptual designs were created by considering the design objectives (Appendix B). These designs were generated by individual members of the team. Some concepts are full designs, while others focus on the placement of various sensors and components of the system. Many of the 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 be determined through surveys and interview feedback the team obtains. Designs also came from researching the prior art. This large compilation of ideas allows the team to narrow the scope to identify the most effective motor assistive device while taking into consideration cost, weight, and other considerations. After examining the initial conceptual designs, the team identified that the project will be composed of three decoupled systems: motors and transmission subsystem, the control subsystem, and the effort sensing subsystem. The subsystems will be integrated but designed separately. This is due to the fact there is a weak coupling between the different subsystems. The major subsystem identified is the drive train, so the team further considered how they could achieve this subsystem. These considerations can be found in Table 2.

V. Planned Approach - Separation of Design Objectives

Currently, we are split up into three sub-teams to achieve these design objectives. A more detailed representation of the division of responsibilities between subteams can be seen in the component integration schematic found in Figure 4, which a key in Figure 5 explaining the meaning of the colors and shapes. The three subteams include the propulsion team, electro-mechanical integration team, and the effort sensing team. The propulsion team has decided from the conceptual designs (Appendix B) that the overall design of the attachment will be a wheel attached to the back of the wheelchair. The rationale for this important decision is described in section VI. Planned Approach - Design Metrics and Specifications. The propulsion team now has to choose a suitable motor, battery, transmission, braking/negative torque system, housing system, and motor driver, which will connect to the Arduino used by the electro-mechanical team to achieve the design objectives of eliminating jerk, applying positive torque, applying negative torque, and allowing folding/interfacing with common wheelchairs. The electro-mechanical integration team is in charge of the steering and controlling functions of the device. They will integrate the motor driver chosen by the propulsion team to help the team achieve the design objective of controlling the direction of the wheelchair. They will also be in charge of measuring the input from the user. This input will be the readings from the joystick, emergency stop, switch, and knob. The inputs into these components will allow the user to decide speed, direction, and amount of added effort from the device. The effort sensing team is in charge of meeting the design objective of measuring the effort of the user. With the accelerometer connected with the wheel from the propulsion team's design, they will work on producing a feedback signal, which is also receiving input from the effort sensors they will design to a PID controller to change the speed of the motor depending on the effort of the user. The main goal will be to determine how to measure the effort of the user. Through subteam and entire team work, the team should be able to successfully create a device that will meet all of the design objectives found in Table 1. This will allow the team to reach the final goal of allowing wheelchair users to be more independent and experience ease when ascending and descending hills and inclines.

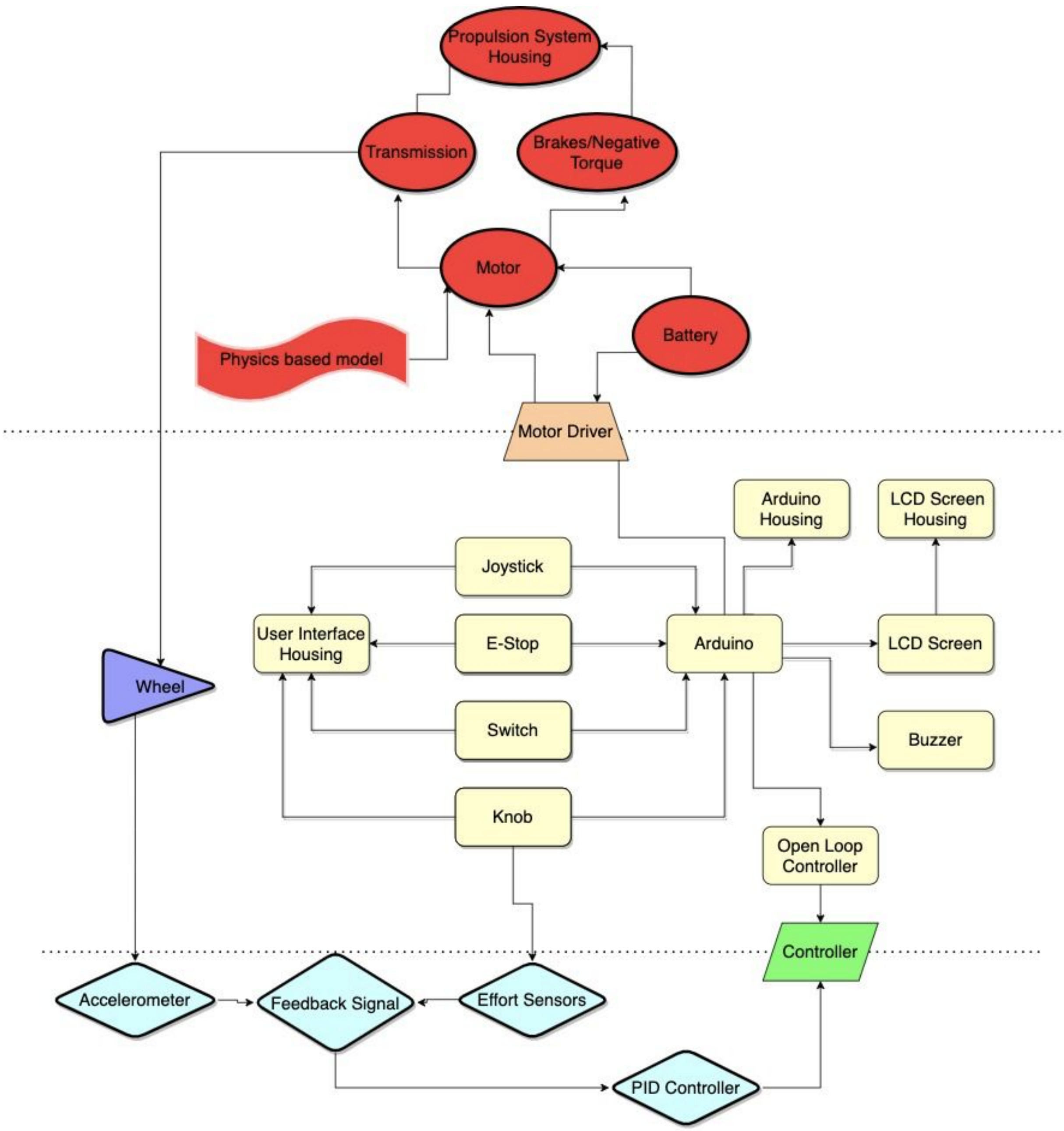

Figure 4 Component Integration Schematic

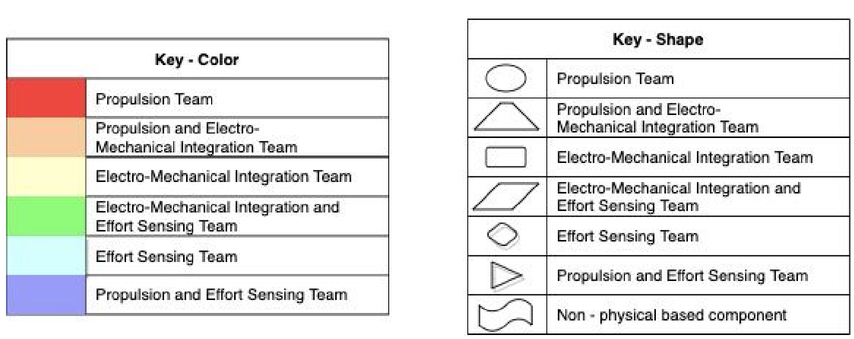

Figure 5 Keys for Figure 4

VI. Planned Approach - Design Metrics and Specifications

Another important part of our planned approach was developing constraints and specifications for our design. The specifications identified are derived from the design objectives. These have been informed by research on the largest areas of improvement for wheelchair users. There are various engineering metrics that will inform the specifications which are found in Table 3. Initially the team developed general specifications, functions and constraints, but as subteam work has developed, subteam specific metrics emerged. Some measurable quantities identified are the velocity, acceleration, weight, cost and incline grade. Metrics that stem from this involve maximum and minimum velocity on level ground, and specified incline or decline (Specifications 5, 6-11). The range of maximum grade was derived from the range that most electric wheelchairs are rated to maneuver [38]. Maximum and minimum velocity was based on the ISO 7176 standards of maximum velocity of electric wheelchairs and the average speed of manual wheelchairs [21 & 39]. Another metric includes waterproofing the housing to ensure the device will be operable in different weather phenomena (Specification 4). All specifications correspond with Table 3. Testing for waterproofing of components will take direction from ISO 7176-9, which describes climatic testing of electric wheelchairs [21]. In addition, the weight and cost of the attachment is another important metric to consider throughout the design process (Specification 1,2). Cost and weight specifications were based on the cost of typical wheelchair add-ons and the maximum weight the wheelchair is rated to carry which can be seen in Table A.2 (Appendix A) [3]. These complement design objectives stated above and are seen in conceptual drawings (Appendix B). Subsystem specifications will be further developed as prototyping and modeling continues.

Table 3: Design Specifications and Metrics

#	Description	Metric/Specification	Minimum Value	Maximum Value	Unit
1	The device cost will not exceed $2500 to stay within competitive pricing of prior art (Table A.2)	Cost of device		$2,500	USD
2	The device added weight to a manual wheelchair allows user to push wheelchair when device is not in use but attached to wheelchair (Table A.2) [3]	Added weight of the device	0	25	lbs.
3	The range of the device on a full battery is comparable and competitive to other prior art (Table A.2)	Range of device on full battery	12	15	Miles

Table 3: Design Specifications and Metrics Continued

#	Description	Metric/Specification	Minimum Value	Maximum Value	Unit
4	The device can withstand weather including snow, and rain based on ISO 7176-9 [21]	Waterproofing housing for electrical components			
5	The device can operate at specified grade [38]	Maximum grade	8.3	12.5	% grade
6	The device can carry a person of 198 lbs at a maximum speed on level ground [21]	Maximum speed attainable on level ground		9.32	mph
7	The device can carry a person of 198 lbs at a minimum speed on level ground [39]	Minimum speed attainable on level ground	2.25		mph
8	The device can carry a person of 198 lbs. at a maximum speed on an 8.3%-12.5% grade incline [21]	Maximum speed attainable on an incline		9.32	mph
9	The device can carry a person of 198 lbs. at a minimum speed on an 8.3%-12.5% grade incline [39]	Minimum speed attainable on an incline	2.25		mph
10	The device can carry a person of 198 lbs. at a maximum speed on an 8.3%-12.5% grade decline [21]	Maximum speed attainable on a decline		9.32	mph
11	The device can carry a person of 198 lbs. at a minimum speed on an 8.3%-12.5% grade decline [21]	Minimum speed attainable on a decline	2.25		mph

The design has additional constraints that have been developed through research and discussion. Moving forward, the design will continue to be informed by further research and community outreach as described below in stakeholder and external partnership. The constraints of this design also stem from ADA regulations [24] and ISO standards [21]. 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]. Table 5 shows the constraints developed from the ISO in regard to physical constraints such as maximum speed or testing guidelines and standards with static and dynamic stability as well as other standards (Constraints 1, 2, 6-11). Additionally, Table 5 shows constraints involving maximum weight derived from the rating of the weight rating of our wheelchair and similar wheelchairs (Constraint 3) [4]. The electrical components have specific constraints that inform the design including keeping the heat transfer of electrical components in a safe operating level (Constraint 5) [41]. The emergency stop that will be used as a fail safe in the design also needs to meet the requirements of commercial grade emergency stops (Constraint 4) [40].

Table 5: Device Constraints

#	Description	Constraint	Max Value	Unit
1	The added width of the device does not exceed the specified length to follow ISO 7176-25 guidelines [21]	Maximum added width	4	in.
2	The device does not exceed the maximum speed of electric wheelchairs standard set up by ISO 7176-6 [21]	Maximum speed of electric wheelchair	9.32	mph
3	The device must be designed such that it can support up to 300 lbs [4]	Maximum weight	300	lbs.
4	Emergency-stop of the device is an approved as an emergency-stop for commercial use [40]	Use of emergency-stop in commercial devices		
5	The device must be designed such that it does not exceed 158 °F [41]	Device temperature range	158	°F
6	The wheelchair design does not violate ISO 7176-1 establishing static stability testing of the chair [21]	Static stability		
7	The wheelchair design does not violate ISO 7176-2 establishing the dynamic stability of electrically powered wheelchairs [21]	Dynamic stability		
8	The wheelchair design does not violate ISO 7176-3 establishing the effectiveness of brakes [21]	Brake Effectiveness		
9	The wheelchair design does not violate the ISO 7176-10 determining the obstacle-climbing ability of electrically powered wheelchairs [21]	Obstacle climbing ability		
10	The wheelchair design does not violate the ISO 7176-14 requirements for power and control systems [21]	Power and control systems		
11	The wheelchair design does not violate the ISO 7176-25 requirements for batteries and chargers [21]	Batteries and charges		

Design decisions have been made to address the different specifications, constraints and functions. As mentioned above, the propulsion team decided to attach the add-on device to the back of the wheelchair. After splitting into subsystem teams, each team created and looked at different specifications, constraints, and functions reflected in the tables above and identified specifically which ones their subteam is responsible for. The propulsion team's main metrics were cost of device (Specification 1), added weight of the device (Specification 2), range of the device Specification 3), waterproofing housing for electric components (Specification 4), and maximum grade (Specification 5). The main constraint considerations for the propulsion system are maximum added width (Constraint 1), maximum speed of a manual wheelchair (Constraint 2), and the maximum weight (Constraint 3). These specifications and constraints at times competed with the desired functions of the device. In particular, the folding ability (Function 2) of the wheelchair and adjustable fit were big concerns as many devices or configurations would limit the folding ability of the wheelchair or the compatibility of the device with other manual wheelchairs. For this reason, the subsystem narrowed the conceptual designs to designs that included systems attaching to the back of the wheelchair (Figures B.2 & B.8, Appendix B) and a system integrated entirely into the wheel of the wheelchair (Figures B.1, B.4, B.5, & B.6, Appendix B). The attachment to the back of the wheelchair would still allow the wheelchair to fold to some extent when not in use and attached to the wheelchair. This would also be more likely to interface with different manual wheelchairs, and it would be an attachable and detachable device. The integration of the system into the wheels were mainly concerning attaching hub motors to the wheels or creating new wheels for the wheelchair that would include hub motors. This design allows the wheelchair to fold when not in use and to interface with many common wheelchairs as it would be a single installation process. The team considered wheel replacements with the team's add-on design. Ultimately, the team looked to specifications and constraints to make the decision between the two different attachment sites. Initial calculations were performed to calculate the stall torque required for the system in each placement (Figure B.14 & B.15, Appendix B). Figure B.14 (Appendix B) shows the stall torque calculations for a wheel in the back, while Figure B.15 (Appendix B) shows the stall torque calculations for hub motor wheels. This showed the needed torque was greater than the hub motor being considered could provide [50]. The motor provided 84 N-m at 48 V and 75 N-m at 36 V [50]. According to the calculation, the minimum stall torque for the hub motors configuration is 266 Nm on a 12.5% grade (Figure B.15 Appendix B). Also, the added width of the hub motors were likely to exceed Constraint 1 [50]. Furthermore, the added weight of the hub motors were likely to exceed Constraint 2 as using two motors would add around 20 lbs of weight [50]. For these reasons, it was decided the add-on would attach to the back of the wheelchair. This placement allows for folding, interfaces with common wheelchairs, will achieve the needed stall torque with a transmission, reduces the weight, and does not add width to the wheelchair. This design does add concerns in regard to the functionality. In particular, the added weight to the back of the wheelchair may change the center of gravity of the wheelchair, making it more likely to flip when going down a hill. Additionally, the propulsion system will not interface directly with the wheels of the wheelchair, making breaking and going down steep inclines more difficult. These are concerns that will be addressed as the propulsion system develops. Overall, the placement on the back of the wheelchair allows the wheelchair to achieve the specifications and mitigate violation of the constraints.

Currently, the specifications, functions, and constraints are fluid as more information develops in regards to industry standards, talk with stakeholders, and further design development. For example, the requirements for batteries and chargers according to the ISO (Constraint 11) are not entirely clarified; lithium batteries have their own set of standards compared to other batteries [21]. Battery type and placement have not yet been chosen creating further need for understanding of this constraint later in the design process. Interactions between subsystems will be further understood as designs develop. Overall, the current specifications and constraints are an efficient measure of what the project needs to accomplish.

The current design is still in development. It will continue to develop throughout the year as more research is done, communication with stakeholders occurs, and concepts are refined. The aim of the project is to develop a device to aid wheelchair users in going up and down inclines. To develop a design and actual device will be a continual process including brainstorming design objectives and conceptual designs as well as setting up constraints and specifications for the design. Ultimately, this will allow for a successful design and product that will enable wheelchair users to have more autonomy.

VII. <u>Roles and Responsibilities</u>

We have organized our team structure into various categories. Our team 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 team reaches 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 team scribe will be in charge of recording minutes for each meeting. The sprint/schedule manager will be in charge of documenting the biweekly plans for what each member is responsible for and writing the progress everyone has 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. Green indicates a task is complete while blue indicates a task is in progress. The technical shop liaison is in charge of revising 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 submit the reports. We also have an IRB team that is in charge of submitting and finalizing the survey/interview documents. These documents will be distributed to participants in the form of surveys and interviews, along with consent and debriefing forms.

Currently, we have the team leader as Charlotte. She took over this role after Professor Utter led the team for about two weeks. The scribe team is composed of Katie, Charlotte, and Nicole. There were multiple people interested in this position, so we created a team to prevent feeling overworked. The budget team has Carolyn, Katie, and Emily. The sprint/schedule leader is Drew. Nicole is the technical shop liaison and the copy editors will rotate with each report. Emily and Carolyn are part of the IRB team and are working with Professors Nees and Vinchur. The first copy editors were Charlotte and Nicole, and currently they are Emily and Drew. The positions can also be held by more than one person at a time. 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. 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. Currently, Nick, Matt, and Geoffrey do not have roles outside of their subteams. As we progress throughout the semester, this will change.

Within the subteams, each member of the class has a position. We currently have three subteams: effort sensing, propulsion, and electro-mechanical integration. The effort sensing team is composed of Nick Moosic and Drew Freeland. They are in charge of creating the effort sensor for the wheelchair. The propulsion team has Charlotte Sullivan, Nicole Stanec, Katie Rice, and Geoffrey Toth. This team is working on the propulsion aspect for the wheelchair as seen in Figure 5 of the Planned Approach - Separation of Design Objectives. The Electro-mechanical team has Emily Eng, Carolyn Pye, and Matt Urban. This team is responsible for steering and electrical integration for the entire system. Within the electro-mechanical integration team, Carolyn is the subteam leader, Emily is the circuit manager, and Matt is the CAD manager. The effort sensing group only has Nick and Drew, so they are splitting the work evenly. In the propulsion group, Nicole is the subteam leader and each member has aspects they will focus on. Charlotte is in charge of the ISO information, Katie is responsible for the motors, Geoffrey is in charge of the batteries, and Nicole is in charge of the transmission. All of these teams are integrated with one another, so although we have everyone designated for a specific team, we are all working together. We communicate with each other frequently to ensure that certain aspects of the project are covered and if so by what team. There is a lot of inter-group communication. Table 6 shows all the positions held by each member of the team.

Table 6: Positions Held by Each Team Member

Name of Team Member	Positions Held	Subteam
Emily	On budget team, subteam circuit manager, current copy editor, IRB team	Electro-Mechanical
Nicole	Technical shop liaison, part of scribe team, subteam leader, subteam transmission leader	Propulsion
Charlotte	Team leader, part of scribe team, subteam ISO leader	Propulsion
Carolyn	Part of budget team, subteam leader, IRB team	Electro-Mechanical
Matt	Subteam CAD manager, Subteam arduino manager	Electro-Mechanical
Nick	Subteam member	Effort Sensing
Drew	Sprint/schedule manager, subteam member, current copy editor	Effort Sensing
Geoffrey	Subteam battery leader	Propulsion
Katie	Part of budget team, member of scribe team, subteam motor leader	Propulsion

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.

VIII. Team Schedule

To keep track of the hours worked by each student, which tasks have been worked on, and who was responsible for each task, the time keeping system known as the Scrum Agile Mindset [32] was implemented. 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.

Internal deadlines to complete a rough draft several days 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 and conceptual designs as well as initial website design. Additionally, the team has fully modeled the wheelchair used as the base for the project in Fusion360. Currently, the team is focused on working within the propulsion, effort sensor, and electro-mechanical integration subteams to develop the subsystems of the project. In addition, the team is currently working through the final processes to be able to send out the survey, found in Appendix D, which will be sent out to related healthcare professionals, the responses to which will help the team further refine the final design.

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.3 and E.4 (Appendix E)) as well as if the task applies to the whole team or to one of the subteams. As the team works through tasks, the color of each task changes to represent progress from future event to current event then to complete. The current Gantt chart has been revised from the rough draft to include the subteams' schedules and tasks. Each task is color coordinated by the subsystem in the leftmost column.

Each subteam will choose and order the components of the respective subsystems through October 24th. The effort sensor subteam and propulsion subteam will be developing conceptual designs and processing mathematical models through October 31st. Starting on October 29th, the effort sensor and propulsion teams will begin design prototyping. The electro-mechanical integration subteam will be designing custom circuit boards through October

31st. The electro-mechanical integration subteam will then be assembling the controller and display through November 24th and will be designing and creating a controller housing through November 30th. The electro-mechanical integration subteam will then complete all controller mathematical models. Finally, all three subteams will have finished subsystem integration by December 9th.

The team goal for the end of the semester is to have a completed CAD model of the system attached to the wheelchair including every physical aspect of the system down to the fasteners as well as an accurate bill of all of the materials. This is reflected in the current schedule. Overall, this will put the team in a good position to complete a fully functional wheelchair add-on by the end of the school year.

IX. <u>Required Resources</u>

The required resources have become more specific as the design has developed. The team has selected and purchased a wheelchair as a base model for testing prototypes. This wheelchair has been modeled in Fusion360. Once the components have been purchased, the team will need time, space, and tools to assemble and store the prototype. Currently, this space has been team member's homes, but in the future, it would be optimal for this space to be in Leopard Works room 006 or another space that the entire team may access on campus. Additionally, the team will be manufacturing components with 3-D printers, the printed circuit board machine, and the shop machines. The prototypes will be tested by members of the team on various inclines and declines around campus, including the hill behind Acopian Engineering Center, down Sullivan Street, and down Hamilton Street. This would only require the team to transport the prototype around Lafayette's campus.

Each subteam has determined a list of components and estimated budget that is needed for their respective responsibilities. The compiled budget estimate is shown in the following table.

Table 7: Updated Conservative Budget Estimate

Component	Description	Estimated Quantity	Estimated Unit Price	Estimated Total
Wheelchair* [4]	use as base model	1	$80-200	$109.29
Motor [1]	changes wheel motion, requires high torque (based on 12V electric bicycle motors)	1-2	$20-100	$200.00
Battery [2, 3]	power motor, control system, rechargable (may be SLA or lithium ion)	1-2	$60-120	$240.00
Additional Wheel [45, 46, 47]	added to the back of the wheelchair	1	$40-75	$75.00
Arduino** [5]	control system inputs and outputs	1-2	$40.30	$80.60
Switch** [20]	turn device on and off	1-2	$6.00	$6.00
Buttons [19]	for emergency shutoff, different modes	1	$6.00	$6.00
Joystick** [9]	for user-controlled maneuvering	1	$16.00	$16.00
Buzzer** [15]	user alerts - auditory	1	$2.00	$2.00
LCD Screen** [18]	user alerts - visual	1	$16.00	$16.00
E-Stop Button** [43]		1	$6.00	$6.00
Knob [44]	Effort Control	1	$1.00	$1.00
Wires** [42]	for connections	1	$7.00	$7.00
Wire Insulation** [48]		1	$5.00	$5.00
Custom Circuit Board		4	$5.00	$20.00
Waterproof housing [49]	either purchase waterproof junction box or 3-D print and spray	5	$6.00	$30.00
Accelerometer [14]	We need to select one based on the resolution we need	1-2	$30.00	$60.00
Other	raw materials, addition wires, fasteners, extra sensors, test dummy, battery charger, transmission and braking components, etc.	n/a	n/a	$300
			Total:	$1,179.89

*purchased and received
**purchase pending

The initial prototype design is likely to go through some changes as it continues to be developed and the team receives feedback from the IRB interviews and surveys. As a result, the budget is anticipated to change slightly as the project continues and specific components are selected. The goal is to continue to reduce the total cost of the product while maintaining product quality.

X. Stakeholders or external partnerships

As with any human centered project, the primary stakeholders are the individuals the project is working to support. In the case of this project, the primary stakeholders are wheelchair users specifically those who are primarily independent or are striving to be primarily independent. In addition to these stakeholders, external partnerships will be formed with a variety of individuals with mechanical or medical knowledge that is beyond the current expertise of the team.

Throughout the design process, the team will consult a combination of individuals with technical backgrounds and individuals who have experience working with or using wheelchairs. At this point, the team has submitted an IRB application and received preliminary feedback that is being addressed, primarily, completing the necessary CITI training for human research. Once the IRB is approved, the team will begin to gather information from a variety of healthcare professionals and wheelchair users. The team plans on conducting interviews with wheelchair users and sending out surveys to healthcare professionals that focus on the current difficulties faced when tackling inclines and declines in a wheelchair as well as user interface preferences. For the surveys, the team hopes 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, the team hopes to have a better idea of what design would best assist wheelchair users who are looking for assistance going up and down hills without giving up the autonomy that comes with a manual wheelchair. Since none of the team members use a wheelchair, it is difficult to design a product without additional feedback. Many of the people the team hopes to interview are friends or relatives who have agreed to help once proper approval is received.

Throughout the design process, feedback will be sought from the faculty advisor, Professor Utter, on aspects of the design that extends past the general level of 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, the team intends to consult the 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, the team has 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, the team may also consult current and past professors on questions related to the subject matter of their expertise. 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 the team hopes to elicit feedback from at this point, the team is continuing to look for additional relationships that may help the design project to be both functional and effective.

XI. Risk and Hazard Identification Management

There are a number of potential risks that have been identified in creating an inexpensive yet versatile wheelchair attachment. One of the primary concerns is waterproofing all of the electrical components of the design. As this attachment will be on a wheelchair that is used outside, it is essential that there are no electrical malfunctions that occur if the wheel chair is being used in rainy conditions. We plan to eliminate this risk by using waterproof housing wherever possible. If there is a malfunction in the device while it's in use, we would like to have a way to safely shut the system down without harming the user. For this reason, we plan to include an emergency stop button in the primary user interface.

Outside of the potential risks with the electrical components, we cognizant of the risks involved with changing the loading on the wheelchair. Any alteration to the center of mass of the wheelchair could result in a wheelchair more likely to tip over. In order to mitigate this risk, we will be conducting center of mass calculations to eliminate changes wherever possible as well as providing the system with an anti-tip device to function as a safeguard against possible tipping.

Additionally, the current design allows the user to be in contact with the wheel while the motor is engaged. In order to reduce the risk of an individual's hand getting pinched or brush burned by the wheel, limits on the speed the motor can go will be added as well as considering the use of separate handles for user to wheel interaction. Specific speed limits and other ISO specifications can be found in table [5].

Finally, there are concerns with the means of testing the wheelchair. As the wheelchair is primarily user-assistive, testing will require a user to be operating the wheelchair during some of the test stages. When possible, a variation of a test dummy for tests that do not require active user input will be used. For tests that require user input, the user will have proper personal protective equipment including but not limited to a helmet and additional padding.

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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.

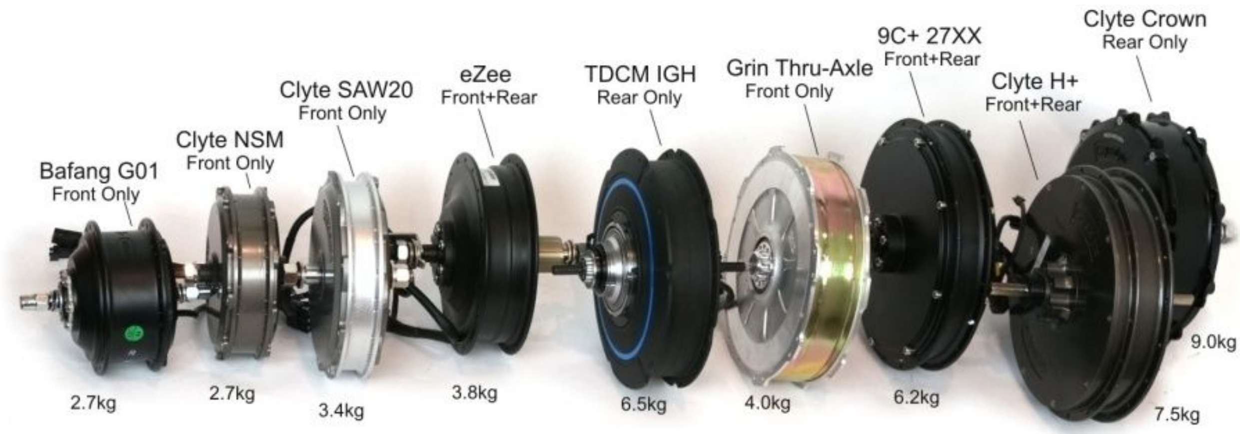


Figure A.1 Hub Motors used in E-Bikes [10]

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

Table A.2: Pricing, Weights, Range and Speeds of Different Wheelchair Add-On Devices currently on the market

	SmartDrive MX2 Power Assist [37]	**Firefly 2.5 [35]**	**E-Motion [34]**	**SMOOOV one [36]**
Price ($)	6,317.90	2,595.00	2,595.00	6,895+
Weight (lbs)	13.5	35 (shipping weight)	22	16
Max Weight (lbs)	331	~	286	310
Range (miles)	12	15	15.53	12
Max Speed (mph)	5.5 (flat ground) 5.3 (6% degree incline)	12	3.73	6

Appendix B: Conceptual Designs and Calculations for the Planned Approach

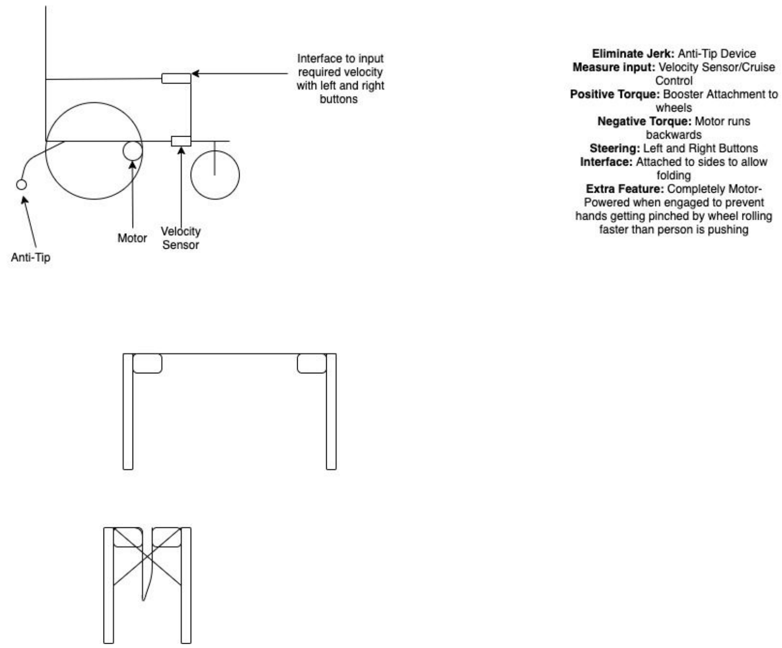


Figure B.1 Wheelchair design with motor-driven wheels

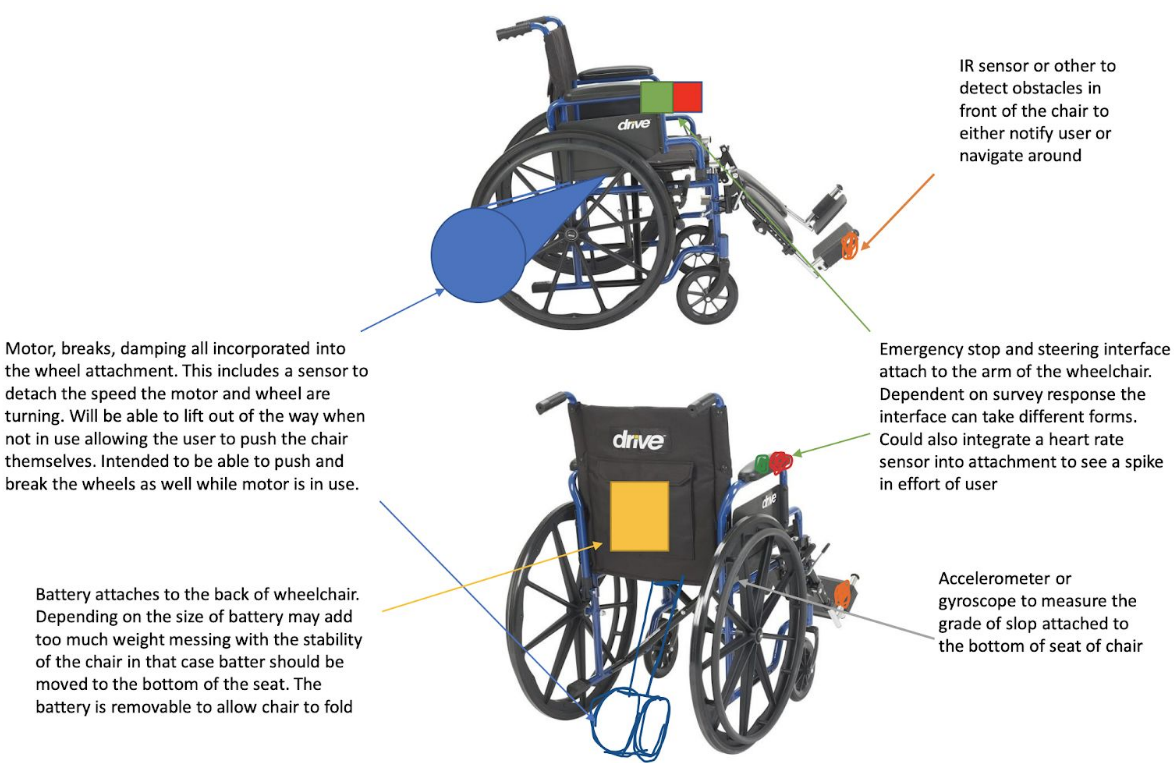


Figure B.2 Attachable wheel to the back of the wheelchair[4, modified]

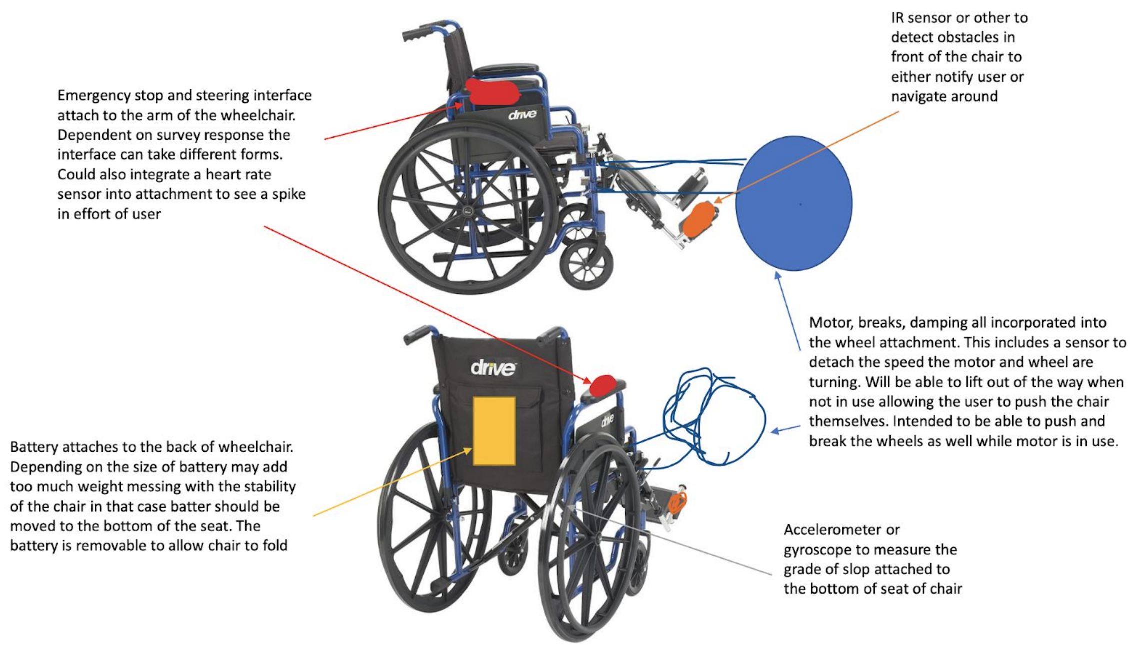


Figure B.3 Attachable wheel to the front of the wheelchair [4, modified]

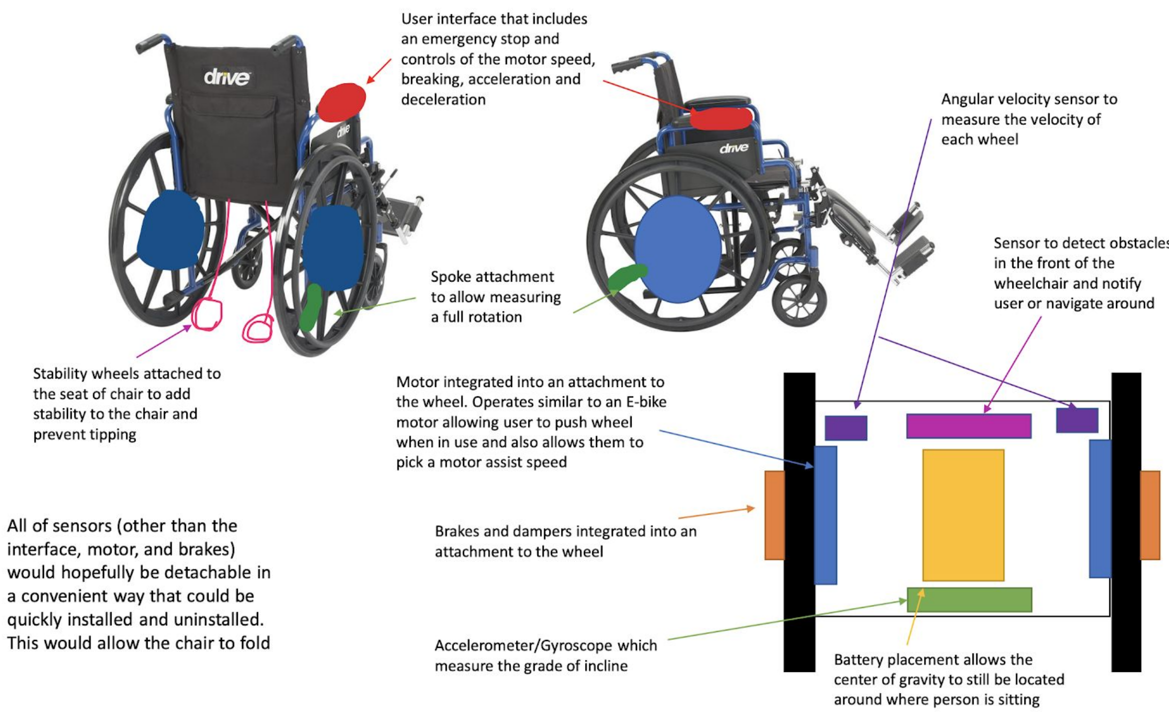


Figure B.4 E-bike mechanism design with layout of various components under the seat [4, modified]

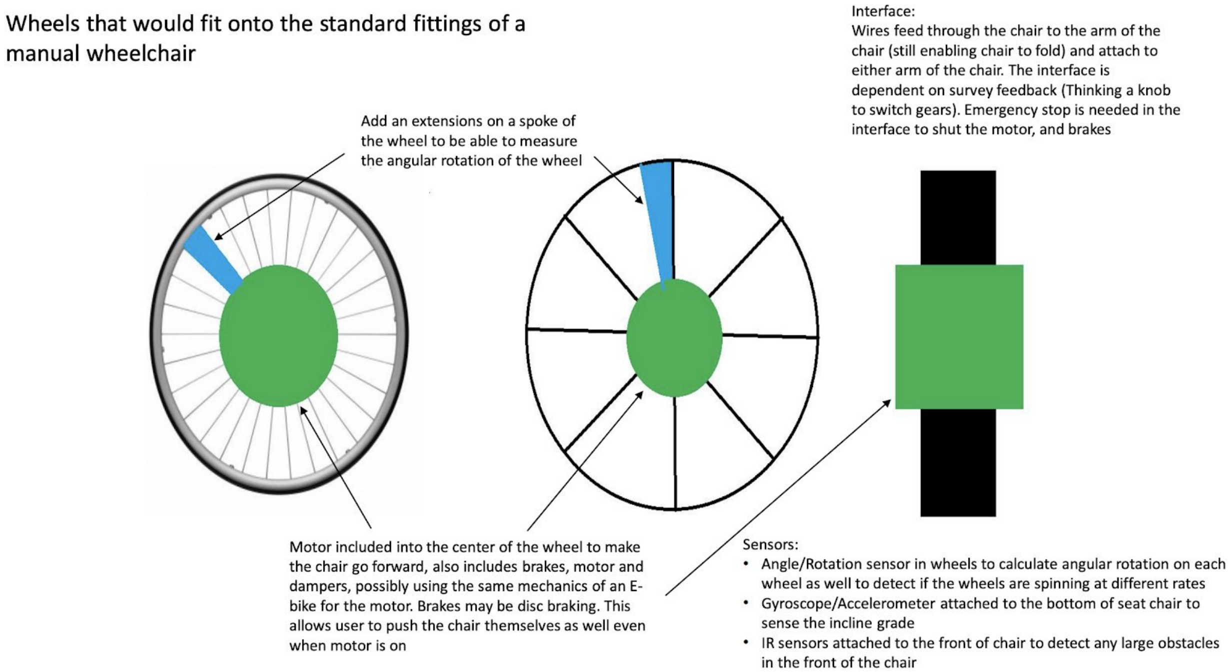


Figure B.5 Detachable wheels powered by motors at the hub

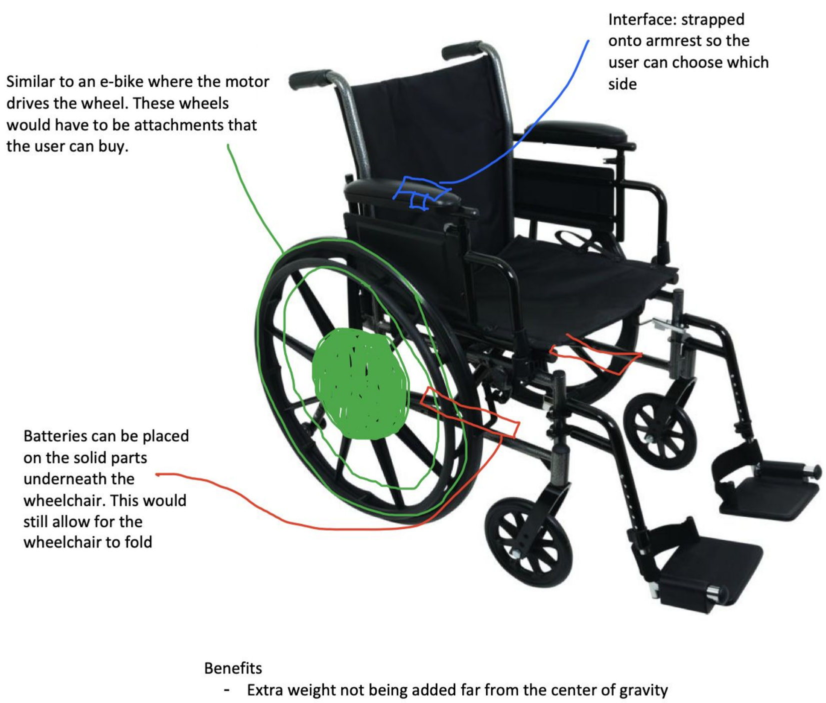
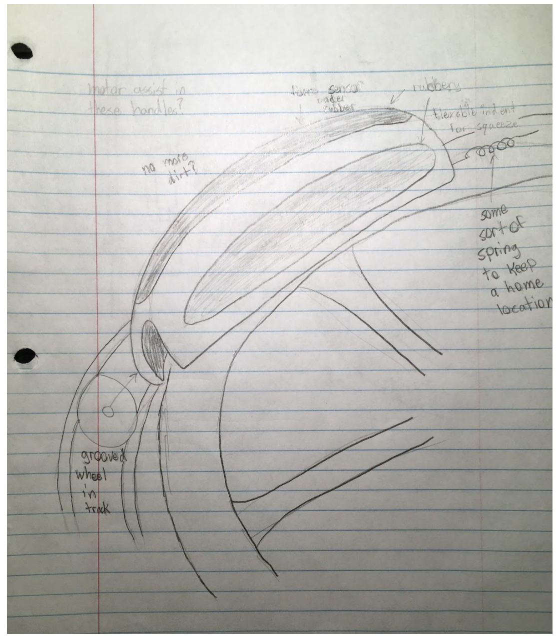


Figure B.6 Wheelchair design with new wheel attachments [30, modified]

(a)

(b)



(c)

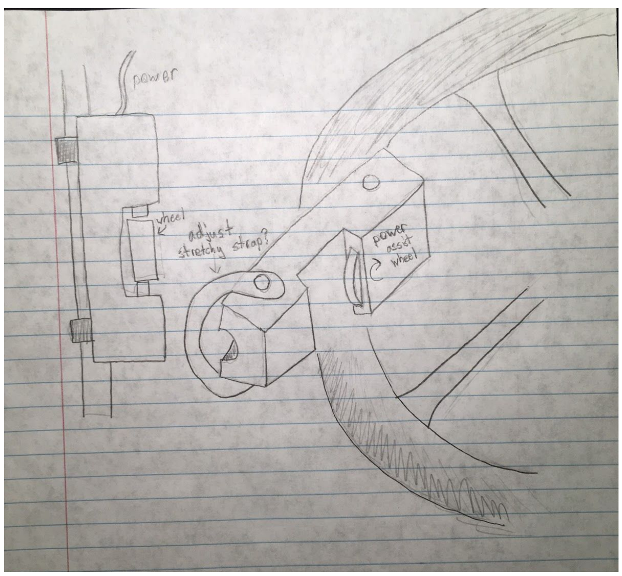


Figure B.7 (a) Overall wheelchair design (b) Force sensor design (c) Motor Attachment

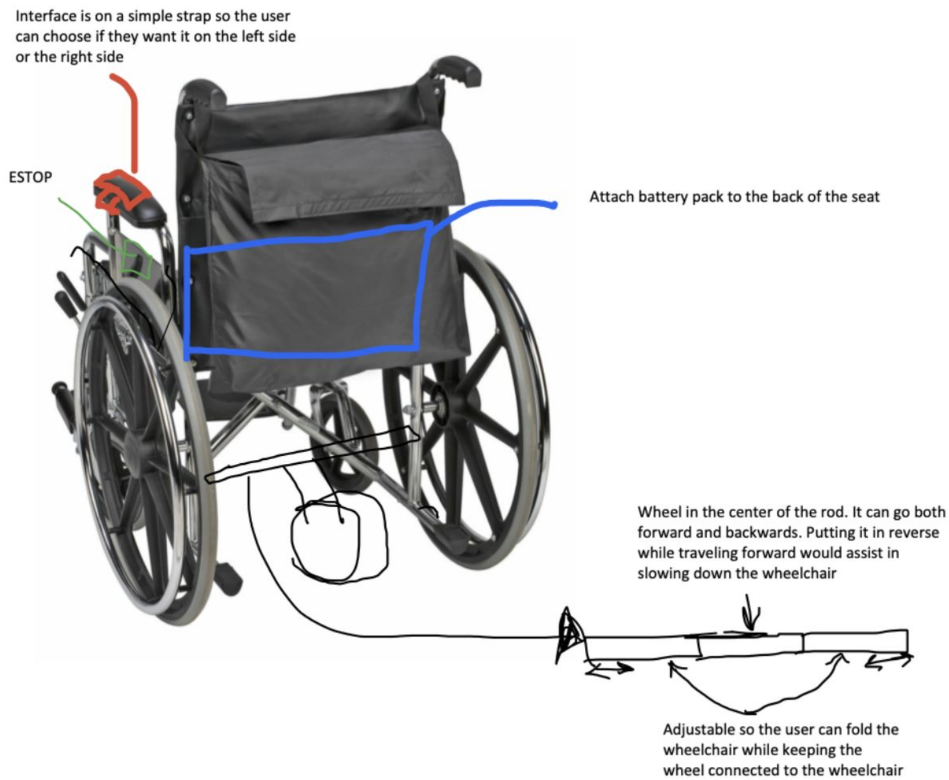


Figure B.8 Rear wheel addition with expandable bar[29, modified]

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

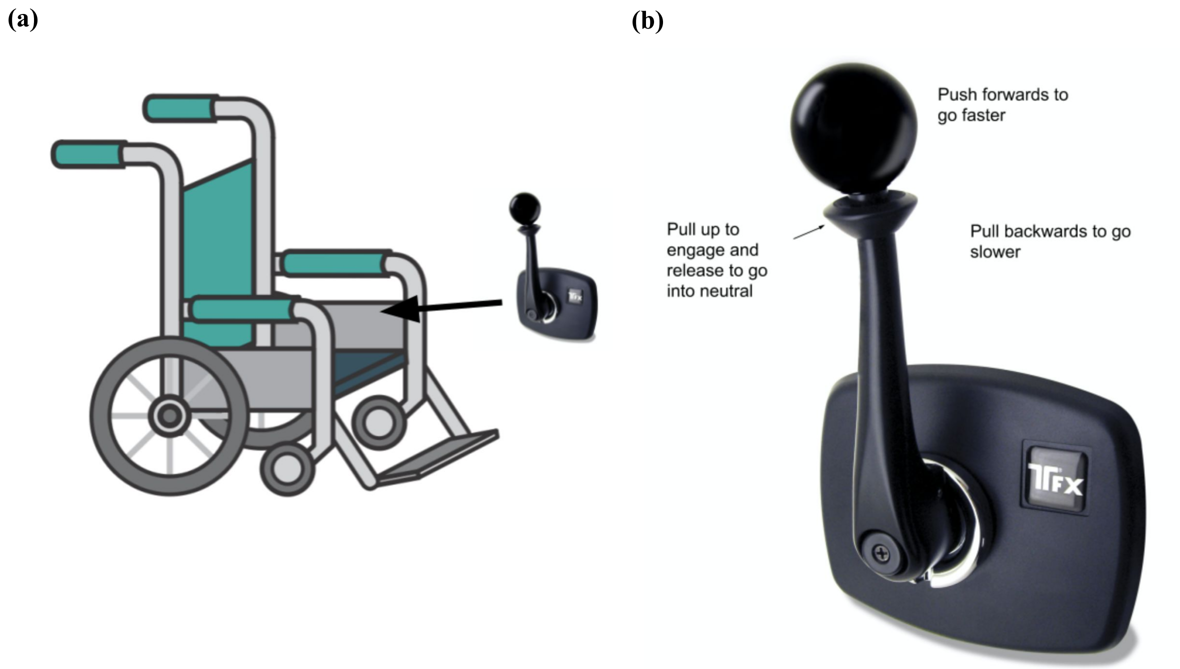


Figure B.10 (a) Placement of throttle (b) Throttle with description of mechanism [26,27, modified]

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

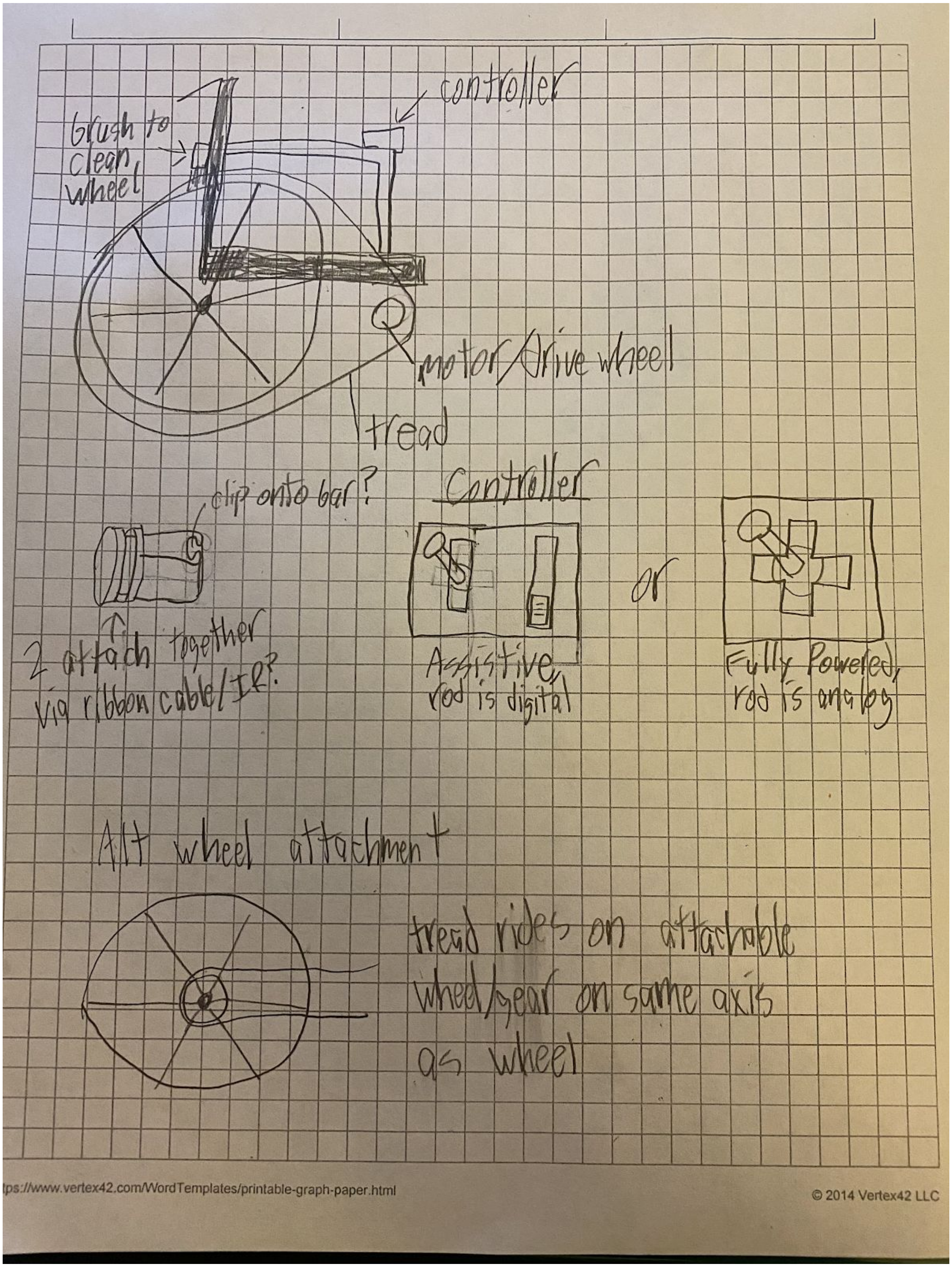


Figure B.12 Motor/drive wheel with a description of a controller

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?

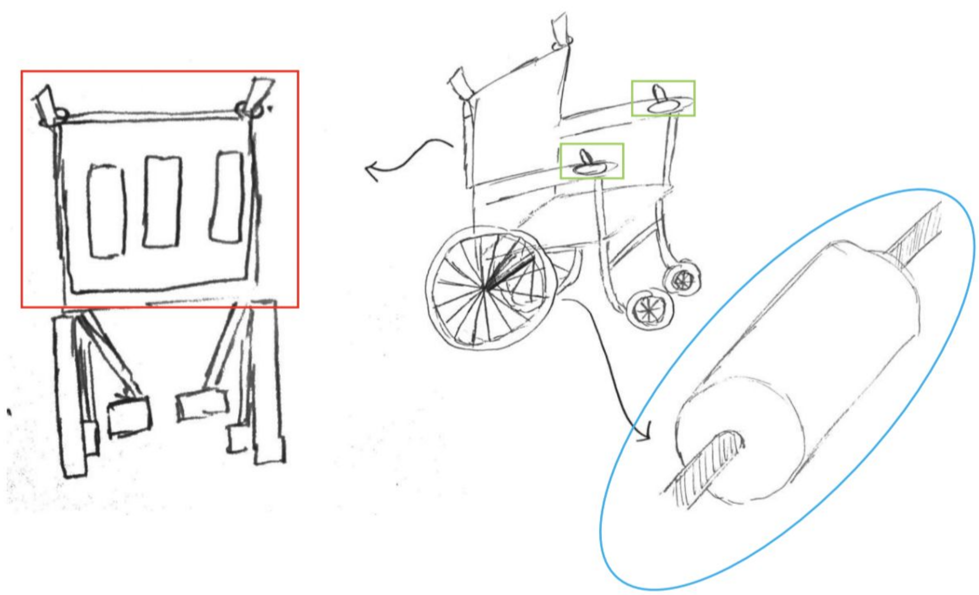
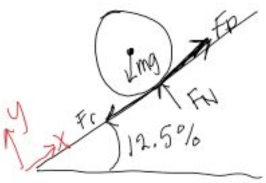


Figure B.13 Wheelchair design with hanging attachment for storage

Wheel in the back



m ≈ 300 lbs + 36.7 lbs = 152.725 kg (300 lbs: person + device; 36.7 lbs: wheel chair)

8.3% grade = 4.76°

12.5% grade = 7.13 deg

D = 24.375" ≈ 0.6191 m

V = 15 Km/hr ≈ 4.167 m/s

$\Sigma F_y = 0 = F_N - mg\cos\theta$

$F_N = mg\cos\theta$

$\Sigma F_x = 0 = -\mu F_N - mg\sin\theta + F_p$

$F_p = \mu(mg\cos\theta) + mg\sin\theta$

μ = static friction because this is what it needs to overcome to move

μ_s for rubber = 0.9

F_N is assuming all weight is on the back wheel (worst case scenario)

12.5% grade

$F_p = 0.9\,(152.75\,kg)(9.81\,m/s^2)\cos(7.13) + (152.75\,kg)(9.81\,m/s^2)\sin(7.13)$

$F_p = 1.524$ KN ← Torque will be dependent on wheel size in the back

---

8.3% grade

$\Sigma F_x = 0 = -\mu F_N - mg\sin\theta + F_p$

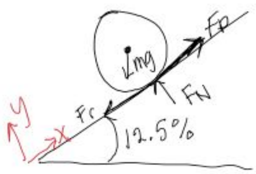
$F_p = \mu(mg\cos\theta) + mg\sin\theta$

$F_p = 0.9\,(152.75\,kg)(9.81\,m/s^2)\cos(4.76) + (152.75\,kg)(9.81\,m/s^2)\sin(4.76)$

$F_p = 1.468$ KN ← Torque will be dependent on wheel size in the back

Figure B.14 Stall torque calculations for wheel in the back

Wheel motors



$\Sigma F_y = 0 = F_N - mg\cos\theta$

$F_N = mg\cos\theta/2$

$\Sigma F_x = 0 = -\mu F_N - mg\sin\theta + F_p$

$F_p = \mu\left(\frac{mg\cos\theta}{2}\right) + mg\sin\theta$

12.5% grade

$F_p = 0.9(\tfrac{1}{2})(152.75\,kg)(9.81\,m/s^2)\cos(7.13) + (152.75\,kg)(9.81\,m/s^2)\sin(7.13)$

$F_p = 855.1\ N$

μ = static friction because this is what it needs to overcome to move

μ_s for rubber = 0.9

F_N is assuming all weight is on the back 2 wheels (worst case scenario)

8.3% grade

$\Sigma F_x = 0 = -\mu F_N - mg\sin\theta + F_p$

$F_p = \mu\left(\frac{mg\cos\theta}{2}\right) + mg\sin\theta$

$F_p = 0.9(\tfrac{1}{2})(152.75\,kg)(9.81\,m/s^2)\cos(4.76) + (152.75\,kg)(9.81\,m/s^2)\sin(4.76)$

$F_p = 796.3\ N$

$T = F(r)$ where $r = 12.25\,in = 0.31115\,m$

12.5% $\Rightarrow$ $T = 855.1\,N(0.31115\,m) = 266.06\ Nm$

8.3% $\Rightarrow$ $T = 796.3\,N(0.31115\,m) = 247.77\ Nm$

Figure B.15 Stall torque calculations for hub motor wheels

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: Human Research Questions

Wheelchair User Interview

Name of Participant: ___________________________

Can we use your name when publishing this interview?   Yes   No

Date of Interview:________________

Instructions: We will be conducting about a 30 minute interview to try and get a better understanding of how we can improve wheelchairs when going up and down hills. We would like to discuss potential solutions for certain issues that you may face. Thank you again for your willingness to participate in our study.

1. Could you start with briefly introducing yourself and give us a fun fact about yourself?
2. Do you ever have safety issues with the wheelchair you use?
3. Are there any major accessibility issues with your wheelchair right now you'd like to see addressed?
4. Is our proposed wheelchair attachment something you would be interested in? If not, please explain why.
5. Are there other wheelchair attachment products on the market that you would like to see improved or potentially incorporated into our design?
6. Do you have issues with your wheelchair on inclines or declines? If so, could you describe those challenges?
7. Is an alternative to a fully motorized wheelchair something that appeals to you or others who use wheelchairs?
8. Of these factors that are associated with wheelchair attachments, could you rank the importance of each of these in a new wheelchair attachment:
    a. Lower the cost
    b. More accessible
    c. Better portability
    d. Easy installation/removal
    e. Longer battery life
    f. Lower weight
9. What are overall the biggest challenges you face as a result of your wheelchair on a daily basis?
10. Are there considerations we should be making that you can think of that haven't already been bought up?
11. Are there any specific accessibility issues that you experience on Lafayette's campus?
12. Would you mind talking about your perspective as a person who uses a wheelchair?
13. Would you like to be updated as we move forward in the project?
14. After seeing the prototype, do you think it is compact enough?
15. After seeing the prototype, do you think the cost is reasonable?
16. After seeing the prototype, do you think the layout would cause any issues?
17. After seeing the prototype, what are your initial impressions?

Health Care Providers Survey

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 know people who use wheelchairs struggle going UPHILL?

1	2	3	4	5
No Difficulty				A lot of difficulty

2. To what extent do you know people who use wheelchairs struggle going DOWNHILL?

1	2	3	4	5
No Difficulty				A lot of difficulty

3. What kind of assistance would you think wheelchair users 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 think wheelchair users 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 do you think a wheelchair user's preference would be 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. Do you think an increase in weight is a large concern?

1	2	3	4	5
No Concern				VERY concerned

8. Do you think wheelchair users would be interested in adding functionality to a wheelchair by installing addons?

1	2	3	4	5
No Interest				VERY Interested

9. How much do you agree with this statement? Wheelchair users would be 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?

13. After seeing the prototype, do you think the cost is reasonable?

14. After seeing the prototype, do you think it is compact enough?

15. After seeing the prototype, do you think the layout would cause any issues?

16. After seeing the prototype, what are your initial impressions

APPENDIX E: Gantt Chart

Table E.1: Semester Gantt Chart Tasks and timeline for the month of September for the full team

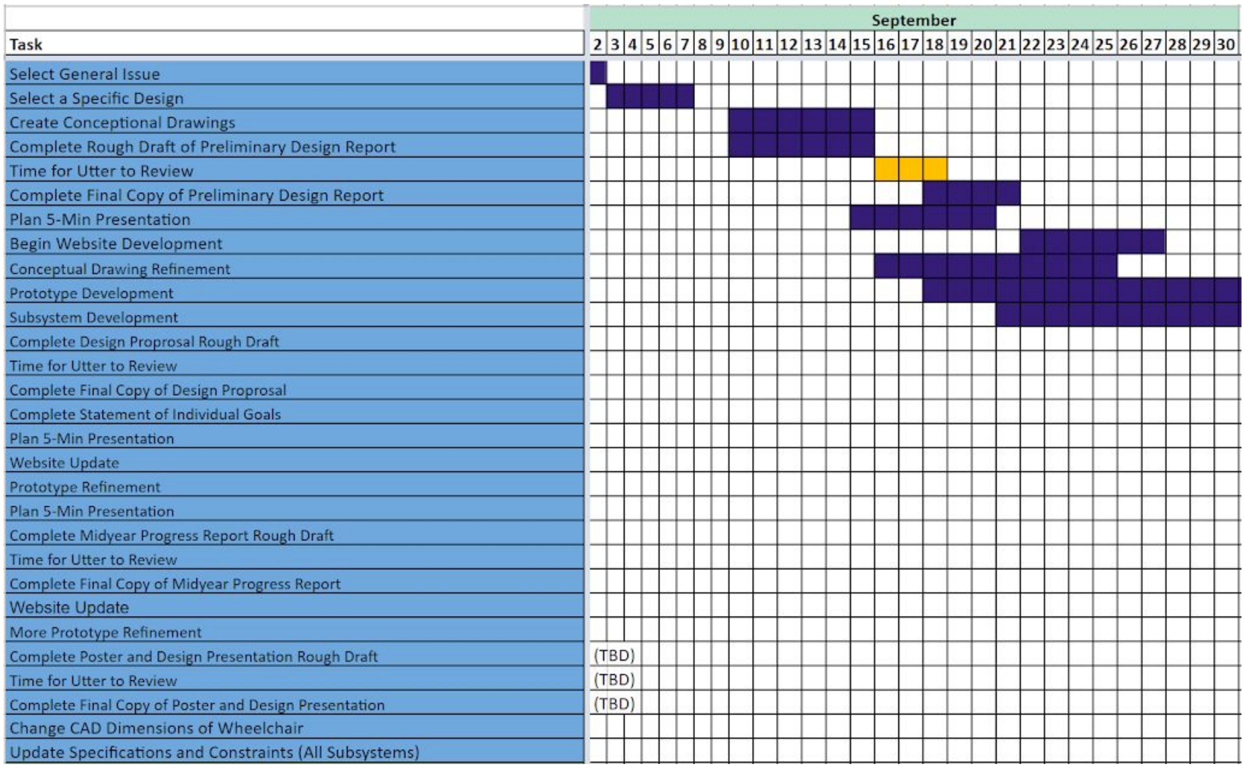
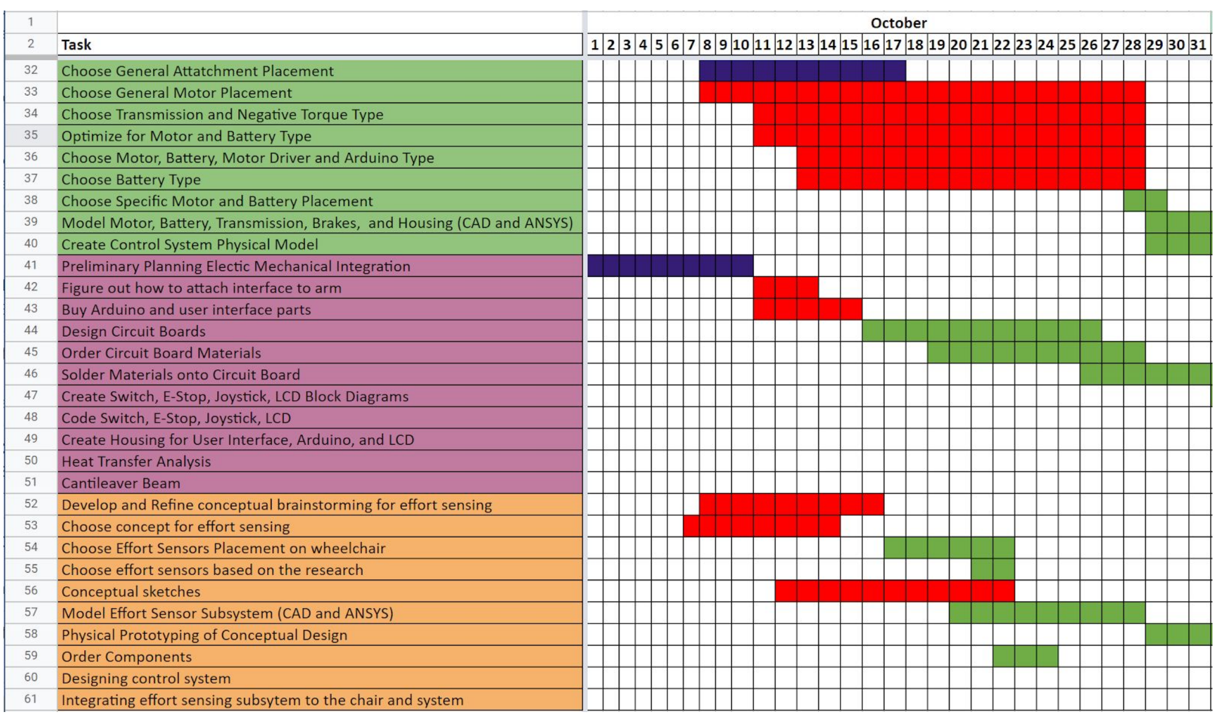


Table E.2: Semester Gantt Chart Tasks and timeline for the month of October for the subteams



For the entire timeline for the team and each of the subteams, please follow this link.

Table E.3 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.4 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)